Water Contaminant Measurement Using Pollution Indexing in Case of ground water

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Abstract. One important factor in human life is the need for water used for bathing, washing, and others. Water quality is determined by the chemical, physical, biological, and radiological characteristics of water. It is a measure of water conditions that are based on the feasibility of use for example used by humans in their lives. Water pollution can be measured by analyzing water samples in physical, chemical and biological tests. Specific contaminants that lead to water pollution include chemical and physical changes such as temperature and discoloration. In this study, a water contaminant measuring instrument was made based on related sensors by utilizing water characteristics from pH, turbidity, temperature, Total Dissolved Solids (TDS) and Oxidation Reduction Potential (ORP) indicators. Calibration of the system is conducted manually by applying the pollution index (PI) method. The proposed system involves a sensor technology and a set of embedded processing systems that are able to make decisions in indication of water pollution. This system has 4 main features: (1) Making measurement with water quality sensors, (2) Data acquisition and pre-processing, (3) Intelligent processing units, (4) Data transmission and visualization. Three parts of the system are (1) Data acquisition unit, (2) Console Unit, and (3) Web visualization. We conducted an experimental study water contaminant measurement at groundwater source points (wells) using a Pollution Index. Based on the experiments, our proposed system measured water contaminants successfully; including can make decision of the water contaminants category.

1. Introduction

Research on the extent of water contamination has been widely carried out by researchers until now. Several previous studies on the measurement of water contaminants: Sritusta et al have measured water contaminants using a modification of the ROV submarine miniature (A remotely operated underwater vehicle) for river water monitoring category [1]. Dito et al. have observed water contaminants based on smart sensor systems for measuring water contamination in the well water category [2]. Data transmission measurements for water contaminants based on sensor systems have used wireless technology. At present, sensor-based research has used wireless technology, in addition to the two studies above, Udin Harun et al. have also used wireless technology (wireless sensor network) as a data transmission medium in their research [3] [4].

The Republic of Indonesia Minister of Health's regulation on water quality requirements and supervision in 1990 was used as a reference for water quality control. The related government agencies conduct intensive and continuous water quality monitoring based on the ministerial regulation to improve public health status so that people are protected from health problems. Another reference used to determine the status of water contaminants is the pollution index method based on the Decree of the State Minister for the Environment of the Republic of Indonesia Number: 115, 2003, article 2 concerning Guidelines for Determining the Status of Water Quality.

This study designed a sensor-based water contaminant measuring device that can be calibrated manually. Decision making of water contaminants in this system uses pollution index method. The built system has been able to read the parameters of water contaminants. The web has been built to provide
information on where the water source is being measured. Additional web-based information in this system is more beneficial to the community as an early warning of water sources that contain contaminants.

2. System Design

The system designed has three main parts including measuring instruments for sensor, console unit and web readings. System design can be seen in figure 1. The water source used in this study is ground water (well water). The well water contaminant data collection model is illustrated in figure 2, based on the data collection model in the previous study [2].

![Figure 1. Design of a well water contaminant measurement system](image)

![Figure 2. Model of data collection of well water contaminants](image)

2.1. Design of sensor unit for data acquisition

The sensor unit for data acquisition is a device that serves to observe the ground water linked to Electro Conductivity (levels of dissolved substances (TDS)), acidity (pH), Oxidation Reduction Potential
(ORP), turbidity and temperature. The sensor used is a water temperature sensor, pH, turbidity, ORP and TDS. The tasks of sensor units are (i). Read the conditions associated with the water temperature, pH, turbidity, ORP and TDS; (ii). Process the data to make decision; and (iii). Send sensor data to the console unit. Block diagram of data acquisition system and its design is shown in figure 3 and 4 respectively.

**Figure 3.** Block diagram of data acquisition system

**Figure 4.** Design of sensor for data acquisition

2.2. Design of Console Unit

The console unit is the main part of this system. The function of the Control Unit is (i). Receiving and processing data from data acquisition unit; (ii). Receiving position of data source from the GPS; (iii). Making decision of water pollution using Pollution Index (PI); and (iv). Sending the decision result and location of the water source (in which contaminants are measured) to the web via the GSM module. Block diagram of console unit and its design are shown in figure 5 (a) and (b) respectively.

2.3. Web readings

Web-based reading is used to facilitate information to the community concerned, regarding the condition of water that is being or will be used. Information on the web includes: (1). Maps: view of the water source that its contaminants observed. (2). Table: results of sensors measurements for water contaminants. In this study, the water contaminant parameters used were pH, turbidity, temperature, Total Dissolved Solids (TDS) and Oxidation Reduction Potential (ORP). These parameters are read by the system using the associated sensors.
2.4. Calculation of water pollution using the pollution index

Processing of water contaminant data is based on the Pollution Index (PI). The output of PI is the result of variable sensor data processing of water contaminants (the water temperature, pH, turbidity, ORP and TDS). This result can provide input to decision makers to assess the quality of water bodies so that the feasibility of using water can be determined by the authorized institution. Calculation of PI pollution index is shown in equation (1).

\[
P_I = \sqrt{\left(\frac{C_i}{L_{ij}}\right)_M + \left(\frac{C_i}{L_{ij}}\right)_P}
\]

Where \( L_{ij} \) is the concentration of water quality parameters (variables) stated in the Water Allocation Quality Standards, \( C_i \) states the concentration of water quality parameters obtained from the measurement results in a water source location, and \( P_I \) is the Pollution Index, a function of \( C_i/L_{ij} \). The PI method directly produces a level of contamination so that the community knows the feasibility of the water.

The level of water pollution based on its contaminants and using PI values is:

- 0 ≤ \( P_I \) ≤ 1.0 : quality standards (good condition)
- 1.0 < \( P_I \) ≤ 5.0 : mild pollutant
- 5.0 < \( P_I \) ≤ 10 : medium pollutant
- \( P_I \) > 10 : heavily pollutant

There are several possible values of \( C_i/L_{ij} \) for each parameter. The following are the possibilities that occur with this value:

i. If the concentration value of the parameter decreases (stating the level of pollution increases) then the \( C_i/L_{ij} \) value is replaced by the following calculation:

\[
\left(\frac{C_i}{L_{ij}}\right)_{new} = \frac{C_{im} - C_i(meas)}{C_{im} - L_{ij}}
\]

Where is \( C_{im} \) = maximum value allowed.

ii. If the default value of \( L_{ij} \) has a range then the value of \( C_i/L_{ij} \) is replaced as follows:

\[
\left(\frac{C_i}{L_{ij}}\right)_{new} = \frac{C_a - C_i(meas)}{C_a - C_{b}}, \quad 0 \leq C_i(meas) < C_0
\]

\[
\left(\frac{C_i}{L_{ij}}\right)_{new} = \frac{C_i(meas) - C_a}{C_b - C_{a}}, \quad C_i(meas) \geq C_0
\]
Where \( C_0 \) is the average value of the upper and lower limits, \( C_a \) states lower limit value, \( C_b \) is the upper limit value.

iii. If the \( C/L_{ij} \) value is greater than 1.0, the \( C/L_{ij} \) value is replaced by the following equation:

\[
\left( \frac{C_i}{L_{ij}} \right)_{new} = 1,0 + P \times \log \left( \frac{C_i}{L_{ij}} \right)_{meas}
\]

(5)

Where \( P \) states constants whose values are based on environmental observations.

Calculation of \( C/L_{ij} \) on each parameter of water pollution is stated as follows:

i. **Parameter pH.** The maximum allowable pH level is between 6.5 and 9.0. The pH measurement data is used in the pollution index calculation using equations (3) and (4). The calculation flowchart is stated in figure 6.

![Figure 6](image_url)

**Figure 6.** The pH, temperature, and ORP flowchart on pollution index

ii. **Amount of total dissolved solids (TDS).** The maximum level allowed for the TDS value is 1500 ml/L. TDS data is used for calculating pollution index calculations using equation (5). Flowchart calculation of TDS and turbidity is shown in figure 7.

iii. **Turbidity.** The maximum turbidity level allowed is 25 NTU. The turbidity level data is obtained from the pollution index calculation using equation (5). The calculation flowchart is stated in figure 7.

iv. **Temperature.** Allowable temperature levels between air temperatures \( \pm 30^\circ C \). Limitation of these levels was obtained from the calculation of the pollution index using equations (3) and (4). The calculation flowchart is explained in figure 6.

v. **ORP (Oxidation-Reduction Potential).** ORP levels that are allowed between 100 and 800 RmV. The level limit is based on the pollution index calculation using equation (5). The calculation flowchart is described in figure 6.
3. Testing of sensors precision

In this session describes the testing of sensors that have been designed to get the precision of those sensors. To obtain data stability, a filter ADC moving average is applied to each sensor data using equation (6).

\[ MA_n = \frac{\sum_{i=1}^{n} D_i}{n} \]  (6)

In which \( n \) is number of periods in the moving average and \( D_i \) = demand in period \( i \).

3.1. Testing of the pH sensor

Testing of pH sensor is done by using initial data retrieval, the results of pH sensor readings can be seen in figure 8. In figure 8, it can be seen that for taking 1000 data, the conversion of the pH value to the ADC is unstable; the value ranges from 476 - 484.

The instability of the pH sensor readings is solved by using a moving average filter. The noise generated on the pH sensor reading can be reduced significantly by using the filter. In figure 9 shows the filtering results from reading the pH sensor in the ADC conversion. The results of the conversion of pH sensor readings on the ADC look more stable in the range of the value of 476. This condition indicates that the results of the pH sensor readings can be used as pH contaminant measurement data at the water source to determine the water pollution.

The maximum allowable pH level is between 6.5 and 9.0. As stated in the previous session, the value of the pH sensor reading will be used to calculate the water pollution index using equations (3) and (4).
3.2. Testing of the turbidity sensor

Testing of turbidity sensors is conducted by using initial data retrieval, the results of turbidity sensor readings can be seen in figure 10. In figure 10, it can be seen that for taking 800 data, the conversion of the turbidity value to the ADC is unstable; the value ranges from 724 - 740.

The instability of the turbidity sensor readings is also solved by using a moving average filter. The noise generated on the turbidity sensor reading can be reduced significantly by using the filter. In figure 11 shows the filtering results from reading the turbidity sensor in the ADC conversion. The results of the conversion of turbidity sensor readings on the ADC look more stable in the range of the value of 740. This condition indicates that the results of the turbidity sensor readings can be used as turbidity contaminant measurement data at the water source to determine the water pollution.

As stated in the previous session that the maximum turbidity level allowed is 25 NTU. The turbidity level data is obtained from the pollution index calculation using equation (5).
3.3. Testing of the TDS sensor

As with other water contaminant parameters, the TDS sensor test has been carried out using the initial data. Figure 12 one of the results of reading the TDS sensor which is converted into the ADC. Approximately 1000 data readings of the TDS values in the ADC have been carried out, where the value of the ADC generated increases from 272 to 308. This condition indicates the instability of the TDS value generated from the related sensor.

Noise reduction in TDS measurements is also done by using a moving average filter as well as filtering on the pH and turbidity parameters. One of the results of filtering on TDS values obtained in the form of ADC conversion value is around 310 for around 500 data retrievals. This condition illustrates that the filtering results produce a more stable TDS value. Figure 13 shows the results of filtering using the moving average in the ADC conversion. This condition indicates that the results of the TDS sensor can be used as TDS contamination measurement data at the water source to determine the water pollution.

The TDS value is the maximum level allowed is 1500 ml / L. The measurement results for use for calculating pollution index using equation (5). The results of the pollution index calculation show the level of water pollution measured.
3.4. Testing of the ORP sensor
Measuring the ORP value using a related sensor has been done and one of the results can be seen in Figure 14 in the form of converting values to ADC for 1000 data. Based on the results of reading the ORP data in the conversion of the ADC, it can be seen that the value fluctuates in the range 373 - 375. This condition implies that the reading of the ORP value is still not stable.

The instability of ORP measurement values can be reduced using a moving average filter as has been done on the results of pH, turbidity, and TDS measurements. One of the results of filtering on ORP values was obtained from the ADC conversion value around 374 for around 900 data retrievals. This condition is a more stable ORP value. Figure 15 shows the results of filtering using moving average in the ADC conversion. This condition indicates that the results of the ORP sensor can be used as ORP contamination measurement data at the water source to determine the water pollution.

ORP value levels are permitted between 100 and 800 RmV. The level limit is based on the pollution index calculation using equation (5). As with other parameters, the results of the pollution index calculation show the level of water pollution measured.
4. Experimental results and discussion

This session consisted of two experimental activities: communication testing between equipment and measurement of water contaminants.

4.1. Testing of communication between equipment designs

Communication between equipment designed is observed. The success rate of transfer of data acquisition from sensors to the console unit is carried out. Data sent using data frames with the format is illustrated in figure 16.

| Code | Data 1 | Data 2 | Data 3 | Data 4 | Data 5 | Data 6 | Data 7 | End |
|------|--------|--------|--------|--------|--------|--------|--------|-----|

**Figure 16.** Protocol data frame

In which *Code* is unique code; *Data 1* is data sensor pH; *Data 2* is data sensor ORP; *Data 3* is data sensor Turbidity; *Data 4* is data sensor Temperature; *Data 5* is data sensor TDS; *Data 6* is data sensor Conductivity; *Data 7* is pollution indexing result; and *End* is the end of the data sent.

Examples of data sent:
- $7.7.20,100.12,5.65,28.21,854.14,1230.31,3$;
- $7.40,130.16,9.65,29.21,554.14,1430.31,2$.

In the console unit, data obtained from the sensor unit is processed, analyzed and decisions are made on the analysis of the data. Data analysis results are displayed on the LCD as information on measurement results about water contaminants.

Data from the analysis of water contaminants that have been calculated are sent from the console unit to the web server. The format for sending data is:

```
gaptech.me/url.php?s2=-&.4243252&s3=112.3134242&s4=28.23&s5=7.88&s6=381.23&s7=3.31&s10=1122.31&s8=2
```

Where *s2* is data Latitude; *s3* is data Longitude; *s4* is data temperature; *s5* is data pH; *s6* is data TDS; *s7* is data turbidity; *s10* is data conductivity; and *s8* is data water contaminant.

One result of sending data from the console unit to the web server is shown in figure 17. The next step after sending data from the console unit to the web server is the web server replying to the console unit. The web server sends replies using a specific format as exemplified in figure 18.

**Figure 17.** Results of sending data from the console unit to the web server

**Figure 18.** Web server reply results when complete shipping data
4.2. Results of water contaminant measurement
In the previous session it was stated that for the measurement of sensor-based water contaminants, a water pollution index (PI) was used. The parameters used are water temperature, pH, turbidity, ORP and TDS. Calculation of water pollution using pollution index is done by equation (1). In this session water samples from several sources were taken and calculated the level of water contaminants based on the level of pollution using the pollution index.

Equation (1) shows that the pollution index $P_I$ is a function of $C_i/L_{ij}$. In which $L_{ij}$ is the concentration of water quality parameters (variables) stated in the Water Allocation Quality Standards, $C_i$ states the concentration of water quality parameters obtained from the measurement results in a water source location. Water pollution levels based on pollution index are stated as follows:

- $0 \leq P_I \leq 1.0$: quality standards (good condition)
- $1.0 < P_I \leq 5.0$: mild pollutant
- $5.0 < P_I \leq 10$: medium pollutant
- $P_I > 10$: heavily pollutant

In the experimental test carried out in this study using eight water samples from various well water sources (ground water) that were different locations. This test the parameters used to observe the level of pollution is TDS, turbidity, temperature, and pH. The results of the calculation of the level of water pollution are presented in table 1.

In table 1 it can be seen that the duration of the time to determine the level of water pollution varies between 4 to 10 seconds. The results of measuring pH values from eight groundwater sources vary between 7.02 - 7.90. While the standard pH values are permitted and are contained in the PI reference between 6.5 - 9.0. All results of measuring pH values meet the standards specified in the PI method. The contribution of pH values in the PI calculation is based on the calculations in equations (3) and (4).

The results of the measurement of TDS values from eight samples of groundwater sources also vary between 100 - 1100. Whereas the standard TDS values in the IP method should not exceed 1500 ml/L. This condition states that all TDS values from eight samples of groundwater sources belong to the allowed quality standard for TDS, which is a maximum of 1500 ml/L. The contribution of the TDS value in determining the level of pollution using a PI method is calculated using equation (5).

| #  | TDS     | Turbidity | Temperature | pH  | IP result | Water contaminant / pollutant |
|----|---------|-----------|-------------|-----|-----------|------------------------------|
| 1  | 1,020.00| 26.34     | 28.22       | 7.87| 0.90      | Good                         |
| 2  | 782.00  | 22.00     | 29.00       | 7.80| 0.73      | Good                         |
| 3  | 100.00  | 4.00      | 27.50       | 7.70| 0.14      | Good                         |
| 4  | 1,100.00| 28.34     | 27.90       | 7.90| 1.04      | mild pollutant               |
| 5  | 888.21  | 24.61     | 29.37       | 7.28| 0.85      | Good                         |
| 6  | 841.00  | 22.21     | 29.50       | 7.39| 0.78      | Good                         |
| 7  | 549.41  | 16.25     | 29.44       | 7.24| 0.70      | Good                         |
| 8  | 655.00  | 56.90     | 27.50       | 7.02| 2.35      | mild pollutant               |

Measurement of turbidity values in eight samples of groundwater sources varies between 4 - 56.90. The standard value of turbidity based on the PI method the maximum allowable is 25 NTU. Based on these quality standards, there are three measurements of TDS values exceeding the maximum limit (more than 25 NTU), namely the first row (= 26.34 NTU), $4^{th}$ (= 28.34 NTU), and $8^{th}$ (= 56.90 NTU) in table 1. Calculation of water pollution levels with turbidity parameters is performed by equation (5).

Measurement of air temperature values in around eight samples of groundwater sources also varies between 27.50 - 29.50. While the standard value of air temperature around water sources based on PI is ± 30°C. In the measurement data of temperature values in table 1 it can be concluded that the value of all
air temperatures is still within the range of quality standards of air temperature around the observed water source. Calculation of PI for air temperature can be conducted by equations (3) and (4).

Based on the values of the four parameters above (pH, turbidity, TDS, and temperature), the PI value is calculated. Table 1 shows the results of the calculation of PI values with details: (1) Lines 1-3 and lines 5-7 have a PI calculation with a value between $0 \leq \text{PI} \leq 1.0$, this condition means that the groundwater source is in good condition. (2) Then in table 1 lines 4 and 8 have PI values 1.04 and 2.35 respectively. This means that the source of groundwater is in a mildly polluted state (PI value: $1.0 < \text{PI} \leq 5.0$).

5. Conclusion

In accordance with the experimental data results with respect to this system can be concluded:

- All sensors used in this study (pH sensor, turbidity, TDS, ORP, and temperature) have taken measurements with the acquisition of sensor data which is quite valid because noise in relative measurements can be significantly reduced using a moving average.
- The proposed system has three main parts, namely the sensor unit, console unit, and web. Communication has been done well between parts, the sensor unit sends sensor data to the console unit, the console unit processes and analyzes the data and sends it to the web, while the web is able to read the results of analysis of data sent from the console unit.
- Based on observations of experimental data from eight samples of groundwater sources, information was obtained that six groundwater sources had met PI quality standards so that said groundwater sources were in good condition (PI values fulfilled the interval of standard PI values: $0 \leq \text{PI} \leq 1.0$), while two samples of groundwater sources have been found to have mild polluted conditions because the PI values obtained are between $1.0 < \text{PI} \leq 5.0$.

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References

[1]. Sritrusta Sukaridhoto, Dadet Pramadihanto, Taufiqurrahman, Muhammad Alif, Andrie Yuwono, Nobuo Funabiki 2015, A design of radio-controlled submarine modification for river water quality monitoring, International Seminar on Intelligent Technology and Its Applications (ISITIA), pp 75 – 80.

[2]. Taufiqurrahman, Tamami, N., Putra, D.A., Harsono, T. 2016, Smart sensor device for detection of water quality as anticipation of disaster environment pollution, Proceedings of International Electronics Symposium IES, Surabaya Indonesia.

[3]. M. Udin Harun Al Rasyid, Bih-Hwang Lee, Amang Sudarsono, Taufiqurrahman 2015, Implementation of Body Temperature and Pulseoximeter Sensors for Wireless Body Area Network, Sensors and Materials, International Journal on Sensor Technology, ISSN 0914-4935 (SCIE, Scopus).

[4]. M. Udin Harun Al Rasyid, Taufiqurrahman, Ali Husein Alasiry, Septian Dwi Utomo, Dimas Jabbar 2014, Performance Analysis of the Topologies for Wireless Body Area Network (WBAN), International Electronics Symposium IES, Surabaya Indonesia.

[5]. Dyah Marganingrum 2013, Assessmet of Citarum River Water quality Using Difference Approximation Results from Two Index Method, Bulletin of Environmental Geology Vol. 23 No. 3, pp. 105 - 114.