Pol. J. Environ. Stud. Vol. XX, No. X (XXXX), 1-14

DOI: *10.15244/pjoes/199768* ONLINE PUBLICATION DATE:

Original Research

Application of Models for Assessing Pollution Load Capacity and Strategic Management of the Klampok Sub-Watershed

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Received: 12 August 2024

Accepted: 3 January 2025

Abstract

The Klampok River, part of the Klampok sub-watershed in Semarang Regency, Central Java, faces reduced carrying capacity and water quality owing to high-intensity anthropogenic activities. This study applied the pollutant index method, based on the Ministry of Environment Regulation 115/2003, to analyze the BOD and COD concentrations in river samples. The results indicated pollution at one or all six sampling points, with the Klampok sub-watershed land classified as class III and IV, showing a land-carrying capacity deficit but a water-holding capacity surplus. The Klampok River cannot accommodate BOD and COD pollution loads in any segment, leading to a mildly to moderately polluted water quality status. SWOT and QSPM analyses suggest an aggressive and progressive management strategy for the sub-watershed, emphasizing three key components: environmental capacity, pollution regulation, and community involvement.

Keywords: carrying capacity, pollution load capacity, watershed, river

Introduction

The sustainability of water resources is facing escalating challenges because of extensive environmental degradation, which can be further exacerbated by alterations in land utilization within the watershed region due to regional growth [1, 2]. A river is a natural or artificial water reservoir in the form of a network of water flows and water within it, with boundaries on the right and left sides. The river is divided into three parts based on its physical characteristics: upstream, middle, and downstream [3]. Topographical features determine the delineation of watershed boundaries on land, while at sea, they extend to water areas that remain influenced by terrestrial activities. Currently, data on watershed area damage continues to increase, with more than 70% of watersheds in critical conditions and as many as 136 rivers in Central Java being polluted [4].

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Watershed area damage can cause rivers to not function optimally, causing many environmental damage phenomena, such as flooding, drought, erosion, and decreased water quality, which indicates the low ecological carrying capacity in the watershed area [5, 6].

The concept of carrying capacity was first introduced in the 1960s in response to socio-economic activities that impacted natural resources and threatened sustainable development [3]. Carrying capacity is the ability of an ecosystem to sustain the survival of humans and other organisms [7], and is the upper limit of population growth until the population size can no longer be supported by existing facilities, resources, and the environment [7-9]. Carrying capacity analysis is a development planning tool that provides an overview of the relationship between population, land use, and the physical environment [10]. [11] defined the carrying capacity as the maximum resource or capacity that the environment can accommodate. Carrying capacity analysis can provide information essential to assess the capacity of land to support all human activities in a given area [12, 13]. Rivers can self-purify and decompose pollutants that enter rivers if the pollution is still below the specified quality standards [14, 15]. Therefore, these conditions affect efforts to restore water quality owing to pollution [9]. Watershed management must be integrated from upstream to downstream by considering various related social aspects. It cannot be separated from coordination between associated institutions and the community as the primary recipient of the impact of watershed management [6, 16, 17].

Klampok River is a river located in the Klampok sub-watershed of Semarang Regency, Central Java, at coordinates between 110°20'45.5" and 110°27'57.1" East Longitude and 7°8'12.5" and 7°11'27.4" South Latitude, and is part of the upstream of the Jragung watershed that empties into Demak Regency. Klampok sub-watershed is located in Semarang Regency and crosses Bandungan Subdistrict, Bergas Subdistrict, Pringapus Subdistrict, and Bawen Subdistrict, where there are industrial areas with a total of 90 industries in 2019 [18, 19]. With its location, the Klampok River becomes a water body that receives wastewater discharges from several industries, and based on the studies conducted, it is suspected that there are 4 (four) industries polluting [20, 21]; several Klampok River parameter concentration values taken at 6 (six) points did not meet the Class II Water Quality Standards according to Government Regulation Number 22 of 2021 [22]. Watershed environmental problems such as water pollution, declining water quality, and sedimentation can cause river capacity to decrease [23]. This is one of the causes of flooding and changes in water class quality. Therefore, this research aims to obtain the benefits of using environmental modeling in the Klampok sub-watershed management efforts so that an optimal formulation of the existing situation will be obtained through the capacity, carrying capacity, and quality status as the role of stakeholders and the community from year to year on the pollution load in river management in the form of determining the Klampok sub-watershed area management strategy that can be used as a reference for related institutions, such as the Semarang Regency Environmental Agency and regional stakeholders in the Klampok sub-watershed.

Materials and Methods

Determination of Klampok River Segments and Sampling Locations

Determination of segments (segmentation) is performed on water bodies with clearly distinguishable boundaries [24]. In this investigation, the Klampok subwatershed was segmented based on land use, which can represent potential sources of pollutants in the river. Segmentation identifies and analyzes differences in dominant contaminant sources affecting water quality between segments [19]. Six sampling points were determined to collect water samples based on the state of the sub-watershed division, land use, topography, physical condition of the river, and administrative boundaries [25]. Table 1 and Fig. 1 show the sampling locations in the Klampok River basin.

Physical, chemical, and microbiological parameters were measured by conducting laboratory tests to fulfill the primary data requirements [23]. This study used the

Table 1. Location of Sampling Points.

Name of Point	Sample Point
P1	Sidomukti, Bandungan Subdistrict: 07°12'17" N.S. and 110º22'19" E. (The river's headwaters and intensity of activities around the river are still relatively low)
P2	Jimbaran, Bandungan Subdistrict: 07°12'48" N-S and 110°23'04" E. (There is a hotel sector around this location)
P3	Poncoruso, Bawen sub-district: 7°13'7" N and 110°24'28" E. (There is population waste and agriculture)
P4	Jatijajar, Bergas Sub-district: 07°12'26" N-S and 110°25'26" E. (Area potentially affected by polluting waste)
P5	Derekan, Pringapus Sub-district: 07°11'31" N and 110°26'47" E.
P6	Pringapus Bridge, Pringapus Subdistrict: 07°11'38" N-S and 110°27'56" E. (Before the confluence of Klampok River and Jragung River, an easily identifiable location)

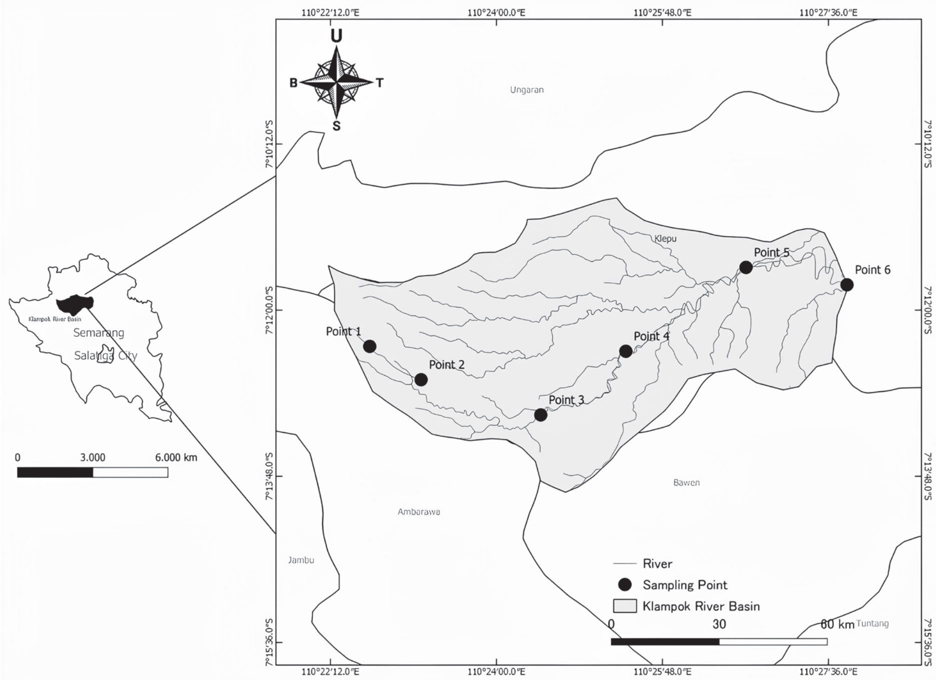

Fig. 1. Sampling Point Location.

chemical parameters BOD and COD to analyze river water quality and compare the results of laboratory parameter tests for each sample with Government Regulation Number 82 of 2001. BOD testing was based on SNI 6989.72.2009 using several tools, such as PM-3045 Nutrionics incubation, DO meter, Water Quality Meter AZ 86031, and oven. COD was based on SNI 6989.73.2009 with several tools, such as a UV-Visible Spectrophotometer Genesys 150 and Thermoreactor ECO25 Velp Scientidfica. The measuring flask, pipette, Erlenmeyer flask, and beaker equipment used Pyrex and Iwakl.

Secondary data related to the role of stakeholders were obtained by conducting interviews and filling out questionnaires. Several control points were used to monitor pollution from industry, hotels, and other sectors in the Klampok River flow. Observation of wastewater samples in the industrial sector was carried out by determining 3 (three) industries, namely PT ABC (beverage industry), PT DEF (herbal medicine industry), and PT GHI (chemical industry). The three types of industries were selected based on the classification of the size of the industrial scale because it affects the amount of wastewater discharged into the water body. The sampling point was determined based on the outlet, before and after the wastewater outlet location, to determine the level of pollution released into the water body. Sampling was carried out at 7 points located at the outlet and around the industry. Meanwhile, observation of wastewater samples in the hotel sector was conducted by determining three selected hotels, namely Hotel K, Hotel P, and Hotel F, and samples were taken at 10 points at the outlet and around the hotel. Three hotels were selected based on their geographical location and classification to determine the hotel activity's effect on river water quality. Similar to the sampling points in the industrial sector, the sampling points in the hotel sector were based on wastewater outlets.

Techniques of Data Collection

The data used in the study consisted of 2 types: primary and secondary. Primary data is obtained from sampling and measuring river flow velocity. Secondary data was obtained from literature studies and related agencies, such as topography and administrative areas. BOD and COD sample testing was conducted using the SNI 6989.72.2009 measurement method. Interviews and questionnaires were also conducted to determine the participation in managing the Klampok sub-watershed that has been, is, or will be carried out. Interviews were conducted by asking for information through oral questions to appropriate sources to provide accurate information on the existing conditions of the Klampok sub-watershed.

Data Processing and Analysis Methods

Pollutant Sources

Pollutant sources are identified using administrative and land use maps to determine land use with the potential to become a pollutant source. Pollutant sources are divided into point sources that are local and relatively fixed in volume, such as markets, and non-point sources carried by water flow, such as agricultural waste [26].

Qual2KW Method for Determining Pollution Load Capacity

Environmental capacity is the capacity of the environment to assimilate substances, energy, and/or other components that are introduced. Meanwhile, water pollution load capacity is the ability of water in a water body to receive pollution load input without causing the water to become polluted [9, 27]. QUAL2KW software is used to create a water simulation for capacity calculation. Fig. 2 shows the stages of using the QUAL2KW software. The QUAL2KW model requires calibration to adjust model predictions to existing data in the field. Calibration was performed by trial and error until the model approached the actual conditions.

The simulation data from Qual2Kw are then used to calculate the pollution load capacity [28]. The calculation of pollution load capacity utilizes the results of the QUAL2KW simulation and the count's initial condition load data. The pollution load in polluted/existing conditions was calculated by subtracting the allowable pollution load according to quality standards for classes I, II, III, and IV from the pollution load capacity. The reduction trial of all classes is because the Klampok River is a river that has not been assigned a water class; therefore, there is no definite river class. From the reduction trial using all quality standards for each class, the allocation of river water utilization is known based on river quality.

Determination of Support Capacity

The analysis is carried out by classifying land capability for allocation of space utilization, analyzing land capability at the processing unit level, evaluating land use suitability, comparing availability with land requirements, and comparing availability with water requirements, referring to the Minister of Environment Regulation 17 of 2009 [29] concerning Guidelines for Determining Environmental Support Capacity in Regional Spatial Planning.

Determination of Water Quality Class and Treatment Strategy for Klampok Sub-Watershed

Water quality was classified using the pollutant index technique. This index is expressed as a pollution index used to determine the pollution level relative to the allowed water quality parameters [28]. The SWOT matrix is a simple and systematic strategic planning method for evaluating a business or system's external and internal management priorities [30]. A SWOT matrix that considers the strengths, weaknesses, opportunities, and threats of the Klampok sub-watershed was selected to determine the management strategy of the Klampok sub-watershed. Subsequently, the priority of the implemented program was determined using the QSPM. The QSPM method is a quantitative decision-making method used to evaluate alternative strategies to objectively determine the best strategy [31].

Results and Discussion

Characteristics of Each Segment and Identification of Pollutant Sources

The river flow is divided into five segments. Each segment has different land use characteristics, representing sectors that have the potential to pollute the river. Fig. 3 shows the percentage of each land-use segment. The river flow path with the identified pollutant sources is shown in Fig. 4.

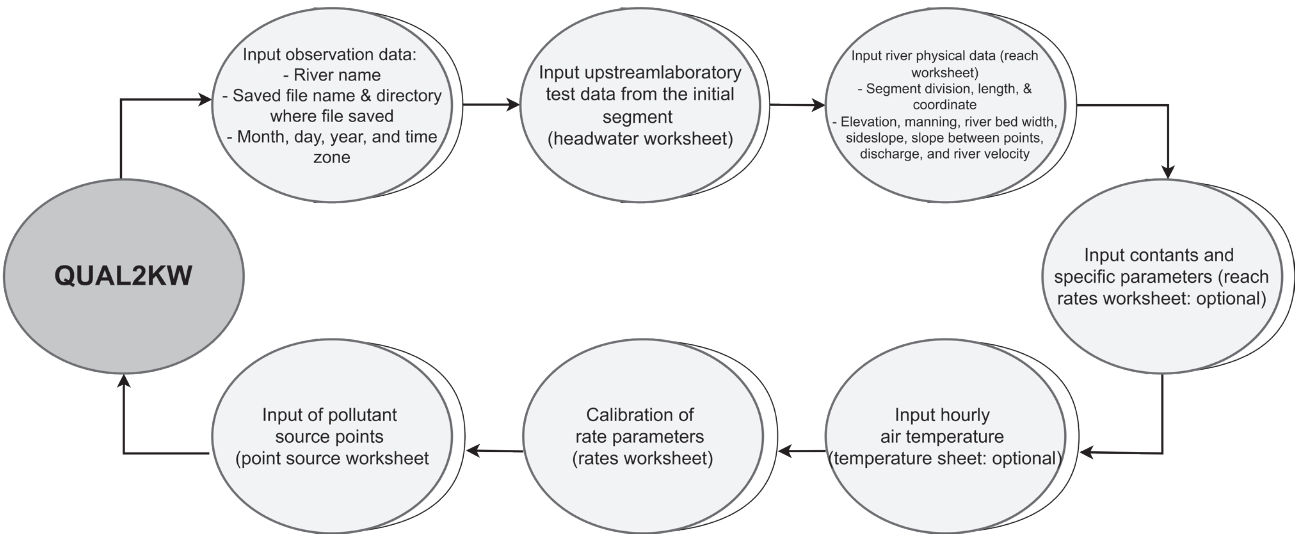

Fig. 2. Stages of using QUAL2KW software.

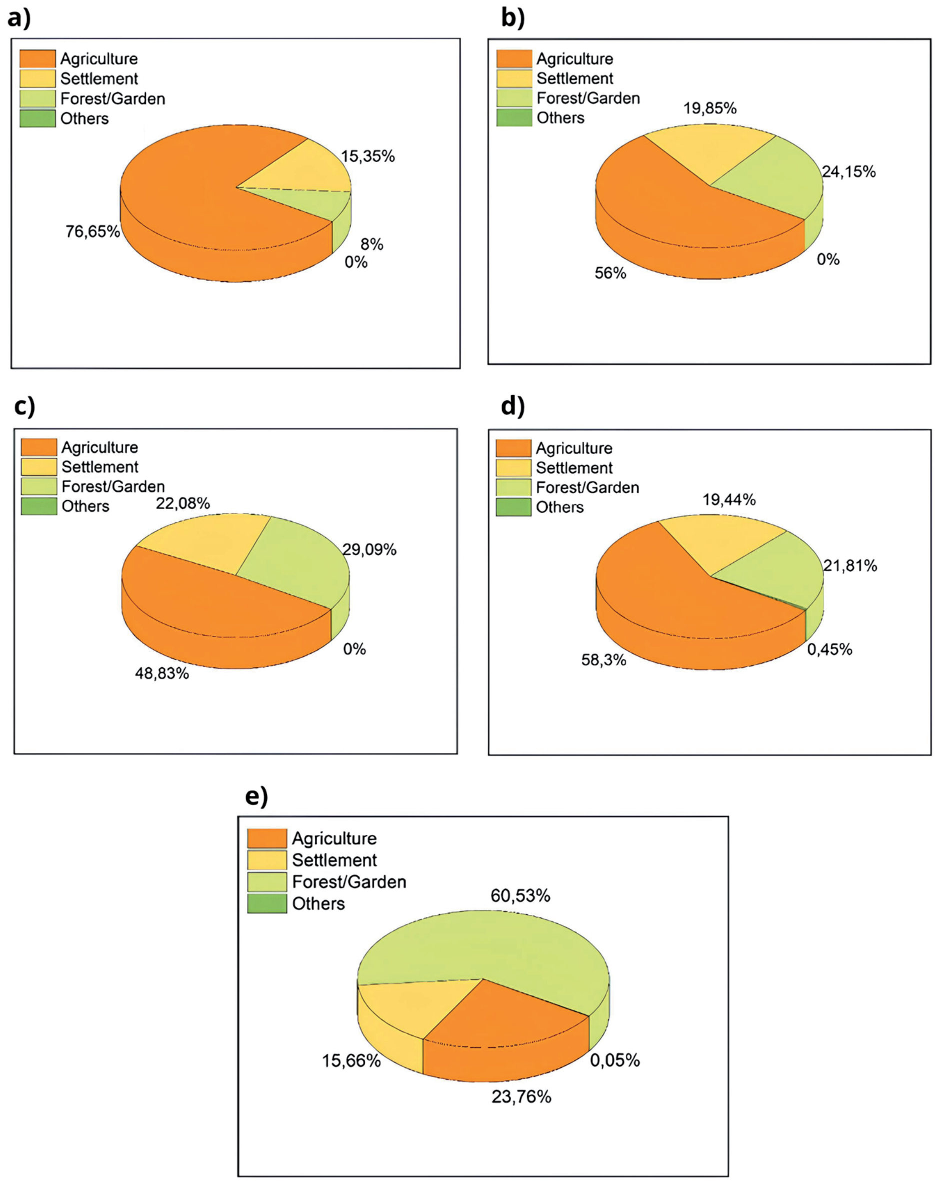

Fig. 3. Diagram of Land Use Percentage of Each Segment. a) Segment 1; b) Segment 2; c) Segment 3; d) Segment 4; e) Segment 5.

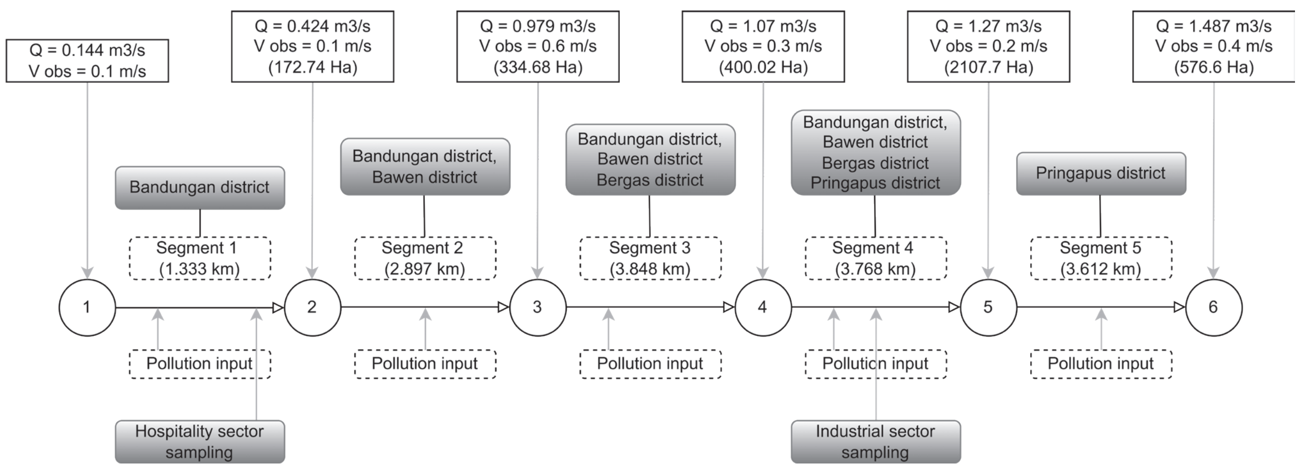

Fig. 4. Klampok River Flow Scheme.

Water Quality Analysis

Biochemical Oxygen Demand (BOD) Parameter

BOD is a parameter that indicates the quantity of dissolved oxygen required by microorganisms to decompose organic matter under aerobic conditions [32]. BOD parameters, together with COD, were able to show the carbon compounds contained in the water [33]. BOD can measure the amount of organic matter through a microbial consortium in 5 days [34]. This study measured the BOD parameter in the Klampok River sample body and the industrial and hospitality sector outlet.

BOD of Klampok River Body

Table 2 and Fig. 5 show the detailed measurement results of the BOD parameters per segment of the Klampok River body.

Based on this data, the BOD values remained the same, exceeding the quality standards in December 2022. This indicates that there is an improvement in the natural and technical conditions, which reduces the BOD of the Klampok River. However, deviations in BOD values occurred in January 2022 at points 1 and 6. Organic pollutants from domestic, agricultural, and livestock activities caused the high concentration of BOD at these points. Segments 1 and 5 have agricultural land, which dominates land use in both segments. In addition, in segment five, five industries affected BOD concentration. Similar research has been conducted in one of the rivers in Madiun City, which shows that the increasing concentration of BOD in river water bodies is caused by domestic waste, which is also related to the increasing population per year [35]. The BOD concentration decreases at points 2-5; this is influenced by the self-purification process in the river body as previously described.

BOD from the Industrial Sector

Fig. 6 shows that the BOD concentrations located next to the industrial discharge outlet have not met the

Table 2. BOD Parameter Values in Klampok River Body Samples.

Point	Unit	Default Quality of Class II	Measurement Value				Debit	Flow velocity
			Dec 2022	Jan 2022	Nov 2021	Oct 2021		
1	mg•L^{-1}	3	1	3.2	2.1	2	0.144	0.1
2			2.9	1.29	4.6	2	0.424	0.1
3			1	0.97	2	2	0.979	0.6
4			2	1.37	3.3	2.4	1.075	0.3
5			2	1.61	2	2	1.268	0.2
6			3	4.03	2	2	1.487	0.4

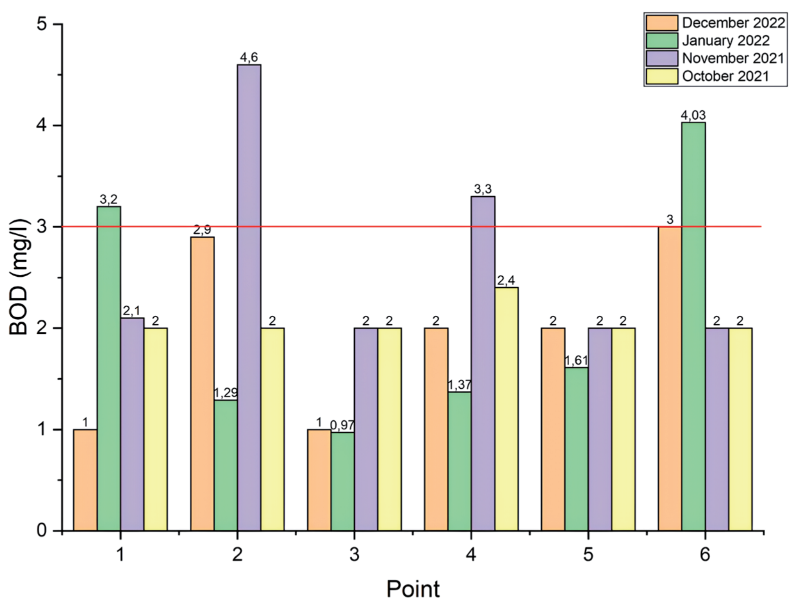

Fig. 5. Klampok River Body BOD Parameter Concentration Chart.

BOD quality standards for river water determined by Government Regulation 22 of 2021 [22] concerning the Implementation of Environmental Protection and Management. This could be caused by runoff from the Limited Liability Company (DEF LCC) and PT GHI industries, which is greater than the runoff from the PT ABC outlet, which also increases the concentration of BOD. However, the discharge from the outlets of the three industries must still be below the quality standard. In addition, runoff from sectors other than industry, mainly the domestic and agricultural sectors, can also influence the increase in BOD concentration. The area around point 5 consisted of several residential areas and irrigated land, whereas the area around point 7 consisted of residential and agricultural land.

Based on the sampling results in Fig. 7, it was found that the BOD concentrations, which are points in the Klampok River water body, did not meet the BOD quality standards for class II river water determined by Government Regulation Number 22 of 2021 [22]. Activities from hotel activities such as human waste, bathing, and washing cause an increase in wastewater, so the concentration of BOD also increases. Hotel waste discharged into the water body will accumulate so that the concentration of BOD increases, especially waste from Hotel F, which also pollutes the water body after its outlet. Hotel activities, runoff from agricultural waste from farmland around the point, and excessive fertilizer use can affect the BOD concentration at the sampling point. In this study, the environmental conditions comprised several houses and rice fields.

Chemical Oxygen Demand (COD) Parameters

Chemical Oxygen Demand (COD) represents the oxygen required to convert organic matter into CO_2 and H_2O [36]. In other words, high COD values indicate organic matter that can or is difficult to degrade biologically [37]. COD is used to measure oxygen consumption by oxidants during the decomposition of organic matter in a short time [33]. This parameter was chosen because it can show carbon compounds contained in water, such as hydrogen, oxygen, and nitrogen. In addition, COD is the fastest parameter that can be used to determine the water quality [33]. This study measured the COD parameters in the Klampok River sample body and at the industrial and hospitality sector outlets.

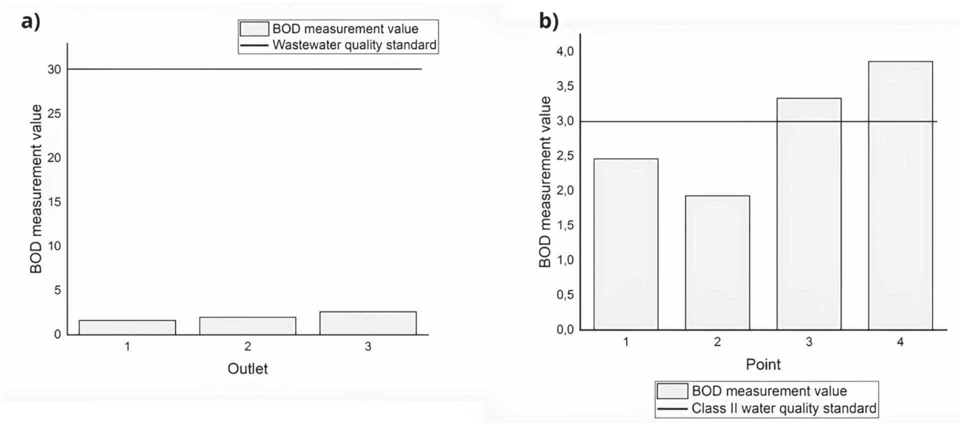

Fig. 6. a) BOD Concentration Chart of Industrial Outlet Parameter, b) Graph of BOD Parameter Concentration around Industrial Outlets.

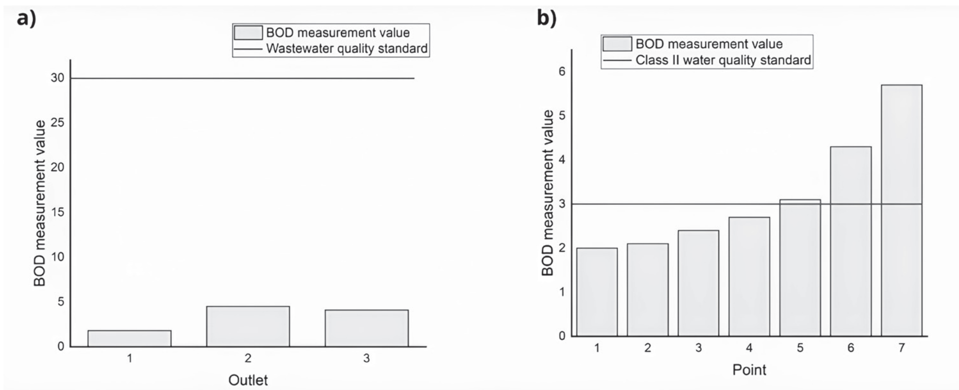

Fig. 7. a) Graph of BOD Parameter Concentration around Industrial Outlets b) Graph of BOD Parameter Concentration around Hotel Outlet.

COD Klampok River Body

Table 5 and Fig. 8 below show the detailed measurement results of COD parameters per segment in the Klampok River body.

Based on the data, COD values deviated from the quality standards in November 2021. This indicates that both technical and natural changes affect the reduction of COD concentrations in the Klampok River body. Deviations in COD values were observed at points 2-4 in November 2021. High COD concentrations at these three points occurred due to increased activity related to waste disposal with high organic compound content. Segments 2, 3, and 4, which are points 2-4 locations, are predominantly agricultural land, followed by settlements. In addition, livestock and fisheries activities also dominate the three segments. Budiyono and Syaichurrozi [38] showed that the increase in COD parameters was also caused by activities such as animal husbandry, the tofu industry, and garbage directly discharged into water bodies. The decrease in COD concentration at points 5-6 can be influenced by the self-purification process that takes place in segments 4 and 5 of the Klampok River as an active decomposition zone, with a self-purification coefficient value of 0.717 and 0.956, respectively [39].

COD Industrial Sector

Based on the sampling results in Fig. 9, it was found that the concentration of COD at the industrial outlets of PT ABC and PT DEF (points 1 and 4) and in the river water body after the industrial outlet (means 5 and 7) did not meet the COD quality standard for wastewater according to the Ministry of Environment Regulation Number 68 of 2016 [29] concerning domestic wastewater quality standards and the quality standard for COD parameters for class II river water according to Government Regulation Number 22 of 2021 [22] concerning the Implementation of Environmental Protection and Management. PT ABC and PT DEF are large industries with high activity, so they tend to produce more liquid waste, thus increasing the concentration of COD. The concentration of waste

Table 3. COD Parameter Value in Klampok River Body Samples.

Point	Unit	Default Quality of Class II	Measurement Value				Debit	Flow velocity
			Dec 2022	Jan 2022	Nov 2021	Oct 2021		
1	$mg \cdot L^{-1}$	25	3	6.4	15.5	9.9	0.144	0.1
2			9	3.2	122.6	17.2	0.424	0.1
3			3	6.4	62.2	34.3	0.979	0.6
4			6.68	6.4	43.1	47.6	1.075	0.3
5			6	9.7	16.3	30	1.268	0.2
6			9	13	17.3	18.4	1.487	0.4

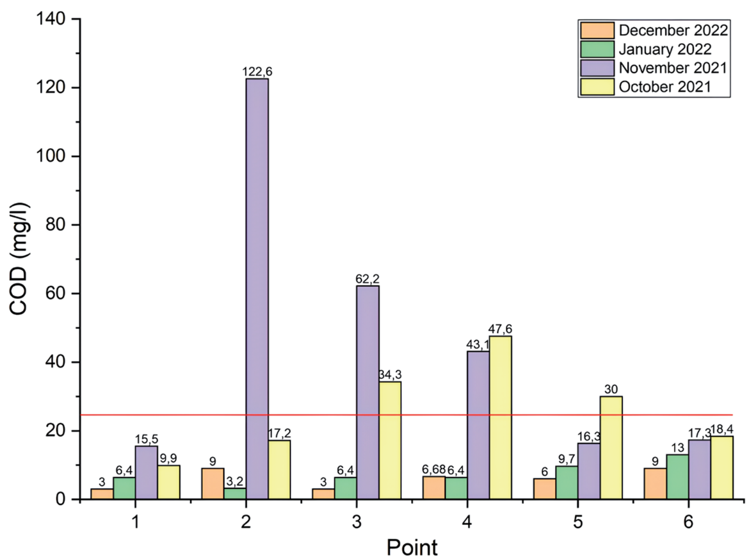

Fig. 8. Graph of COD Parameter Concentration.

produced by PT DEF contributes to the increase in COD concentration at point 5, located after the PT DEF outlet. Not only activities from the industry but also wastewater runoff from other activities and environmental conditions around the polluted point are influenced. The environment of point 5 includes several residential areas and irrigated land, while the climate of point 7 includes residential areas and agricultural land.

COD of the Hospitality Sector

Based on the sampling results in Fig. 10, it is found that the COD concentration at point 5, which is the outlet of Hotel P, has not met the COD quality standard for wastewater according to Minister of Environment Regulation Number 68 of 2016 [40] concerning domestic wastewater quality standards. Activities from hotel activities such as human waste, bathing, and washing can affect the concentration value of the COD parameter. The size and capacity of the hotel itself can also affect the amount of liquid waste released. Hotel P is included in the medium hotel category according to the Decree of the Minister of Culture and Tourism Number KM.03/HK.001/MXP.02 with a room capacity of 62 people.

COD Analysis

Based on the land capability evaluation results, the Klampok sub-watershed segment 1 area is classified as class IV land. On class IV land, land conservation measures are more difficult to carry out than on higher classes. Class IV land can be agricultural land (pasture, production forest, etc.) or non-agricultural land. In this segment, the slope is the inhibiting factor or subclass in the segment 1 area. Segment 1 has a hilly, sloping surface slope (15-30% slope) because most of the area has a 16-25% slope. Segment 2 of the Klampok sub-watershed is classified as class III land. Land use in this class specializes in agriculture (grassland, production forest, etc.) and non-agriculture. The inhibiting factors

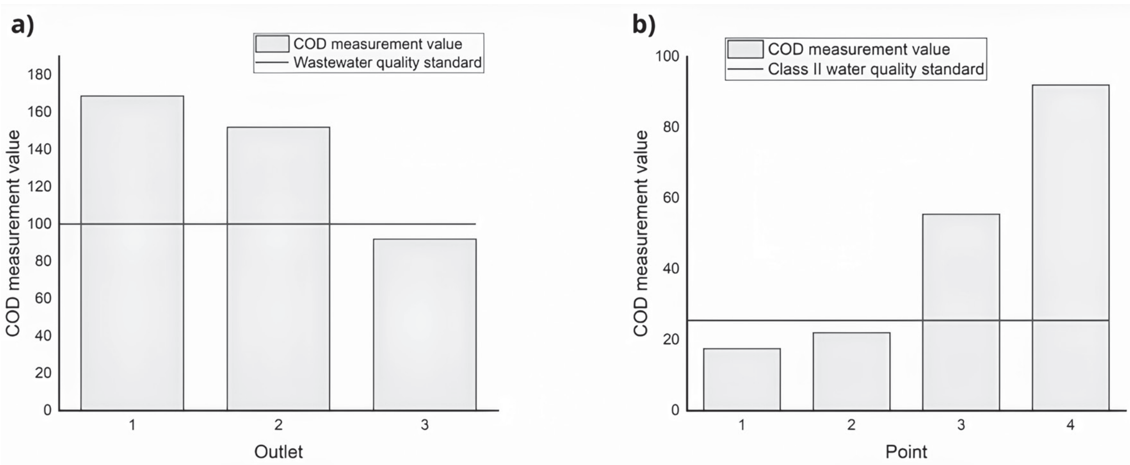

Fig. 9. a) Concentration Chart of the Industrial Outlet COD Parameter b) Graph of COD Parameter Concentration around Industrial Outlet.

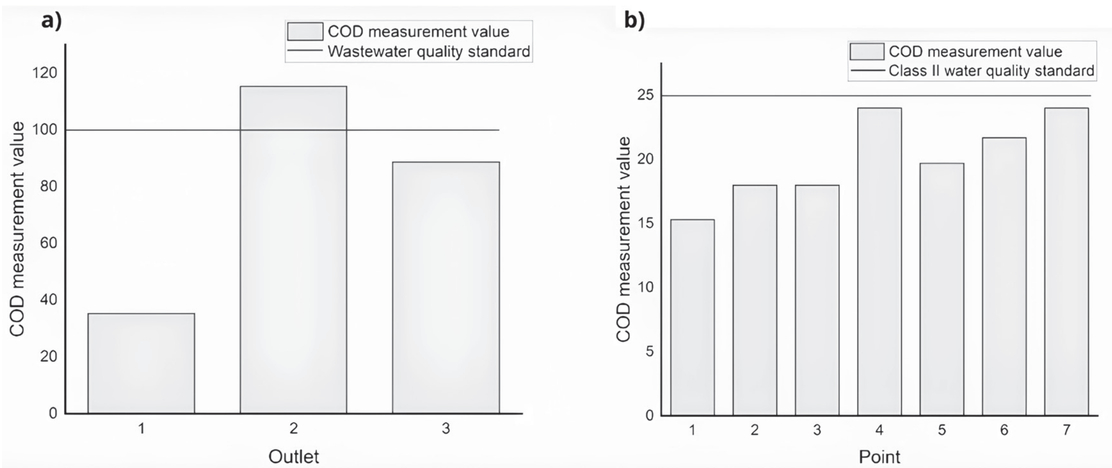

Fig. 10. a) Graph of COD Parameter Concentration at Hotel Outlet b) Graph of COD Parameter Concentration around Hotel Outlet.

or subclasses in this segment are slope and soil depth. The Segment 2 area has a slope that is classified as moderately sloping (8-15%); the majority of the Segment 2 area has a pitch in the 9-15% range. In addition, the soil depth in the segment 2 area is included in the medium depth, which ranges from 90-50 cm. Segment 3 of the Klampok sub-watershed is classified as class III land, like segment 2. As explained in the previous description of class III land classification, degree of constraint, and its use, the land use in segment 3 is by the rules, where segment three land is generally used as rice fields, agricultural land, and settlements. The inhibiting factor or subclass in this segment is soil depth. The soil depth in the segment 2 area is included in the medium depth, which ranges from 90-50 cm. The same also describes the location of segment 4 of the Klampok sub-watershed. Segment 5 of the Klampok sub-watershed is classified as class IV land, like segment 1. Based on the description of class IV land classification, degree of constraint, and its use, land use in segment five follows the rules, where segment five land is generally used as paddy fields, agricultural land, and settlements. In segment 5, slope and erosion rate are the inhibiting factors or subclasses. The majority of land in segment 5 has a slope of 16-25%, according to the hilly slope category of the Ministry of Environment Regulation Number 17 of 2009 [29] concerning Guidelines for Determining Environmental Support Capacity in Regional Spatial Planning, which is 15-30%. Segment 5 has a greater risk of erosion than the previous segments. According to Minister of Environment Regulation Number 17/2009 [29], this condition is characterized by 25-75% loss of topsoil and less than 25% loss of subsoil.

The status of the carrying capacity of land (DDL) obtained a deficit value; the availability of land covering an area of 15,313.25 Ha is smaller than the land requirement of 27,535.27 Ha. It can be seen that the status of the carrying capacity of agricultural land in the segments in the Klampok sub-watershed area has a carrying capacity status in the deficit condition of agricultural land with the status category in poor condition or exceeded. This indicates that the availability of land can no longer fulfill the existing land needs. As for the status of water carrying capacity (DDA), a water deficit was also found, with water availability of 25,340,887.44 m^3 smaller than the water demand of 105,735,433.13 m^3. However, the research on water availability for the Klampok sub-watershed area was conducted by only considering surface water derived from rain. Besides being obtained from rainwater, water resources can be found underground, consisting of free and depressed groundwater. The availability of underground water can be determined from an analysis of the groundwater basin maps. The amount of groundwater in the Semarang Regency area can be seen in the CAT Ungaran section. CAT Ungaran shows that the free groundwater flow is estimated at 145,000,000 m^3/year. In contrast, the amount of depressed groundwater flow is calculated at 8,000,000 m^3/year, so the underground water supply for Semarang Regency can reach 153,000,000 m^3 /year. Although this figure denotes the underground water supply for the entire Semarang Regency area, the Klampok sub-watershed already has a surface water supply of 25,340,887.44 m^3/year. Thus, the underground water availability of the Semarang Regency can fulfill the total water demand of the Klampok sub-watershed and increase its Water Supportability (WSS) status to surplus.

Pollution Land Capacity

The calculation of the pollution load capacity determines the total concentration of parameters that contaminate the aquatic environment of the Klampok River. The water quality simulation results from Qual2Kw were used to calculate the pollution discharge capacity of the Klampok River. The results of the calculation of BOD capacity in water samples taken in December 2022 and October 2021 show that the capacity of the Klampok River is negative, which means that the Klampok River is no longer able to accommodate the BOD pollution load for Class I to Class IV in each segment in both sampling periods. Thus, based on Government Regulation Number 22 of 2021 [22], Klampok River water in each segment cannot be used as drinking water, raw water, water recreation infrastructure/facilities, agricultural waters, freshwater fish and livestock breeding water, or other designations that require the same water quality as water classes I to IV.

The results of the calculation of COD capacity in water samples taken in October 2021 show that the COD capacity meets class IV water in all segments. According to Government Regulation Number 22 of 2021 [22], the Klampok River water included in this class can be used for agricultural irrigation. However, as of December 2022, the COD capacity in segment 2 for class IV water was negative or unmet. This indicates a decrease in water quality that causes segment two to be unable to accommodate the COD pollution load.

Since most of the calculations of pollution load-carrying capacity result in point B showing negative values (no longer able to accommodate the pollution load), simulations will be carried out for alternative scenarios. The simulation will be carried out with a domestic discharge scenario of 0 or no domestic waste discharged into the Klampok River. For the rest, the calculation method for the existing pollution load for this scenario will be the same as the previous calculation in point B. In addition, this simulation can also be used to get an overview of the analysis of pollution load capacity for the industrial and hospitality sectors for 2022 because the input data for industrial and hospitality discharges in 2022 are still included in this simulation.

The BOD capacity also shows an increase, where the BOD capacity is positive or fulfills class III and IV water. Meanwhile, the COD capacity has decreased compared to the October 2021 period, where the COD capacity only meets class IV water. However, overall, the condition of the pollution load capacity in December 2022 continued to increase, and the power of the Klampok River met the pollution load capacity for class IV water for the parameters BOD and COD. The increase in results after the application of the 0 domestic discharge scenario can be considered in the formulation of Klampok Sub-watershed management policies, and it is known that the establishment of a policy not to discharge domestic waste in the river can have a significant effect on increasing the capacity of the Klampok River.

Quality Status

This water class value is known through the Pollutant Index Method [41], which is based on the results of comparison with water quality criteria based on Government Regulation Number 22 of 2021 [22] concerning the Implementation of Environmental Protection and Management. In general, the water quality status of Klampok River is in the category of mild to moderate pollution, with the pollutant index (IP) value in the range of 0.353-8.458. The lowest average IP value is sample point 1 because fewer parameters exceed the quality standards at sample point 1 than at other sample points. The most considerable average IP value is sample point 6 because sample point 6 is close to the industry, and the fecal coliform value in January 2022 reached 150,000 MPN/100ml.

Watershed Management Stakeholders

Sustainable environmental management and the involvement of various stakeholders can only run well with all stakeholders. The state of the environment and its management is strongly influenced by all stakeholders' policies, activities, and responsibilities, where institutions around the sub-watershed area have a vital role in fostering and assisting community institutions [42]. Environmental agencies, the Health Office, Barenlitbangda, four sub-districts in the Klampok sub-watershed area, and several companies in the Klampok sub-watershed area have collaborated, driven by the same goal. So far, relevant stakeholders have formed an industry forum and received full support from the Indonesian River Conservation Organization (OPSI). Communities that still dispose of waste and carry out domestic activities along the Klampok River, as well as degradation of the quality of the sub-watershed environment due to cropping patterns and other factors, are obstacles to watershed management. In general, the control of the Klampok sub-watershed is included in the "good" criteria with an index number of 120.58. All four variables are included in the "good" standard, with the coordination variable having the best value rating.

Strategy Formulation

SWOT Analysis

The SWOT method was chosen because this method can formulate management strategies based on the existing conditions of the research [43]. The management program formulated according to the selected strategic direction will then be further analyzed using the QSPM method to determine which programs receive priority to be implemented first [44]. In this study, SWOT and QSPM strategy analyses were conducted using data from five respondents who were experts and practitioners in the environmental field. Before performing a comprehensive SWOT analysis, the first step is to identify the external and internal factors of the Klampok sub-watershed management using Internal Factor Evaluation (IFE) and External Factor Evaluation (EFE) matrices [45]. The internal and external factors of Klampok sub-watershed management are determined based on observations of the research location and interviews. The next step in formulating a management strategy is to evaluate the factors in the IFE and EFE matrix to determine what kind of strategic direction will be applied to the management of the Klampok sub-watershed [46]. The scoring process is carried out by distributing questionnaires containing the IFE and EFE matrices to experts or practitioners who are competent in their fields. Each factor in the questionnaire was scored on a scale of 1-4. Respondents can then determine and prioritize external and internal factors by scoring, which researchers then process to calculate the weight, rating, and final score. The results of processing questionnaire data filled in by experts/practitioners in the environmental field show that external factors are opportunities and threats, while internal factors are strengths and limitations. A score above 2.5 indicates that strengths and opportunities outweigh weaknesses and threats, while a score below 2.5 indicates the inverse [47].

Based on the analysis, the commitment of DLH Semarang Regency to managing Klampok River is considered a more meaningful opportunity, with a weight of 0.24 and a score of 0.888. The threat of degradation of the quality of the Klampok sub-watershed area, which natural factors and cropping patterns can cause, needs to be considered as the main threat, based on the calculation results, namely a weight of 0.12 and a score of 0.22. The summation of the EFE factor scoring is 2.78, which shows that the threats in the Klampok Sub-watershed benefit the various opportunities to support the management of the Klampok Sub-watershed [48].

Thus, the final scores for Strengths, Weaknesses, Opportunities, and Threats are 2.56, 0.37, 2.29, and 0.4, respectively. The strengths aspect has the highest value of the other three aspects, indicating that the planning and implementation of the Klampok sub-watershed management strategy must consider the existing internal strengths. The final calculation of the IFE and

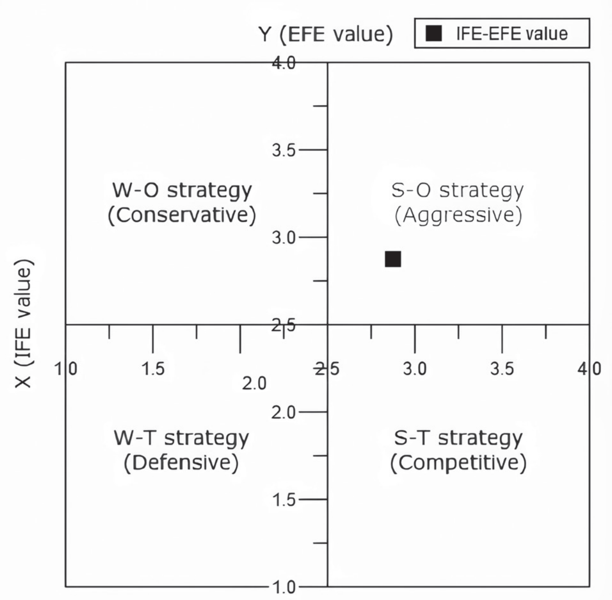

Fig. 11. SWOT Matrix of Klampok Sub-Watershed Management.

EFE matrix is then entered into the SWOT matrix. The placement of IFE and EFE values is in quadrant I (S-O strategy), as shown in Fig. 11. The proposed central hypothesis is proven by the S-O strategy, which is aggressive or progressive. The Klampok sub-watershed conditions in quadrant I of SWOT also show that the Klampok sub-watershed area has both internal and external advantages and potential. If this situation is utilized as much as possible, the progressive strategy created can enormously benefit the Klampok sub-watershed.

QSPM Analysis

QSPM is a quantitative decision-making technique that evaluates a number of alternative strategies to determine the optimal strategy [49]. Using the weights derived from the IFE and EFE matrices and the Attractiveness Score (AS/attractiveness value) established based on the opinions of experts or practitioners, the QSPM method is used to determine the optimal strategy [47]. The attractiveness score is on a scale of 1-4. The strategy that received priority for implementation is synergy and empowerment of related parties in integrated sub-watershed management planning from upstream to downstream, including but not limited to budget planning, programs, drafting regulations, and managing the Klampok sub-watershed.

Conclusions

The Klampok sub-watershed faces critical environmental challenges, evidenced by elevated Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD) across multiple segments. BOD levels in the river body range from 1 to 4.6 mg•L^{-1}, while COD values peak at 122.6 mg•L^{-1}, both exceeding the permissible thresholds for class II water quality, as stipulated by Government Regulation 22 of 2021. These findings underscore the river's inability to adequately assimilate pollution loads, with water samples from December 2022 confirming a persistent deficit in the river's BOD carrying capacity, rendering it unsuitable for use under the water quality classes I-IV. Despite the groundwater availability of 153,000,000 m^3/year providing a regional water surplus, the surface water supply alone, at 25,340,887.44 m^3/year, falls short of meeting demand, which totals 105,735,433.13 m^3/year. This deficit is further aggravated by runoff from agricultural activities, industrial waste, and domestic discharge, resulting in moderate pollution along the watercourse. The study simulates an alternative scenario excluding domestic waste discharge, demonstrating that such measures can significantly enhance water quality. Under this scenario, BOD and COD levels across segments align with class IV water quality standards, offering insights into more sustainable management practices.

The study emphasizes the need for a progressive and integrated management strategy based on SWOT and QSPM analyses. Key priorities include enforcing pollution regulations, synergistic collaboration between local stakeholders, and active community participation. Such strategies are essential not only to restore water quality but also to ensure the long-term sustainability and resilience of the watershed ecosystem. This holistic approach highlights that stakeholder involvement from upstream to downstream, combined with effective regulatory frameworks, is crucial for maintaining the environmental and ecological health of the Klampok sub-watershed. This study was limited to four months. Similar research with the same regional conditions should be conducted every season of the year and used as a reference in decision-making.

Acknowledgments

This research was gratefully supported by National Research Agency 2022 research funds, number 353/UN7.A/HK/XII/2022.

Conflict of Interest

The authors declare no conflict of interest.

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