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Regional Case Study

Spatial Modeling for River Quality Assessment to Enhance Sustainable Water Resource Management Regulations

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Abstract.

Water is a crucial asset and serves as a significant factor in the quality of life, especially in supporting key sectors such as agriculture, energy, industry and conservation of natural ecosystems. Water quality can be significantly affected by pollution from effluents, especially in developing countries such as Indonesia which faces the added challenge of rapid population growth. This research focuses on monitoring water quality in the Garang River Sub-region, Semarang, by utilizing Internet of Things (IoT) technology for real-time monitoring. The methods used include the Storm Water Management Model (SWMM) model and an IoT-based monitoring system to measure important parameters such as temperature, pH, turbidity, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), and nitrate and phosphate concentrations. The results showed that the Chemical Oxygen Demand (COD) parameter often exceeded quality standards, especially in areas with domestic and industrial activities. The IoT monitoring system facilitates precise and instantaneous data gathering., supporting sustainable water resources management. This research emphasizes the need for evaluation and adjustment of policies related to waste management and spatial planning to reduce pollution and improve water quality.

Keywords: Water quality index; monitoring system; internet of things; water managements

1. Introduction

Water is a fundamental and indispensable resource that profoundly affects the quality of life due to its ubiquitous presence and its critical role in sustaining all living organisms, particularly humans. Beyond direct human consumption, water is essential for supporting key sectors such as agriculture, energy, industry, and the conservation of natural ecosystems. However, the quality of water in any given region can be significantly compromised by the introduction of wastewater into the system (Siregar et al., 2017). In developing countries like Indonesia, rapid population growth exacerbates this issue, presenting various challenges. As the global population continues to rise, land use has gradually adapted to accommodate this growth, often leading to the conversion of land into residential and industrial areas to maintain stability. These changes in land use, in turn, increase the production of wastewater wastewater from residential and industrial activities (Kumar Sarangi et al., 2023). Consequently, densely populated settlements that lack adequate wastewater treatment facilities, combined with shifts in land use, contribute significantly to the pollution of water bodies (Widiyanto et al., 2015).

The city of Semarang is experiencing notable population growth, with a total population of 1,659,975 people and a 0.9% rise in population density between 2022 and 2023 (Indonesia, 2023). One notable river within this city is the Garang River. The Garang River Watershed (DAS) fulfills diverse functions, encompassing agriculture, household, and industrial activities, alongside supporting fisheries and tourism (Sarminingsih et al., 2024). Nonetheless, the river is predominantly recognized for its role as a disposal site for domestic and industrial waste (Ujianti et al., 2018). This problem is particularly prevalent in residential areas located near the river's source. The conversion of land use to residential purposes in these upstream areas has led to the overflow of wastewater into the watershed, causing a deterioration in water quality, as evidenced by increased turbidity, Chemical Oxygen Demand (COD), and nitrate concentrations (Adjovu et al., 2023). The shift in land use associated with economic activities has adversely affected water quality.

To address this issue, continuously and in continuous monitoring of water quality is crucial, which can be achieved through Internet of Things (IoT) modeling. This technology facilitates water quality assessment by utilizing sensors submerged in the water to capture various parameters (Deng et al., 2021). By deploying different types of sensors, the system can measure key water quality indicators, including Dissolved Oxygen (DO), pH, turbidity, Total Dissolved Solids (TDS), temperature, and other relevant metrics. The innovation in this research is the integration of water quality changes with modifications in land use conditions

Therefore, an analysis of water quality in the Garang River watershed was conducted to understand the impact of land-use changes on the river's water quality, enabling the development of appropriate regulatory management. This water quality analysis was carried out using the Storm Water Management Model (SWMM), an evaluation of the Water Quality Index, and the implementation of a real-time water quality monitoring system utilizing Internet of Things (IoT) technology. Multiple parameters, such as temperature, pH, turbidity, COD, and nitrate levels, were analyzed from water samples, as these indicators reflect river water quality and require real-time testing. The system is designed with comprehensive calibration of the monitoring equipment data, ensuring accurate and reliable measurements of water quality parameters (Deng et al., 2021). The results of these measurements were then compared with the applicable water quality standards outlined in Government Regulation No. 22 of 2021 (Indonesia, 2021).

The development and analysis of the new model through simulation tests directly contribute to enhancing regulations for sustainable water resource management. This effort is aimed at preventing massive damage caused by land-use changes that lead to water source pollution, as evidenced by real-time and automated water parameter monitoring. By employing the Integrated Spatial Model within the Real-Time Monitoring System (RTMS) for river quality assessment, accurate identification of key environmental parameters and rapid data convergence enable more effective monitoring and decision-making processes. Some of the parameters detected by the RTMS include pH, temperature, dissolved oxygen (DO), turbidity, and total dissolved solids (TDS). This improvement in real-time data collection and analysis supports the formulation of more precise and responsive regulations, ensuring better management of water resources in line with sustainability goals. The enhanced model thus plays a crucial role in informing and refining policies aimed at protecting and optimizing water resource usage.

2. Methods

2.1 Research Site

In this study, several important parameters were measured. Specific parameters were directly measured using various devices: pH with a digital pH meter, temperature with a thermometer, water turbidity with a nephelometer, and dissolved oxygen (DO) with a DO meter. Further measurements were conducted in the laboratory to assess chemical oxygen demand (COD), nitrate, and phosphate. Ten sets of samples were systematically collected from distinct locations with varying coordinates, as detailed in Table

1. At each of the ten sampling points, five measurements were conducted and recorded. Sampling was carried out over two months, with one sampling session in March and one in April. In addition to water quality evaluation, flow rate data were obtained using a rating curve. The regulation of water flow rate was influenced by both flow velocity and the cross-sectional area of the watercourse.

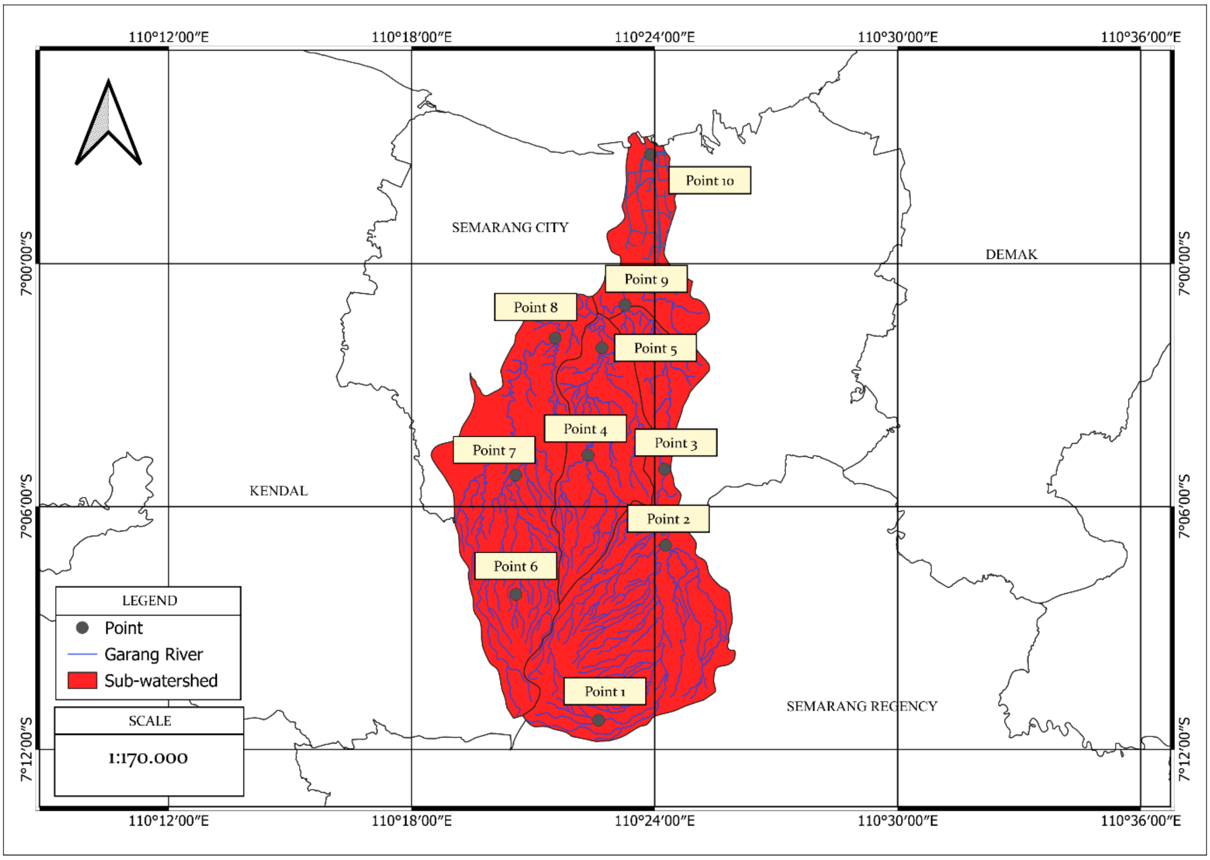


Figure 1. Sampling point and subcatchment location

Table 1 Location of sampling points.

Sampling Point	Location	Coordinate	Location
1	Dusun Lempuyangan	7°11'16"S 110°22'36"E	The upper reaches of the Garang River were selected because there is minimal activity along the river, resulting in little to no pollution.
2	Suwaktu, Bandarjo Village, West Ungaran Sub-District, Semarang Regency	7°06'57"S 110°24'15"E	There are residential activities around the area, placing it in a location that has already been exposed to waste.
3	Jl. Tanah Putih Ii, Pudakpayung, Banyumanik District, Semarang City, Central Java Central	7°05'04"S 110°24'13"E	It has a mixed land use of forest and plantation areas, which allows for natural self-purification.
4	Gunung Pati District, Semarang City	7°04'42"S 110°22'22"E	The presence of settlement activities around the area has led to it being

Sampling Point	Location	Coordinate	Location
			situated in a location that has been exposed to sewage.
5	Sukorejo Village, Gunung Pati District, Semarang City	7°02'04"S 110°22'39"E	The presence of agricultural activities around the area has resulted in it being situated in a location that has been exposed to sewage.
6	Kendal Regency	7°08'12"S 110°20'33"E	The Garang Sub-upperstream was chosen because there are still limited activities along the river, resulting in little to no pollution.
7	Gunung Pati District, Semarang City	7°05'10"S 110°20'35"E	The presence of settlement activities in the area means it is located in a place that has been subjected to sewage exposure.
8	Sadeng, Gunung Pati District, Semarang City	7°01'47"S 110°21'35"E	The location of the river after the Jatibarang Dam is downstream
9	Bendan Village, Gajahmungkur Subdistrict, Semarang City	7°01'02"S 110°23'14"E	The confluence of the Garang Hulu, Kreo River, and Kripik River is the meeting point where these three watercourses converge.
10	North Semarang District, Semarang City	6°57'21"S 110°23'54"E	The downstream area of the Garang watershed experiences the accumulation of pollutants that flow from upstream to downstream.

2.2 Data Analysis

In the development of a robust model, we conducted an extensive review of various existing systems proposed by researchers. Various methods have been developed for water quality monitoring, utilizing different approaches in prior research. In the realm of smart methods, the advancement of a Smart Water Quality Monitoring System (SWQMS) exemplifies the use of sensors and intelligent technology to observe water quality continuously by measuring critical actors such as temperature, conductivity, and pH (Dong et al., 2015). Additionally, other literature discusses the implementation of a water quality monitoring system using IoT, which introduces the use of an Arduino board to measure pH values and a GSM module to transmit data via messages, accompanied by an LED display for continuous monitoring. This project was further expanded by sending sensor data to the cloud for worldwide water quality monitoring (Moparthi et al., 2018).

For our research, we adopted a quantitative descriptive methodology to systematically analyze and document the field conditions, relying on the acquisition of quantitative data. Multiple parameters, such as temperature, turbidity, pH, and DO, were analyzed from these water samples, as they are crucial indicators of the quality of river water necessitates real-time monitoring (Schmitt et al., 2008). Furthermore, COD, nitrate levels, and phosphate levels were also tested to offer a more thorough evaluation of the water's overall quality (Jena et al., 2016).

The research emphasizes the importance of measuring COD, nitrate concentrations, and phosphate concentrations as key indicators of water quality. COD, assessed through potassium dichromate oxidation, plays a critical role in planning and monitoring wastewater quality, particularly in rivers affected by domestic and industrial discharges (Sarminingsih et al., 2024). This parameter reflects the level of organic pollution and the effectiveness of wastewater treatment processes. Additionally, monitoring nitrate levels is crucial because nitrates and nitrites are associated with severe health risks, including cancer, methemoglobinemia, thyroid gland enlargement, and diabetes mellitus (Rezvani et al., 2019). Furthermore, the accumulation of phosphates in water bodies can lead to eutrophication, a severe environmental issue characterized by excessive algal growth, which degrades water quality and disrupts aquatic ecosystems. The role of oxidized nitrogen in inhibiting phosphate release from sediments highlights its ability to stabilize the redox potential of surface sediments, which is essential for managing phytoplankton proliferation in aquatic systems and ensuring water quality(Wu et al., 2019). Therefore, by integrating the measurement of COD, total nitrate, and phosphate concentrations, this study aims to enhance sustainable water resource management and support the development of robust regulatory frameworks and policies for real-time river quality assessment.

The Garang watershed can be mapped and divided into several subcatchments to determine the river's flow and output. The subdivision of subcatchments is conducted based on DEM data processed using GIS methods for Watershed Delineation with QGIS software. Subsequently, modeling using Storm Water Management Model (SWMM) is carried out, resulting in graphs and tables that illustrate the relationship between pollutant concentrations and water flow under three different scenarios: current conditions, maximum rainfall, and minimum rainfall. The Garang watershed is divided into ten subcatchments, each representing a sampling point. The network model is developed by incorporating hydrological and hydraulic data, including information from the subcatchments and rain gauges, which provide details on rainfall intensity, volume, and timing. This calculation following equation (1) is referred to as Event Mean Concentration (EMC), representing the average pollutant concentration for a rain event (Perera et al., 2021).

$$EMC = \frac{M}{V} = \frac{\Sigma_{i=1}^{n} C_i Q_i \Delta t}{\Sigma_{i=1}^{n} Q_i \Delta t} \quad (1)$$

Information:
M= mass of politant (mg)
V= total volume runoff (L)
Q= discharge at each time interval (L/s)
C_i= Pollutan concentration at each time interval (mg/L)
Δt = time interval (seconds)

3. Result And Disscusion

The planning area within the Garang watershed covers 20,792.89 hectares, comprising nine different land use types: secondary dryland forests, forest plantations, cultivated plantations, and dryland farming areas, industrial areas, residential areas, unoccupied land, diversified dryland farming, and reservoirs. The planning area is divided into three sub-watersheds: the Upper Garang Sub-Watershed, the Kripik Sub-Watershed, and the Kreo Sub-Watershed. The Upper Garang Sub-Watershed includes five monitoring points: points 1, 2, 3, 9, and 10. The Kripik Sub-Watershed contains four monitoring points: points 4, 5, 9, and 20. Finally, the Kreo Sub-Watershed consists of five monitoring points: points 6, 7, 8, 9, and 10.

The primary contributors to wastewater in the Garang watershed are domestic, agricultural, and industrial activities, each introducing different types of pollutants. The water discharge throughout the Garang watershed is significantly varied, influenced by weather conditions. Among the 10 water sampling sites, the highest discharge was recorded at point 8, situated in the Kreo Sub-Watershed within Gunung Pati District, Semarang City, with a flow rate measured at 18.76 m^3/s.

Water temperature in the Garang watershed tends to increase along with rising water discharge, with temperatures ranging from 20°C to 32°C. Various factors such as elevation, time of day, cloud cover, air circulation, and water flow contribute to these temperature variations(Laizé et al., 2017). Higher temperatures result in lower dissolved oxygen levels in the water (Rajwa-Kuligiewicz et al., 2015). Similarly, the pH levels in the Garang watershed were found to remain relatively stable, ranging between 7.1 and 8.8, with the highest pH observed at point 10, a predominantly residential area. The toxicity of chemical compounds is influenced by pH levels, as increased pH results in greater alkalinity and lower concentrations of carbon dioxide.

Turbidity levels in the Garang watershed are largely determined by the surrounding land use. Areas used for agriculture exhibit high turbidity, as farmers often clear the land of grass and other vegetation, leading to erosion during rainfall. The eroded soil is carried by surface runoff into the river, causing an increase in water turbidity (Sherriff et al., 2015). The highest turbidity recorded in the Garang watershed was 838 NTU at the fifth sampling point in the second month. This likely occurred due to rainfall before the sampling was taken, which caused the transport of small particles, such as dust, sediment, and organic material, by the strong currents from the rain (Solano-Rivera et al., 2019).

Elevation at sampling points was measured using Google Earth and the GPS Map Camera application. The physical characteristics of the river cross-section were determined by measuring the length of the river from the upstream to the downstream sampling points, as well as the river's width, depth, and flow velocity (Pan et al., 2016). The length from upstream to downstream was measured using a tape measure, which also helped in calculating the flow velocity. The river's width was divided into several transects and measured using a tape measure (Gore and Banning, 2017). The depth of the water was measured with a wooden rod to calculate the wet cross-sectional area of the river at both the upstream and downstream sampling points (Furukawa et al., 2021). The average of these wet cross-sectional areas was then calculated as the total wet cross-sectional area of the river (Wang et al., 2020).

3.1 Water quality analysis

The water quality measurements for chemical oxygen demand (COD), nitrate, and total phosphate were conducted in a laboratory. Samples were collected from 10 different locations at five distinct time intervals. The first three samples were taken in March at 07:00, 11:00, and 15:00 on the same day, while the remaining two samples were collected in April at 08:00 and 14:00, also on the same day. This systematic sampling approach provided a comprehensive dataset for analyzing water quality over time. The measurement results are presented in Table X and have been compared to the applicable standards outlined in Government Regulation (PP) No. 22 of 2021, which specifies Class 1 water quality standards (Indonesia, 2021).

Table 3 Water quality Analysis

Point	COD (mg/L)			Nitrate (mg/L)			Total Phosphate (mg/L)		
	Highest	Average	Lowest	Highest	Average	Lowest	Highest	Average	Lowest
1	59.37	52.518	44.6	2.79	0.69	0.00	0.05	0.02	0.00
2	60.95	52.736	42.53	0.46	0.39	0.19	0.24	0.07	0.02
3	65.16	52.212	39.37	0.43	0.36	0.20	0.27	0.07	0.02
4	64.63	55.266	38.32	2.92	1.85	0.25	0.46	0.12	0.01
5	83.05	53.684	28.32	2.93	1.82	0.08	1.86	0.41	0.00
6	89.37	59.58	37.26	2.90	1.76	0.01	0.02	0.02	0.01
7	101	67.064	32.53	0.47	0.17	0.02	0.67	0.17	0.03
8	103.6	53.582	3.58	0.29	0.11	0.01	0.36	0.10	0.02
9	102	72.21	43.05	0.40	0.29	0.10	0.18	0.07	0.03
10	71.47	52.632	27.26	0.38	0.28	0.03	0.10	0.05	0.04

Measurement Point 1, located in the Garang Hulu Sub-Watershed, was chosen due to minimal human activity along the river, resulting in minimal or no pollution. COD values at Point 1 ranged from 44.6 mg/l to 59.38 mg/l. Measurement Point 2, situated in a residential area, has COD values varying from 42.53 mg/l to 60.95 mg/l, reflecting contamination due to waste discharge in the vicinity. Point 3, located in the Garang Hulu Sub-Watershed within Banyumanik District, features land use involving forests and plantations, which allows for natural purification processes. COD values at this point ranged from 39.37 mg/l to 65.16 mg/l over five sampling events.

Point 4, located in a residential area, has COD values varying from 38.32 mg/l to 62.53 mg/l, with a recorded phosphate level of 0.460 mg/l, indicating contamination from waste discharge. Point 5, influenced by agricultural activities in the surrounding area, also showed COD values that do not comply with quality standards. Point 6, also in the Garang Hulu Sub-Watershed, has COD values ranging from 37.26 mg/l to 62.53 mg/l due to minimal river activity and thus minimal pollution.

Measurement Point 7, situated in a residential area, showed COD values ranging from 39.90 mg/l to 101 mg/l, with a total phosphate level of 0.671 mg/l, indicating significant pollution. Point 8, located downstream of the Jatibarang Dam, recorded COD levels of 62.00 mg/l, 57.26 mg/l, and 41.47 mg/l, with a peak COD value of 103.58 mg/l at 14:00, and a total phosphate level of 0.364 mg/l. Point 9, where the Garang Hulu River, Kreo River, and Kripik River converge, had COD values ranging from 43.05 mg/l to 102 mg/l. Finally, Point 10, located in the lower part of the Garang Watershed, showed COD values between 27.26 mg/l and 71.74 mg/l, reflecting pollutant accumulation from upstream sources.

According to these standards, the permissible limits for Class I water quality are 10 mg/L for COD, 0.2 mg/L for total phosphate, and 10 mg/L for nitrate. These measurements indicate that chemical oxygen demand (COD) consistently fails to meet the Class I water quality standards as outlined in Government Regulation No. 22 of 2021 concerning Environmental Protection and Management (Indonesia, 2021). Furthermore, nitrate levels also fail to meet the standards at several sampling points and times, though total phosphate remains within the permissible limits for Class I water quality throughout all sampling locations and periods.

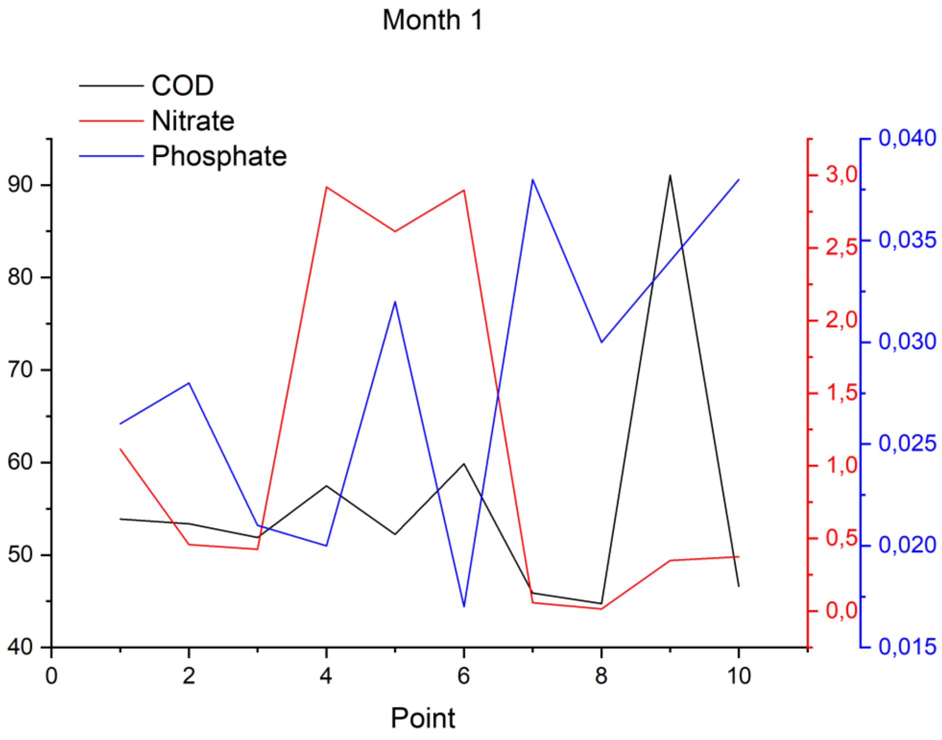
3.2 Storm water management model

In this study, SWMM is employed to simulate and assess the effectiveness of various runoff control measures, particularly in the Garang River Watershed (DAS Garang). Essential precipitation data for the simulation is collected from three nearby rain gauge stations around DAS Garang: Ungaran Rain Gauge, Sumur Jurang Rain Gauge, and Simongan Rain Gauge. This data provides the necessary precipitation input for accurately modeling runoff events within the watershed.

The variability in the percentage of impervious surfaces (% imperv) based on land use types is a critical component of the simulation, as it directly affects runoff volume and pollutant loads. This variability is meticulously accounted for in the SWMM input data, allowing the model to realistically reflect urban conditions. Land use types impact river water quality due to their association with pollutant wash-off during rainfall events, leading to variations in event mean concentration (EMC) values. EMC calculations represent the average pollutant concentration during a rainfall event (Perera et al., 2021). Typically, EMC values are determined through laboratory analysis of collected samples. To minimize laboratory costs associated with analyzing multiple points along the hydrograph, EMC is often the sole sample analyzed. This parameter is widely recognized as the most common metric for estimating nonpoint source pollution loads in models such as SWMM and many others (Rossman and Huber, 2016).The EMC is determined by calculating the total mass of pollutants divided by the total volume of runoff observe during the event.

The Garang Watershed is divided into ten subcatchments, each corresponding to runoff sampling points. GIS analysis was used to define these subcatchments, with DEM (Digital Elevation Model) data processed in ArcGIS to map the watershed and determine flow areas. The resulting shapefiles, representing 10 subcatchments, were then imported into Google Earth to aid in developing the subcatchment model in EPA SWMM (Storm Water Management Model) version 5.1.

This model includes 10 subcatchments, 11 junctions, 11 conduits, 8 land use types, 3 rain gauges, and 8 pollutants. It enables detailed simulations of runoff and pollutant transport and supports the evaluation of various stormwater management scenarios. By incorporating land-use data and output flow points from GIS analysis, the model provides a robust framework for analyzing water quality in the Garang Watershed.



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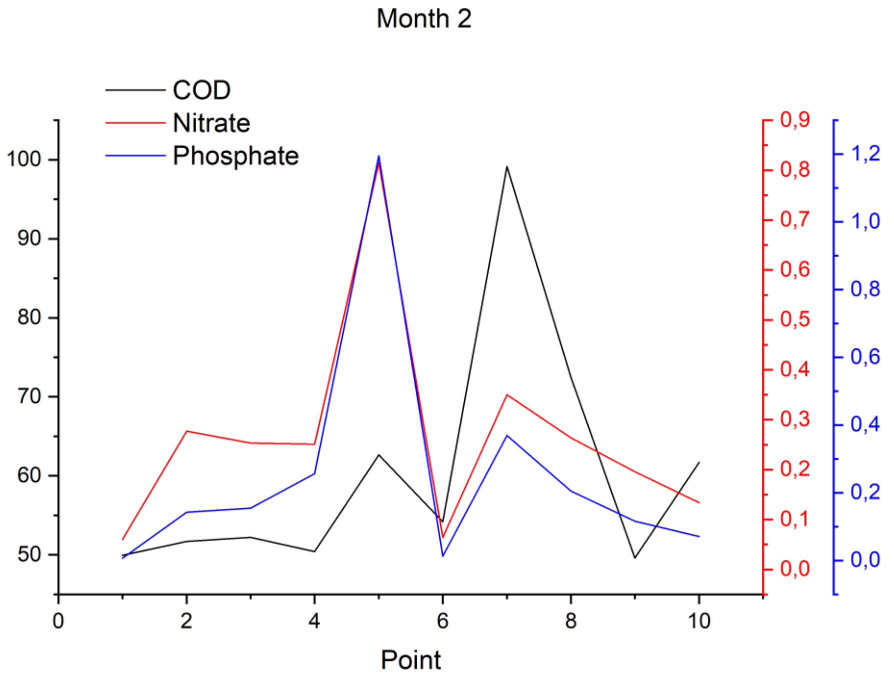

[b]

Figure 2. Composite EMC value of each month [a] Month 1; [b] Month 2

Each catchment area within the Garang watershed contains multiple land use types, leading to composite EMC values calculated from these various land uses. These EMC values function as washoff inputs in water quality modeling using SWMM. However, since the model is limited to current conditions (rainy season), observed flow and parameter data can be directly input as base-flow, without considering EMC washoff values, which would otherwise inflate pollutant concentration loads in conduits. Variations in EMC at different sampling points are attributed to land use differences; industrial and commercial areas with higher impervious surface percentages result in more efficient pollutant transport and runoff, while open areas, forests, and densely vegetated lands exhibit lower pollutant concentrations due to reduced impervious surfaces (Beck et al., 2016)

The infiltration of rainwater into the soil and the resulting surface runoff in the Garang Watershed are influenced by various land-use types, which also affect water quality and pollution loads. The variation in land use across each subcatchment impacts the soil's infiltration capacity and the amount of runoff generated, leading to differences in flow rates. Larger impervious areas result in higher runoff levels, increasing the water discharge. Based on water quantity and quality data, the Event Mean Concentration (EMC) is calculated for each subcatchment. EMC values tend to increase as the proportion of impervious surfaces rises. The average pollutant concentration (EMC) entering the water body reflects the water quality. This water quality value is used to assess the water status by weighing the influence of each parameter on overall water quality.

From the water status, we can identify which river flows require continuous water quality monitoring. The design of the water quality monitoring system aims to provide real-time data on the effects of land use and rainfall input on water quality in the Garang Watershed. The water status value is derived by multiplying the weight (Wi) of each parameter that influences water quality by the quality index (Li), which is obtained by plotting the measured data against a pollution index curve. The sum of all Wi x Li values across the parameters gives the final water status score, where higher Wi x Li values indicate better water quality conditions.

Table 4 Recapitulation of Wi x Li Values of Garang Watershed

Location	Month 1 (07:00)	Month 1 (11:00)	Month 1 (15:00)	Month 2 (08:00)	Month 2 (14:00)
Point 1	67.10	65.06	66.67	72.22	74.89
Point 2	65.08	65.09	64.73	69.08	56.54
Point 3	64.70	67.24	64.69	67.68	54.87
Point 4	65.11	60.13	65.24	67.68	53.28
Point 5	63.40	65.50	63.21	61.41	46.63
Point 6	67.30	67.82	67.61	69.27	69.20
Point 7	61.85	63.87	61.88	64.72	55.63
Point 8	61.81	63.86	61.10	67.30	54.91
Point 9	63.75	60.52	64.43	65.01	61.89
Point 10	57.34	62.54	57.70	55.24	65.44

The Recapitulation of Wi x Li Values of Garang Watershed was calculated based on various parameters. The Recapitulation of Wi x Li Values of Garang Watershed was calculated based on various parameters. The NSF-WQI (National Sanitation Foundation Water Quality Index) criteria categorize water quality into different levels based on a calculated score. A score between 0 and 25 represents very poor water quality, scores ranging from 26 to 50 indicate poor water quality, while scores in the range of 51 to 70 suggest moderate water quality. Higher scores, specifically between 71 and 90, represent good water quality, and scores between 91 and 100 reflect excellent water quality (Effendi and Wardiatno, 2015). The recapitulation of Wi x Li values in the Garang Watershed primarily indicated medium water quality.

Notably, the first sampling point exhibited good water quality during the second month at 8:00 and 14:00. Conversely, bad water quality was observed at the fifth sampling point during the second month at 14:00 .

3.3 Design of a Real-Time Water Quality Monitoring System Based on the Internet of Things (IoT)

The water quality monitoring system in the Garang watershed is designed to measure five key parameters using a set of predetermined sensors. A microcontroller within the LattePanda V1 module records the sensor readings for processing. The processed water quality data is then transmitted via the internet to a website in real time.

The monitoring system is designed to operate across multiple nodes within a given location, allowing for data collection from various preselected river stations. The core structure of each node station comprises a sensor node unit, a central database, and a web server.

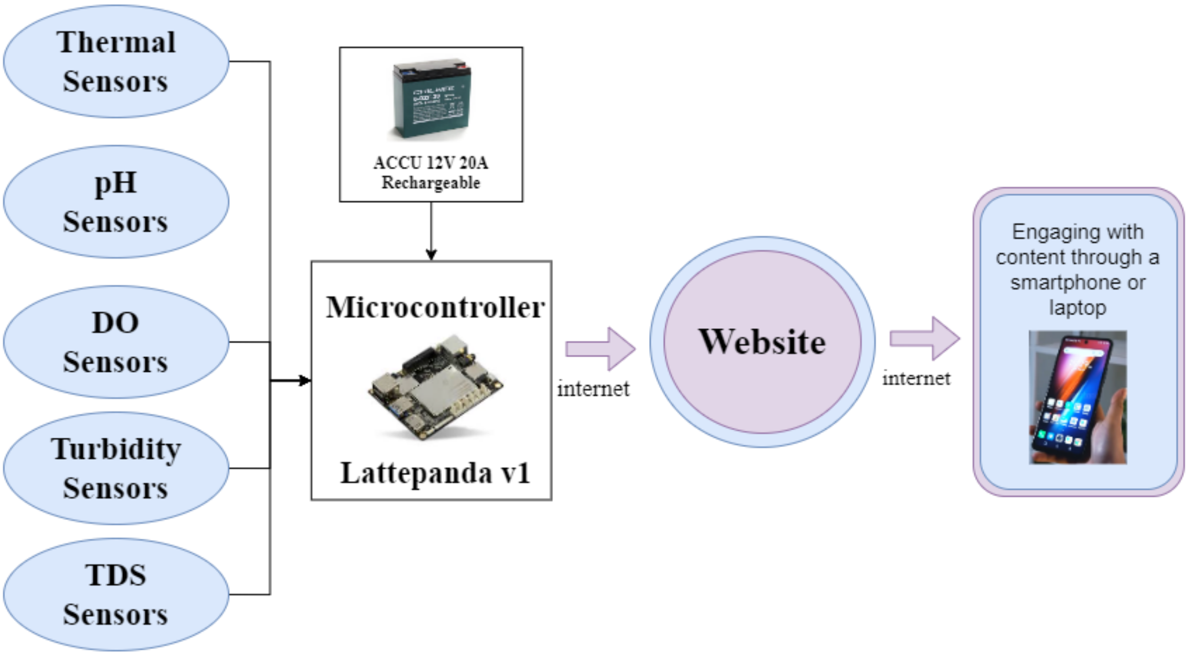

Figure 3. Block diagram of an online water quality monitoring system

The diagram above illustrates the block diagram of a water quality monitoring device. This device is equipped with five sensors: a turbidity sensor, a dissolved oxygen (DO) sensor, a total dissolved solids (TDS) sensor, a pH sensor, and a temperature sensor. The sensors provide real-time readings every 30 minutes. The collected data is recorded and processed by a microcontroller. Subsequently, the data is transmitted to a website in real-time via the internet. Users can access the monitoring results in graphical and tabular formats through the website, which can be freely accessed using either smartphones or computers. The block diagram of the online water quality monitoring system is described as follows:

a. Temperature Sensor: Utilizes the DS18B20 sensor to detect and monitor the water temperature, with its output connected to the LattePandaV1 microcontroller.
b. pH Sensor: Employs the SKU: SEN1283758 sensor to detect and monitor the water pH level, with its output linked to the LattePandaV1 microcontroller.
c. DO Sensor: Uses the SKU: SEN0237 sensor to detect and monitor the dissolved oxygen level in the water, with its output connected to the LattePandaV1 microcontroller.
d. TDS Sensor: Incorporates the SKU: SEN0244 sensor to detect and monitor the total dissolved solids concentration in the water, with its output linked to the LattePandaV1 microcontroller.
e. Turbidity Sensor: Utilizes the SKU: SEN0189 sensor to detect and monitor the water turbidity, with its output connected to the LattePandaV1 microcontroller.

f. Microcontroller: The LattePandaV1 functions as the central microcontroller, processing and transmitting data from the temperature sensor, pH sensor, DO sensor, TDS sensor, and turbidity sensor via the internet to the master data.
g. 12V 20A Rechargeable Motorcycle Battery: Serves as the power source for storing and supplying electricity.
h. Internet: Facilitates the uploading and transmission of data from the LattePandaV1 microcontroller to the website and from the website to the users' smartphones and computers.

The water quality monitoring device operates using a single-board computer (LattePanda V1) equipped with an LCD screen, which functions like a standard Windows 10 computer. This device is integrated with an Arduino Leonardo microcontroller, Wi-Fi, and a display record. The system is powered by a 12V 20A motorcycle battery, which is connected separately to the device through a power socket. Once the battery is connected, it powers both the microcontroller and the LCD, activating the monitoring system and displaying the Windows interface.

To begin operation, the device is turned on by connecting the 12V power source, which boots up the system. The sensors are then submerged in the water to be tested. The system will automatically detect the water's parameters once the sensors stabilize. After all the parameters from the sensors are read, users can open the program to synchronize the data to the internet. Once synchronized, the collected data is automatically recorded in the central database and can be accessed via the website.

When the monitoring system is active, the sensors gather data, which is sent to the LattePanda V1 node within the microcontroller. The data is processed and transmitted via the internet to a dedicated website every 30 minutes. The data, displayed in both graphical and tabular formats, can be downloaded by users for further analysis.

The monitoring results for the Garang Basin's water quality are accessible through the website https://waterquality.my.id/TL_UNDIP/. The website provides two main tools: "Home," which displays real-time water quality readings from multiple stations in graphical form, and "Acquisition Log," which presents the data in tabular format that can be downloaded by users.

4. Regulations and Policies

With the implementation of modeling, real-time water quality monitoring can be achieved, ensuring that water conditions are maintained according to their intended use. In the Das Garang area, which includes the Semarang Regional Drinking Water Company (PDAM), it is crucial to maintain water quality for drinking purposes, as stipulated by Government Regulation No. 22 of 2021 for Class 1 water (Government, 2021). This regulation mandates that water parameters must meet specific standards. Therefore, it is essential that the water supplied to PDAM adheres to these regulations and intended uses.

The research findings revealed that the Chemical Oxygen Demand (COD) levels frequently exceeded the quality standards set by regulations, with measurements ranging from 44.75 mg/L to 99.13 mg/L. This indicates that activities in Dinoyo Urban Village have contributed significantly to the pollution of the Garang River. Major contributing activities include residential and commercial establishments such as schools, campuses, small shops, malls, offices, and hospitals. Human activities have a profound impact on environmental conditions, particularly in terms of water pollution.

Furthermore, the study involved dividing the catchment area based on its spatial planning. Several parameters exhibited significant spikes, suggesting that policies regarding wastewater discharge into rivers and spatial planning need to be carefully evaluated and adjusted

5. Conclusion

Monitoring various water parameters is essential to maintain the surface water quality in accordance with applicable regulations. Policies and regulations play a crucial role in safeguarding groundwater and river conditions. Effective land use management policies are vital, as changes in land use within each sub-watershed significantly impact the quality of water entering the Garang watershed is influenced by land use. It is noted that residential areas comprise 32.31% of the total land use, while agricultural activities are estimated to cover approximately 25.25% of the watershed area.Domestic and agricultural activities contribute to high concentrations of BOD and COD due to the influx of organic materials into the river through surface runoff.

The integration of the Storm Water Management Model (SWMM) with Geographic Information System (GIS) is critical for spatial modeling and the development of Real-Time Monitoring Systems (RTMS). Values below 50 are categorized as moderate, whereas those above 70 are considered good. In the Garang watershed, poor water quality was observed at 14:00 during the second month, with a value of 46.63.

Testing of COD, phosphate, and nitrate parameters in the Garang River showed that COD levels consistently failed to meet standards, with the highest value recorded at point 9 in the first month at 91.05 mg/L. Phosphate and nitrate levels also exceeded quality standards at several points. Conversely, the Water Quality Index (WQI) analysis indicates that the overall water quality status of the Garang watershed is "medium" at most locations. However, point 1 exhibited a "good" status at certain times, while point 5 was classified as "bad."

The use of Internet of Things (IoT) technology allows for real-time water condition monitoring via mobile devices. This study utilized five sensors to measure five different parameters, enhancing the capability to assess river quality and support sustainable water resource management through spatial modeling and real-time monitoring systems. The modeling results demonstrate the feasibility of real-time water quality monitoring to ensure compliance with intended use. Furthermore, a spatial analysis of the watershed revealed significant deviations in certain parameters, indicating the need for a comprehensive review and adjustment of wastewater discharge regulations and spatial planning policies. The consistently elevated levels of Chemical Oxygen Demand (COD), exceeding regulatory standards, highlight the significant contribution of anthropogenic activities to water pollution. To maintain the required Class 1 water quality as stipulated in Government Regulation No. 22 of 2021, a thorough evaluation and revision of wastewater management and spatial planning policies are imperative.

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