Article

Land-Use Impact on Water Quality of the Opak Sub-Watershed, Yogyakarta, Indonesia

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Abstract: The integrated monitoring system of water quality is eminently reliant on water quality trend data. This study aims to obtain water quality patterns related to land-use change over a periodic observation in the Opak sub-watershed, Indonesia, both from a seasonal and spatial point of view. Landsat image data from 2013 to 2020 and water quality data comprising 25 parameters were compiled and analyzed. This study observed that land use remarkably correlated to water quality, especially the building area representing the dense population and various anthropogenic activities, to pollute the water sources. Three types of pollutant sources were identified using principal component analysis (PCA), including domestic, industrial, and agricultural activities, which all influenced the variance in river water quality. The use of spatiotemporal-based and multivariate analysis was to interpret water quality trend data, which can help the stakeholders to monitor pollution and take control in the Opak sub-watershed. The results investigated 17 out of 25 water quality parameters, which showed an increasing trend from upstream to downstream during the observation time. The concentration of biological oxygen demand over five days (BOD5), chemical oxygen demand (COD), nitrite, sulfide, phenol, phosphate, oil and grease, lead, Escherichia coli (E. coli), and total coli, surpassed the water quality standard through spatial analysis.

Keywords: Escherichia coli; land use; spatial; temporal; water quality

1. Introduction

Rapid and vast land-use change generated environmental carrying capacity deterioration, thereby significantly decreasing water quality along with the watershed. According to some studies, green space and agricultural areas have changed extensively to become settlement and industrial areas in many big cities of Indonesia. For the last three decades in the primary watershed, which covered Jakarta, Bogor, Depok, Tangerang, and Bekasi (Jabodetabek), the building area grew more than 12 times and up to 30% of natural vegetation was lost [1]. Agricultural land in Kartamantul (Sleman, Yogyakarta and Bantul), Yogyakarta was converted into settlement area for 1.19%/year from 1994–2000 [2]. According to Statistics of D.I. Yogyakarta, from 2012 to 2014, 1149 Ha of agricultural land was converted into non-agricultural purposes in 3 regions of the Winongo River [3]. The upstream of the Brantas sub-watershed reported a drastic increase in the resident area from 2520.74 Ha to 4830.62 Ha in 7 years (2006–2013) [4]. As the change of land cover and land use related to quality and quantity of river water occurred, the Ministry of Environment and Forestry of Indonesia identified that more than 68% of water quality in all regions of Indonesia have been heavily polluted [5]. The 421 fountains, which fell to 57 fountains in less than 5 years [6] and about 119 wellsprings

in Kulonprogo. Yogyakarta has been identified as being critical and in an endangered status [7], and there are around 160 natural water sources in Bandung City, only 67 of which produce water [8]. Declining water quality encourages other serious problems associated with decreased water quality and public health risks.

Land cover and land use are critical components of water quality. Both point and non-point pollution sources from land use are pivotal issues to monitor watershed management and planning. Different contaminant sources run into nearby water bodies. For instance, ground and surface water aggravate water quality itself. Much research has been conducted to investigate the correlation between the effect of land use and water quality. Camara et al. found that 87% of urban land use was a significant source of water pollution [9]. In comparison, 82% identified agricultural land use, 77% forest land use and 44% other land uses. The correlation revealed that the related activity of agriculture and forest had a more significant impact on water quality due to their physical and chemical water quality indicators. At the same time, urban development activities are more affected due to changes in hydrological processes, such as runoff and erosion. Using satellite images from 2007 until 2017, Tahiru et al. found the impact of land use and land cover changes on water quality parameters, such as turbidity, ammonia, and total coliform counts [8]. Remote sensing and statistical analysis were employed to divide three ‘effluents’ of built-up areas, agriculture areas, and open space [10]. These groups significantly correlated to declining water quality, including Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD$_5$), Chemical Oxygen Demand (COD), $E.\ coli$, and several metals. Another interesting finding was that of $E.\ coli$ and sediment parameters in changing land use land cover using water quality index and modelling water discharge [11]. Over eight years, $E.\ coli$ data was collected, and Landsat data between 2001 and 2018 was used and showed a negative correlation between $E.\ coli$ loading and expanded land use land cover. In addition, the higher the water discharge, the more sediment loading is possible in the sub-basin.

Several approaches are utilized to investigate other relations between land use and various water contaminants, such as the pairing of spatial and multivariate statistical analysis. By understanding and observing numerous water quality parameters simultaneously and their related factors, principal component analysis (PCA) is applicable to support an interpretation of the results. Tripathi and Singal [12] applied PCA to represent 9 out of 28 water quality parameters that possessed significant results and less bias to determine Water Quality Index (WQI) in the Ganga River. Furthermore, Lee et al. [13] examined the correlation with a significant level ($p < 0.05$) and PCA on water quality parameters regarding land use covered. Each source positively associates with specific parameters; examples for the residential area are BOD$_5$, COD, NH$_3$, and PO$_4$ while for agricultural land, examples are TSS, NO$_3$, and PO$_4$; as well as BOD$_5$, COD, NH$_3$, and NO$_3$ for livestock. The integrated method by PCA/FA principal component analysis/factor analysis, analysis of variance (ANOVA), and cluster analysis (CA) were employed to identify source pollution due to land-use changes in northern Iran [14]. Another particular result shows that most inorganic ions and land-use characteristics are examined for small river basins in central Japan [15]. The urban development and residential area showed a significant positive correlation to farmland-exposed, noticeable ions of pollutants.

Previous research has analyzed the relationship between land use and water quality measures in Indonesia. A study using the pollution index method in Semarang City indicated that the water pollution index was above government regulation standard [16]. Another study conducted by Nugraha [17] simulated the influence of land use on water quality via the QUAL2E model and pollution index in Central Java. Unfortunately, detailed spatial land-use data did not support that research. Moreover, research conducted by Indriyani et al. [18] exposed where BOD$_5$ and COD loading from the residential area resulted in the worst water quality on the Ciracab River. Inversely, the forest area had opposite conditions. However, the land-use data were supported by GIS-based analysis data, only after being investigated for a few water parameters and lack of statistical analysis. In Yogyakarta, some investigations were done by combining spatial and multivariate
analysis. Suharyo [19] and Hamid [20] studied the water quality of the Opak watershed. They found a positive correlation between chemical and microbial parameters and land use, although the multivariate analysis was not significant \( r \leq 0.5 \) due to limited temporal data. Munawar [21] and Pratama [22] did comprehensive and multi-analysis research on the Code River. The initial study explained not only the spatial data and water quality analysis but also economic analysis. Then, the later study coupled LULC (land use land change) and multivariate analysis.

Although many researchers have analyzed the relationship between land use and water quality, only a few of them utilized principal component analysis (PCA) in Indonesia. In addition, PCA analysis is an appropriate data representation technique to imagine and recognize the kind of pollutants in the Opak sub-watershed [23,24]. In the current study, a spatiotemporal analysis is applied on the water quality of the Opak sub-watershed focused on the Winongo River and its land use for the period of 2013–2020. PCA further analyzed the critical and selected data out of 25 water quality parameters at 8 sampling points to identify the possible pollution sources. Subsequently, the seven-year water quality trend data were analyzed by multivariate statistical correlation with land use.

2. Materials and Methods

2.1. Study Area

Opak watershed, located in Yogyakarta Province, Indonesia, has a length of 65 km and a catchment area of ±1398.18 km². The watershed consists of the Tambakbayan, Code, Winongo, Gajahwong, and Oyo sub-watersheds. One of the biggest sub-watersheds that crosses three regions in Yogyakarta is the Winongo sub-watershed [25]. The Winongo River has a total coverage area of 47.83 km². It has a length of 23.49 km, flowing from the upstream located on Sleman Regency and through the middle stream on Yogyakarta City, finishing downstream in Bantul Regency. The width of the surface rivers is averaged to about 10.2 m, while the width of the bottom is ranged around 8.5 m [26]. The Winongo River is a pivotal river for three regions of Yogyakarta, i.e., Sleman Regency, Yogyakarta City, and Bantul Regency, used for water drinking resources, irrigation, household cleaning, fish-farming, dams, sand quarries, and as a tourist destination.

The catchment area of the Winongo River of the Opak sub-watershed tends to decline, starting from 112 km² (2002) [27], then decreasing to 88.12 km² (2012) [28], and finally 47.83 km² (2021). The average annual rainfall is 1466.55 mm/year and shows a drought index from 24.56% to 36.87% (mid to heavy drought), with a basin coefficient of 0.875 [29]. Statistics of D.I. Yogyakarta reported the average annual temperature to be about 26 °C; the maximum temperature in August is 34.8 °C and the minimum temperature in July is 18.40 °C. Furthermore, annual relative humidity is measured at ±86% [30]. Besides, urbanization and rapid population growth without proper control and management triggered many citizens to build their residence along the riverbank. In addition to coming from inside Yogyakarta, such as Wonsari and Kulon Progo, nonnative people came to Yogyakarta from Wonigiri, Solo, and Madura. This resulted in many issues that other cities in Indonesia also faced, such as heavily polluted rivers, high sedimentation, fast erosion level, and flooding [31–33]. Furthermore, the middle stream flows through the tight urban population and home industries caused various water contaminants to enter the sub-watershed [34–36]. Also, numerous fishery activities generate algae blooming phenomena in several river flow components [37,38].

In this study, the water quality of the sub-watershed was monitored in eight sampling points (S1–S8), spreading into three segments. Those segments were divided based on boundary administration and slope regions. The first segment upstream (UP1), whose 100–150 m of river slope was in the Sleman region, was then observed by the S1 station. Secondly, the middle stream (MD2) that sloped ranged from 50 to 100 m, which crossed the Yogyakarta City monitored by the S2 to S4 stations. The water quality of the sub-watersheds downstream (DW3) was sampled from the S5 to S8 stations laid on the Bantul region with a slope of fewer than 50 m. Table 1 shows the geocoordinates of sampling
points. Furthermore, all the sampling locations and those segments were visualized in Figure 1.

Table 1. Sampling Coordinates.

<table>
<thead>
<tr>
<th>Points</th>
<th>Latitude</th>
<th>Longitude</th>
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</thead>
<tbody>
<tr>
<td>Point 1</td>
<td>−7.8861111111</td>
<td>110.5116667</td>
</tr>
<tr>
<td>Point 2</td>
<td>−7.6778333333</td>
<td>110.3763056</td>
</tr>
<tr>
<td>Point 3</td>
<td>−7.7769444444</td>
<td>110.3573889</td>
</tr>
<tr>
<td>Point 4</td>
<td>−7.7897777778</td>
<td>110.3573889</td>
</tr>
<tr>
<td>Point 5</td>
<td>−7.8083611111</td>
<td>110.3537222</td>
</tr>
<tr>
<td>Point 6</td>
<td>−7.8403333333</td>
<td>110.3403333</td>
</tr>
<tr>
<td>Point 7</td>
<td>−7.9127555555</td>
<td>110.3470278</td>
</tr>
<tr>
<td>Point 8</td>
<td>−7.9787222222</td>
<td>110.3134167</td>
</tr>
</tbody>
</table>

Figure 1. Sampling points of Opak sub-watershed.
2.2. Water Quality and Geographic Information

The water quality data of the sub-watershed was taken from the Environmental Agency of Yogyakarta Province from 2013 to 2020. The data was collected three times a year from the eight sampling stations explained before (S1–S8). Every monitoring data point consists of 25 parameters, which were physical parameters: temperature, pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS), and color; chemical parameters: Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD$_5$), Chemical Oxygen Demand (COD), Chlorine (Cl$_2$), nitrate (NO$_2$), nitrite (NO$_3$), ammonium (NH$_4$), detergent, phenol, phosphate (PO$_4$), oil and fat, iron (Fe), manganese (Mn), cadmium (Cd), lead (Pb), zinc (Zn), and copper (Cu); and biological parameters: Total coliform and E. coli.

For spatial processing data, two types of satellite images were used. First, land use classification data was extracted from Landsat data collected by the United States Geological Survey (USGS) from 2013 to 2020. Second, to determine the sub-watershed boundary, the satellite data was delineated and extracted by a mask manually using ArcGIS 10.8. Exact steps were defined for deciding river segments (upstream, middle stream, and downstream). The shapefile images were gathered from the Environmental Agency of Yogyakarta Province.

2.3. Land-Use Classification

ArcGIS 10.8 extracted and processed each satellite image of USGS from 2013 to 2020 and broken into layers. The land-use classification was based on the most similar images of training sample drawing tools, conducted by interactive supervised classification. After the final conversion, land uses were categorized and divided into the National Standard Indonesia (SNI 7645-1:2014) three main cover types, namely building (BU), agriculture (AG), and VA (Vegetation). Those categories were considered according to the dominant coverage area in three representative regions.

2.4. Statistical Analysis

Pearson correlation analysis was used to assess the close link between the data variables of water quality parameter in each sub-watershed and the quantity of land use utilized. To determine correlation coefficients, a correlation matrix was created by calculating the coefficients of different pairings of parameters, and the correlation was then checked for significance using the p value. The significance was assessed at the 0.05 level (2-tailed analysis). If $p < 0.05$, the differences were substantial, and if $p > 0.05$, they were not. The Pearson correlation coefficient was appropriate for normally distributed data, whereas Spearman-rho ($\rho$) and Kendall-tau ($\sigma$) were not regularly distributed [39–41]. Besides the Pearson correlation, this study also applied principal component analysis (PCA) so that multivariate normal data could be obtained. The first stage in the PCA approach was to determine factor analysis and identify the original variables among sub-watershed water qualities. PCA analysis has initial eigenvalues greater than 1 supported by the rotation matrix method, containing the number of factors to be selected from the variable [42–44]. By following and interpreting, the rotation outcome factor was going to reveal factors and variables regarding the water quality in the Opak sub-watershed. Moreover, to validate, the PCA analysis was assessed by preliminary tests, such as the Kaiser–Meyer–Oklin (KMO) Test, Bartlett Test, anti-image, and scree plot. The KMO test was considered appropriate to use after reaching a value of one. The Bartlett and anti-image significant tests might be less than 0.5 [45,46]. Finally, the scree plot was evaluated to identify the number of elements or categories retrieved in a matrix [47].

3. Results and Discussion

3.1. Temporal Analysis of the Opak Sub-Watershed’s Water Quality

The temporal trend of the Opak sub-watershed was classified based on the season from 2013 to 2020. As explained by the Meteorological, Climatological, and Geophysical Agency (BMKG) of Yogyakarta Province [30,48], in Table 2, the wet season (or rainy season)
peaked in February/March and the peak of the dry season was in September/October. Furthermore, water quality parameters were clustered into a gradual decline and rising in median parameters from the wet to dry season. The trend of decreasing median parameters from wet season to dry season includes temperature, pH, TDS, DO, chlorine, nitrate, sulfide, detergent, phenol, phosphate, Fe, Mn, Cd, Cu, Pb, colour, *E. coli*, and Total Coliform. On the other hand, there is the increasing concentration of water quality parameters, such as TSS, BOD$_5$, COD, nitrate, ammonia, oil and grease, and zinc (Zn).

**Table 2.** Climate data in Yogyakarta Province.

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Precipitation</td>
<td>Feb/March</td>
<td>mm/month</td>
<td>369</td>
<td>337</td>
<td>182</td>
<td>323</td>
<td>349</td>
<td>337</td>
<td>337</td>
<td>317</td>
</tr>
<tr>
<td></td>
<td>Sept/Oct</td>
<td>mm/month</td>
<td>92</td>
<td>2</td>
<td>NA*</td>
<td>324</td>
<td>60</td>
<td>20</td>
<td>NA*</td>
<td>44</td>
</tr>
<tr>
<td>Relative humidity</td>
<td>Feb/March</td>
<td>%</td>
<td>87.5</td>
<td>85.5</td>
<td>88.0</td>
<td>89.3</td>
<td>87.3</td>
<td>86.8</td>
<td>87.5</td>
<td>87.6</td>
</tr>
<tr>
<td></td>
<td>Sept/Oct</td>
<td>%</td>
<td>80.5</td>
<td>76.7</td>
<td>77.1</td>
<td>86.0</td>
<td>82.5</td>
<td>81.0</td>
<td>77.3</td>
<td>81.1</td>
</tr>
</tbody>
</table>

* NA: Not available.

It can be seen in Figure 2 that the temperature of water in the Opak sub-watershed was not dissimilar between wet and dry seasons. The median of both seasons ranged from 27.36–27.66 °C. The minimum temperature was reported in the wet season of 26.0 °C and the maximum temperature in the dry season was 28.6 °C. Furthermore, dissolved oxygen (DO) levels were at their highest during the rainy season, while during the dry season, concentration was the lowest.

In tropical countries, surface water quality has been shown to shift seasonally in response to changes in temperature and rainfall [49–51]. In Indonesia, the difference between low and high precipitation during the dry and wet seasons impacted the water quality of the watershed significantly [52,53]. Subsequently, TDS and TSS parameters for solids in river water exhibited the same pattern in both seasons. The TSS value was higher than the TDS during the dry season. It was thought that suspended particles make up most solids in the Opak sub-watershed, making it difficult for particles to settle even in the dry season. The sources of suspended solids came from erosion and runoff, human pollution, algae, and sediment disruption. The sediment and the Opak sub-watershed were also contributed to via volcanic activity from Mount Merapi [54].

Based on DO measurement results, previous research shows that rainfall had a positive connection with DO [55–58]. Rainwater entering the riverbanks allowed aeration of the water body that increased the river current and speed flow. The levels of BOD$_5$ and COD in river water of the Opak sub-watershed were inversely related to this. BOD$_5$ and COD levels in the wet season were lower than in the dry season due to the dilution process. The high percentage of vegetation land (32.2%) in the overall watershed produced a lot of organic matter from decaying leaves and wood transported by water run-off into the water body so that BOD$_5$ level was high [59–61]. Furthermore, wastewater incredibly contributed to the rise of BOD$_5$ and COD values, typically in organic matter from settlement point sources.

Several parameters primarily found in industrial wastewater, such as chlorine, sulfide, and phenols, were reported to have a decreasing trend from wet to dry season. Similarly, the elements N (nitrate) and P (phosphate) in the waters followed a similar pattern, with those concentrations being higher in the wet season than in the dry season. According to Ling et al., pollutant matters dissolved and accumulated at the bottom of the sediment river were released quickly and well mixed within the water column during the wet season [62,63]. Furthermore, a significant volume of inflow following heavy rainfall encourages mixing and disrupts reservoir stratification. In the nitrogen cycle, the level of nitrate was opposite to nitrite and ammonia parameters. Nitrite was the only form of partially oxidized nitrogen that formed during ammonia oxidation to nitrate and lasted only a short period [64–67].
Then, denitrification occurred at low levels of dissolved oxygen-producing ammonia. These facts are associated with the data collected in the Opak sub-watershed that the depletion of dissolved oxygen levels during the dry season generated lifted ammonia levels.

Figure 2. Cont.
Almost all metals, both essential (Fe, Mn, and Cu) and non-essential (Cd and Fb), decreased from wet to dry season. Anthropogenic and industrial activities and natural phenomena contributed to the metal sources inside the water body. Metals could be in water structures as colloids, particles, or dissolved or adsorbed to sediment [68]. Dissolution and precipitation processes during the rainy season played a role in metal transport in aquatic environments [69,70]. Thus, metals stored in the mountain rock or soil layers that originated in a volcano might be easily washed off during rainfall and enter river bodies. The metal that has been deposited in the sediment originated from domestic, industrial, and agricultural activities.

Water contained fecal contamination indicators that were critical for determining the quality of the water. Total coliforms and E. coli were the most extensively used bacteriological assays to detect harmful bacteria in animal and human feces [71]. In this study, the highest total coliforms and E. coli in the dry season were 1,296,125 MPN/100 mL and 183,500 MPN/100 mL, respectively. Their quantities at all monitoring stations were negatively under the most minimum water quality criteria. The presence of these bacteria in the Winongo River was highly concerning to residents around the Opak Sub-watershed.

The high percentage of vegetation land (32.2%) in the overall watershed produced a controlling element in bacterial growth. Similarly, the elements N (nitrate) and P (phosphate) in the waters followed a similar pattern, originating in a volcano might be easily washed off during rainfall and enter river bodies. The metal that has been deposited in the sediment originated from domestic, industrial, and agricultural activities.

Several parameters primarily found in industrial wastewater, such as chlorine, sulfate, phenols, and heavy metals, the highest total coliforms and E. coli levels were the most extensively used bacteriological assays to detect harmful bacteria in animal and human feces [71]. In this study, the highest total coliforms and E. coli in the dry season were 1,296,125 MPN/100 mL and 183,500 MPN/100 mL, respectively. Their quantities at all monitoring stations were negatively under the most minimum water quality criteria. The presence of these bacteria in the Winongo River was highly concerning to residents around the Opak Sub-watershed. The health risks had increased due to the chance of their exposure to these microorganisms.

Figure 2. The temporal tendency of water quality in Opak sub-watershed: Trend of decreasing median parameters from wet season to dry season (a); Trend of increasing median parameters from wet season to dry season (b).

Nevertheless, the findings revealed contrary results. It was clear that the microenvironment influenced their appearance or reappearance and the number of coliforms present [72–74]. Changes in the number and diversity of bacteria were observed as the season altered. When water temperatures rose above 15 °C, the existence of total coliforms increased considerably. This was assumed since the temperature was a significant controlling element in bacterial growth.
3.2. Spatial Analysis of the Opak Sub-Watershed’s Water Quality

In the spatial analysis data, water quality parameters are divided into two groups, i.e., the trend of increasing and random median parameters from upstream, middle stream, and downstream, respectively. Random trends sometimes mean the highest concentration accumulated on the middle stream, and occasionally they fluctuated among three sampling points. Overall, water parameters in the Opak sub-watershed climbed up from upstream to downstream, such as temperature, TDS, TSS, COD, nitrate, nitrite, sulfide, ammonia, detergent, phosphate, Fe, Mn, Cd, Zn, Cu, colour, E. coli, and total coliform. That aside, pH, BOD$_5$, phenol, oil and grease reached the largest concentration in the middle stream. Chlorine and Pb levels shifted for every observation point. Then, dissolved oxygen (DO) concentration steadily decreased from upstream to downstream.

As shown in Figure 3, the temperature between the middle stream (MD2) and downstream (DW3) is invariable, around 28 °C. Moreover, TDS gradually climbed up to the third monitoring station, whereas the TSS value remained stable. Furthermore, several parameters showed a random trend, such as chlorine, phenol, Pb, oil, and grease. The chlorine and Pb levels peaked in the last stream while phenol, oil, and grease surged in the second stream of the Opak sub-watershed.

The upstream (UP1) is 3 °C cooler than the others, which is different from the two sites before. The temperature of the surrounding air had a significant impact on the temperature of the river water. Warmer urban surfaces caused temperature surges in streams. According to the landscape of the study area, MD2 and DW3 is located in the tight, densely population area. Land-use changes linked to urbanization lead to changes in the temperature regime of the air in cities, resulting in urban heat islands [75–77]. Furthermore, domestic residential wastewater was a pivotal contributor to rising river water temperatures [78–80].

The sources of solids inside the water column were dominated by outside factors, such as erosion, run-off, flooding, etc. In UP1, the riverbanks’ vegetation could hold the soil, so it was not be carried away by the water flow. The combined impacts of leaves, stems, roots, and litter allowed plants to intercept rainfall and control surface run-off, thus fulfilling the function of soil and water conservation [10,81–84]. Furthermore, TSS concentration was influenced by the material derived from land carried by river flows [85–87].

By comparing BOD$_5$ and COD, the median of BOD$_5$ rose from UP1 to MD2, then fell as it entered DW3. Generally, the DO level is constantly depleted in the three monitoring points. On the contrary, BOD$_5$ and COD increased. A similar phenomenon happened for other parameters, such as NO$_2$, NO$_3$, NH$_3$, PO$_4$ and detergent. A lot of dissolved oxygen is used inside the water body. The oxidation process of those matters rapidly occurs and generates a high concentration of not only BOD$_5$ and COD but also N and P elements. Commonly, organic matters originated from settlements and industrial activities. In addition, the MD2 and DW3 were circled by several kinds of home industries, such as tofu industries. Previous research shows that approximately five tofu home industries did not treat their wastewater and discharged it directly into the river [88]. Through observing around the study area, the numerous sewer pipes flew directly to the water body of the Winongo river.

The presence of phenolics in water could be attributed to the deterioration or decomposition of natural organic materials in the water and the discharge of industrial and residential wastewater and runoff from agricultural lands [89]. On the other hand, chlorine was also used in wastewater treatment plants and swimming pools as a disinfectant, as a bleaching agent in textile manufacturers and paper mills, and as an element in many laundry bleaches [90,91]. Both phenol and chlorine were poisonous to aquatic organisms even at deficient levels.

Furthermore, as one of the heavy metals, Pb possessed a bizarre phenomenon in this study. All the metals concentration, substantial and non-substantial, steadily increasing from UP1 to DW3, except Pb. The level of Pb was high in two monitoring locations, upstream and downstream, 0.03 and 0.05 ppm, respectively. In the middle stream, Pb concentration jumped down to 0.02 ppm. It was assumed that Pb metal was easier to settle
and bond to other elements due to the affinity sequence; therefore, the concentration of Pb did not accumulate in the following sampling point. The source of Pb in the upstream river was river rocks, and volcanic activity carried downstream by water currents. Consequently, the concentrations of Pb in each stream was different. Despite this, the majority of the Pb in the downstream came from human activities.

Figure 3. Cont.
Based on spatial analysis, the microbial parameters exceed the water quality standard for all monitoring locations of the Opak sub-watershed. The presence of high levels of coliform can be caused by various reasons, particularly sanitation issues such as the usage of septic tanks and the distance between water sources and pollutants. Furthermore, coliform bacteria from the digestive systems of human and animal bodies could be released by organism generated waterborne illness through surface water [92–94]. Before flowing into the MD2, the Opak sub-watershed flows through the agricultural land. It assumed that the high \( E. \ coli \) and total coliform number were caused by mammal feces-based fertilizer. Subsequently, \( E. \ coli \) and total coli bacteria parameters originated from the black water of domestic activity [95–97]. Water quality characteristics of Winongo river as Opak sub-watershed, in 2012–2014 was classified as heavily polluted [98–100]. It was indicated by the high \( E. \ coli \) and total coliform number were caused by mammal feces-based fertilizer. 

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Subsequently, \( E. \ coli \) and total coli bacteria parameters originated from the black water of domestic activity [95–97]. Water quality characteristics of Winongo river as Opak sub-watershed, in 2012–2014 was classified as heavily polluted [98–100]. It was indicated by the high \( E. \ coli \) and total coliform number were caused by mammal feces-based fertilizer. 

### 3.3. Land Use Impact to Water Quality

The Landsat satellite captured the land use images and the Opak sub-watershed for 2013–2020. Figure 4 shows the proportion of land use in three categories and three river zones. Significantly, vegetation land decreased from 2013 to 2014 in all stream areas, and then it was the relatively stable condition under 30% of coverage area up to 2020. Complementary to this, building area was dominated more than 60% in the middle and downstream. Moreover, the agriculture area was the most fluctuated trend in the upstream zone. The sizeable vacant space and cooler altitude temperature upstream were utilized for seasonal cultivated vegetation, such as paddy, corn, potatoes, etc. So that the percentages of agriculture area were up and down ranging from 20–45% for seven years, it can be seen in river zone, and upper area exhibited different pattern compared to middle and down zones. In upstream, natural vegetation and building had contrary trend, while crop area varies changed. On the other hand, settlement and non-settlement areas reached more than 80% and about 60% in the middle and downstream.

![Figure 3. The spatial tendency of water quality in the Opak sub-watershed: Trend of increasing median parameters from upstream, middle stream, and downstream, respectively (a) and random trend of parameters from upstream, middle stream, and downstream (b).](image-url)
Figure 4. Percentage of land use in the Opak sub-watershed.

To elaborate on the quantity of land use in the Opak sub-watershed and image data, Figure 5 shows the visual land cover from 2013 to 2020. The greenest area in the upstream (UP1) was significantly changed in 2013–2014. In the middle (MD2), it constantly exposed red areas dominated by buildings. The combination between building and agriculture are located in the last stream (DW3). The impact of land use on the water quality in the Opak sub-watershed was calculated by Pearson correlation coefficient ($r$). Table 3 exhibits the most significant relation ($r > 0.6$) between two variables, land use and water quality parameters, in the upper, middle, and downstream.

Figure 5. Land Use Land Change of Opak sub-watershed from 2013 to 2020.
Table 3. Pearson correlation between the land use and water quality parameter.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Upstream</th>
<th>Middle Stream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VA</td>
<td>AB</td>
<td>AG</td>
</tr>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>TDS</td>
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<td></td>
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<tr>
<td>TSS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DO</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BOD$_5$ (*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>COD</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chlorine</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nitrite</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfide (*)</td>
<td>0.876</td>
<td>−0.742</td>
<td>0.865</td>
</tr>
<tr>
<td>Ammonia (*)</td>
<td>−0.821</td>
<td></td>
<td>−0.871</td>
</tr>
<tr>
<td>Phenol (*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phosphate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil &amp; grease</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mn (*)</td>
<td>−0.748</td>
<td></td>
<td>−0.766</td>
</tr>
<tr>
<td>Cd (*)</td>
<td></td>
<td>0.807</td>
<td>−0.833</td>
</tr>
<tr>
<td>Zn (*)</td>
<td>0.738</td>
<td>0.723</td>
<td></td>
</tr>
<tr>
<td>Cu (*)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pb (*)</td>
<td>0.765</td>
<td>−0.748</td>
<td>0.752</td>
</tr>
<tr>
<td>Color</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>E. coli</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total coliform</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(*) Significant correlation Significant area: <−0.707 or >0.707.

The results of land cover mapping supported by another research that the land cover of Winongo river, part of Opak sub-watershed, was geographically variable. The woodland and plantation regions were dominated the upstream basin [101]. Besides, in the city of Yogyakarta, settlements spots were the most common land cover. Furthermore, Paddy fields mostly covered Bantul and Sleman regencies. In UP1, sulfide, ammonia, and some metals (Mn, Zn, Pb) strongly correlated. The green area (VA) upstream owned the positive correlation (0.876) with sulfide. In the natural condition, sulfide was formed by the decomposing process of organic matter, such as plant material [102,103]. Additionally, semi and non-permanent buildings in the upstream associated positively to Zn and Pb parameters, 0.738 and 0.765, respectively. Complementary to this, ammonia (−0.821) and Mn (−0.748) had a strong negative correlation between structured area (AB) and organic and metal contaminants. The significance of r values in the middle stream was not different from the previous watershed part that was still sulfide, ammonia, and metals parameters. The run-off accumulation of sulfide sources from upstream areas, vegetation, and agriculture generated a high correlation coefficient, 0.865 and −0.718, respectively. Not only from plant decaying but also dissolved evaporite mineral from fertilizer and soil sulfates become the other sources of sulfide [104–106].

The dense population and various home industries (AB) contributed to metal contamination in the middle stream. In the last part of the Opak sub-watershed, numerous water quality parameters exhibited high correlation, such as BOD$_5$, detergent, phenol, Cd, Pb, and Cu. BOD$_5$ possessed a remarkable correlation up to 0.886 of VA and −0.936 of AB. It was expected from the organic compound degradation process that originated domestic wastewater [107–109]. Phenol was found strong relation with VA (0.713) and AB (−0.816) that indicated pollution from industrial, agricultural, and home sources. Cd and Pb showed a significant correlation with VA and AB. Besides industrial sources, Cd and Pb in the water body came from the atmosphere [110–112]. The fuels used from the engine of
transportation emitted to the atmosphere, and during the rainy season was dropped into surface water and was expected through run-off from open space.

More importantly, an unexpected correlation was found, for example, between Cd and Pb and vegetation (0.837 and 0.752, respectively). Such strong correlation was not found in previous research [22] so that further investigations are required to explain the association between heavy metal and vegetation. Another essential point, the determination of VA (vegetation area), is needed to be clarified. It was supported by previous finding that cadmium became an issue combining phosphorus fertilizers [113]. Replanting or revegetation in such blank areas using fertilizer could contribute heavy metal sources through run-off into riverbanks.

3.4. Principal Component Analysis (PCA) of Pollution Source

Principal component analysis (PCA) was used to determine the pollution sources in the Opak sub-watershed. To validate the statistical requirement of PCA analysis, preliminary tests, such as KMO, Bartlett, and anti-image matric tests, were done. Four out of 25 water quality parameters, i.e., TSS, chlorine, COD, and sulfide, were eliminated from the analysis due to over 0.5 anti-image correlation. Subsequently, six components were obtained from the total variance calculation. The eigenvalue of those components should be more than 1.0. The sampling adequacy of the Kaiser-Meyer-Okin (KMO) test showed a value of 0.628 to continue the analysis. Furthermore, by calculating the next step of the rotated component matrix, BOD$_5$ was ineligible (<0.5) so that the twenty remaining parameters are re-extracted and displayed in Table 4.

Table 4. Six components (Co) extracted from 20 parameters of water quality.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Co1</th>
<th>Co2</th>
<th>Co3</th>
<th>Co4</th>
<th>Co5</th>
<th>Co6</th>
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</thead>
<tbody>
<tr>
<td>Temperature</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
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<td></td>
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<tr>
<td>TDS</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
<td></td>
<td>0.828</td>
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<tr>
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<td></td>
<td></td>
<td>0.818</td>
<td></td>
</tr>
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<td>Ammonia</td>
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<td></td>
<td></td>
<td></td>
<td>-0.806</td>
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<tr>
<td>Detergent</td>
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<td>0.742</td>
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<td></td>
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<td>0.864</td>
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<tr>
<td>E. coli</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.765</td>
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<tr>
<td>Total coliform</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.788</td>
</tr>
</tbody>
</table>

| Eigenvalue       | 4.279| 3.162| 2.094| 1.734| 1.439| 1.156|
| %Variance explained | 21.393 | 15.809 | 10.468 | 8.671 | 7.194 | 5.778 |

The source of pollution was represented by six extracted components with a total variance of 69.313% (Table 3). The first component, 21.393% of the total variance, consisting of temperature, TDS, detergent, E. coli, and total coliform, described domestic activities and human fecal contamination. As identical sub-watershed in Yogyakarta Province, Code River showed a different pattern with the present study that COD and BOD$_5$ [21] classified the main organic compounds. The second, fourth, and sixth components, 15.809%, 8.671%, and 5.778% of the total variance, respectively, defined an industrial characteristic regarding Mn, Cd, Zn, Fe, Pb, Cu, pH, phenol, and oil and grease. Additionally, the third (10.468%) and
fifth (7.194%) components portrayed the contaminant from agriculture activities correlating with nitrate, nitrite, phosphate, ammonia, and DO parameters.

The selected components were loaded in the scatter plot imagined in Figure 6 for each location of the sub-watershed. In Figure 6a, the dots are centered in negative value both an x-axis and y-axis tend to disperse in a horizontal line (Component 1). The purple triangle (downstream), the green triangle (upstream), and the brown circle (middle stream) were represented by organic contaminants from domestic activities. It can be seen in Figure 6b, the points are more aligned with the x-axis than the y-axis, not only in the positive value but in the negative values. Most middle and downstream scatters represented component 2 (industrial activities) since the heavy metal was the primary source. As well as Figure 6c also presented the sources of organic contaminant from oil and grease and inorganic compound, cuprum (component 6). In addition, Figure 6d explains the organic compound from agriculture activities. The finding correlated with the cropland use in the upstream and lowest stream. Significantly, the downstream showed a more dispersed pattern into x-axis (component 3) and y-axis (component 5) than two others.

Figure 6. The load of components in scatter plot (a) organic compounds of domestic activities (b) inorganic compounds of industrial activities (c) metal compounds and (d) organic compounds of agricultural activities.
The presence of *E. coli* and total coliform in the water indicated that the water had been contaminated by human feces or animal waste [90]. The animal waste potentially originated from organic fertilizer used in an agricultural area, while the human feces were from black water contaminating the surface water. By observing the riverbank area of the Opak sub-watershed, several home industries (building area) were operated surrounding the water body, for instance, a jewelry plating home industry. The outlet of the kinds of industries was used to generate a point source of surface water contaminant. Based on land-use findings in the middle and downstream, the rapid settlements, hotels, restaurants, laundries, and so on, produced the domestic wastewater that is often directly discharged into the water body. Components 3 and 5 described nitrate, nitrite, phosphate, and ammonia parameters. The impact of agricultural activities would produce solid runoff from fertilizer containing nitrate and phosphate. The compounds flew into surface water and caused the rise in nutrients inside the river [114–116].

4. Conclusions

This study investigated the relationship between land use and river water quality in the Opak sub-watershed represented on Winongo River, Indonesia. The temporal (seasonal time) and spatial analysis were employed based on multivariate and GIS methods. By utilizing PCA analysis, three main kinds of pollutant sources were obtained, such as domestic, industrial, and agricultural activities that contributed and influenced the variance of river water quality. The different land uses exhibited a significant correlation of contaminant sources that ranged between 0.712 and 0.936 (0.05 significance level, \( p < 0.05 \)). This study also found that the water quality trend based on the concentration value has increased for all parameters spatially. The water quality tended to decline from upstream to downstream. While the seasonal trend of water quality fluctuated, this explained the local climate’s contribution to contaminant spreading and degrading. The findings of this study can be expanded to guide water quality management in the Opak sub-watershed and assist the stakeholders in selecting wastewater pollution control actions.

**Author Contributions:** Conceptualization: W.B. and A.A.A.; methodology: A.A.A.; validation: W.B., A.A.A., R.J., A.Y. and S.R.; formal analysis: A.A.A.; investigation: A.A.A.; resources: W.B. and A.A.A.; data curation: A.A.A., R.J. and S.R.; writing—original draft preparation: W.B. and A.A.A.; writing—review and editing: W.B. and A.A.A.; project administration: A.A.A.; funding acquisition: W.B. and A.A.A. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author. The data are not publicly available due to university’s policy.

**Acknowledgments:** The authors thank Direktorat Pengembangan Akademik, Universitas Islam Indonesia for financial support for publishing this article.

**Conflicts of Interest:** The authors declare no conflict of interest.

**References**


35. Susanti, P.D.; Miardini, A. The Impact of Land Use Change on Water Pollution Index of Kali Madiun Sub-Watershed. Forum Geogr. 2017, 31, 128–137. [CrossRef]
39. Nugoehro, S.; Akbar, S.; Vuvitasari, R. Kajian Hubungan Koefisien Korelasi Pearson ($r$), Spearman-Rho ($\rho$), Kendall-Tau ($\tau$), Gamma ($G$), And Somers ($Dxy$) [Study of Correlation between Pearson ($r$), Spearman-Rho ($\rho$), Kendall-Tau ($\tau$), Gamma ($G$), and Somers ($Dxy$) Coefficients]. J. Gradien 2008, 4, 372–381.


73. Egberongbe, H.O.; Bankole, M.O.; Popoola, T.O.S.; Olowofeso, O. Seasonal Variation of Enteric Bacteria Population in Surface Water Sources among Rural Communities of Ijebu North, Ogun State, Nigeria. Agro-Science 2021, 20, 81–85. [CrossRef]


78. Kinouchi, T.; Yagi, H.; Miyamoto, M. Increase in Stream Temperature Related to Anthropogenic Heat Input from Urban Wastewater. J. Hydrol. 2007, 335, 78–88. [CrossRef]


