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Brantas watershed sustainability analysis: water quality aspects

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Abstract. Watersheds are complex natural-human systems because they involve various interacting biogeophysical and socio-economic-cultural components. Degradation of forest, land, and water resources and population pressure have caused a decline in watershed sustainability, which is the biggest obstacle to sustainable watershed management in most developing countries in the humid tropics. The purpose of this study was to analyze the sustainability of the Brantas Watershed. Secondary data collection includes water quality. Data collection was carried out at Perum Jasa Tirta 1. Data analysis was carried out based on a sustainability index that included aspects of water quality. The study showed that the water quality of the Brantas River has decreased and is currently at class 4 (lowest) quality. The sustainability of the Brantas River Basin has decreased and, in 2023, will be in the low category.

1 Introduction

The Brantas Watershed, located on the island of Java, Indonesia, is one of the most critical watersheds in the region due to its role in supporting various socio-economic activities, including agriculture, fisheries, industry, and urban water supply. As the second longest river in Java, the Brantas River and its watershed are vital to the livelihoods of millions of people. However, the rapid growth of population and industrial activities, along with climate change impacts, have posed significant challenges to the sustainability of this watershed, particularly in terms of water quality [1].

Water quality in the Brantas Watershed is deteriorating due to various sources of pollution, such as agricultural runoff, industrial effluents, and untreated domestic wastewater. These pollutants contribute to the increasing levels of nutrients, heavy metals, and other contaminants in the water, affecting aquatic ecosystems and human health [2]. Furthermore, the limited enforcement of environmental regulations and the lack of integrated management strategies exacerbate these issues, making water quality monitoring and improvement efforts more complex [3].

In response to these challenges, sustainable management of the Brantas Watershed is essential to ensure its long-term functionality and ecological integrity. Recent studies highlight the need for an adaptive management approach that incorporates both water quality

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assessments and socio-economic considerations to address the multifaceted impacts on the watershed [4].

This paper aims to analyze the current state of water quality in the Brantas Watershed, identify the key sources of pollution, and evaluate the effectiveness of existing management strategies. By providing a comprehensive overview of water quality aspects, this study seeks to contribute to the development of more effective policies and practices for the sustainable management of the Brantas Watershed.

2 Method

1 The research was conducted from January to April 2024, with the focus of the research being on the Brantas Watershed. It is in East Java Province and lies between 110° 30' and 112° 55' eastern longitude and between 7° 01' and 8° 15'southern latitude. The Brantas Watershed Map is presented in Figure 1.

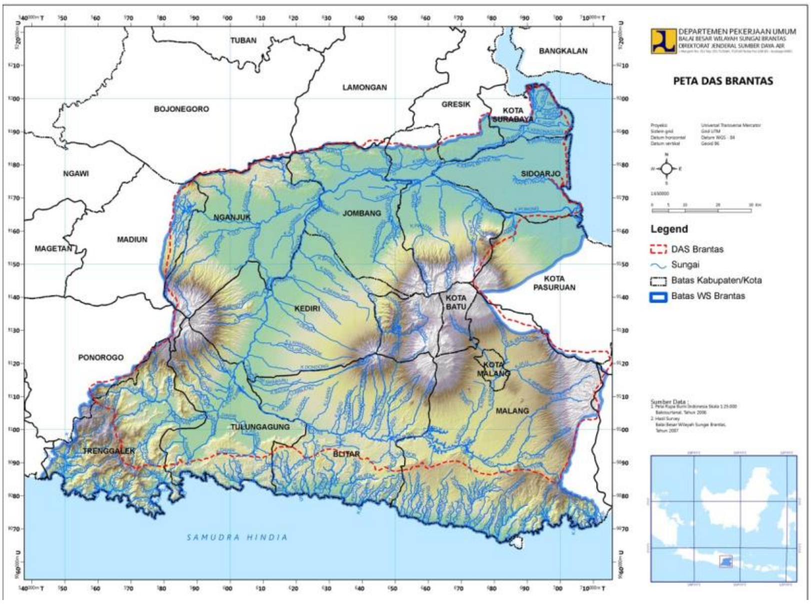

Fig. 1. Brantas Watershed.

This research method consists of 3 stages, namely data collection, data analysis, and drawing conclusions. Data collection was carried out at Perum Jasa Tirta 1 Malang. The data taken was water quality (BOD) in 2014-2023 in the Brantas Watershed. Data was taken from three sub-watersheds, namely the Brantas Hulu Sub-Watershed, Lahar Sub-Watershed, and Brangkal Sub-Watershed.

Data analysis was carried out by calculating the difference between measurements at one time and the previous time in percentage [10] as follows:

$\Delta 2 > 20\%$	0.00
$20\% > \Delta 2 > 10\%$	0.25
$0 < \Delta 2 < 10\%$	0.50
$-10\% < \Delta 2 < 0\%$	0.75
$\Delta 2 < -10\%$	1.00

Sustainability categories are divided into five, namely

0.0 - 0.2 very low
0.2 - 0.4 low
0.4 - 0.6 medium
0.6 - 0.8 High
0.8- 1.0 very high

Conclusion drawing is done based on data analysis. What category is the sustainability of Brantas Watershed included in. From the category position, suggestions for improvement can be made.

3 Results and Discussion

3.1 Physical Conditions of the Brantas Watershed

The Brantas Watershed has a varied topography, ranging from lowlands to highlands. In general, the upstream part of this watershed is dominated by mountains and hills, while the downstream part consists of lowlands that cross several districts in East Java. The water system in the Brantas Watershed is reflected in the network of rivers and tributaries. The Brantas River, as the mainstream, flows through various areas, collecting water from tributaries and other waterways.

Soil conditions in the Brantas Watershed vary greatly, including fertile volcanic soil in mountainous areas and denser alluvial soil in the lowlands. These soils provide fertility that supports agricultural activities along the watershed. Land cover in the Brantas Watershed includes various types of land use, such as agricultural land, forests, settlements, and industry. Increasing the conversion of agricultural land to settlements and industrial areas can reduce the availability of land for agricultural activities.

3.2. Non-Physical Conditions of Brantas Watershed

Social is an important dimension in the non-physical conditions of the Brantas Watershed. The high population along this watershed causes high pressure on natural resources, especially in the context of agriculture and settlements. Social aspects also include community structure, community participation, and local wisdom. Economic conditions in the Brantas Watershed affect land use patterns and community economic activities. Agriculture remains the main sector, but urbanization and industrialization are also growing.

5 The institutional system in the Brantas Watershed plays an important role in decision-making related to resource management. The involvement of local governments, non-governmental organizations, and the private sector determines the success of watershed management policies. Community participation in the management of the Brantas Watershed is a key element in achieving sustainability. Involving local communities in the decision-making process, empowering farmer groups, and increasing awareness of the importance of environmental conservation.

The non-physical conditions of the Brantas Watershed are also related to the level of environmental education in the community. Increasing awareness of the importance of maintaining the balance of the watershed ecosystem through environmental education and advocacy programs.

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3.3. Water Quality (BOD)

The Upper Brantas Sub-Watershed is in the upstream part of the Brantas Watershed and plays a critical role in the hydrological and ecological systems of the region, providing essential water resources for various sectors, including agriculture, industry, and domestic use. However, water quality degradation has been a persistent challenge, particularly due to increased urbanization, industrial discharges, and agricultural runoff. One key indicator of water quality is the Biochemical Oxygen Demand (BOD), which measures the amount of oxygen required by aerobic microorganisms to decompose organic matter in water. Elevated BOD levels often indicate the presence of organic pollutants and can lead to detrimental effects on aquatic life and overall water usability.

Table 1 presents the BOD levels in the Upper Brantas Sub-Watershed over a ten-year period from 2014 to 2023. This data is crucial for understanding the temporal trends in water quality and assessing the effectiveness of existing watershed management and pollution control measures. The analysis of BOD trends helps in identifying critical periods and sources of pollution, which are essential for planning targeted interventions to improve water quality in the watershed.

Table 1. Water Quality **(**BOD) Upper Brantas Sub-Watershed 2014-2023 (mg/l).

Yr/Mnt	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Class
2014	5,5	3,1	3,2	4,1	6,6	3,8	3,5	3,1	2,5	2,8	3,4	3,5	3,7	3
2015	5,5	6,7	5,8	8,7	2,2	3,4	4,4	3,75	4,5	4,4	3,8	8,9	5,1	3
2016	10,2	4,9	4,8	7,8	5,8	4,6	5,6	3,8	5,3	4,5	5,9	4,9	5,7	3
2017	3,9	5,3	9,9	5,7	6	6	7,45	8,9		7,1	6,2	7,9	6,7	4
2018	13,8	15,	8,5	11,6	5,7	7,3	11,4	8,15	5,3	7,0	8,7	10,6	9,4	4
2019	8,3	11,5	14,0	11,0	9,0	7,1	6,98	6,49	7,6	7,5	7,9	7,7	8,8	4
2020	8,3	7,7	20,7	7,6	7,5	8,1	7,42	8,71	7,2	7,3	7,0	6,6	8,7	4
2021	7,7	22,0	8,3	8,5	7,2	7,0	7,48	7,94	6,8	7,4	7,1	7,8	8,8	4
2022	8,2	9,5	5,8	7,2	8,4	7,1	7,11	6,76	7,1	7,0	7,4	7,1	7,4	4
2023	7,4	6,6	6,6	7,2	7,1	8,3	7,2	7,14	7,2				7,2	4

Source: Perum Jasa Tirta 1

The water quality in the Upper Brantas Sub-Watershed has shown a concerning trend over the past decade, particularly in terms of Biochemical Oxygen Demand (BOD) levels, which are indicative of organic pollution. According to Government Regulation of the Republic of Indonesia No. 82 of 2001, water bodies are classified into four categories based on their BOD levels: class 1 water (≤ 2 mg/L BOD) suitable for drinking, class 2 water (≤ 3 mg/L BOD) suitable for water recreation facilities, class 3 water (≤ 6 mg/L BOD) suitable for freshwater fish farming, and class 4 water (≤ 12 mg/L BOD) suitable for crop irrigation.

Table 1 illustrates that from 2014 to 2016, the water quality in the Upper Brantas Sub-Watershed generally aligned with class 3 standards, making it suitable for freshwater fish farming. However, starting in 2017, the BOD levels exceeded 6 mg/L, signaling a decline

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from class 3 to class 4 water quality. This shift indicates that the water has become less suitable for fish farming and is now more appropriate only for irrigation purposes, reflecting a significant degradation in water quality.

Several factors may have contributed to this decline. Increased anthropogenic activities such as industrial discharges, agricultural runoff containing fertilizers and pesticides, and untreated domestic wastewater have been identified as major contributors to the rising BOD levels in watersheds across Indonesia [5]. The Upper Brantas Sub-Watershed, which traverses densely populated and industrialized areas, is particularly vulnerable to these pressures. Studies have highlighted that inadequate enforcement of environmental regulations and insufficient infrastructure for wastewater treatment are exacerbating the pollution load in many of Indonesia's watersheds, including Brantas [6, 7].

Moreover, climate change may also play a role in altering water quality dynamics. Changes in precipitation patterns and increased frequency of extreme weather events can lead to higher runoff and erosion, thereby transporting more pollutants into the water bodies [8,15]. In the Upper Brantas Sub-Watershed, such climatic factors, combined with existing anthropogenic pressures, may be accelerating the deterioration of water quality.

The implications of this decline are significant. The shift from class 3 to class 4 water restricts the use of the Upper Brantas Sub-Watershed for aquaculture, a vital livelihood for many communities in the region. Furthermore, this degradation poses broader ecological risks, threatening biodiversity and disrupting aquatic ecosystems that depend on higher water quality standards [11].

To address these challenges, integrated watershed management approaches are needed that emphasize pollution prevention, stricter regulation enforcement, and improved wastewater treatment infrastructure [9,10]. Additionally, adaptive management strategies that consider the impacts of climate change are crucial for sustaining the health and functionality of watersheds in the Anthropocene [8,15]. Enhancing sectoral integration and stakeholder collaboration will also be key in reversing the declining trend of water quality in the Upper Brantas Sub-Watershed and ensuring its sustainable use for various purposes.

The Lahar Sub-Watershed is in the central part of the Brantas Watershed, a vital component of the larger watershed network that supports a range of ecological and socio-economic activities, including agriculture, fisheries, and domestic water supply. However, increasing anthropogenic pressures such as urbanization, industrial activities, and agricultural runoff have raised concerns about the water quality in this sub-watershed. A critical indicator of water quality is the Biochemical Oxygen Demand (BOD), which measures the amount of oxygen required to decompose organic matter present in the water. Elevated BOD levels can lead to oxygen depletion, adversely affecting aquatic life and reducing the suitability of water for various uses.

Table 2 provides a comprehensive overview of the BOD levels in the Lahar Sub-Watershed from 2014 to 2023. This data set is essential for evaluating the trends in organic pollution over the past decade and assessing the impact of watershed management efforts. Understanding these trends helps identify periods of significant water quality degradation and informs the development of targeted interventions to restore and maintain the health of the watershed. The findings from Table 2 will be crucial for policymakers, environmental managers, and local stakeholders aiming to safeguard the water resources of the Lahar Sub-Watershed.

The analysis of water quality in the Lahar Sub-Watershed from 2014 to 2023 reveals a concerning trend of increasing Biochemical Oxygen Demand (BOD) levels, which is indicative of worsening water quality. According to the Government Regulation of the Republic of Indonesia No. 82 of 2001, water quality classifications based on BOD levels are as follows: class 1 water (≤ 2 mg/L BOD) for drinking purposes, class 2 water (≤ 3 mg/L

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BOD) for water recreation infrastructure, class 3 water (≤ 6 mg/L BOD) for freshwater fish farming, and class 4 water (≤ 12 mg/L BOD) for crop irrigation.

Table 2 shows that from 2014 to 2015, the Lahar Sub-Watershed maintained BOD levels consistent with class 3 standards, making it suitable for freshwater fish farming. However, starting in 2016, the BOD levels began to exceed 6 mg/L, resulting in a decline in water quality classification from class 3 to class 4. This shift indicates that the water is now only suitable for irrigation purposes, representing a significant degradation in water quality that has persisted in the subsequent years.

Table 2. Water Quality (BOD) of Lahar Sub-Watershed 2014-2023 (mg/l).

Yr/Mnt	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Class
2014	3,4	3,35	4,05	6	5,65	4,8	2,9	2,3	5,0	4,1	5,3	3,8	4,2	3
2015	2,5	6,05	9,4	4,2	3,65	4,6	4	3,21	3,1	6,7	3,3	4,1	4,58	3
2016	6	4,8	31,9	3,9	5,4	5,1	5,9	4,35	3,4	5,6	3,8	5,1	7,12	4
2017	6,0	6	5,9	4,7	11,6	8,3	5,4	6,6	7,9	7,7	7,8	7,1	7,12	4
2018	4,5	7,7	7,3	7,2	5,6	6	5,7	7,9	6,3	8,8	9,1	9,9	7,2	4
2019	6,9	10,8	8,7	15,9	8,9	9,5	7,9	8,2	8,8	8,3	9,6	8,4	9,3	4
2020	7,4		7,9	8,5	8,5	8,6	7,3	7,8	6,8	7,3		7,3	7,7	4
2021	7,0	9,3	7,4	7,8	7,4	6,9	8,0	7,4	7,2	8,0	9,0	5,6	7,6	4
2022	8,2	5,8	5,1	6,7	7,7	7,2	7,0	7,1	7,0	7,4	7,3	7,2	7,0	4
2023	7,7	7,0	7,1	7,0	7,2	6,9	6,8	7,85	7,9				7,3	4

Source: Perum Jasa Tirta 1

The decline in water quality in the Lahar Sub-Watershed can be attributed to several factors. Rapid urbanization and industrialization in the watershed area have significantly increased the pollution load, with untreated industrial effluents and domestic wastewater being major contributors to the elevated BOD levels [5]. Agricultural activities also play a critical role, as runoff from farmland often carries high levels of organic matter, nutrients, and pesticides into the water bodies [6]. The inadequate implementation of waste management and pollution control measures has further exacerbated the situation, leading to a steady decline in water quality.

Furthermore, the impacts of climate change, such as altered precipitation patterns and increased frequency of extreme weather events, may be contributing to the observed degradation. Climate variability can influence runoff patterns, leading to higher loads of pollutants entering the sub-watershed, thereby increasing BOD levels [8,15]. These climatic factors, combined with inadequate infrastructure for managing wastewater and agricultural runoff, underscore the multifaceted challenges faced in maintaining water quality in the Lahar Sub-Watershed.

The transition from class 3 to class 4 water quality has significant implications for the local communities and ecosystems. The decrease in water quality restricts the use of the Lahar Sub-Watershed for aquaculture, which is a crucial source of income and food for many residents. Additionally, the degradation poses risks to aquatic biodiversity, as elevated BOD

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levels can lead to hypoxic conditions, which are detrimental to fish and other aquatic organisms [7,12].

Addressing the declining water quality in the Lahar Sub-Watershed requires a coordinated and integrated approach to watershed management. Strengthening pollution control regulations, enhancing wastewater treatment facilities, and promoting sustainable agricultural practices are essential steps towards mitigating the impact of pollution [9] [10]. Moreover, adaptive management strategies that account for the effects of climate change are crucial for ensuring the resilience of the watershed in the face of evolving environmental challenges [8,15]. Effective stakeholder engagement and cross-sectoral collaboration will be key to reversing the declining trend and achieving sustainable water resource management in the Lahar Sub-Watershed [5].

The Brangkal Sub-Watershed is one of sub-Watershed in the downstream part of the Brantas, contributing significantly to the region's water resources used for agriculture, domestic purposes, and industrial activities. Maintaining the water quality in this sub-watershed is critical for sustaining its ecological health and supporting the various socio-economic activities that depend on it. One of the key parameters used to assess water quality is the Biochemical Oxygen Demand (BOD), which measures the amount of oxygen required by microorganisms to break down organic matter in water. High BOD levels indicate higher organic pollution, which can lead to oxygen depletion and adverse effects on aquatic ecosystems.

Table 3 provides a detailed analysis of the BOD levels in the Brangkal Sub-Watershed from 2014 to 2023. This data is crucial for understanding the temporal changes in water quality over the past decade and evaluating the effectiveness of existing watershed management strategies. By examining these trends, stakeholders can identify periods of significant water quality deterioration and develop targeted interventions to address pollution sources. The insights gained from Table 3 will aid in guiding policy decisions and management practices aimed at preserving the water quality of the Brangkal Sub-Watershed for sustainable use.

The water quality trends in the Brangkal Sub-Watershed, as depicted in Table 3, reveal a critical decline in Biochemical Oxygen Demand (BOD) levels, specifically in the years 2017 and 2023, where the water quality dropped from class 3 to class 4. According to the Government Regulation of the Republic of Indonesia No. 82 of 2001, class 3 water (≤ 6 mg/L BOD) is deemed suitable for freshwater fish farming, while class 4 water (≤ 12 mg/L BOD) is only suitable for crop irrigation. The deterioration from class 3 to class 4 reflects a significant increase in organic pollution, limiting the water's use and posing risks to aquatic life and local livelihoods dependent on the watershed.

The sporadic decline in water quality in the Brangkal Sub-Watershed during these years can be attributed to a combination of anthropogenic and environmental factors. Key contributors include industrial discharges, agricultural runoff, and untreated domestic wastewater, all of which introduce high levels of organic matter and nutrients into the water system, elevating BOD levels [5]. The Brangkal Sub-Watershed is particularly susceptible to these pressures due to its proximity to urban and industrial areas, where enforcement of environmental regulations and wastewater treatment infrastructure are often inadequate [6].

The observed water quality degradation in 2017 and 2023 may also be influenced by episodic events such as heavy rainfall or flooding, which can increase runoff and transport larger amounts of pollutants into the sub-watershed. Climate change is exacerbating these conditions by altering precipitation patterns, leading to more frequent and intense runoff events that overwhelm the natural and engineered systems designed to manage pollution loads [8]. These environmental dynamics suggest that the declines in 2017 and 2023 could be part of broader, climate-related impacts on watershed health.

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Table 3. Water Quality (BOD) of the Brangkal Sub-Watershed 2014-2023 (mg/l).

Yr/ Mnt	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Class
2014	7,9	3,8	6,8	8,4	2,4	2,7	1,8	4,1	2,2	4,2	2,1	3,6	4,2	3
2015	3,11	3,58	3,97	3,3	5,1	3,2	1,9	3,3	1	4,1	3,5	1,5	3,1	3
2016	3,5	5,2	4,3	2,7	2,9	1,8	4,6	6,3	2,3	4,5	1,9	4,9	3,7	3
2017	3,1	8,5	5,4	7,0	4,4	3,3	18,9	4,9	5,9	8,2	3,6	2,6	6,3	4
2018	3,7	4,7	3,4	2,4	1,3	2,6	2,6	3,9	4,9	1,6	1,6	2,4	2,9	3
2019		4,44	2,81	4,5	3,2	3,3	3,3	2,3	1,3	2,8	1,9	4,5	3,1	3
2020	3,3	10,6	5,17	4,7	2,1	3,4	4,4	3,8	2,2	2,1	3,9	4,6	4,2	3
2021	4,1	5,2	5,9	4,7	3,6	6,0	3,2	3,5	3,5	3,4	3,9	9,0	4,7	3
2022	6,4	3,6	4,4	5,0	2,7	4,7	4,9	3,6	3,3	7,4	5,5	8,0	5,0	3
2023	7,7	7,0	7,1	7,0	7,1	6,9	6,8	7,8	7,9				7,31	4

Source: Perum Jasa Tirta 1

The implications of this decline are significant for the Brangkal Sub-Watershed's ecological and economic functions. The transition from class 3 to class 4 water reduces its suitability for aquaculture, impacting the livelihoods of communities that rely on fish farming as a primary source of income and nutrition. Additionally, higher BOD levels can lead to hypoxic conditions, which are harmful to aquatic species and disrupt the overall biodiversity of the watershed [7].

To address these challenges, it is essential to adopt an integrated approach to watershed management that emphasizes pollution prevention, improved regulation enforcement, and enhanced infrastructure for wastewater treatment [9][10]. Strategies should include promoting sustainable agricultural practices to reduce nutrient runoff, upgrading industrial waste management protocols, and increasing community awareness and involvement in watershed conservation efforts. Moreover, adaptive management practices that incorporate climate resilience are necessary to mitigate the impacts of extreme weather events on water quality [8,15]. Strengthening cross-sectoral collaboration among government agencies, industries, local communities, and environmental organizations will be crucial for reversing the declining trends and ensuring the long-term sustainability of the Brangkal Sub-Watershed [5].

3.4. Sustainability of Water Quality Aspects

5 The sustainability of water quality in the Upper Brantas Sub-Watershed is crucial for maintaining the ecological balance and supporting the diverse needs of communities,
3 industries, and ecosystems that rely on this vital water resource. Biochemical Oxygen Demand (BOD) is a key indicator of water quality, reflecting the amount of oxygen required by microorganisms to break down organic matter in the water. High BOD levels indicate

elevated organic pollution, which can threaten aquatic life and reduce water usability for various purposes.

Table 4 presents the sustainability of BOD levels in the Upper Brantas Sub-Watershed from 2014 to 2023, highlighting trends and fluctuations in organic pollution over this period. The data provides valuable insights into the effectiveness of watershed management practices and the resilience of the sub-watershed in maintaining acceptable water quality standards. By examining these trends, stakeholders can assess the progress made towards achieving sustainable water management and identify areas where additional efforts are needed to enhance water quality and ecosystem health. The findings from Table 4 will inform policy decisions and strategic interventions aimed at improving the sustainability of the Upper Brantas Sub-Watershed.

Table 4. Sustainability (BOD) of the Upper Brantas Sub-Watershed 2014-2023.

Yr/Mnt	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Class
2014	4,93	2,12	1,99	2,49	6,0	2,9	2,6	2,3	1,4	1,6	2,4	1,9	2,7	0,75
2015	4,27	5,88	4,36	8,44	0,7	2,2	3,5	2,5	3,5	3,6	1,4	7,7	4,0	0,50
2016	9,77	3,92	3,16	7,11	5,00	3,45	4,92	2,41	4,45	3,18	5,1	4,1	4,7	0,50
2017	2,6	3,5	9,3	4,6	5,0	4,7	6,2	8,1	6,3	4,9	6,1		5,6	0,25
2018	12,7	14,7	7,2	11,2	4,4	5,7	10,7	7,5	4,0	5,8	7,5	9,8	8,4	0,25
2019	6,9	10,3	13,3	10,3	8,3	6,2	6,1	5,3	6,7	6,5	6,9	6,7	7,8	0,25
2020	7,38	5,12	20,4	6,7	6,4	7,3	6,3	7,9	6,2	6,4	6,2	5,5	7,6	0,25
2021	4,8	21,6	7,3	7,7	6,3	5,9	6,4	7,1	5,7	6,5	6,1	6,8	7,7	0,25
2022	7,1	8,9	4,6	6,1	7,6	6,1	6,2	5,71	6,1	5,9	6,5	6,1	6,4	0,25
2023	6,5	5,6	5,8	6,3	5,9	7,4	6,2	6,1	7,2				6,3	0,25

Source: Data analysis

The sustainability of water quality in the Upper Brantas Sub-Watershed, as indicated by Biochemical Oxygen Demand (BOD) levels from 2014 to 2023, shows a worrying trend of decline. Table 4 illustrates that the sustainability index, which measures the capacity of the watershed to maintain acceptable BOD levels, was high at 0.75 in 2014. However, starting in 2015, the sustainability index dropped to the medium category (0.5) and further deteriorated into the low category from 2017 onwards. This decline suggests that the Upper Brantas Sub-Watershed has increasingly struggled to maintain water quality standards, reflecting a broader issue of environmental stress and ineffective management interventions.

Several factors contribute to this decline in sustainability. The Upper Brantas Sub-Watershed is subject to significant anthropogenic pressures, including rapid urbanization, industrial activities, and agricultural expansion, which have collectively increased the load of organic pollutants entering the water system. Industrial discharges, untreated domestic sewage, and agricultural runoff containing fertilizers and pesticides are major sources of pollution that elevate BOD levels, compromising water quality [5, 13]. The inadequate enforcement of environmental regulations and limited infrastructure for wastewater treatment

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exacerbate these challenges, undermining efforts to manage and mitigate pollution effectively [6].

Moreover, climate change has compounded the difficulties in maintaining water quality sustainability. Altered rainfall patterns and increased incidence of extreme weather events such as floods and droughts can exacerbate pollutant runoff, thereby elevating BOD levels in the watershed. These climatic changes disrupt the natural hydrological cycles, making it harder for the watershed to self-regulate and recover from pollution loads [8, 15]. As a result, the resilience of the Upper Brantas Sub-Watershed has been weakened, contributing to the observed decline in sustainability.

The shift from high to low sustainability has significant implications for the ecological health and socio-economic functions of the Upper Brantas Sub-Watershed. High BOD levels indicate a higher presence of organic pollutants, which can lead to oxygen depletion in water bodies, adversely affecting aquatic life and biodiversity. This degradation reduces the suitability of the water for various uses, including drinking, recreation, and aquaculture, thereby impacting the livelihoods of local communities and industries that depend on the watershed [7].

To address the declining sustainability of water quality in the Upper Brantas Sub-Watershed, a comprehensive and integrated approach to watershed management is required. Key strategies should include strengthening pollution control measures, enhancing wastewater treatment infrastructure, and promoting sustainable land-use practices that reduce runoff and erosion [9,10]. Additionally, implementing adaptive management strategies that consider the impacts of climate change is essential for building resilience and sustaining water quality in the long term [8,15]. Collaborative efforts involving government agencies, local communities, industries, and environmental organizations are crucial for developing and executing effective interventions that can restore and preserve the sustainability of the Upper Brantas Sub-Watershed.

The sustainability of water quality in the Lahar Sub-Watershed is critical for maintaining its ecological health and supporting the diverse needs of local communities, agriculture, and industry. Biochemical Oxygen Demand (BOD) serves as a key indicator of water quality, reflecting the degree of organic pollution in the water. High BOD levels can lead to oxygen depletion, negatively affecting aquatic life and limiting the suitability of the water for various uses.

Table 5 provides an analysis of the sustainability of BOD levels in the Lahar Sub-Watershed from 2014 to 2023, showcasing trends over the past decade. This table highlights the watershed’s ability to maintain acceptable water quality standards amid increasing pressures from urbanization, agricultural activities, and climate change. By examining the sustainability index, which categorizes water quality as high, medium, or low, stakeholders can assess the effectiveness of current management strategies and identify critical periods of decline. The findings from Table 5 are crucial for guiding future interventions aimed at improving water quality sustainability and ensuring the resilience of the Lahar Sub-Watershed against ongoing environmental challenges.

The sustainability of water quality in the Lahar Sub-Watershed, as measured by the Biochemical Oxygen Demand (BOD) levels, has shown a marked decline from 2014 to 2023. As presented in Table 5, the sustainability index was categorized as medium (0.5) in 2014, but it dropped into the low category from 2016 onwards. This decline indicates that the watershed's ability to maintain water quality standards has been compromised, reflecting broader challenges in managing water resources effectively in the face of increasing environmental and anthropogenic pressures.

The persistent decline in water quality sustainability in the Lahar Sub-Watershed can be attributed to several key factors. One of the primary drivers is the rapid urbanization and industrial development within the watershed area.

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Table 5. Sustainability (BOD) of Lahar Sub-watershed 2014-2023.

Yr/Mnt	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Class
2014	2,4	2,1	2,6	5,1	4,8	4,2	2,1	0,1	4,2	2,9	4,6	3,2	3,2	0,50
2015	0,1	4,5	8,9	3,3	2,4	3,8	3,2	2,2	1,0	6,2	2,1	2,7	3,4	0,50
2016	5,32	-3,6	31,8	2,5	4,4	3,9	5,2	3,6	1,7	4,9	2,5	3,9	5,5	0,25
2017	5,1	5,0	5,2	2,2	10,9	7,7	4,2	5,4	6,9	6,7	6,9	6,5	6,1	0,25
2018	2,8	6,7	6,4	6,4	4,5	5,0	4,4	7,1	4,9	7,8	7,9	9,3	6,1	0,25
2019	5,3	9,9	6,9	15,4	7,8	8,7	6,9	7,1	7,9	7,2	8,7	7,6	8,3	0,25
2020	7,4		6,8	7,6	7,5	7,8	6,3	7,0	5,7	7,1			7,1	0,25
2021	5,7	8,5	6,4	6,88	6,5	5,8	7,1	6,5	6,1	6,9	8,4	4,1	6,6	0,25
2022	7,5	4,9	3,8	5,6	6,8	6,3	6,1	6,2	6,0	6,4	6,4	6,1	6,0	0,25
2023	6,8	6,0	6,2	6,0	6,2	6,0	5,7	6,8	7,9				6,4	0,25

Source: Data analysis

These activities have increased the discharge of untreated wastewater, containing high levels of organic pollutants, which directly elevate BOD levels [5]. The surge in industrial effluents and the lack of adequate wastewater treatment infrastructure have overwhelmed the natural capacity of the watershed to assimilate and degrade organic matter, contributing to the observed decline in water quality [6].

Agricultural runoff also plays a significant role in degrading water quality in the Lahar Sub-Watershed. The use of fertilizers, pesticides, and other agrochemicals in upstream agricultural areas results in nutrient-rich runoff, which accelerates eutrophication and increases BOD levels in downstream water bodies [7]. Additionally, poor land management practices, such as deforestation and inadequate soil conservation, exacerbate sediment and pollutant runoff into the watershed, further compromising water quality [10].

Climate change adds another layer of complexity to the sustainability challenges faced by the Lahar Sub-Watershed. Alterations in precipitation patterns, increased intensity of extreme weather events, and prolonged dry spells can all impact water quality. For instance, heavy rainfall events can lead to increased runoff, transporting larger loads of organic pollutants into the watershed, while periods of drought can concentrate pollutants, thereby raising BOD levels [8,15]. These climatic factors disrupt the natural balance of the watershed, reducing its resilience and sustainability over time.

The decline in water quality sustainability has significant implications for both the environment and the communities that rely on the Lahar Sub-Watershed. Low sustainability levels indicate a reduced capacity to support healthy aquatic ecosystems, potentially leading to losses in biodiversity and adverse effects on fish populations, which are crucial for local fisheries [10]. Furthermore, deteriorating water quality limits the watershed's suitability for domestic and recreational uses, affecting the quality of life for residents and potentially leading to economic losses, particularly in sectors dependent on clean water resources.

To address the declining sustainability of water quality in the Lahar Sub-Watershed, a multifaceted approach is required. Key mitigation strategies include enhancing wastewater treatment facilities, promoting sustainable agricultural practices to reduce nutrient runoff, and implementing reforestation and soil conservation measures to improve land management [9]. Strengthening regulatory frameworks and improving enforcement of environmental laws are also essential to reduce pollution loads from industrial and urban sources [5].

4 Additionally, integrating adaptive management practices that consider the impacts of climate change is crucial for building the resilience of the watershed [14,17]. This includes developing early warning systems for extreme weather events, enhancing monitoring and data collection, and engaging local communities in watershed protection efforts [8,15]. By implementing these strategies, stakeholders can work towards reversing the decline in water quality sustainability and ensuring the long-term health and functionality of the Lahar Sub-Watershed.

The sustainability of water quality in the Brangkal Sub-Watershed is a critical concern, given its importance in supporting local ecosystems, agriculture, and communities that depend on this water resource. Biochemical Oxygen Demand (BOD) is a key indicator used to assess water quality sustainability, as it reflects the degree of organic pollution present in the water. High BOD levels indicate a greater amount of organic matter, which can deplete oxygen in the water, adversely affecting aquatic life and reducing the usability of the water for various purposes.

Table 6 provides an analysis of the sustainability of BOD levels in the Brangkal Sub-Watershed from 2014 to 2023, highlighting changes in the watershed's ability to maintain acceptable water quality standards over this period. The table categorizes sustainability levels into high, medium, and low, offering insights into the trends and challenges faced by the watershed. By examining these trends, stakeholders can evaluate the effectiveness of current management practices and identify critical periods where water quality sustainability declined. The findings from Table 6 are essential for guiding future interventions aimed at enhancing the resilience and sustainability of the Brangkal Sub-Watershed against ongoing environmental and anthropogenic pressures.

The sustainability of water quality in the Brangkal Sub-Watershed, as indicated by Biochemical Oxygen Demand (BOD) levels, has shown a notable decline from 2014 to 2023. Table 6 reveals that the sustainability index, which was categorized as high (0.75) in 2014, decreased to the moderate category (0.5) starting in 2017. This decline reflects a reduced capacity of the Brangkal Sub-Watershed to maintain acceptable water quality standards, underscoring the growing pressures from environmental and human activities.

The transition from high to moderate sustainability can be attributed to several interrelated factors. One of the main drivers is increased pollution from urban, industrial, and agricultural sources within the watershed. Rapid urbanization has led to the expansion of residential areas and industries, resulting in higher volumes of untreated wastewater and stormwater runoff entering the water system [5]. Industrial discharges, often containing high levels of organic matter, chemicals, and nutrients, contribute significantly to elevated BOD levels, thus degrading water quality [6].

Agricultural activities within the Brangkal Sub-Watershed also contribute to the decline in water quality sustainability. The use of fertilizers and pesticides leads to nutrient-rich runoff, which promotes algal blooms and increases BOD levels as the organic material decomposes [7]. Additionally, poor land management practices, such as deforestation and insufficient soil conservation measures, exacerbate erosion and sedimentation in waterways, further contributing to water quality degradation [9,11].

Climate change plays a compounding role in the declining sustainability of water quality. Altered precipitation patterns, including more frequent and intense rainfall events, increase runoff and the transport of pollutants into the watershed. At the same time, prolonged dry periods can concentrate pollutants and reduce the natural dilution capacity of water bodies, exacerbating BOD levels [8,15].

Table 6. Sustainability (BOD) of Brangkal Sub-watershed 2014-2023.

Yr/Mnt	Jan	Feb	Marc	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average	Class
2014	7,3	2,1	5,6	8,2	1,3	2,1	-0,5	3,5	0,3	3,6	0,4	2,7	3,0	0,75
2015	1,96	2,5	3,1	1,7	4,5	2,6	0,2	3,0	-3,1	3,2	3,1	-0,8	1,8	0,75
2016	2,0	4,4	3,68	1,6	2,2	-0,7	3,2	5,9	0,3	4,1	-0,7	4,2	2,5	0,75
2017	0,4	7,9	4,2	6,4	3,6	-2,4	18,7	3,7	4,5	7,8	2,8	1,2	4,9	0,75
2018	2,5	4	2,65	1,8	-0,6	1,5	1,1	2,6	4,6	0,5	0,1	0,6	1,8	0,75
2019		3,8	1,2	3,8	2,1	2,3	2,6	1,7	-0,7	2,0	-0,4	3,74	2,0	0,75
2020	0,1	10,1	4,3	4,3	0,4	2,1	3,5	3,3	1,3	0,2	2,7	3,8	3,0	0,75
2021	2,8	4,0	5,2	4,0	1,9	5,5	2,1	2,6	2,2	2,3	1,7	8,4	3,6	0,50
2022	5,9	2,4	3,4	4,52	0,9	3,7	4,5	2,6	1,2	6,7	4,1	7,3	3,9	0,50
2023	4,83	4,57	4,1	3,58	6,53	4,63	4,95	4,32					4,69	0,50

Source: Data analysis

These changes in hydrological conditions reduce the resilience of the Brangkal Sub-Watershed, making it more vulnerable to the impacts of pollution and other stressors.

The decline in water quality sustainability has significant ecological and socio-economic implications. Moderate sustainability levels indicate a reduced ability to support diverse aquatic ecosystems, potentially leading to losses in biodiversity and disruptions in aquatic food webs. This can have a cascading effect on local fisheries, which are important for the livelihoods of communities around the watershed [10]. Furthermore, reduced water quality can limit the use of water for drinking, recreation, and agricultural purposes, affecting both human health and economic productivity.

To address the decline in water quality sustainability in the Brangkal Sub-Watershed, a comprehensive approach is necessary. Key mitigation strategies include enhancing wastewater treatment infrastructure, implementing stricter pollution controls, and promoting sustainable agricultural practices. Upgrading existing wastewater treatment plants and expanding their capacity can significantly reduce the organic load entering the watershed [9]. Additionally, implementing best management practices in agriculture, such as precision farming, controlled use of agrochemicals, and soil conservation techniques, can help minimize runoff and reduce BOD levels [9].

Improving land use planning and incorporating green infrastructure, such as riparian buffers and constructed wetlands, can further enhance the watershed's ability to filter pollutants and maintain water quality [7]. Strengthening regulatory frameworks and ensuring compliance with environmental standards are also critical to reducing pollution from industrial and urban sources [5]. Moreover, integrating adaptive management practices that consider the impacts of climate change is essential for building the resilience of the watershed to future environmental stressors [8,15].

By implementing these strategies, stakeholders can work towards reversing the decline in water quality sustainability and enhancing the resilience of the Brangkal Sub-Watershed. A coordinated and adaptive approach that involves government agencies, industries, communities, and environmental organizations will be key to achieving long-term water quality improvements and ensuring the sustainability of this critical water resource.

4 Conclusion

The study concluded that in the period 2014-2023 the water quality of the Brantas Watershed has decreased and is currently at class 4 (the lowest) quality. The sustainability of the Brantas Watershed has decreased and in 2023 it will be in the low category. The decline in water quality is mirrored by the overall sustainability index of the Brantas Watershed, which has also decreased, falling into the low category by 2023. This low sustainability rating indicates that the watershed's capacity to maintain its ecological functions, provide clean water, and support biodiversity has been severely compromised. The factors contributing to this decline are multifaceted and include increased pollution from urban, industrial, and agricultural sources, ineffective wastewater treatment, deforestation, and poor land management practices. Additionally, climate change has exacerbated these issues by altering hydrological patterns, leading to more extreme weather events such as heavy rains and droughts that increase pollutant runoff and reduce water quality resilience.

This downward trend has serious implications for the communities and industries that rely on the Brantas Watershed. As water quality declines, the risks to public health, aquatic life, and economic activities such as fisheries and tourism increase. The decreased sustainability of the watershed further signals potential long-term challenges in meeting the water needs of the region's growing population and economy. Addressing these challenges requires a comprehensive approach that includes strengthening pollution control measures, enhancing wastewater treatment infrastructure, promoting sustainable land use and agricultural practices, and implementing adaptive management strategies that account for the impacts of climate change. Collaboration among government agencies, industries, local communities, and environmental organizations will be essential to reversing the current trends and restoring the Brantas Watershed's water quality and sustainability.

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