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# The impacts of land use and cover change on water quality of watershed basin

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## ABSTRACT

**BACKGROUND AND OBJECTIVES:** Land use and cover change are the leading causes of water quality decline in a body of water. However, understanding spatial and temporal variability in land use and land cover change and its relationship with water quality parameters in the eucledian distance area is still limited. In order to address these constraints, the study explored the relationship between changes in land use and land cover and their effects on water quality parameters, including chemical, physical, and biological aspects, within the Upper Bekasi Watershed, West Java, Indonesia. This study aims to explore the connection between different types of land cover and the water quality of rivers within the designated.
**METHODS:** Water quality data of Upper Bekasi Watershed comes from six monitoring stations. The river water quality monitoring data period is 4 years, 2018-2022, excluding 2020. The monitoring process includes 15 parameters related to water quality, addressing chemical, physical, and biological charactristics. The water sub-catchment area employs a Euclidean distance-based approach, and land use and land cover classes are obtained based on Landsat image data processed using Geographic Information System. Measurement of Pearson correlation is carried out to determine whether there is a linear relationship between the and use and land cover change variable, considered an independent variable, and the water quality variable as a dependent variable. The primary purpose of principal component analysis is to ascertain the significant water parameters influencing the variability in the dataset. The calculation of the Pearson correlation coefficient and Principal component analysis use statistical package for the social sciences.
**FINDINGS:** The land use and land cover change class in the Upper Bekasi Watershed obtained five classes: built-up areas, agriculture and forests occupying more than 90 percent of the Upper Bekasi Watershed area. From 2018 to 2022, there was a 10.38 percent rise in the built-up area, in contrast to an 11.57 percent reduction in agricultural land. The concentration of nitrate, nitrite, phosphate, copper and fecal coliform experienced an increasing trend at all monitoring stations every year. Conversely, the river water quality standards were only satisfied by the total dissolved solids and nitrate parameters. A significant relationship exists between forest cover and levels of dissolved oxygen and phosphate, as well as between agricultural areas and nitrite and chemical oxygen demand. Additionally, built-up regions show a strong association with fecal coliform levels. The number of key component obtained three components: the first varifactors had a strong relationship with the total suspended solids, biochemical oxygen demand, and chemical oxygen demand, the second varifactor had a relationship with the total dissolved solids, and the third varifactor had a relationship with the potential of hydrogen and fecal coliform.
**CONCLUSION:** The correlation between land use and land cover changes and water quality in the Upper Bekasi watershed was quantified using the Pearson correlation coefficient and principal component analysis. The analysis revealed that changes in land use and land cover had a notable influence on the water quality within the Upper Bekasi watershed. The results of this study can be used as a basis for water quality management in the Upper Bekasi watershed to help stakeholders select intervention methods to control wastewater pollution.

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## INTRODUCTION

The Upper Bekasi Watershed is a vital area supporting the water needs of the surrounding communities. In the context of regional development and accelerated urbanization, changes in land cover within this watershed have become a prominent challenge. The occurrence of land use changes from natural land such as forests, agricultural land, or natural vegetation to urban, residential, and industrial areas significantly impacts the local ecosystem, especially on river water quality. The transformation of land use and development is shaped by various factors, including climate, topography, soil conditions, natural disasters, and human activities affecting a specific area. Such land use change and growth can degrade water quality, increase the volume and velocity of surface water, raise the frequency of floods, double the amount of water flowing through natural forests, destroy materials, and deplete groundwater (Setyowati, 2016). To successfully plan and manage watersheds, it is essential to grasp the connection between land use and land cover change (LULC) and water quality. This knowledge is vital for identifying how non-point source pollution affects water quality (Ding *et al.*, 2016). Runoff from catchment areas introduces land use-related pollutants that influence the connection between surface water quality and changes in land use/land cover (LULC) as it flows into rivers. These contaminants can be quantitatively correlated (Rodríguez-Romero *et al.*, 2018). Many studies have shown that there is a significant correlation between land use and water quality parameters such as studies conducted by Namugize *et al.* (2018) in the uMngeni river catchment, South Africa; Zhang *et al.* (2023) in Dianchi Lake Basin, Southwest of China; Clark *et al.* (2022) in the Almirante Bay catchment, Panama. Numerous studies have integrated Geographic Information System (GIS) analysis of land use and land cover (LULC) changes with correlation analysis to examine the relationship between these two variables through the Pearson Correlation coefficient (Thomas, 2023; Kadir *et al.*, 2022; Umwali *et al.*, 2021) and Spearman correlation (Ding *et al.*, 2015). In addition, the combination of Geographic Information System based analysis and LULC changes can also be used for multivariate statistical analysis to identify the main sources of surface water quality variability using principal component analysis (PCA) (Roy *et al.*, 2024; Benkov *et al.*, 2023; Yang *et al.*, 2020), cluster analysis (Varol, 2020) or a combination of both (Nong *et al.*, 2019). To date, there has been no investigation into how alterations in land use and land cover affect river water quality on a smaller scale. In this study, Euclidean distance was used at each monitoring station to see changes in LULC and its effect on water quality at the monitoring station. Utilizing the Euclidean distance method can result in research data that is both more specific and accurate. The water quality of rivers in the Upper Bekasi Watershed was analyzed in this study using both geographical and temporal trend analysis. The results of the analysis were subsequently utilized to identify which LULC types had a significant effect on particular water quality parameters. The aims of the current study is to examine the relationship between land cover types and river water quality in the Upper Bekasi Watershed. This study has been carried out at six monitoring stations in the Cileungsi River, Cikeas River and Upper Bekasi River from 2018-2022.

## MATERIALS AND METHODS

### *Study area*

The overall area of the Upper Bekasi Watershed is ±390 square kilometers ($km^2$) and located in three administrative areas, namely Bogor Regency, Bekasi City, and Depok City. Within the Upper Bekasi Watershed, three significant rivers can be identified, namely the Cikeas River, the Cileungsi River, and the Upper Bekasi River. The length of the Cikeas River is 49,924 meters (m), the longest in the Upper Bekasi Watershed. In comparison, the length of the Cileungsi River and the Upper Bekasi River are 41,829 m and 10,596 m, respectively. The Bekasi River will be formed by the confluence of the Cileungsi and Cikeas rivers, eventually reaching the northern coastline of Java (Pasisingi *et al.*, 2014). The climatic condition of the Upper Bekasi Watershed is a tropical monsoon climate with relatively constant humidity and temperature. Generally, the rainy season lasts from October through April, while the dry season is observed from May until September. The average temperature in the downstream portion of the Upper Bekasi Watershed, a lowland, is around 26 degrees Celsius (°C), while in the upstream part, which is a highland, the minimum air temperature is 20°C. The average humidity in the downstream part is about 70 percent (%), while in the upstream

part, it is about 80%. Average annual rainfall varies between 1,000 – 3,000 millimeters (mm). The local community makes significant use of the rivers in the Upper Bekasi Watershed for a range of activities, such as irrigation, sourcing drinking water, engaging in fisheries, and additional activities. The rising population and changes in land use contribute to a yearly deterioration in river water quality, a reduction in the width of river bodies, accelerated erosion, and sediment accumulation. Consequently, these issues often lead to flooding in several areas of the Upper Bekasi Watershed, especially at the confluence of the Cikeas and Cileungsi rivers. The Upper Bekasi watershed analyzed in this study consists of six monitoring stations. In the Cileungsi River basin, there are two monitoring stations, namely Sungai Cileungsi 1 (SCL1) and Sungai Cileungsi 2 (SCL2). Likewise, in the Cikeas River and the Upper Bekasi River, there are four monitoring stations, namely Sungai Cikeas 1 (SCK1), Sungai Cikeas 2 (SCK2), Kali Bekasi Hulu 1 (KBH1) and Kali Bekasi Hulu 2 (KBH2), and a description of the sampling points can be seen in Table 1. The location of all monitoring stations in the Upper Bekasi Watershed is shown in Fig. 1.

*Water quality data*

Data on the water quality of the Upper Bekasi watershed is gathered from observational data by

Table 1: Description of sampling points for water sampling stations

| Sample site | X-coordinate | Y-coordinate | Brief description of the site |
|---|---|---|---|
| SCL1 | 062713 | 1065527 | Upper stream (Gunung Putri), where the river is polluted with industry waste. |
| SCL2 | 062251 | 1065741 | At PDAM bridge of Kota Wisata, where the river is polluted with domestic waste, runoff etc. |
| SCK1 | 062221 | 1065627 | At Mayor Oking, where the river is polluted with domestic waste, runoff etc. |
| SCK2 | 062850 | 1065204 | At Nagrak, where the river is polluted with domestic waste, runoff etc. |
| KBH1 | 061650 | 1065859 | At Kemang Pratama, where the river is polluted with domestic waste, runoff etc. |
| KBH2 | 061459 | 1065951 | The site downstream at Bekasi dam. |

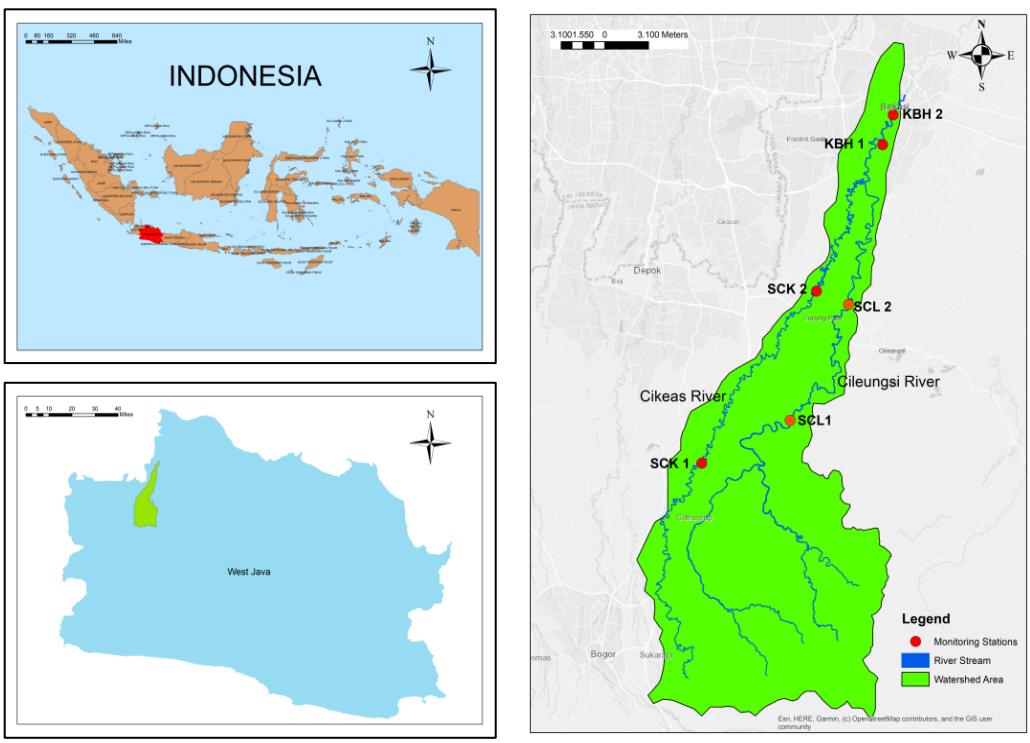


Fig. 1: Geographical location of the study area in the upper Bekasi watershed and water monitoring stations, West Java, Indonesia

Balai Besar Wilayah Sungai Ciliwung Cisadane (BBWS CC/ the River Basin Organization for Ciliwung Cisadane, the Ministry of Public Works and Housing), and Dinas Lingkungan Hidup (DLH/Environmental Agency) Bekasi City. Covering a period of four years, the Upper Bekasi Watershed water quality data set includes data from 2018 to 2022, with the exception of 2020. This was due to the Coronavirus-2019 (COVID-19) pandemic 2020, which prevented riveriwateriquality monitoring inithe Upper Bekasi Watershed. While short-term variations may not be entirely represented by sampling events, the study encompasses multiple years (2018–2022), thus delivering an extensive perspective on the trends in water quality. This temporal scope enables us to identify consistent patterns and relationships between land use changes and water quality. The sampling frequency during this period varied from two to three times yearly. Water sampling was planned to occur 2 to 4 times each year, a decision influenced by the logistical and resource challenges typically associated with large-scale field studies. Additionally, this frequency aligns with standard practices in similar studies conducted in tropical river systems, where significant trends can often be observed over longer timescales. Field sampling begins in the morning until the afternoon. Correspondingly, the measurement of river water temperature occurs concurrently with the sampling, which results in the recorded temperature being influenced by the ambient temperature during the sampling process. The sampling technique based on the scope of work is that river water quality sampling is carried out momentarily, according to the specified time. For each location, a composite sampling is carried out (mixing locations on both banks of the river and the middle, according to Standard National Indonesia (SNI): 8995: 2021. The quantity of samples collected for both field and laboratory analysis is determined by the nature of the examination being conducted. To examine the physical and chemical properties of water, approximately 3 liters are required. Sampling points are chosen based on activities that may contribute to river water pollution, including both industrial and residential practices. The observed parameters are: 1) Physics parameters: T, total dissolved solids (TDS), total suspended solids (TSS). 2) Chemical parameters: potential of hydrogen (pH), biochemical oxygen demand (BOD), chemical oxygen demand (COD), DO, nitrate ($NO_3$), nitrite ($NO_2$), $PO_4$, iron (Fe), cobalt (Co), zinc (Zn), copper (Cu). 3). Biological parameters: Fecal coliform (FC). The measurement of these parameters is categorized into two conditions: in situ measurements and laboratory analyses. In situ sampling was conducted using direct measurement techniques. pH and temperature samples are measured directly, while other parameters are measured through laboratory tests. Additionally, all chemical, physical, and biological characteristics were sampled using approved standard procedures by KAN No.LP-195-IDN and analyzed following international standards in an International Organization for Standardization (ISO 9001) accredited testing laboratory.

*LULC information*

Several public and private organizations provided the historical LULC maps used in this investigation. To ascertain the percentage of each LULC class in the Upper Bekasi Watershed, the maps were processed using Geographic Information System (ArcGIS Pro) to correlate the land cover classifications from different sources.

*Statistical analysis*

Descriptive statistical methods were used to determine the Mean, Standard error (SE), Median, Standard deviation, Skewness, Kurtosis, Range, Minimum and Maximum of river water quality at different periods, as seen in Table 2. In this study, the standards for river water quality are aligned with Government Regulation Number 22 of 2021, which pertains to the Implementation of Environmental Protection and Management, specifically detailed in Appendix 6. In the Upper Bekasi Watershed, encompassing the Cileungsi River, Cikeas River, and Bekasi River, the water quality is classified as class 2.

Following the approach of Giao *et al.* (2021), the Pearson correlation was conducted to ascertain whether the water quality variable, which was the dependent variable, and the LULC variable, which was deemed the independent variable, had a linear relationship. Utilizing the Pearson correlation coefficient through SPSS-25 can enhance our understanding of the relationship between two variables, clarifying whether their association is positive, negative, or absent. Based on the Pearson correlation coefficient, the relationship between two variables is considered very strong, strong,

Table 2: Summary of water quality in Upper Bekasi Watershed from six monitoring stations 2018–2022

| Parameter unit | T °C | pH | TDS Milligram per liter (mg/L) | TSS mg/L | BOD mg/L | COD mg/L | DO mg/L | $NO_3$ mg/L | $NO_2$ mg/L | $PO_4$ mg/L | Fe mg/L | Co mg/L | Zn mg/L | Cu mg/L | Fecal coliform (FC) Most probable number (MPN) /100mL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 28.57 | 7.06 | 176.13 | 128.82 | 10.67 | 31.40 | 3.57 | 0.915 | 0.069 | 0.474 | 0.139 | 0.009 | 0.028 | 0.026 | 29899.68 |
| Standard error | 0.16 | 0.06 | 8.68 | 56.14 | 1.07 | 2.85 | 0.15 | 0.084 | 0.008 | 0.032 | 0.029 | 0.001 | 0.003 | 0.003 | 6973.06 |
| Median | 28.90 | 7.00 | 160.00 | 38.00 | 8.00 | 23.90 | 4.00 | 0.790 | 0.050 | 0.500 | 0.030 | 0.010 | 0.020 | 0.015 | 10000.00 |
| Standard deviation | 1.51 | 0.55 | 80.95 | 523.65 | 9.98 | 26.62 | 1.40 | 0.786 | 0.073 | 0.299 | 0.270 | 0.009 | 0.024 | 0.027 | 65040.34 |
| Skewness | -0.30 | 0.16 | 0.72 | 8.79 | 3.68 | 2.85 | 0.14 | 1.828 | 1.958 | 0.123 | 3.628 | 2.395 | 0.985 | 0.705 | 6.02 |
| Kurtosis | 0.71 | -0.06 | -0.01 | 80.00 | 17.95 | 11.87 | 0.16 | 6.010 | 5.264 | -0.93 | 15.455 | 6.100 | -0.17 | -1.31 | 43.42 |
| Range | 7.90 | 2.70 | 352.00 | 4858.00 | 70.91 | 177.95 | 6.71 | 4.756 | 0.398 | 1.232 | 1.712 | 0.039 | 0.099 | 0.069 | 533999.00 |
| Minimum | 24.80 | 5.60 | 59.00 | 2.00 | 2.09 | 5.05 | 0.50 | 0.064 | 0.002 | 0.018 | 0.008 | 0.001 | 0.001 | 0.001 | 1.00 |
| Maximum | 32.70 | 8.30 | 411.00 | 4860.00 | 73.00 | 183.00 | 7.21 | 4.820 | 0.400 | 1.250 | 1.720 | 0.040 | 0.100 | 0.070 | 534000.00 |
| Quality standard (class 2) | ±3°C | 6.0-9.0 | 1000.00 | 50.00 | 3.00 | 25.00 | Min. 4 | 10.000 | 0.060 | 0.200 | 0.000 | 0.200 | 0.050 | 0.020 | 1000.00 |

Table 3: LULC classification

| LULC type | Code |
|---|---|
| Build up area | BA |
| Industry | IN |
| Agriculture | AG |
| Forest | FO |
| Open land | OL |

moderately strong, low and very low depending on whether the absolute value of r is 1-0.80, 0.799-0.6, 0.599-0.40, 0.399-0.20, and 0.199-0.00, respectively. An analysis was conducted on the annual average concentrations of various water quality parameters at each monitoring station for the years 2018, 2019, 2021, and 2022, followed by a correlation with the LULC information from those same years. PCA was used to determine the main water parameters in the data set's variation. This technique facilitates the minimization of baseline parameters that do not substantially influence data variability, leading to the development of a new set of parameters referred to as key components or factors (PC). PCA was applied to the dataset to identify the most representative water quality parameters that better explain the sources of variance (Paná *et al.*, 2024). The eigenvalue associated with each factor is utilized to determine the principal components. A higher eigenvalue indicates a greater contribution to explaining the variability within the original dataset. Principal components extracted from the analysis to have eigenvalues greater than 1 to be further analyzed. The research employed the varimax rotation technique, leading to the identification of varifactors (VFs) that elucidate the water quality parameters most significantly influencing the variability observed in the water quality data. The validity of the PCA results was evaluated with the Kaiser–Meyer–Olkin (KMO) test and Bartlett's test of sphericity. High values close to 1.0 in the KMO test and small values (less than 0.05 of the significance level) in Bartlett's test indicate that PCA might be helpful to apply to the water quality data (Pratama *et al.*, 2020). This study employs Pearson correlation and PCA to reveal important associations between changes in LULC and various water quality parameters. This dual statistical approach not only strengthens the findings but also identifies key pollution drivers and their specific impacts on water quality.

*Land use and land cover reclassification*

In contrast to the prevalent studies that focus on the influence of LULC changes on water quality across extensive watershed or sub-watershed areas, this study utilizes a Euclidean distance-based approach. This method allows a more localized and precise correlation between LULC changes and water quality parameters at specific monitoring stations. The study involved the calculation of the proportion of land use types contributing to the sampling location through the delineation of Euclidean distance from each of the six monitoring stations. Euclidean distance was determined along 500 m at the monitoring station buffer (left and right of the monitoring station) and 1 kilometers (km) upstream at each monitoring station. The Geospatial Information Agency provided the land use data from 2018 to 2022, along with the drainage network and digital elevation model (DEM) data. LULC classification was performed using the guided classification method on Landsat data. Utilizing ArcGIS Pro, the maximum likelihood classification technique assigns each pixel to the class with the highest probability or similarity, relying on the information obtained from the designated training areas. Following successful extraction, LULC was classified using the Indonesian National Standard (SNI-7645-1-2014), which classifies LULC into five cover types, as shown in Table 3.

## RESULTS AND DISCUSSION

*Spatial trend of upper Bekasi watershed quality*

Water temperature at the six monitoring stations (SCL1, SCL2, SCK1, SCK2, KBH1 and KBH2) fluctuates greatly and there is no significant difference in the range of 24.80 - 32.70°C. River water temperature fluctuations are shaped by the discharge of industrial waste and are also influenced by various weather and climate factors (Wiriani *et al.*, 2018). While temperature itself does not have a direct impact on

health, it plays a significant role in the activity of microorganisms, the equilibrium of chemicals, and the increased solubility of different compounds. TDS is the portion of organic and non-organic solids that are able to pass through filters that have pores ≤2 micrometers in size (Butler and Ford, 2018). Based on Fig. 2, it can be seen that the TDS concentration at stations SCK1 and SCK 2 is the lowest compared to the other four monitoring stations, but the TDS concentration at all monitoring stations is remaining below the river water quality standard for class 2 referring to Peraturan Pemerintah (PP) No. 22 of 2021 which is 1000 mg/L. Syawal *et al.* (2016) indicated that elevated levels of organic matter contamination are associated with low total dissolved solids (TDS), suggesting that this phenomenon occurs due to the precipitation of dissolved minerals or their transformation into colloids. The concentrations of TSS, BOD and COD in this study were found to be very high and very significant compared to the average concentrations at other monitoring stations. At SCK2 there are large concentrations of TSS of 4860.00 mg/L, BOD of 73.00 mg/L and COD of 183.00 mg/L. This SCK2 monitoring station is the downstream part of the Cikeas River which is in the Upper Bekasi Watershed. Water quality in the Cikeas River is strongly influenced by anthropogenic activities in the form of settlements and housing complexes along the Cikeas River (Effendi *et al.*, 2021). The introduction of organic matter from restaurant activities, agricultural

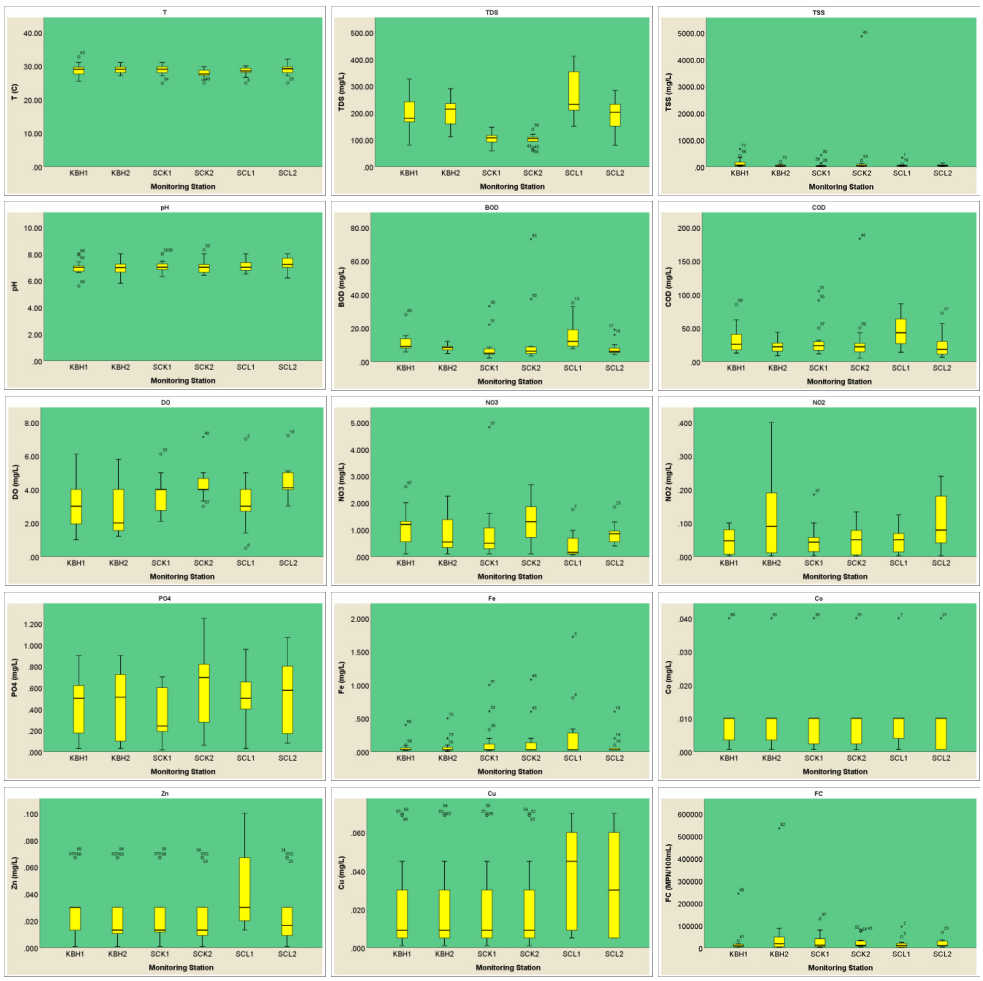


Fig. 2: The spatial trend of water quality in upper Bekasi Watershed

practices, and plantation operations may lead to elevated TSS, BOD, and COD levels in the Cikeas River. Residential settlements are the largest contributor of waste and increase organic matter to the river (Supardi *et al.*, 2017). Furthermore, elevated levels of organic matter in river water can stimulate microbial activity, leading to the breakdown of this matter into organic acid compounds through both aerobic and anaerobic processes. This decomposition can result in the production of unpleasant gases such as methane (CH4), ammonia (NH3), and hydrogen sulfide (H2S) (Ariani *et al.*, 2021). The pH level of river waters in the Upper Bekasi Watershed fluctuates in the range of 5.60-8.30 where generally the river pH ranges from 4-9 (Siahaan *et al.*, 2011). The pH of river water can be affected by rainfall and waste water entering the waters (Ramadhawati *et al.*, 2021). Supriatin *et al.* (2017) indicated that increased rainfall correlates with a decrease in the pH of rainwater, making it more acidic. This phenomenon occurs because heavy rainfall effectively removes airborne pollutants, such as sulfates and nitrates, which in turn influences the pH levels of the rainwater. DO is an importantiparameter for the survival of all aquatic organisms (Yaakub *et al.*, 2018). The DO concentration in the waters of the Upper Bekasi watershed fluctuates in the range of 0.50-7.10 mg/L. The concentration of DO is influenced by several factors, including water temperature, hydrometeorological conditions, and the rates of biological processes such as respiration, photosynthesis, and the decomposition of organic matter (Rajwa-Kuligiewicz *et al.*, 2015). $NO_3$ concentration was found to be 0.064-4.820 mg/L and remaining below the river water quality requirement for class 2 set at 10 mg/L. Water temperature, precipitation, and discharge levels all play a significant role in determining the distribution of NO3 concentration (Sutrisno *et al.*, 2018). Point sources of pollution such as industrial and domestic wastewater and the heavy use of fertilizers in agriculture can cause an increase in $NO_3$ in river water (Zhang *et al.*, 2021). $NO_2$ concentrations at all monitoring stations exceeded the river water quality standard ofi0.06 mg/L.

Nitrogen in $NO_2$ is in a relatively unstable oxidized form and $NO_2$ has a high level of toxicity for living things so that it can cause methaemoglobinaemia, cyanosis and asphyxia at higher concentrations (Sato *et al.*, 2018). The detection of $NO_2$ in river water indicates the active biological decomposition of organic material, which is associated with significantly low levels of DO (Effendi, 2003). Among the chemical factors influencing the quality of water is the $PO_4$ parameter. The concentration of $PO_4$ in the waters of the Upper Bekasi Watershed is in the range of 0.018-1.250 mg/L. The entry of $PO_4$ into a water body naturally can be caused through the process of rock weathering into $PO_4$ minerals (Wulandari *et al.*, 2021), agricultural waste in the form of phosphorus-based inorganic fertilizers (Patricia *et al.*, 2018) as well as the application of detergents (Wiriani *et al.*, 2018). The presence of the PO4 parameter is regarded as toxic because it includes nitrogen, a substance that can encourage the growth of algae, resulting in algal blooms (Karima and Kaswanto, 2017). The heavy metal parameters studied in this study are Fe, Co, Zn and Cu where these four metals are pollutants in water bodies. The presence of Fe metal is derived from the weathered rocks and crustal materials. In contrast, Co and Zn metals primarily originate from human activities, including industrial waste, coal combustion, and vehicle emissions. Additionally, Co metal can be sourced from both anthropogenic activities and natural occurrences (Chai *et al.*, 2021). When seen in Fig. 2, the highest average heavy metal concentration is at SCL1. Station SCL1 is the upstream part of the Cileungsi River where there are many industries around it that affect the river Cileungsi's water quality (Effendi *et al.*, 2021The extensive mining operations in the upper reaches of the Cileungsi River also play a significant role in this influence. The heavy metals Fe and Zn found in aquatic ecosystems can accumulate in water hyacinth plants and goldfish (Riani *et al.*, 2024) and Pennahia argentata is one of the fish commonly consumed in Southeast Asia (Takarina *et al.*, 2023). The European Environmental Agency has identified FCias as a key microbiological indicator for assessing the quality of drinking water (Zhang *et al.*, 2020). *Escherichia coli* (*E. coli)* bacteria are FC bacteria that are used as sanitation parameters in general because *E. coli* bacteria are indicators of fecal pollution and pathogenic bacteria in food and water and detection is easier and cheaper than detection of pathogenic bacteria. It is well-documented that specific strains of E. coli bacteria can be pathogenic, exhibiting symptoms that are akin to those of cholera and shigellosis (Soewandita and Sudiana, 2018). FC was found at all monitoring stations in the waters of

the Upper Bekasi Watershed and exceeded the class 2 river water quality standard set at 1,000 MPN/100 mL. The highest FC concentrations were in KBH1 and KBH2 where KBH1 is upstream of the Bekasi River, while KBH2 is downstream of the Bekasi River. The Bekasi River originates from the merging of the Cileungsi River and Cikeas River. The Bekasi River flows through low-lying areas, surrounded by numerous residential communities and housing developments. Based on the results of Li *et al.* (2022) research, urban domestic waste and agricultural activities are the main sources of FC pollution in the river.

*Temporal Trend of Upper Bekasi Watershed Quality*

Based on the temporal trend analysis from 2018-2022, there are several parameters with increasing concentration trends, namely $NO_3$, $NO_2$, $PO_4$, Cu and FC as presented in Fig. 3. The parameters exhibiting a declining concentration trend include DO, whereas the other parameters display fluctuations on an annual basis. The water temperature in the Upper Bekasi Watershed is affected by the climate during river water sampling. The study area experiences only two distinct seasons: the dry season and the rainy season. Consequently, water temperature readings taken during the dry season tend to be higher. Conversely, when sampling is done during the rainy season, the water temperature becomes lower. Annually, there is a reduction in the concentration of dissolved oxygen within the waters of the Upper Bekasi Watershed. Rajesh and Rehana (2022) stated that the ecosystem's health in river water bodies is determined by the proportion of DO, so this needs to be a concern in carrying out watershed management. COD, BOD and TSS parameters in the waters fluctuate annually, indicating the consistency of domestic and industrial wastewater entering the waters. The concentrations of NO3, NO2, and PO4 have risen annually, attributed to the growing levels of organic matter in the water. This increase in organic content subsequently elevates the amounts of nitrogen, PO4, and other inorganic nutrients, which are recycled to nourish phytoplankton, potentially resulting in eutrophication in aquatic environments. The overflow of river water from the mainland that transports nutrients and organic waste discharges due to household, agricultural and industrial activities is an organic matter source entering the waterways. From 2018 to 2022, there was an increase in the concentration of copper in the waters of the Upper Bekasi Watershed. Cu metal is a heavy metal that is not biodegradable and tends to accumulate in living organisms and is carcinogenic. Cu metal is a micronutrient that, along with other proteins and enzymes, is crucial for the creation of bones. However, at larger doses, Cu metal can have extremely harmful effects (Ding *et al.*, 2014). The sources of Cu metal pollution are diverse and include waste from several industrial sectors, such as metal cleaning and coating baths, fertilizer manufacturing, paperboard production, paint and pigment industries, mining, smelting, petroleum refining, brass rinsing, wood pulp production, and the fabrication of printed circuit boards (Arbabi and Golshani, 2016).

FC concentrations from 2018-2022 also increased. The lowest FC concentration was 1.00 MPN/100mL and the highest was 534,000.00 MPN/100mL. The occurrence of FC in the Upper Bekasi watershed raises significant concerns, particularly since the average concentration at all monitoring locations is above the acceptable limits for class 2 river water quality. In addition, exposure to FC bacteria directly increases the health risk for residents in the Upper Bekasi watershed. A time series is a collection of data points that are usually measured at regular intervals between one another (Parmar and Bhardwaj, 2014). The field of time series analysis encompasses various methods aimed at evaluating time-ordered data to uncover valuable statistics and attributes, while also facilitating the forecasting of future events grounded in previously observed data, allowing for the anticipation of data points before they are recorded. The time series model reflects that observations are more closely related together in time than observations further apart. The time series for all monitoring stations for river water quality parameters in 2018-2022 is presented in Fig. 4.

The findings of the study indicated that seasonal fluctuations affected the time series data at multiple monitoring stations concerning water quality parameters. This time series can be seen in the time series of T, TDS and pH parameters where the trend in February the measured values were lower than in other months, while in August, the T, TDS and pH values were higher. The analysis of the time series for TSS, BOD, and COD parameters revealed a stable trend. There was no fluctuation, but there was a similarity in the presence of very high pollution by

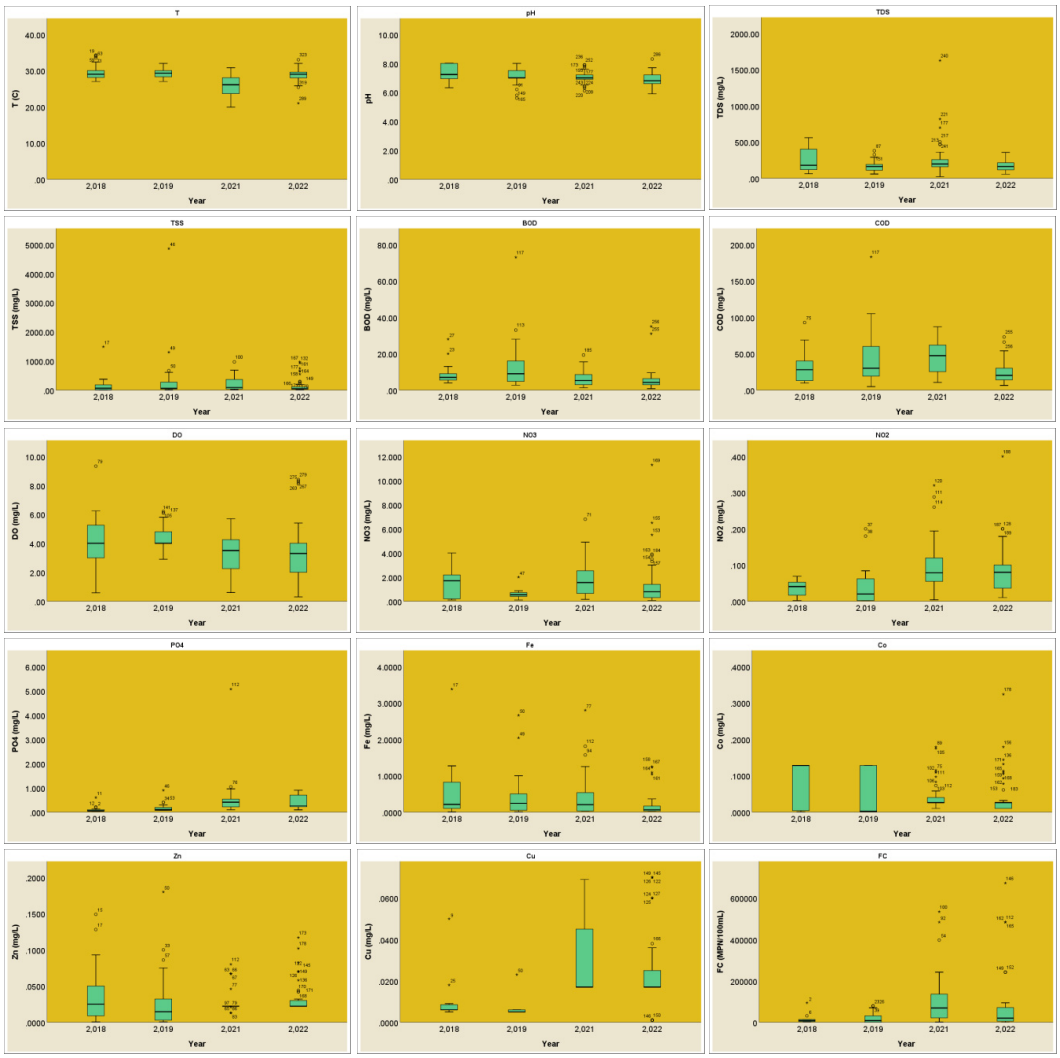


Fig. 3: Temporal trend of the water quality in Upper Bekasi Watershed

the three parameters in February 2019 at SCK2. The $NO_3$, $NO_2$, and FC parameters have a time series that fluctuates over time and at the same time, there was very significant pollution in August 2021. The time series data for heavy metals, including Co, Zn, and Cu, revealed elevated pollutant levels in February 2021, which subsequently decreased in 2022. Unlike the time series for the DO and $PO_4$ parameters, which have irregular variations, the time series for the Fe parameter obtained a high concentration in February 2019. Then, they stagnated from February 2021 to November 2022. In this study, there was no water quality in the Upper Bekasi watershed in 2020 due to the COVID-19 pandemic. The decision to exclude data from 2020 was influenced by the logistical difficulties presented by the COVID-19 pandemic, which limited field sampling efforts. It is possible that 2020 exhibited distinct pollution patterns as a result of decreased industrial and human activities during the lockdown periods. However, as this study focuses on long-term trends (2018–2022) and the relationship between land use changes and water quality, the absence of one year of data is unlikely to affect the robustness of the observed correlations significantly. In order to limit bias, the analysis focuses on the available multi-year data, omitting 2020, to revea consistent trends.




Fig. 4: Time series of water quality parameters at six monitoring station of the Upper Bekasi Watershed

*LULC Changes*

The categorization of LULC in the Upper Bekasi Watershed was carried out alongside the water quality monitoring efforts during the period of 2018 to 2022, with the exception of 2020. The LULC classification in the Upper Bekasi Watershed consists of five classes, namely build-up area (BA), industry (IN), agriculture (AG), forest (FO), and open land (OL) with the distribution of LULC shown in Table 4, while Fig. 5 illustrates the LULC classification results based on the Euclidean distance from each water monitoring station in the Upper Bekasi Watershed. The main land cover in the entire Upper Bekasi Watershed based on Table 4 is BA with an area of 37.46 - 47.84%, AG with an area of 13.16 - 36.18% and FO with an area of 13.38 - 29.89% of the total area of the Upper Bekasi Watershed.

The BA class shows an increase in area in the 2018-2022 period of 10.38% of the total area of the Upper Bekasi Watershed. The development of constructed environments results in a higher prevalence of impervious surfaces, including streets, building tops, and paved areas. These surfaces prevent water infiltration into the soil, leading to increased surface runoff. Meanwhile, the negative trend is shown by the AG and OL classes where there was a decrease in area by 11.57% and 4.59% during the 2018-2022 period. Changes in land use, such as the conversion of agricultural and open land into urban developments or industrial zones, can lead to a

Table 4: Distribution of LULC changes in DAS upper Bekasi from 2018 to 2022

| | | 2018 | | 2019 | | 2021 | | 2022 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Area | Area | Area | Area | Area | Area | Area | Area | % of change |
| No | LULC Class | $Km^2$ | % | $Km^2$ | % | $Km^2$ | % | $Km^2$ | % | 2018-2022 |
| 1 | Build up Area | 147.1 | 37.46 | 159.9 | 40.71 | 172.6 | 44.00 | 187.8 | 47.84 | 10.38 |
| 2 | Industry | 7.2 | 1.84 | 8.5 | 2.16 | 8.1 | 2.06 | 11.1 | 2.81 | 0.97 |
| 3 | Agriculture | 106.6 | 27.13 | 142.1 | 36.18 | 51.6 | 13.16 | 61.1 | 15.56 | -11.57 |
| 4 | Forest | 98.5 | 25.09 | 52.5 | 13.38 | 98.0 | 24.98 | 117.4 | 29.89 | 4.80 |
| 5 | Open Land | 33.3 | 8.49 | 29.7 | 7.57 | 62.4 | 15.80 | 15.3 | 3.90 | -4.59 |
| | Total | 393 | 100.00 | 393 | 100.00 | 393 | 100.00 | 393 | 100.00 | |

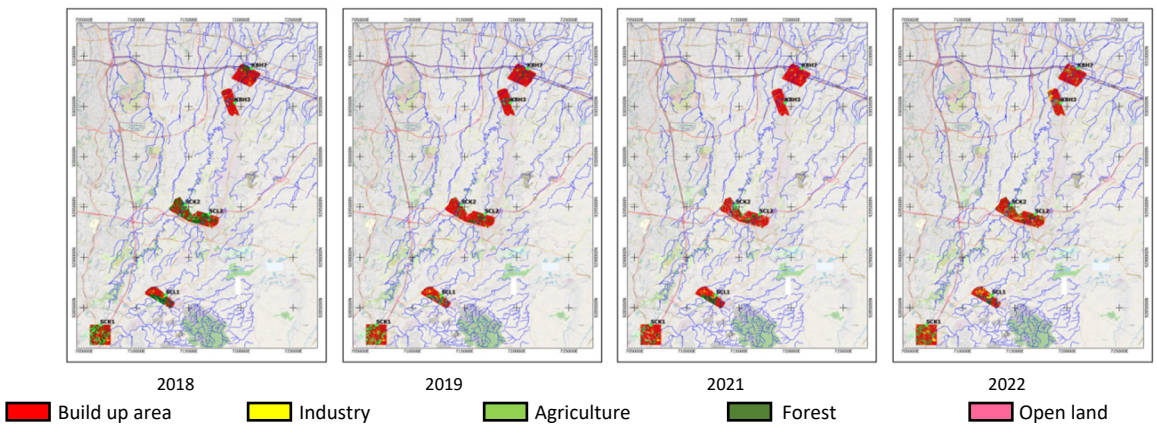


Fig. 5: LULC classification of the Upper Bekasi watershed in 2018–2022

decrease in available area Kaswanto *et al.* (2021) stated that population size and population density are some of the factors driving changes in land cover. As depicted in Fig. 6, the area of each land cover class obtained from the Euclidean distance is subsequently expressed as a percentage of the total area for each class. The land cover class determined is the same as the land cover class studied in the Upper Bekasi Watershed, namely five classes with a period of 2018-2022 (excluding 2020). Based on the percentage of land use distribution in Fig. 6, KBH1 and KBH2 stations have the largest built-up area compared to other monitoring stations. This situation arises from the fact that the two stations are positioned downstream of the Cileungsi and Cikeas Rivers, in an area with a relatively level topography. Consequently, the vicinity is largely occupied by residential areas, housing complexes, and business establishments. In addition, the Upper Bekasi River is also located in an urban area so that changes in land cover tend to increase built-up land as a consequence of regional development (Husodo *et al.*, 2021).

The largest industrial land use class is in SCL1 in the 2022 period of 9.29% of the Euclidean distance area of SCL1 station. SCL1 station is located in the upstream part of the Cileungsi River where there is a dense industrial area around the Cibinong Cement Factory, Holcim Cement Factory and the Branta-Mulia industrial area (Djamudin *et al.*, 2012). A significant decrease in land cover area occurred in forest land where in 2018 the forest area ranged from 10.37 - 36.80%, while in 2022 the forest area was only in the range of 0.72 - 12.68%. Acting as natural shields, forests diminish the speed of runoff, cleanse pollutants, and help maintain river temperatures through their shading effects. Deforestation in upstream areas undermines these ecological services, leading to heightened pollutant concentrations and thermal stress within aquatic environments. Changes in land cover can be caused by changes in the function of forest land into built-up land, open land and agricultural land that can

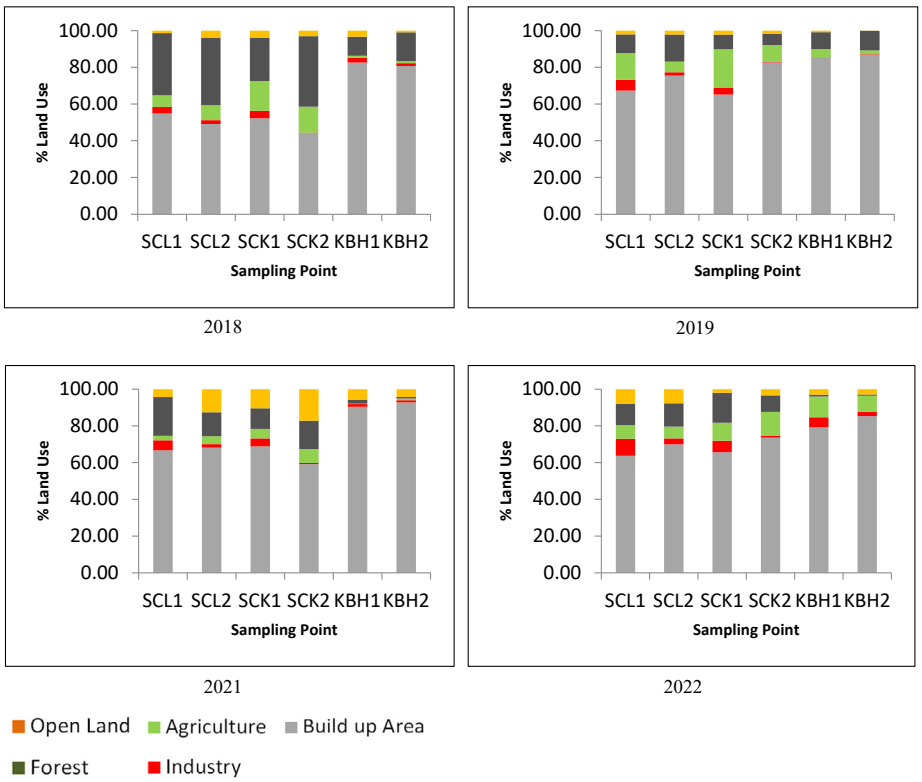


Fig. 6: Percentage of land use distribution in six sampling points for 2018-2022

be used directly for anthropogenic activities.

*Correlation analysis between the LULC changes and water quality*

The correlation between LULC changes and water quality in the Upper Bekasi Watershed was quantified using the Pearson correlation coefficient. The correlation between annual LULC changes in the six Euclidean distance areas and each water quality parameter was examined, and the results are detailed in Table 5. In the Cileungsi River waters, there are two monitoring stations, namely SCL1 and SCL2. At both stations, a very strong correlation was obtained between BA and $NO_3$ and Fe parameters of 0.974 and -0.902. Then there was also a strong and significant correlation between AG and TDS and COD parameters at SCL1 of -0.937 and 0.984, while SCL2 had no significant correlation with other parameters. The robust connection between AG and COD is probably a result of agrochemical usage, with substances like fertilizers, pesticides, fungicides, and herbicides infiltrating agricultural areas (Setyowati, 2016). For this reason, the nutrient management plans needed to optimize fertilizer application, reducing excess nutrient runoff into water bodies. A very strong correlation was also seen between FO and the parameters pH, $NO_2$ and Fe with coefficient values of 0.911, -0.907 and 0.956 respectively. This study includes two monitoring stations, SCK1 and SCK2, located along the flow of the Cikeas River. The Pearson correlation coefficient obtained a very strong correlation between BA and TDS at SCK1, while at SCK2 there was no significant relationship between BA and other parameters.

In line with Rahman *et al.* (2014) research, it was found thatithe type of residential land use has a positive relationship with TDS, where this relationship shows that the larger proportion of settlements has the potential to increase TDS values logarithmically. In SCK1, a very strong negative relationship was obtained between AG and the parameters $NO_2$, Co, and Zn with coefficient values of -1,000, -0.954, and -0.912. This is consistent with the study conducted by Putri *et al.* (2021), which demonstrates a negative correlation between the NO2 parameter and the extent of

Table 5: Pearson correlation coefficients between the LULC and water quality parameters

| Parameter | SCL1 | | | SCL2 | | | SCK1 | | | SCK2 | | | KBH1 | | | KBH2 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BA | AG | FO | BA | AG | FO | BA | AG | FO | BA | AG | FO | BA | AG | FO | BA | AG | FO |
| T | -0.714 | 0.291 | 0.535 | 0.474 | -0.390 | -0.435 | 0.846 | 0.034 | **-.989*** | 0.305 | -0.216 | -0.075 | 0.377 | -0.516 | 0.829 | -0.583 | -0.437 | **.922*** |
| pH | -0.671 | -0.42 | **.911*** | -0.371 | 0.229 | 0.523 | -0.681 | 0.718 | 0.126 | -0.830 | 0.367 | **.929*** | 0.205 | -0.621 | 0.098 | -0.425 | -0.601 | 0.590 |
| TDS | -0.054 | **-.937*** | 0.863 | 0.526 | -0.588 | -0.512 | **.914*** | -0.702 | -0.495 | 0.386 | -0.226 | -0.610 | 0.388 | -0.083 | 0.317 | 0.510 | 0.629 | **-.951*** |
| TSS | -0.819 | -0.26 | 0.796 | -0.738 | 0.793 | 0.676 | 0.098 | 0.834 | -0.569 | 0.708 | -0.392 | -0.521 | 0.402 | -0.026 | -0.869 | -0.398 | 0.035 | 0.539 |
| BOD | -0.131 | 0.428 | -0.804 | 0.200 | -0.121 | -0.149 | 0.013 | 0.865 | -0.538 | 0.689 | -0.364 | -0.493 | 0.671 | -0.380 | 0.308 | -0.852 | 0.097 | 0.774 |
| COD | -0.380 | **.984*** | -0.620 | 0.069 | -0.032 | 0.071 | 0.083 | 0.738 | -0.650 | 0.598 | -0.411 | -0.412 | 0.658 | -0.540 | 0.533 | -0.468 | -0.715 | **.948*** |
| DO | -0.170 | 0.03 | 0.649 | -0.494 | 0.348 | 0.748 | -0.154 | 0.727 | 0.014 | 0.628 | -0.751 | -0.576 | 0.061 | -0.555 | **.994*** | -0.489 | -0.673 | **.951*** |
| $NO_3$ | **.974*** | -0.44 | -0.161 | 0.773 | -0.802 | -0.766 | 0.683 | -0.851 | -0.418 | 0.332 | -0.711 | -0.628 | 0.463 | 0.039 | -0.890 | 0.857 | 0.149 | **-.913*** |
| $NO_2$ | 0.466 | -0.78 | 0.033 | 0.819 | -0.718 | **-.907*** | 0.490 | **-1.000*** | 0.012 | -0.133 | -0.216 | -0.176 | -0.463 | 0.712 | -0.868 | 0.539 | 0.570 | **-.949*** |
| $PO_4$ | 0.860 | -0.55 | -0.219 | 0.518 | -0.498 | -0.682 | -0.026 | -0.418 | 0.566 | 0.661 | -0.226 | -0.799 | -0.234 | 0.714 | **-.952*** | 0.434 | 0.767 | **-.936*** |
| Fe | -0.797 | 0.158 | 0.626 | **-.902*** | 0.874 | **.956*** | -0.527 | **.956*** | -0.054 | 0.028 | 0.146 | 0.256 | 0.043 | -0.174 | 0.813 | -0.395 | -0.430 | 0.803 |
| Co | 0.812 | -0.73 | 0.047 | 0.563 | -0.653 | -0.457 | 0.635 | **-.954*** | -0.237 | -0.112 | -0.512 | -0.225 | 0.544 | -0.157 | -0.799 | 0.749 | -0.002 | -0.783 |
| Zn | 0.866 | 0.258 | -0.711 | 0.613 | -0.657 | -0.623 | 0.778 | **-.912*** | -0.302 | 0.068 | -0.366 | -0.377 | 0.240 | 0.086 | **-.901*** | 0.717 | 0.347 | **-.950*** |
| Cu | 0.576 | -0.62 | -0.193 | 0.504 | -0.528 | -0.585 | 0.570 | -0.876 | -0.297 | -0.189 | -0.631 | -0.145 | 0.709 | -0.360 | -0.653 | 0.846 | -0.208 | -0.698 |
| FC | -0.686 | -0.13 | 0.829 | 0.719 | -0.766 | -0.437 | 0.568 | 0.003 | -0.877 | 0.896 | -0.760 | **-.961*** | **.907*** | -0.592 | -0.392 | 0.882 | -0.438 | -0.536 |

*Statistically significant

Table 6: Three extracted VFs from the 6 parameters of water quality

| Parameter | VF1 | VF2 | VF3 |
|---|---|---|---|
| TSS | 0.804 | | |
| BOD | 0.971 | | |
| COD | 0.929 | | |
| TDS | | 0.923 | |
| pH | | | 0.751 |
| FC | | | 0.722 |
| Eigenvalue | 2.491 | 1.102 | 1.091 |
| % of variance | 41.510 | 18.367 | 18.181 |
| Cumulative % | 41.510 | 59.877 | 78.057 |

agricultural land. In other words, larger agricultural areas are associated with lower concentrations of NO2 in aquatic environments. It is assumed that the conversion of $NO_2$ to $NO_3$ in the nitrogen cycle is rapid. However, at this monitoring station, AG has a very strong positive correlation with the Fe parameter. In addition, in the Cikeas River waters, a very strong negative relationship was found between FO and the temperature parameter of -0.989 and the FC parameter of -0.961. In a negative relationship, an increase in one variable leads to a reduction in the other. Consequently, a larger forest area in SCK1 correlates with a lower temperature of the river water. Vegetation cover in forested regions plays a crucial role in lessening the amount of sunlight that penetrates to the river's surface, thereby contributing to a decrease in the temperature of the river water. In line with thestudy by Suharyanto *et al.* (2023), if the vegetation index decreases, the built-up index increases, and land surface temperature also increases. Vice versa, if the vegetation index increases, the built-up index decreases, and the land surface temperature also decreases. There is a negative correlation between the FC parameter and FO, suggesting that larger forest areas correspond to a reduced presence of FC in the river water. This is because the wider the forest area means a low population density and population, so that the number of FC bacteria from human feces/ excrement entering the waters is getting smaller. The Upper Bekasi River is the downstream of the Cileungsi River and the Cikeas River. Along the Upper Bekasi River, there are two monitoring stations in this study, namely KBH1 and KBH2. There is a very strongipositiveicorrelationiof 0.907 between BA and the FC parameter. A large concentration of residential areas, housing complexes, and commercial buildings can be found near the Upper Bekasi River, contributing to a notably high population in the vicinity. Urbanization increases population density, which correlates with higher volumes of domestic waste, including human feces. When sanitation systems are inadequate, these wastes contribute to elevated FC levels in water bodies. In addition, many urban areas in the Upper Bekasi Watershed do not yet have a comprehensive wastewater treatment system, resulting in a lot of untreated or partially untreated domestic wastewater being discharged into rivers. Urban stormwater runoff serves as a pathway for fecal contaminants originating from multiple sources, such as human and animal waste, malfunctioning septic systems, and unregulated sanitation methods. In KBH1 and KBH2, no relationship was found between AG and other parameters. There is ainegative relationship between FO and the $PO_4$ and Zn parameters, namely -0.952 and -0.901 (KBH1) and -0.936 and -0.950 (KBH2). A positive relationship was also obtained at the KBH2 station between FO and the COD and DO parameters (0.948 and 0.951). Consequently, effective management of urbanized areas in the Upper Bekasi Watershed calls for specific interventions, such as upgrading wastewater treatment systems, employing green stormwater management strategies, and rehabilitating riparian zones to boost pollutant filtration. Sources of Upper Bekasi watershed pollution were identified on the basis of the PCA results. Preliminary tests, including the KMO, Bartlet test, anti-image test, and scree plot, were conducted prior to the analysis in order to determine whether the water quality data conformed to the statistical criteria. Based on the test results, 9 of the 15 river water quality monitoring parameters, namely T, DO, NO3, NO2, PO4, Fe, Co, Zn, and Cu, were not included in the PCA because the anti-image test's MSA value was more than 0.5. Thus, the remaining water quality parameters included in the PCA were TSS, BOD, COD, TDS, pH, and

FC. Table 6 shows the PCA results, extracting the three rotated principal components (VFs) and the significant loadings of the water quality parameters for each PC.

In Table 6, the variance factors extracted from the water quality data are illustrated, revealing that they represent 78.057% of the total variance in the dataset. VF1 explained 41.510% of the total variance in the water quality data and had a strong positive loading on the parameters TSS, BOD and COD. VF1 can represent organic pollutants in the waters of the Upper Bekasi Watershed. According to a study by Nascimento *et al.* (2019), PCA in the Rio do Peixe watershed, a tributary of the Rio Doce River, located in the Iron Quadrangle, extracted the main VFs and had a positive loading effect on TSS,BOD and COD. The key components were connected to both natural decay processes and waste produced by human activities in domestic settings. VF2 explained 18.367% of the total variance in the water quality data and had a positive loading effect on TDS. PC2 can represent the source of nutrient pollutants in the waters of the Upper Bekasi Watershed originating from agriculture. Surface water often receives agricultural runoff that is rich in nutrients, particularly phosphorus and nitrogen. VF3 explained 18.181% of the total variance of water quality data, having a positive loading effect on pH and FC. PC3 may represent pollutants originating from industrial wastewater for pH parameters, while FC may originate from domestic wastewater in residential areas, livestock farms and recreational areas (Camara *et al.*, 2019).

## CONCLUSION

The findings of this study highlight the application of GIS-based spatiotemporal analysis in understanding the fluctuations in water quality in the Upper Bekasi River, Indonesia. Furthermore, it pinpoints the key sources that may lead to water pollution in these aquatic environments. The water quality in each river varies, as evidenced by the different pollution levels in the Cileungsi River, Cikeas River and Upper Bekasi River. The disparities in river water quality arise from various pollution sources and differing land cover and usage changes, which are not uniform across the catchment area in each river. The highest pollution in the Cikeas River was the TSS parameter of 4860.00 mg/L, BOD of 73.00 mg/L and COD of 183.00 mg/L. The quality of water in the Cikeas River is heavily affected by anthropogenic factors, particularly from the settlements and housing complexes that line its shores. The highest pollution in the Cileungsi River was found at the SCL1 monitoring station, where the concentrations of heavy metals Fe, Co, Zn and Cu were measured, which exceeded the river water quality standards. SCL1 station is located in the upstream part of the Cileungsi River, which is a dense industrial area. In the Upper Bekasi River, the highest pollution measured was the FC parameter of 534,000 MPN/100mL. Originating from the merging of the Cileungsi and Cikeas Rivers, the Bekasi River traverses lowland areas that are home to various settlements and housing developments. The water quality in the Upper Bekasi Watershed fluctuates on average yearly. However, based on the results of the study obtained in 2018-2022, there was an increase in the concentration of $NO_3$, $NO_2$, $PO_4$, Cu and FC every year. Parameters $NO_3$, $NO_2$, and $PO_4$ increased in concentration every year. The observed changes are a result of heightened organic matter presence in the water, leading to increased levels of nitrogen, PO4, and various other inorganic nutrients. This is different from the DO parameter, where there is a decrease in concentration every year based on the study results. The main land cover in the entire Bekasi Hulu watershed is BA, with an area of 37.46 – 47.84%; AG, with an area of 13.16 – 36.18%; and FO, with an area of 13.38 – 29.89% of the total area of the Bekasi Hulu watershed. The BA class shows an increase in area in the 2018-2022 period of 10.38% of the total area of the Upper Bekasi Watershed. Conversely, the AG and OL classes reflect a downward trend, experiencing a decline in their areas of 11.57% and 4.59% during the timeframe of 2018 to 2022. The decrease in area can be caused by changes in land use cover in agricultural areas and open land to built-up areas, industry or other land cover. KBH1 and KBH2 stations have the most significant built-up area compared to other monitoring stations. In 2022, the predominant industrial land use category is SCL1, accounting for 9.29% of the Euclidean distance area. A significant decrease in land cover area occurred in forest land where in 2018, the forest area ranged from 10.37 - 36.80%, while in 2022, the forest area was only in the range of 0.72 - 12.68%. The findings of the study indicated a relationship between land use practices and the quality of river water. At the SCL1 monitoring station, a very strong correlation was obtained between BA and $NO_3$ and Fe parameters of 0.974 and -0.902, between AG and TDS and COD parameters of -0.937 and 0.984, between FO and the parameters

pH, $NO_2$ and Fe with coefficient values of 0.911, -0.907 and 0.956 respectively. At the Cikeas River monitoring station, a robust correlation was found between BA and TDS. Furthermore, a pronounced negative association was observed between AG and the parameters $NO_2$, Co, and Zn with coefficient values of -1,000, -0.954, and -0.912 at SCK1. A very strong negative relationship was found between FO and the temperature parameter of -0.989 and the FC parameter of -0.961 at SCK2. At the monitoring station located in the upstream Bekasi River, a very strong positive correlation of 0.907 between BA and FC was obtained. A negative relationship was also obtained between FO and the $PO_4$ and Zn parameters, namely -0.952 and -0.901 (KBH1) and -0.936 and -0.950 (KBH2). A positive relationship was also obtained at the KBH2 station between FO and the COD and DO parameters (0.948 and 0.951). The number of PCs obtained in this study had three components: VF1 explained 41.510% had a strong relationship with TSS, BOD, and COD parameters; VF2 explained 18.367% had a relationship with TDS parameters; and VF3 explained 18.181% of the total variance had a relationship with pH and FC parameters. This study's outcomes serve as a critical reference for water quality management in the Upper Bekasi River Basin and similar regions. It will support stakeholders, especially the Government of Indonesia, in identifying appropriate intervention techniques to address wastewater pollution. Based on the findings of this study, stakeholders are encouraged to adopt stricter regulations for wastewater treatment in both urban and peri-urban settings. The formulation of nutrient management plans aimed at optimizing fertilizer use is also recommended to mitigate excess nutrient runoff into water bodies. Furthermore, it is important to initiate reforestation efforts in regions with diminished forest cover. Increasing local community awareness regarding the negative consequences of improper waste disposal on water quality is vital. Lastly, promoting collaboration among urban planners, ecologists, and policymakers will facilitate a more integrated approach to watershed management.

## AUTHOR CONTRIBUTIONS

D.P. Marisi contributed to this work by conceptualizing the study, applying for funding, designing the experimental work, analyzing the data, writing the initial manuscript, and finalizing the manuscript. Suprihatin contributed to conceptualizing the study, supporting the manuscript writing, reviewing, and revising. S. Hariyadi contributed to conceptualizing the study, supporting the manuscript writing, reviewing, and revising. L.R. Kaswanto contributed to conceptualizing the study, supporting the manuscript writing, reviewing, and revising.

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## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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## ABBREVIATIONS

| | |
|---|---|
| *%* | Percent (part per hundred) |
| *µm* | Micrometer |
| *AG* | Agriculture |
| *BA* | Build-up area (BA |
| *BBWS CC* | Balai Besar Wilayah Sungai Ciliwung Cisadane |
| *BOD* | Biological oxygen demand |
| *$CH_4$* | Methane |
| *Co* | Cobalt |
| *COD* | Chemical oxygen demand |
| *COVID-19* | Coronavirus disease-2019 |
| *Cu* | Copper |
| *DEM* | Digital elevation model |
| *DLH* | Dinas Lingkungan Hidup |
| *DO* | Dissolved oxygen |
| *FC* | Fecal coliform |
| *Fe* | Iron |
| *FO* | Forest |
| *$H_2S$* | Hydrogen sulfide |
| *IN* | Industry |
| *ISO* | International organization for standardization |
| *KAN* | Komite akreditasi nasional (National accreditation committee) |
| *KBH* | Kali Bekasi Hulu (Upper Bekasi river) |
| *$Km^2$* | Square kilometer |
| *KMO* | Kaiser–Meyer–Olkin (KMO) |
| *L* | Liter |
| *LULC* | Land use and land cover |
| *m* | Meter |
| *mL* | Milliliter |
| *mm* | Millimeter |
| *MPN* | Most probable number |
| *$NO_2$* | Nitrite |
| *$NO_3$* | Nitrate |
| *$^oC$* | The degree celcius |
| *OL* | Open land |
| *PC* | Key component or factor |
| *PCA* | Principal component analysis |
| *pH* | Potential of hydrogen |
| *$PO_4$* | Total phosphate |
| *PP* | Peraturan Pemerintah |
| *SCK* | Sungai cikeas (Cikeas river) |
| *SCL* | Sungai cileungsi (Cileungsi river) |
| *SE* | Standard error |
| *SNI* | Standard National Indonesia (Indonesian National Standard ) |
| *SPSS* | Statistical package for the social sciences |
| *T* | Temperature |
| *TDS* | Total dissolved solids |
| *TSS* | Total suspended solids |
| *VFs* | Varifactors |
| *Zn* | Zinc |

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