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Regional Case Study

Assessment of Surface Water Quality Status Using the Pollution Index Method in Tukad Badung River

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Abstract
This research proposes to find out the present state of the water's purity in Tukad Badung through an examination of the Pollution Index (PI) adopted from the methodology presented by the Water Quality Index (WQI), which was presented by the Indonesian Ministry of Environment. A series of water samples were taken at three river flow points in the Denpasar City area, representing the upstream, middle, and downstream areas. The water quality parameters were determined based on the characteristics of domestic wastewater pollutant sources that are identified in watershed areas. In accordance with Regulation 22 of the Government of 2021 concerning quality standards for river water used for drinking water, the average concentrations of Total Suspended Solid (TSS), Ammonia, Biological Oxygen Demand (BOD), and Chemical Oxygen Demand (COD) parameters have exceeded quality standards. Meanwhile, the oil and grease parameter, as well as detergents, still meet quality standards. The PI at three monitoring points was obtained at 2.41 – 4.27, categorized as lightly polluted. In the future, efforts to deal with water pollution are critical to meet the downstream water quality standards used as drinking water.

Keywords: River pollution; water quality; watershed; pollution index; tukad badung

1. Introduction

Surface water pollution, caused by activities of anthropogenic and natural processes in the vicinity, is still a major problem worldwide. Decreased surface water quality can have a bad effect on meeting the needs of clean water and the sustainability of the aquatic ecosystem itself (Tian et al., 2019). Examining the purity of the water near the surface, especially raw water sources used for drinking water, is important because it can be one of the reasons for toxic chemicals spread and pathogenic microorganisms (Haseena et al. 2017, Bwire et al., 2020). Determining water quality using a simple method and easy-to-understand interpretation of results is necessary, given the complexity of the data resulting from the water quality assessment process (Nurrohman et al., 2019).

Referring to the general condition of surface water in Indonesia, the Ministry of Environment adopted an index developed by Sumitomo and Nemerow from the University of Texas in 1970, as explained in Appendix II to the Decree of the State Minister for the Environment Number 115 of 2003 concerning Instructions for Assessing the Current Condition of Water Quality. This index relates to the content of contaminants, which is a key parameter for a water allotment which is expressed as the

Pollution Index. Pollution categories that are relative to the water quality parameters required quality standards can be determined from the Pollution Index. The index concept is different from the Index of Water Quality.

The Index of Pollution assessment relates to a water allotment in part or all river water bodies. The administration of water quality standards determined by the level of the Pollution Index can be utilized as input for relevant stakeholders in assessing a river's water body's degree of purity used as a water source for a particular designation, as well as in carrying out quality improvement efforts if the pollutants cause a decline in water quality. The Pollution Index is determinable using various independent the quality of water parameters (Decree of the State Minister for the Environment Number 115 of 2003). The calculation of the Pollutant Index is based on a criterion of assessed water quality pollutant parameters. The standards that can be referred to at this time in determining the class of water according to its designation are the criteria for the purity of the water in the river and other similar waters, which are regulated in Appendix VI of Government Regulation Number 22 of 2021 concerning Implementation of Environmental Protection and Management (Government Regulation Number 22 of 2021). In connection with indications of wastewater pollutants entering the waters, parameters can be determined based on parameters of domestic wastewater quality, referring to the Minister of Environment and Forestry Regulation Number 68 of 2016 concerning Domestic Wastewater Quality Standards (The Ministry of Environment and Forestry Regulation Number 68 of 2016). The significant area expansion in most watershed areas in developed urban areas in Indonesia, such as the Denpasar City of Bali Province, has affected the water quality. The change in land use is assumed as the source of water pollutants that increases the pollution index. Periodic monitoring and assessment of water quality status are essential concerning the indication, as the water quality has to meet a certain standard to be utilized for other purposes.

Tukad Badung Watershed is one of the watersheds in Bali Province, which crosses two administrative areas, i.e., Badung Regency and Denpasar City. Apart from being an aquatic ecosystem for aquatic biota, the main use of the Tukad Badung River is as a raw clean water source for services in the two watershed administrative areas, which are areas with high population and economic growth in the Province of Bali (Raeskyesa et al., 2019; Trimandala, 2021). However, several of the findings of studies conducted on the quality of the water of Tukad Badung indicated that river pollution had occurred. (Pradnyamita et al., 2014; Mahendra et al., 2015; Partama et al., 2019; Gupta et al., 2020; Harmayani et al., 2021). According to the previous studies, water quality parameters of pH, oil, TSS, COD, BOD, ammonia, fat, oil and grease, detergent content, and coliform exceeded the standards. The quality of the water was rated as mildly into extremely polluted comparing the standard of water quality. According to the findings of previous analysis and considering the characteristics of pollutant sources, the parameters of TSS, Ammonia, BOD, COD, oils and grease, and detergents were identified as factors that influenced the overall water quality in the Tukad Badung River.

An anthropogenic and wide variety of natural variables can affect the quality of the river water (Yotova et al., 2021). Domestic wastewater from anthropogenic activities around rivers, such as settlements, small and household industries, and livestock, has the potential to become a source of pollution to the Tukad Badung River. Water quality will decrease as long as proper management efforts are not made (Pohan et al., 2016). In determining river water management strategies, data related to water quality is required. In this regard, it is important to monitor water quality on an ongoing basis as a form of providing periodic data (Saraswati et al., 2017; Sari and Wijaya, 2019). Therefore, the purpose of carrying out this research was to analyze the current state of the water quality of the Tukad Badung River and determine the correlation of land use as the pollutant source of the river. This information is essential for agencies who manage water quality, especially downstream water quality, utilized as a water resource for drinking water.

2. Methods

The research was conducted in Tukad Badung, a river that flows from Badung Regency passes through the city of Denpasar, and empties into Benoa Bay. Data collection was carried out using both primary and secondary sources of information. The collection of primary data consisted of taking samples at 3 points in the Tukad Badung area, which represented the downstream, middle, and upstream areas. Taking the water samples were in early October, at the beginning of the rainy season. It's when the wet season begins and the dry season ends so that the data can demonstrate a condition affected by both seasons. At this time, low rainfall has not yet impacted the dilution of water due to the influx of rainwater and floodwater from surrounding areas compared to high rainfall in the rainy season (Mondol et al., 2013). Table 1. Presents the coordinates of the sampling locations. Figure 1 shows the map of Tukad Badung watershed, land use in the watershed area, and sampling location points.

Table 1. Sampling point locations

No.	Sampling Point	Coordinate		Location Areas	Land Use	Condition of the Sampling Point
		South Latitude (LS)	East Longitude (E)			
1	Point 1	08°38' 52.0"	1150 12' 41.4"	Sutomo III Road, Pemecutan Kaja, North Denpasar	Rice Fields, Settlements	
2	Point 2	080 40' 35.7"	1150 12' 05,3"	Pulau Indah Road, Dauh Puri Kauh, South Denpasar	Settlements, Rice Fields, Bare Land	
3	Point 3	08°41' 21.8"	1150 11' 52.7"	Fishing Park, Tukad Baru Road No. 29, Pemogan, North Denpasar	Trade and Services, Bare Land, Settlements	

Surface water sampling methods are outlined in Indonesian National Standard (SNI) 6989.57:2008, which serves as the basis for the sampling procedure (Gupta et al., 2020). The process of sampling was performed in the afternoon by grabbing a sample (temporary sample) using a vertical water sampler. Sample water is placed in a container with a volume of 2 liters and stored in a low-temperature cooler box. After that, it is tested at the Bali Province Health Laboratory Center Regional Technical Implementation Unit, including the parameter content of oil and grease, COD, BOD, TSS, ammonia, and detergents. Laboratory tests for TSS, ammonia and detergent parameters use the Spectrophotometric method. BOD refers to the APHA method, 23rd Edition 2017 (Section 5210.B), and COD is according to the Indonesian National Standard (SNI) 6989.2:2019 method and the Gravimetric method for oil and grease parameters.

Water quality data from the test results were analyzed utilizing the Pollution Index technique in accordance with the Decree of the Minister of Environment Number 115 of 2003 using Equation (1). The Pollution Index's calculation is influenced by the maximum value and the average value of the ratio of each parameter's concentration.

$$IP_j = \sqrt{\frac{\left(\frac{C_i}{L_{ij}}\right)^2 max + \left(\frac{C_i}{L_{ij}}\right)^2 avg}{2}} \quad (1)$$

Where:

IPj	= Pollution index for designation j		
	$0 \leq Pij \leq 1.0$	:	Water quality fulfils standards of quality (good condition)
	$1.0 \leq Pij \leq 5.0$	:	Lightly contaminated water quality
	$5.0 \leq Pij \leq 10$	:	Polluted water quality is moderate
	$Pij \geq 10$	:	Quality of heavily polluted waters
Ci	= Water quality concentration parameters i		
Lij	= Water quality concentration parameters i listed in the quality standard for water use j		
Ci/Lij max	= Maximum value of Ci/lij		
Ci/Lij avg	= Average value of Ci/Lij		

3. Result and Discussion

Test results and the comparison with quality standards for each parameter are shown in Figure 2. The description of the water quality conditions for each analyzed parameter is as follows:

A. Total Suspended Solids (TSS)

TSS stands for total suspended solids (diameter > 1μm), such as microorganisms, fine sand, and silt that are formed as a result of sandblasting or erosion of soil carried into bodies of water (Saraswati et al., 2017). The suspended concentration matter in the Tukad Badung river water samples ranged from 38 – 281 mg/L. TSS concentrations exceeding the quality standard were found at point 2 (middle) and point 3 (downstream), where point 2 had the greatest concentration with 281 mg/l. The high Total Suspended Solids in the waters may be brought on by the type of land used as pollutant sources at the sampling point, i.e., settlements, plantations, and shrubs. Meanwhile, the concentration of TSS at point 1 (upstream) has met the quality standard.

Pollutant sources from settlements and agricultural uses impact the increasing TSS parameters in the water (Nurrohman et al., 2019). This land use allows erosion of suspended soil particles that enter the river and increases the concentration of suspended solids (Agustira and Jamilah, 2013). Figure 1 shows more settlements or housing areas around the Tukad Badung River at sampling points 2 and 3 compared to sampling point 1. This is in line with the study by Baharem et al. (2014), which states that high community activity will tend to increase TSS pollution. Besides, there are plantations around sampling point 2. The agriculture area also tends to increase TSS concentrations. However, the effect varies greatly depending on local and natural factors, for example, the shape of the watershed or land management practices (Merchán et al., 2019).

B. Ammonia ($NH_3 - N$)

Samples taken from the waters of the Tukad Badung river have ammonia concentrations ranging from 0.075 – 0.791 mg/L. Point 3 (downstream) of 0.791 mg/L obtained the greatest amount of ammonia in concentration. The content of ammonia at point 1 (upstream) has met the quality standard, while point 2 (middle) and point 3 (downstream) exceed the quality standard. Ammonia comes from the decomposition of organic material that contains protein. The accumulation of the ammonia increases when the nitrifying decomposition process takes place, which eventually disrupts the river ecosystem and aquatic biota (Harahap, S., 2013).

The increase in the value of the amount of ammonia pollution that occurs is indicated to originate from household activities, i.e., washing, batch, and toilet. Household activities that occur in settlements or housing areas emit protein that can be contained in human feces and urine (Rahayu et al., 2018). In addition, ammonia and nitrite are parameters that can be used as indicators of entry of residential waste into water bodies (Hamuna et al., 2018; Saputra et al., 2017). As described in Figure 1, larger settlement areas are signified at around sampling points 2 and 3 than sampling point 1, as described in the map of Figure 1.

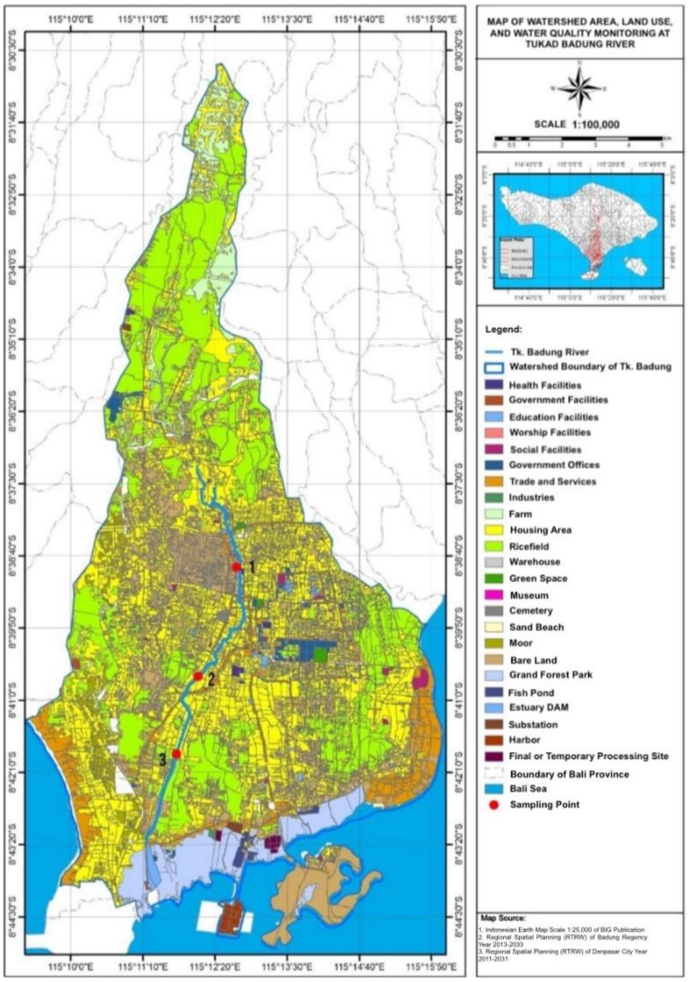


Figure 1. The watershed area map, land use, and sampling points

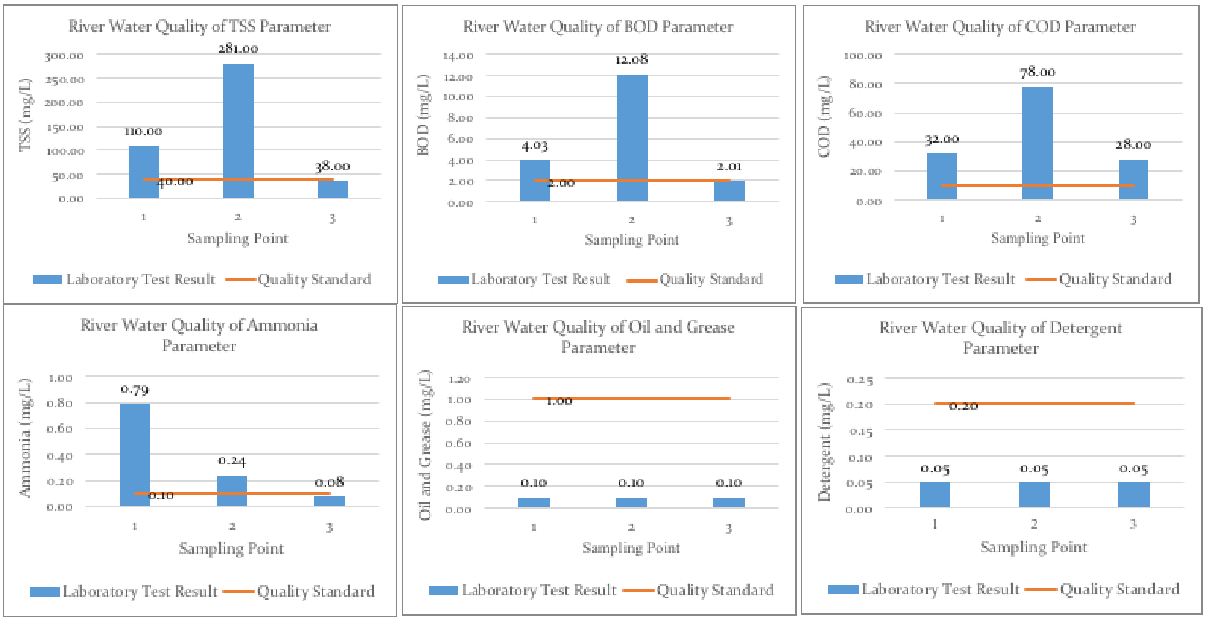


Figure 2. Water quality analysis results for TSS, BOD, COD, ammonia, oil and grease, and detergent parameters

C. Biological Oxygen Demand (BOD)

Indicators of organic matter content in water can be known by determining the appropriate level of oxygen consumption to stabilize the water. The need for oxygen is expressed in the parameters BOD and COD (Nurrohman et al., 2019). The BOD5 concentration in river water samples ranged from 2.01 – 12.08 mg/L, which indicates water conditions that do not meet quality standards at all sampling points. The sample point 1 (upstream) shows compliance with the highest quality standard with a difference in excess water concentration to the standard of only 0.01 mg/L.

The high BOD content indicates the occurrence of water pollution by organic compounds, both plants, and animals, that have undergone decomposition so that aquatic organisms require oxygen in large quantities to degrade the organic waste materials contained in the water. Factors of salinity, temperature, turbulence and atmospheric tension affect the quantity of oxygen contained in the water. At high temperatures and low atmospheric pressure, the dissolved oxygen content will decrease (Nurrohman et al., 2019). According to the map of land usage, which is presented in figure 1., all of the sampling points are covered with settlements

The organic waste contained in the river can come from residential areas. Only a little oxygen can enter the water in this type of land use because the built-up area blocks their entry. There are piles of organic waste originating from settlements and human activities that can inhibit oxygen transfer (Sara et al., 2018). Therefore, it can be figured out that the level of high BOD depends on the density of the settlement. The highest BOD value is indicated at sampling point 2 in accordance with the density of the settlements in the area, and so forth, the less dense sampling point of point 3 and 1.

D. Chemical Oxygen Demand (COD)

COD expresses the need for oxygen which is needed in the process of chemically oxidizing organic compounds in water (Harmayani et al., 2021). COD concentrations in river water samples ranged from 28 – 78 mg/L, with the maximum concentration at point 2 (middle) of 78 mg/L. All monitoring points showed conditions that could not achieve the required level of COD quality, which is 10 mg/L. High COD content indicates the presence of heavy metals and non-degradable sediments in high concentrations in waters (Sumantri, A. and Rahmani, RZ, 2020). The main sources that can cause an increase in COD concentrations are household, industrial, and livestock wastewater (Lumaela et al., 2013).

E. Oil and Grease

Grease and oil are two instances of organic molecules that are generally stable and hard to degrade. (Andreozzi et al. 2000). Oil and fat concentrations in three river water samples had a value of <0.1 mg/L, which met the quality standard of 1 mg/L. The amount of grease and oil present in the water as a concentration is from household activities, such as kitchen activities, that are observed at each sampling point. The typical daily consumption of oil in a family was 149.2925 grams, whereas the typical consumption of oil by an individual was 39.6927 grams on a daily basis (Salehzadeh et al., 2019). The content of the oil and grease source from the kitchen is not entirely wasted by the water bodies resulting in a small number of parameters.

F. Detergent

The detergent parameter is an indicator of pollution due to community washing and toilet activities in the river. Based on the test results, it was found that the detergent concentration in three river water samples was <0.05 mg/L, indicating compliance with the quality standard of 0.200 mg/L. Detergent content can be sourced from household activities, such as washing. There were household land uses in the three samples, as shown in Figure 1. However, the average household consumption of detergent cake was only 3.2 g per person per day (Gadgil et al., 2018). The result of low detergent concentration indicated that only a small amount of detergent content is wasted on surface water bodies.

According to the result observed in the dry season by Harmayani et al. (2021), the detergent parameter was undetected. It demonstrated that the analysis results were conducted in the transition period with a low concentration of detergent, corresponding to the results taken in the dry season.

Table 2. provides an explanation of how the Index of Pollution is able to be utilized to evaluate water quality.

Table 2. Pollution index value in Tukad Badung River

Sampling Point	Pollution Index	Pollutant Parameters					
		TSS	**Ammonia**	**BOD**	**COD**	**Oil and Grease**	**Detergent**
1	Test Result (Ci)	38.00	0.08	**2.01**	**28.00**	< 0.10	< 0.05
	Quality Standard (Lij)	40.00	0.10	2.00	10.00	1.00	0.20
	(Ci/Lij)	0.95	0.75	1.01	2.80	0.10	0.25
	(Ci/Lij) New	0.95	0.75	1.01	3.24	0.10	0.25
	(Ci/Lij) Maximum	3.24					
	(Ci/Lij) Average	1.05					
	Pollution Index (IPj)	2.41					
	Category	Light Polluted					
2	Test Result (Ci)	**281.00**	**0.24**	**12.08**	**78.00**	< 0.10	< 0.05
	Quality Standard (Lij)	40.00	0.10	2.00	10.00	1.00	0.20
	(Ci/Lij)	7.03	2.41	6.04	7.80	0.10	0.25
	(Ci/Lij) New	5.23	2.91	4.91	5.46	0.10	0.25
	(Ci/Lij) Maximum	5.46					
	(Ci/Lij) Average	3.14					
	Pollution Index (IPj)	4.46					
	Category	Light Polluted					
3	Test Result (Ci)	**110.00**	**0.79**	**4.03**	**32.00**	< 0.10	< 0.05
	Quality Standard (Lij)	40.00	0.10	2.00	10.00	1.00	0.20
	(Ci/Lij)	2.75	7.91	2.02	3.20	0.10	0.25
	(Ci/Lij) New	3.20	5.49	2.52	3.53	0.10	0.25
	(Ci/Lij) Maximum	5.49					
	(Ci/Lij) Average	2.51					
	Pollution Index (IPj)	4.27					
	Category	Light Polluted					

The Tukad Badung Watershed is one of the watersheds in Bali Province, which crosses two administrative areas, namely Badung Regency and Denpasar City. Apart from being an aquatic ecosystem for aquatic biota, the main use of the Tukad Badung river is as a raw water source for clean water services in the two watershed administrative areas, which are areas with high population and economic growth in the Province of Bali. Downstream of the river, water is stored in the Muara Nusa Dua Reservoir for further processing at the Water Treatment Plant (IPA) and distributed. However, various research on the quality of Tukad Badung's water indicated that river pollution had occurred (Pradnyamita et al., 2014; Mahendra et al., 2015; Partama et al., 2019; Gupta et al., 2020; Harmayani et al., 2021).

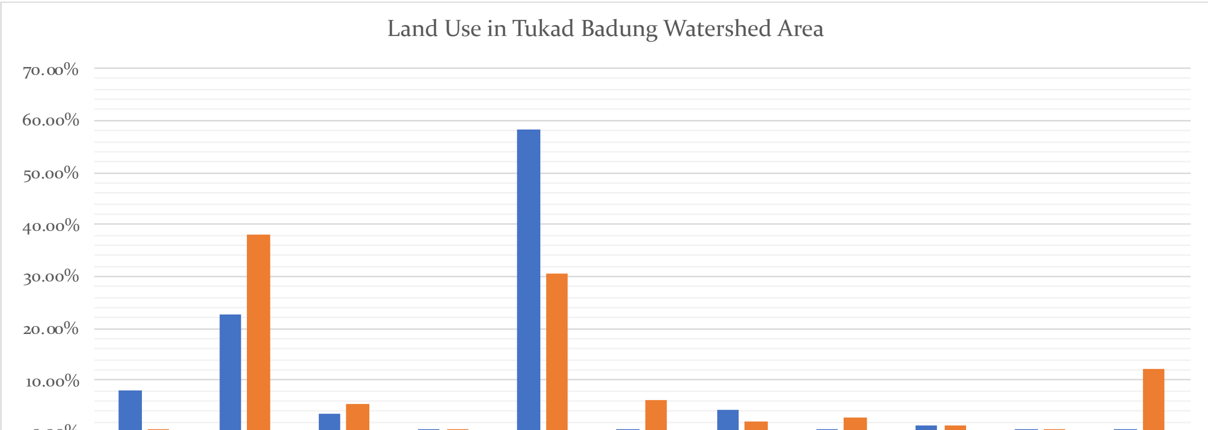
Tukad Badung water quality monitoring conducted in 2014 revealed that the Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) parameters no longer met the quality criteria for Class I, II, III, and IV based on Government Regulation Number 82 of 2001 (Pradnyamita et al., 2014). Another study conducted in 2015 also explained the concentration of coliform in Tukad Badung, which exceeded the quality standards for class I, II, III, and IV water according to the Governor of Bali Regulation Number 8 of 2007 with an Index of Pollution ranging from 1.28 to 1.43, which is classified as lightly polluted (Mahendra et al., 2015). In 2021, a monitoring result in downstream location signified that BOD, COD, and ammonia parameter values met the standards of water quality for drinking water (Harmayani et al., 2021).

Furthermore, according to the water quality result in 2019, STORET assessment applied in the upstream Tukad Badung area had a score of -41 (severely polluted) compared to class I quality standard, a score of -35 (severely polluted) compared to class II quality standard. , a score of -23 (moderately polluted) compared to class III quality standards and a score of -17 (moderately polluted) compared to class IV quality standards (Pertama et al., 2019). Based on monitoring data from Bali - Penida River Basin Office in

2020 at five sampling points using the method of Pollution Index, 100% of the river water was found to be lightly polluted. In the same year, test results at three sampling points in the downstream, middle, and upstream parts of the Tukad Badung river also showed water quality conditions that could not exceed the standards of quality from the parameter's pH, BOD, COD, TSS, fat, oil and detergent content (Gupta et al., 2020).

Present data can be observed in accordance with the analysis of the Index of Pollution at three monitoring points for the Tukad Badung river water that passes through Denpasar City in 2022. Values were obtained of 2.41 upstream (point 1), 4.46 in the middle (point 2), and 4.27 downstream (point 3). The water quality rating in accordance with the Pollution Index shows the slightly polluted category for three locations. Pollution Index value increases from point 1 (upstream) to point 2 (middle), which shows the highest value of the three monitoring points. The pollutant sources were identified according to the land uses around the sampling points, i.e., point 1 (rice fields and settlements), point 2 (settlements, rice fields, and bare land), and point 3 (trade and services, bare land, settlements). The current water quality condition signified that related agencies should establish appropriate water resource management for conservation.

One of the aspects that determines the quality of water in a watershed is the way the land is used. On the basis of the findings of studies carried out within the Cimanuk Watershed, West Java, pH, BOD, and COD parameters with the highest concentrations were found at the point which was dominated by paddy fields and settlements (Nurrohman et al., 2019). Several activities obtained along the river of the watershed potentially become a source of river water pollution in Tukad Badung, e.g., household waste, laundry, goat livestock waste, chicken livestock, tofu factories, motorbike washing, and textile waste. The most significant pollutant source is the household with the largest area. The trash that is able to be broken down or recycled by the action of microorganisms can be in the form of solid or liquid, organic compounds, or in the form of inorganic compounds such as soap, detergent, shampoo, and other cleaning agents that can contaminate water (Debataraja et al., 2018).



	Building	Paddy Field	Combined Gardens	Beach Sand	Hosing Area	Grass	Mangrove	Ponds	Dryland Farms	Estuary dam area	Bare Land
2000	8.10%	22.63%	3.61%	0.08%	58.38%	0.66%	4.48%	0.26%	1.46%	0.23%	0.10%
2021	0.73%	38.14%	5.58%	0.41%	30.61%	6.09%	2.02%	2.73%	1.34%	0.25%	12.11%

Figure 3. Land use change in watershed area of Tukad Badung River

Concerning land use, secondary data of the Regional Spatial Plan for the Denpasar City and Badung Regency that covered the Tukad Badung Watershed area is available in 2000 and 2021. Figure 4 presents the percentage of land use types. The impact of the environmental quality can be predicted by comparing the pre- and post-development conditions of land use (Jaya et al., 2022), in this case, the land use in 2000 and 2021. The residential type of land use dominated the Tukad Badung Watershed area both in 2000 and 2021, with the highest increase of 27.77%. The expansion also occurred in building land use, with a percentage of 7.38%. In addition, there was an increase in the land use types of mangrove and dryland farms in the watershed area. Other land use types have decreased, i.e., paddy fields, combined gardens, beach sand, grass, ponds, estuary dam area, and bare land. A relatively high decrease occurred in paddy field land use of -15.50% and bare land of -12.01%.

According to the water quality result observation, point 2 is located in the Dauh Puri Kauh Village area, South Denpasar District, where the types of land use include settlements, rice fields, and bare land, which is also used for livestock. Parameters with the highest concentrations were found at the sampling point, which was dominated by rice fields and settlements, such as point 2. Meanwhile, at point 3 (downstream), an improved condition is obtained over point 2 (middle), which is shown by the decrease in the value of the Pollution Index. From 2004 to 2014, with indications of wastewater contamination in the Tukad Badung River, the relevant government built a centralized Wastewater Treatment Plant (WTP) in Suwung, Denpasar. The wastewater pipeline network also covers the area of Dauh Puri Kauh Village, South Denpasar. The WTP was built and maintained the area around sampling point 2. However, the system has not yet covered the site before and after the sampling point. Moreover, there has been a significant increase in population around the watershed, as shown by the increase in residential buildings in 2021 of about 8.10% (Figure 3). Regarding the residential area expansion, infrastructure should be established following the development. With conditions that are still lightly polluted, in the future, efforts are still needed to manage the quality of Tukad Badung water used as the source of drinking water.

4. Conclusions

A study of the Pollution Index was utilized in order to find the current state of water quality at three river flow monitoring points in the Denpasar City area, representing the upstream (point 1), middle (point 2), and downstream (point 3), shows the lightly polluted category with the lowest value at point 1 of 2.41 and the highest value is 4.46 at point 2. The comparison of test results against specifications for the purity of the water in the river for drinking water (Class I), according to Government Regulation Number 22 of 2021, shows that the Biochemical Oxygen Demand and Chemical Oxygen Demand parameters no longer meet quality standards, while the concentrations of oils and fats and detergents still met the quality standards at three monitoring points. The TSS concentration and ammonia parameters failed to meet the established criteria for quality at point 2 and point 3 and still met the quality standards at point 1. Domestic activities carried out along the river flow, which are settlements, industry, rice fields, and livestock, produce wastewater that causes pollution. Despite the utilization of land use in determining pollution sources, as demonstrated in this study, data on the number and types of pollution investigated in the field are more significant for assessing the pollution load. Therefore, studies of the pollution sources are necessary to identify the quality of water status. Furthermore, management of the water's quality is essential to be done according to the current river pollutant parameter characteristic data. Regarding this matter, planning for the appropriate technology in water treatment.

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