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Development of Web-based Geographic Information System for Water Quality Monitoring of Watershed in Malang

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[1*]Novita Rosyida, [2]Layta Dinira, [3]Alfi Nur Rusydi, [4]Agung Dwi Saputra, [5]Ginanjar Setiabudi
[1,4,5]Vokasi, Universitas Brawijaya
[2]Imu Pengetahuan Alam, Universitas Brawijaya
[3]Ilmu Kelautan dan Perikanan, Universitas Brawijaya
E-mail: [1]novitarosyida@ub.ac.id, [2]laytadinira@ub.ac.id, [3]alfi.nurrusydi@ub.ac.id, [4]agungds8@student.ub.ac.id, [5]ginanjar_sb@student.ub.ac.id

*Corresponding Author

Abstract— Human activity and climate change significantly impact water quality, especially in Malang's watershed. This research aims to develop a web-based Geographic Information System (Web- GIS) for water quality monitoring in that watershed. The water quality data had been collected from Enviromental Office of Malang District and Malang City. Water quality in this application was determined using the STORET method, comparing water quality data to water quality standards according to Government regulation so that the water quality status at each monitoring point will be known. The total 57 monitoring points are visualized spatially in this application based on the sampling location plotted by Global Positioning System (GPS). The longitude and latitude coordinates of the monitoring location had been converted in GeoJSON using Quantum GIS (QGIS) software. Google Map API key was used to display a sampling location map on the website. Web-GIS application was tested functionally using a black box, compatibility, and usability testing. Based on the testing results, it worked correctly on Chrome, Edge, Mozilla, and Opera browsers for PC/Laptops and also for browsers on Android smartphones version 4 and above. The application could be appropriately used and efficiently based on usability testing results.

Keywords—Water Quality; Web-GIS; Mapping

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Corresponding Author:

Novita Rosyida,
Vokasi,
Universitas Brawijaya,
Email: novitarosyida@ub.ac.id

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I. INTRODUCTION

Water is vital in the ecosystem since it is a fundamental requirement for all living organisms to survive[1]. The river has become one of the potential water resources used in Indonesia. Generally, the most potent pollution sources come from an area's geological conditions, industry, agricultural activities, and wastewater treatment[2]. Domestic wastes caused by increasing human activity can pollute and affect river water quality along the watershed.

Water quality is determined by several factors, including physical and chemical properties[3][4]. Temperature, electrical conductivity (DHL), suspended residue or total suspended solids (TSS), and total dissolved solids (TDS) are some of the physical characteristics[5]. The degree of acidity (pH), BOD, COD, DO, ammonia as N (NH3-N), nitrite as N, fatty oils, and metals (Cu, Fe, Cd, Mn, and Zn) are chemical parameters [4][6]. It can be said that the water is polluted if the parameter value exceeds the government's quality standard.

Several studies below have shown that the river water quality in Malang City is decreasing. Research results in the Brantas watershed, Dinoyo area, stated that BOD and COD levels exceed the water quality standards according to government regulations for class II. That water should be functionated for water recreation infrastructure/facilities, freshwater fish cultivation, livestock, crops irrigation, and or for other functions that require the same water quality as that standard [3]. The new study also supported it, claiming that the Brantas river could no longer bear the pollution load caused by high BOD levels, which have exceeded the quality standard[2]. The observation results of one segment in Metro River showed that COD levels exceeded the water quality standards required by the government. Meanwhile, the Metro River water flowing along the areas of Pisang Candi, Karang Besuki, Bandulan, and Sitirejo was moderately polluted water with an ASPT value of 4 – 6.2[7].

Other studies showed the same condition for river water quality in Malang Regency. Metro River flowing Pakis district was heavily polluted, even most of the river in the Upper Brantas watershed area of Malang was no longer suitable for agricultural use according to Government Regulation no. 82 of 2001 [8]. Another study result on Metro River in 2015 showed that the BOD and TSS parameters in the monitoring points of the downstream area exceeded the class II of water quality standard requirements[3]. Several years after that research, observations of rivers in Malang Regency were still being carried out. Analysis of the Metro river section of Pakisaji – Kepanjen District showed that the existing condition of the river exceeded the pollution load capacity of class II water quality standard [9].

The previous research below used GIS for monitoring water quality to support water quality assessment. Study [10] explained the fundamental concepts of Internet Geographic Information

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System (GIS) technology for water quality monitoring in San Diego Bay Watershed, California. The design, architecture, and capabilities of this Internet GIS application were addressed, as well as the lessons learned and the prospects for Internet GIS development. Research [11] used remote sensing and GIS application to monitor water quality parameters such as suspended matter, turbidity, phytoplankton, and dissolved organic matter to support water quality management.

Research [12] showed the implementation of GIS software to verify the river water quality model because of insufficient information in the research area. Research [13] shared an overview of the combination of GIS implementation and other technologies such as the Internet of Things [14], remote sensing, wireless sensor network, web, et cetera for water quality management and monitoring to maintain the water resources properly. GIS implementations were used to manage groundwater exploitation[15][16]. The web-GIS model was also used to control some agricultural land in Papua[17].

Preventive action has been taken by Malang Environment Office (Dinas Lingkungan Hidup) by watershed water quality observation in specific measurement points every year. However, the data measurement was only stored and classified using a simple database in the office. Even the water quality condition of the watershed is not widely known yet by the public.

Controlling and managing the data measurement was done by providing a database that consistently records the periodic data. The database could be linked to the watershed measurement points, including the water quality parameters as indicators of the watershed condition. Therefore, it requires a web-based Geographic Information System (Web-GIS) to accommodate and support the system[10]. Decision Support System can be integrated with GIS based on user requirements [18], so that it can be easy to use for any user for their activity. Therefore, we developed a Web-GIS to monitor the watershed's water quality in Malang. We used the STORET method compared with the measurement results based on water quality standards [1][19].

II. RESEARCH METHOD

Malang is located in East Java province Indonesia, dominantly consisting of the highlands. It lies astronomically at 112º17'10.9"-112º57'0.0" East Longitude and 7º44'55.11"-8º26'35.45" West Latitude and has sub-districts distributed in urban and rural areas, as shown in Figure 1. The Tengger Mountains surround the geographical location of Malang on the east side, Mount Kawi and Kelud on the west, and Mount Arjuna and Welirang on the north.

Due to its various elevation and topographical conditions, the Malang area belongs to several watersheds providing primary water resources. The sampling points/location available in the Web-GIS application was determined based on the monitoring points of the Malang City and

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Malang Regency Environment Protection Agency. The total sampling points were 57 points in all watersheds around Malang.

Figure 1. MAP OF MALANG RAYA [20]

The development of the Web-GIS application procedure refers to the modification of the System Development Life Cycle (SDLC) or waterfall model method[17]. According to [21][22], the information system development stages consist of 1) requirements/need analysis, 2) conceptual design, 3) database design, 4) application development, and 5) Web-GIS implementation and evaluation, as shown in Figure 2.

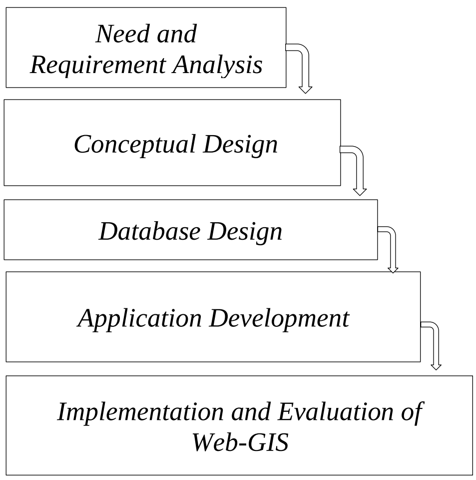

Figure 2. WEB-GIS DEVELOPMENT PROCEDURE

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Requirement analysis was used to identify the information system development, primarily to design the database, UI/UX, and software needs. Some information was collected by interviewing Malang Environment Office staff in Malang city and Malang District to discuss the required scope of the information system. The data used for the system development were watershed measurement results in Malang city and Malang Regency taken from 2018 to 2020. There were 57 measurement points.

The conceptual design was performed following needs and requirement analysis so that the application will be relevant to stakeholders as the system users[23]. Use case diagram and relation diagram were used to design the prototype of the system and the user interface. The Web-GIS application was developed using PHP programming language by Laravel framework, MySQL database, and QGIS software to convert mapping location/point into Geo-JSON format.

The information system was created using the system requirements already defined in the previous stage. The following steps were the system testing/implementation and evaluation to determine the suitability and verify the application as the final design. The system testing used a black box approach with several scenarios to determine the system functionality[24]. The usability was tested to find out whether the proposed system was suitable or not[25]. The system adjustments would be made based on the stakeholder's needs if the recent design were not ideal as the previous design.

The Web-GIS development for water quality monitoring in Malang Watershed was initiated by the several problems identified in the Malang City and Malang District Environment Service. The difficulties and expected solutions identified by interviewing with Malang Environment Office staff were as follows:

a. Data recording of water quality measurement results was stored locally using Ms. Excel and Portable Document Format (PDF) format. The expected solution offered was to develop an information system with an integrated database.

b. Monitoring results were only well known by one division, so only one administrator could access the latest update of the data report. The expected solution was to create an information system with the latest data update that has opened access, so that the administrators could access the updated data.

c. There was no data history of water quality measurement/sampling results. The expected solution was to add sampling data history and to display the water quality parameters in time series format.

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The Web-GIS development of water quality monitoring has three main actors for different user interfaces and access. The use case diagram can be seen in Figure 3. The role and features/access for each actor/user are as follows:

1. Super Administrator

The features that super-admins can access are as follows:

a. Super-admin can add or remove users in the application (CRUD User)

b. Managing sub-district and urban village data (CRUD sub-district and urban village data)

c. Managing river monitoring point data (CRUD monitoring point data)

d. Managing related articles displayed on the initial home page

e. Adding and removing water quality parameters to be displayed and updating the water quality parameters threshold.

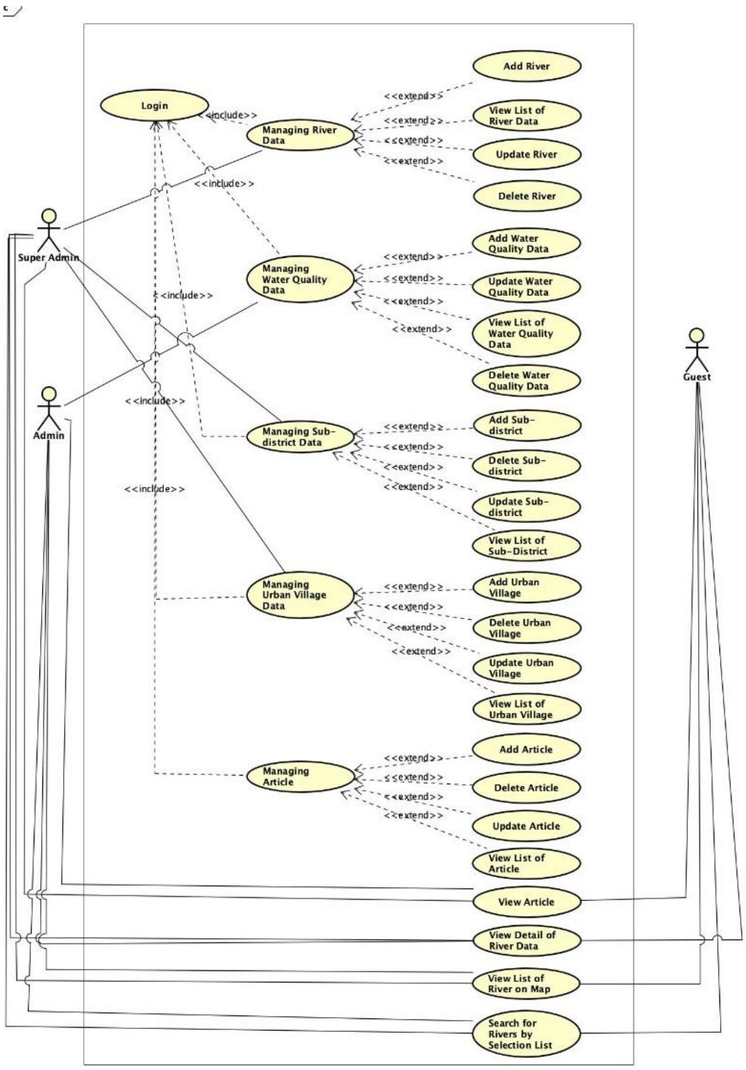

Figure 3. USE CASE DIAGRAM OF WEB-GIS WATER QUALITY MONITORING

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2. Administrator

The admin's role is to update the water quality data from direct measurement on each watershed monitoring point. The admin role is divided into two areas, Malang City Administrator and Malang District Administrator. The feature of each administrator is:

a. Managing water quality data of the city/district (CRUD data on water quality parameters of the city/district)
b. Importing or exporting water quality data files into excel/Comma Separated Values (CSV) format.

3. Guest

The guest's role is to view news and water quality data directly at the home page without login into the application.

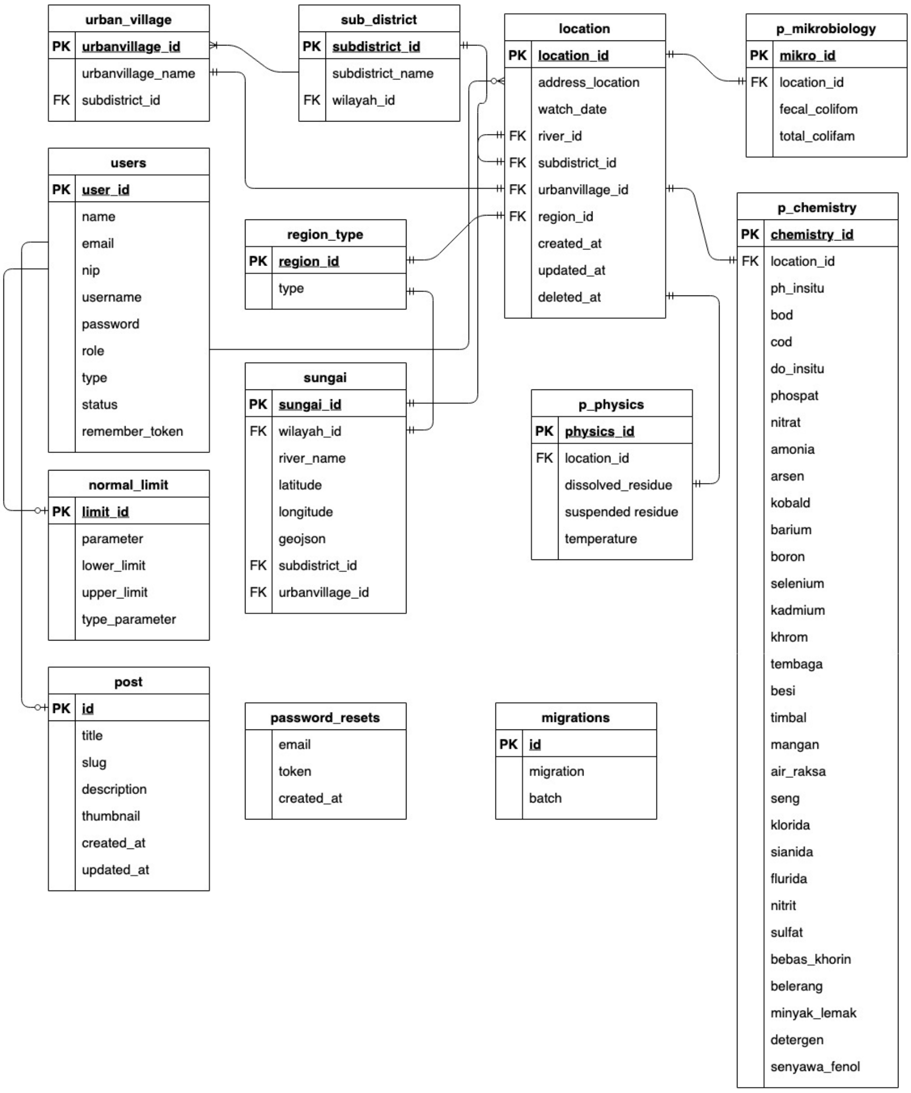

Figure 4. RELATION DIAGRAM OF WEB-GIS WATER QUALITY MONITORING

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MySQL database was used for this application development because the system required transparent relationships to reduce the possibility of table relations. Figure 4 shows a relationship diagram that describes the table's relationship. There were 13 tables in the database: user tables, *kelurahan*/urban village tables, sub-district tables, region tables to distinguish between city and district areas, location tables, biological parameter tables, physical and chemical parameters, river tables, password reset tables, and migration tables. The water quality parameter table was determined based on the analysis results of water quality parameters tested by the Environment Office of Malang City and Environment Office of Malang Regency.

III. RESULT AND DISCUSSION

This part discussed the results of a water quality monitoring application based on Web-GIS that has already been designed and developed. Figure 5 shows the dashboard page of that Web-GIS on desktop and mobile platforms. Every user can choose the map view integrated with the google map in any type, such as the default map, satellite, or terrain. On this page, we can also see the location point and list of rivers inside Malang city and Malang Regency watershed. The marker or color symbol of each point indicates the pH and BOD parameters of the river. The green color symbol indicates that they are still within the standard limit; the blue color symbol means that they are below that limit and the red one means that they are above that limit. The water quality parameters were determined based on the comparison between field measurement results and the water quality standard of Indonesian Government Regulation No. 82 year 2001, or STORET method [26], as shown in Table 1. The water quality standard implemented in this application is water class IV since the river function in Malang is mainly used for irrigation infrastructure and aquaculture.

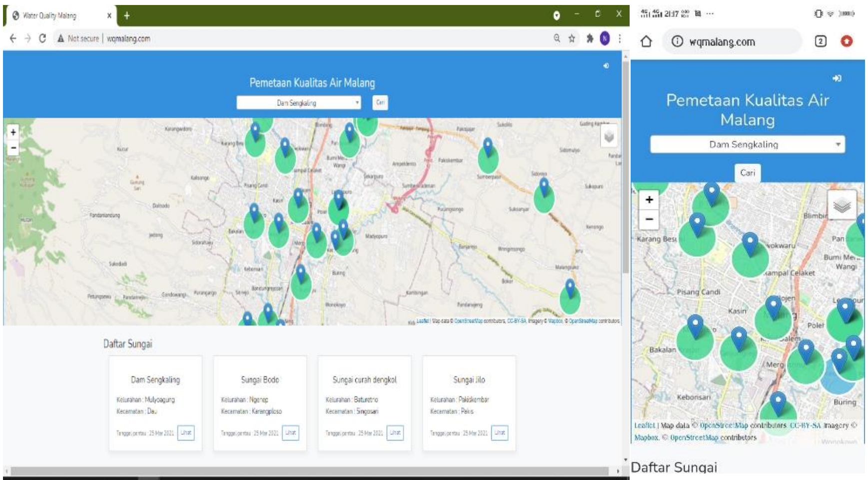

Figure 5. DASHBOARD PAGE OF WEB-GIS WATER QUALITY MONITORING

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Users can look for the water quality information on the dashboard by selecting the available location in the search box. Figure 6 shows the detailed search results for the point or place of the river open in the information system. The user can see 30 river monitoring points in Malang Regency and 27 points in Malang City according to the sampling location provided by the Malang City and Malang Regency Environment Office.

Table 1. WATER CRITERIA STANDARD REFERS TO GOVERNMENT REGULATION NO. 82, THE YEAR 2001

Parameter	**Unit**	**Class**		
		II	**III**	**IV**
Physical Parameter				
Temperature	°C	Deviation 3	Deviation 3	Deviation 5
Dissolved Residue	mg/L	1000	1000	2000
Chemical Parameter				
pH		6-9	6-9	5-9
BOD	mg/L	3	6	12
COD	mg/L	25	50	100
NH_3-N	mg/L	≤0,5	≤0,5	≤0,5
Nitrit as N	mg/L	10	20	20
Fe	mg/L	≤0,3	≤0,3	≤0,3
Cu	mg/L	0,02	0,02	0,2

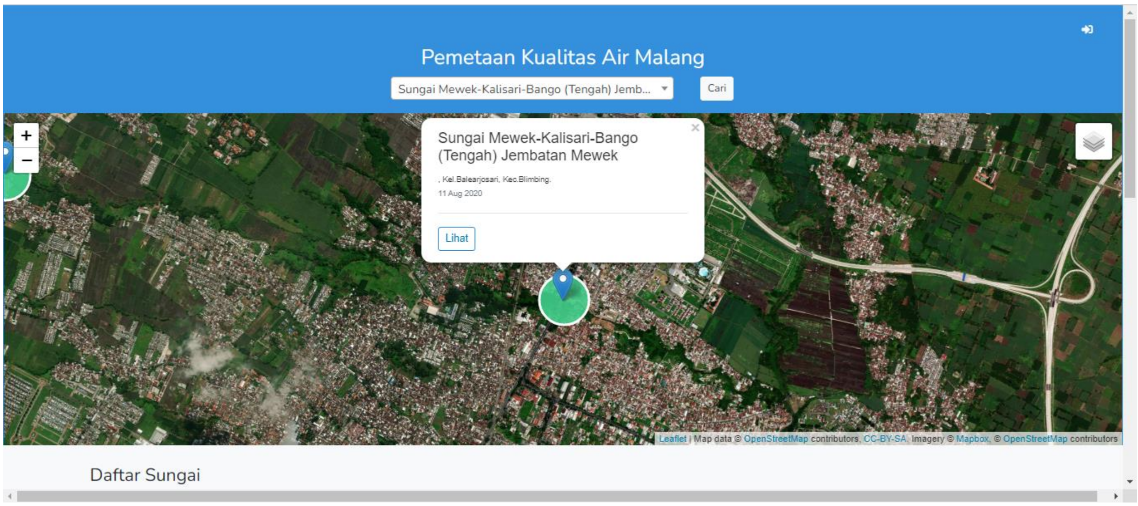

Figure 6. POINT OF MONITORING SEARCH RESULT ON WEB-GIS APPLICATION

The water quality parameter values can be seen in Figure 7. The time series of water quality data can also be displayed by clicking on the details at each desired monitoring point. The water quality parameter values are visualized in the bar chart showing each physical water quality parameter and chemical water quality parameter.

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Figure 7. DETAILED DISPLAY OF WATER QUALITY PARAMETERS AT EACH MONITORING POINT

The super admin carried out the river data input process through the dashboard, as shown in Figure 8. It was initiated by inputting the sub-district and urban village area data, including longitude and latitude data converted in Geo-JSON format. Those data were transformed using Quantum Geographic Information System (QGIS) software to mark the desired location. Longitude and latitude coordinate data were obtained from field sampling using Global Positioning System (GPS) according to sampling location by Environment Office.

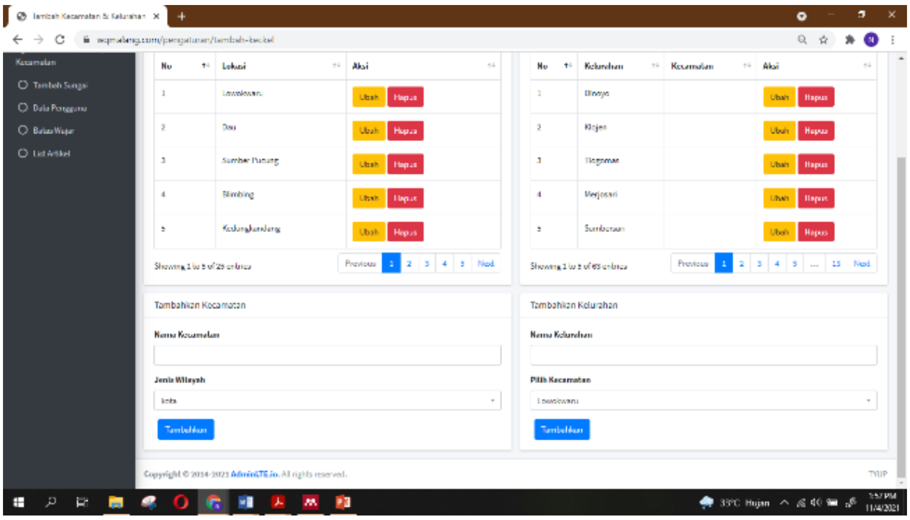

Figure 8. THE INPUT OF POINT MONITORING BY SUPERADMIN

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Data input of each water quality parameter and monitoring date for the city area and district area were carried out by their administrator, respectively, as shown in Figure 9. They were imported from the excel file format to simplify the data input process. City and district administrators could download their own water quality data for each monitoring point in excel/CSV file format. They were used for water quality reporting and time series data analysis.

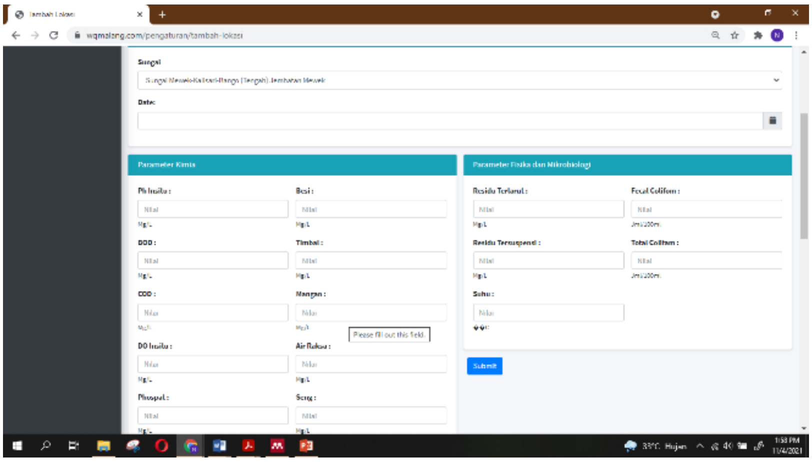

Figure 9. ADMIN DASHBOARD TO INPUT WATER QUALITY PARAMETER

The next step following the development of this information system prototype was system testing by users (which were Environment Office staff of Malang City and Malang District). The system testing was implemented using black box methods and involved numerous actions managed in the information system. The testing results are shown in Table 2.

Table 2. TESTING RESULT OF WEB-GIS WATER QUALITY MONITORING

No	Page	Feature	Result
1	Home	Showing the initial dashboard (home page) with the view of the map and point marker	Success
2	Location search	Showing the search location page and finding a searching location	Success
3	Detail location	Showing the detail of the latest water quality sampling	Success
4	Login	Showing login page and log as admin or super-admin	Success
5	Add river	Showing the page to add point location of measurement and super-admin can add a new point	Success
6	Threshold parameter	Showing the threshold parameter and super-admin can edit the parameter	Success
7	Log	Showing the latest water quality monitoring that has already input	Success
8	Upload data	Admin can upload water quality data manually or import using excel	Success

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In addition, compatibility testing was also carried out by accessing the application through several browser types using both PC/notebook and smartphone. The browser types used for PC/laptops in this testing were Chrome, Edge, Mozilla Firefox, and Opera browser, whereas the browser types for smartphones were Chrome and Opera Mini browser. Based on compatibility testing results, all browsers were compatible to access the WebGIS applications. For the Android platform, the minimum application requirement was Android version 4 or above. Eight people who acted as guess, admin, and administrator tested the application's usability. Each user was required to:

a. open the Web-GIS application, which was already hosted
b. Search river or location point
c. log in as an administrator to add river data
d. log in as an administrator to change physical and chemical parameters
e. log in as an administrator to input Malang City and Malang District water quality data according to the monitoring point.

Based on the usability testing result, all respondents said the application was user-friendly and easy to use. All features could work properly, and the system was ready to apply in Environment Office if the navigation pane was enlarged on the login form.

IV. CONCLUSION

A Web-GIS had been developed for water quality monitoring of watershed in Malang. The water quality parameters included both physical and chemical water quality parameters. They were based on monitoring data provided by the Malang City and Malang Regency Environment Office. The threshold of water quality parameters is based on water quality class IV following Environmental Regulations issued by the government. The Web-GIS application was developed using Laravel framework, MySQL database, QGIS, and Google Map API key to display google Maps on the website. It was tested using a black box, compatibility, and usability testing. Based on the testing results, it worked correctly on Chrome, Edge, Mozilla, and Opera browsers for PC/Laptops and also for browsers on Android smartphones version 4 and above. The application could be appropriately used and efficiently based on usability testing results.

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