Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control
Journal homepage: http://kinetik.umm.ac.id
ISSN: 2503-2267
Vol. 6, No. 3, August 2021, Pp. 259-268

Internet of Things: Water quality classiffication based on estimation of dissolved oxygen solubility and unionized ammonia for small-scales freshwater aquaculture

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Article Info
Keywords:
Internet of Things, Water quality, Fuzzy logic, Dissolved Oxygen, Unionized Ammonia

Article history:
Received: August 27, 2021
Accepted: August 31, 2021
Published: August 31, 2021

Cite:
Shandikri, R., & Erfianto, B. (2021). Internet of Things: Water Quality Classifying Based on Estimation Dissolved Oxygen Solubility and Estimation Unionized Ammonia for Small-scales Freshwater Aquaculture. Kinetik: Game Technology, Information System, Computer Network, Computing, Electronics, and Control, 6(3). https://doi.org/10.22219/kinetik.v6i3.1329

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Abstract
In aquaculture, poor water quality affects fish growth and mortality. Water quality parameters such as ammonia, temperature, pH, and dissolved oxygen must be thus controlled and monitored. Measuring devices for dissolved oxygen and ammonia levels are vailable, but measurements cost is not suitable for small-scale aquaculture and are manually processed. This experimental study proposes the Emerson formula to navigate the estimated value of unionized ammonia and the Benson-Krause formula to navigate the estimated dissolved oxygen solubility value without using an ammonia sensor or dissolved oxygen sensor. Internet of things (IoT) is applicable for aquaculture to monitor and collect water parameter data without human intervention. The values of both estimates are validated by applying the Seneye Sensor. RMSE and MAE are implemented to calculate the performance evaluation between the Seneye value and the estimated value. Fuzzy logic clasify water quality is derived from the estimations of unionized ammonia and estimates of dissolved oxygen as input.

1. Introduction

The term Internet of Things (IoT) has gained attention from academia, industry, and governments in recent years. IoT aims to connect people and physical objects, communicate and to improve the quality of life [1]. IoT has been implemented in smart homes, smart buildings, smart agriculture, smart E-health, military IoT, and aquaculture. Research [2] has been conducted for automated process control and supervision to reduce human interaction in monitoring and controlling [3] aquaponic systems. Aquaponic combines aquaculture and hydroponics (growing plants without soil), which do not require soil for plants of certain types. Plant energy resources are obtained from excess nutrients from the fish feed. This method is able to minimize water resources, providing an alternative for fish farming in limited areas. In the implementation of aquaculture, balance and supervision are required in maintaining water quality [4], which affects the growth of fish and plants. Seven parameters must be considered, including: temperature, pH, salinity, phosphate, nitrate, ammonia, and Dissolved Oxygen.

Research [5] describesif the water contains too many toxins, it will probably cause fish death in the aquaculture system, further according to research [6],dissolved oxygen affects the physical size of fish. Several studies have been conducted to analyze the best time to obtain water samples in aquaculture systems, [7] illustrated in Table 1.

Rozie's research [8] created an aquaculture system to control the two critical parameters of temperature and ammonia employing fuzzy logic as a decision-making control method for AC motor water pump speed. Meanwhile, the author cites numerous related works on aquaculture systems. The novelty in Rozie's research lies in the experiments on the calibration of the Ammonia Sensor and the pH Sensor, conducted by employing the MQ-135 sensor to determine the value of ammonia in the fishpond through several water samples tests. The results were then compared with the ammonia test kit.

Most of the studies were however focused on simple aquaculture systems without involving artificial intelligence. Acknowledged in IoT 5.0 goal, the devices must be added with artificial intelligence to create computing decisions. This study hence involves the artificial intelligence through the computational process to meet the needs of IoT 5.0 in general with [9] . One of the methodologies that include artificial intelligence is fuzzy logic. In addition, the main objective of this research is to design a water quality clasiffication in aquaculture to minimize human intervention [3], subtituting the conventional water quality monitoring systems through collecting water parameters. However, another problem for small-scale aquaculture entrepreneurs lies in the high cost of measuring ammonia and dissolved oxygen in the market [10]. Seneye is a product which monitors water quality parameters at a low price and is suitable for small scales aquaculture, despite requiring an additional monthly fee to activate the free ammonia and dissolved oxygen calculation features.

This study particularly estimated the dissolved oxygen solubility value by employing the Benson-Krause model formula [11], including thethree parameters of: dissolved oxygen, salinity, and temperature. At the same time, the Emerson formula [12] is utilized to navigate the value of Unionized Ammonia, which requires the three parameters of: temperature, pH, and Total Ammonia Nitrogen. The approach is conducted without using ammonia and dissolved oxygen sensor.

2. Research Method

2.1 Water Quality

Water quality becomes a critical factor in aquaculture, affecting the quality of the aquatic product itself; and water quality must be maintained to obtain optimal results for fish and plants.. Several parameters, such as pH, temperature, dissolved oxygen, and ammonia must be maintained to remain stable [13]. The following are some limitations depicted in Table 1 as adopted in the research.

Table 1. Water Quality Parameters and Sample Measurement

Parameter	Optimal threshold	
pH	7	Measurement done 1 time a day Morning Before Feeding
Temperature	25 – 27 Celcius	
Disolved Oxygen	>5ppm	
Electro-conductivity	524	
Total Ammonia Nitrogen	1<ppm	Water filter cleaning Three times a week
Nitritee (NO2-N) dan Nitrate (NO3-N)	1<ppm and <5-150ppm	
Alkalinity	100ppm	2 times per week
Phosphate	10 – 20	
Sulphate	5	

Based on the research [14], the optimal water quality performance based on Figure 1 utilize parameters and ph, temperature, oxygen solubility, and total ammonia nitrogen to classify the water quality parameters in the experiment. The residue from the fish feed is further mixed with another acid by releasing nitrogen to make ammonia. Ammonia is turned into nitrite nitrated by bacteria. For plants such as vegetables and fruit, ammonia and nitrites are harmless chemicals for plants, but for fish, they are toxic [15].

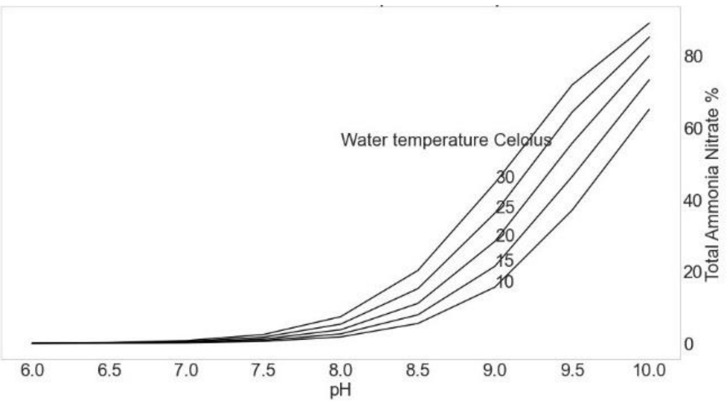

Figure 1. The Influence of Water Temperature and pH on the Percentage of Unionized Ammonia [16]

The two parameters, including temperature and pH are employed to obtain the value of free ammonia, [1]. High level of water's pH is high increases the total ammonia nitrogen in the water, less-preferrable for the fish, and vice versa. The following Equation 1 is presented to measure the fraction of unionized ammonia as follows:

$$fractionUnionizedAmmonia = \frac{1}{10^{(pKa-pH)}+1}$$
$$pKa = 0.0901821 + \left(\frac{2729.82}{T}\right) \quad (1)$$
$$T = Temperature + 273.15$$

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Lee [17] proposed a cloud-based IoT monitoring system for fish metabolism and activity in mini-type aquaculture by employing EBB as irrigation. In addition, this research utilized water-test kits to compare the standard water analysis methods (such as by Seneye slide kit, Tetra EasyStrips, API test strips, Seachem Ammonia Alert, Salifert Profi test kit, and Hach dissolved oxygen (DO) and alkalinity kit) [18]. Furthermore, in his study, the formula from the Benson-Krause [11] was applied to estimate the dissolved oxygen levels with an atmospheric pressure of 1 atm and salinity of 0. The oxygen solubility is implemented into this research without a dissolved oxygen sensor. The actual amount of oxygen solubility (in mg/L) varieddepending on temperature, pressure and salinity [11]. Figure 2 illustrates the decreasing oxygen solubility concentrations along with the increasing temperature indicating that warmer surface water requires less oxygen solubility to reach 100% of air saturation than does the deeper and cooler water.

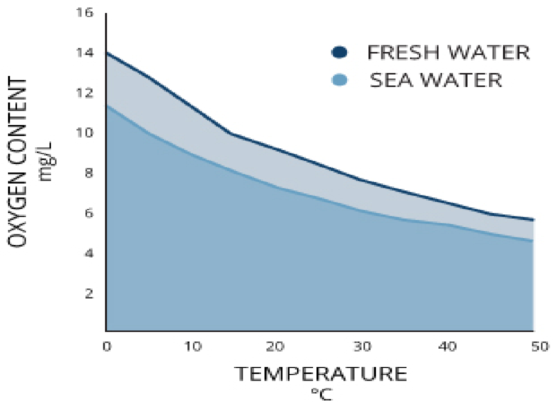

Figure 2. Oxygen Solubility Concertation [19]

To compute oxygen solubility and percent saturation on aquaculture, the Benson and Krause equations were applied in Equation 2, indicating oxygen solubility in mg/L, and the baseline DO concentration at zero salinity and one atmosphere is as follows:

$$DO = exp\left[-139.34411 + \frac{1.575701 \times 10^{5}}{T} + \frac{6.642308 \times 10^{6}}{T^{2}} + \frac{1.243800 \times 10^{10}}{T^{3}} - \frac{8.621949 \times 10^{11}}{T^{4}} \right] \quad (2)$$

In addition to calculating the oxygen solubility concentration, the Benson and Krause equations also applied to calculate salinity and barometric pressure. The following equations are presented to calculate salinity Equation 3 and barometric pressure Equation 4.

$$F_s = exp\left[-S \times \left(0.017674 - \frac{10.754}{T} + \frac{2140.7}{T^{2}}\right)\right] \quad (3)$$

$$\theta_0 = 0.000975 - 1.426 \times 10^{-5} t + 6.436 \times 10^{-8} t^{2} \quad (4)$$

2.2 Internet of Things

As summarized from research [20] regarding fish farming, the purpose of designing and implementing this IoT architecture is to facilitate the remote monitoring of dissolved oxygen, pH, and water quality temperature. In aquaculture, changes in water parameters are less-predictable if dramatic changes occur due to environmental factors. When manually monitored, water quality changes require longer time, cost, and talented resources.

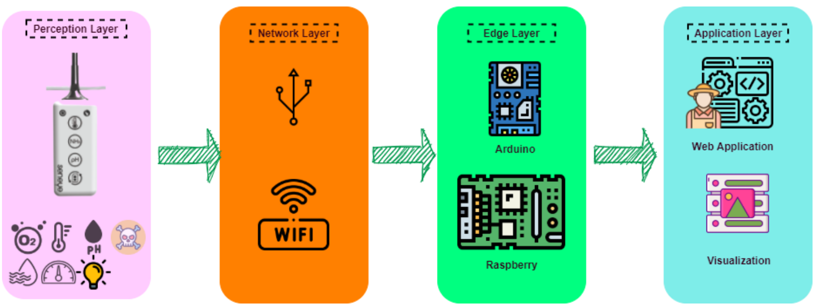

Figure 3. Four Layer IoT Architecture

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As illustrated in Figure 3, the four-layer Internet of Things architecture [21] is used in this research described as follows. The Preception Layer becomes the first layer of the four previously described criteria to provide data or values from water quality sensors placed in aquaculture. The network layer refers to the network layer connecting and transmitting the values obtained from sensors, through the USB, BLE network, Wifi, Zigbee. Edge Layer also refers as middleware, collecting data from sensors, further processed into a value by the embedded systems such as Arduino or Raspberry. The application layer provides the data for the end-user.

2.3 Model Development

The overall methodology of this study is illustrated in Figure 4 divided into the four stages and explained in the following sub-paragraph:

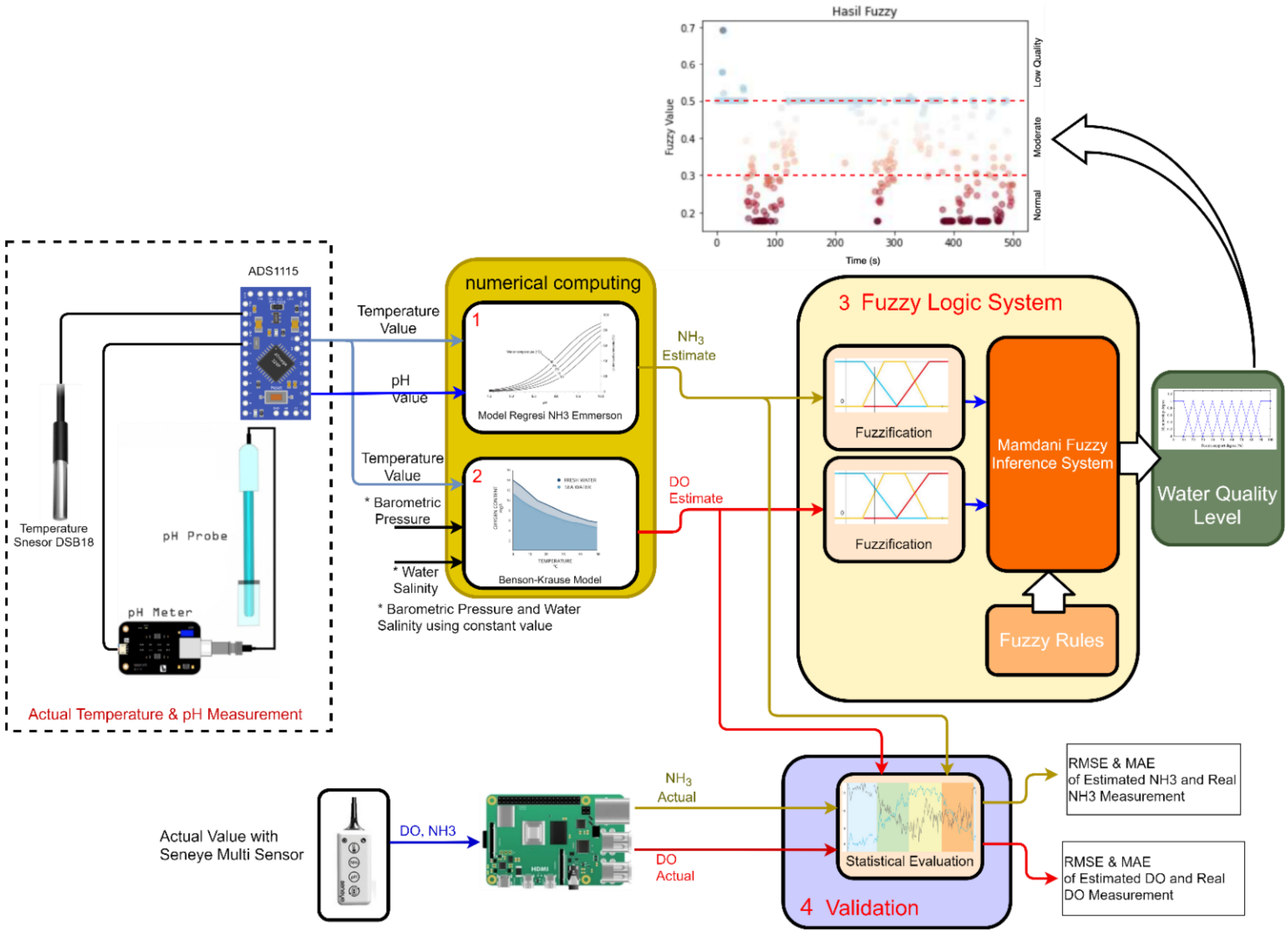

Figure 4. Proposed Computation Model

The seneye sensor has the feature of calculating the value of free ammonia and dissolved oxygen, but there is a monthly fee to activate the feature. This study however only utilized a temperature sensor and a pH sensor, assisted by the formulas Equation 1 and Equation 2. The seneye sensor was applied to validate the estimated value d.

As described in Figure 4, the actual temperature value is obtained by using the DS18B20 sensor. Meanwhile, the actual pH value is obtained by using the ph-4502c module connected to Raspberry via the ADS1115 module to provide a digital output value. A linear equation is applied to discover the estimation of unionized ammonia. PH and temperature are employed to discover correlations on water quality. Temperature and pH are employed as the independent variables that are easier to measure than oxygen solubility and TAN as a dependent. The regression model refers to a statistical technique that uses the relationship between two or more variables to discover a fit line in order to predict one variable or estimated based on other variables. Based on section 1, pH and temperature are considered as two independent variables to predict unionized ammonia by using Equation 1. To find the estimated value of dissolved oxygen, Equation 2 is applied. The depth of the fishpond in the aquaculture system is not more than one cubic meter. The oxygen value

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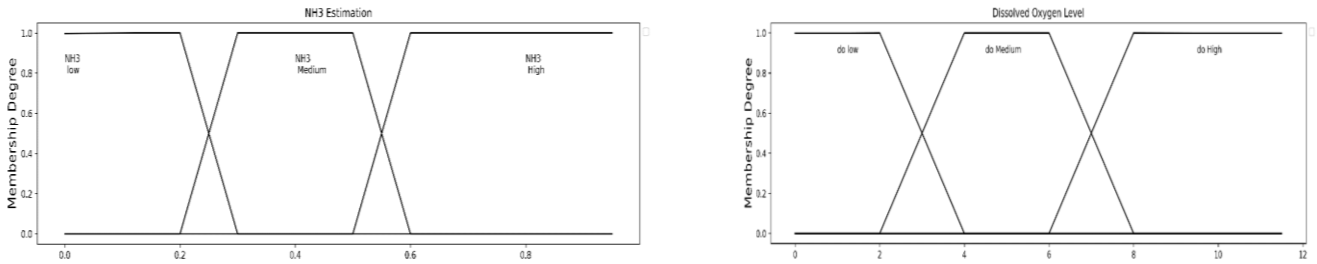
that the water absorbs is still 100%. In a study conducted by Benson Krause, it was stated that the value of the oxygen content is less if the water is more profound than the water on the upper surface, absorbing oxygen by 100%.

Furthermore, upon obtainingthe estimated value of unionized ammonia and oxygen solubility, the value will be validated with the value obtained from the Seneye sensor, further processed with fuzzy logic to classify water quality.

In general, the difference between fuzzy logic and digital logic (Yes / No or ON / OFF or High / Low and others) lies in its adaptability to human thinking by using the concept of continuous values from zero to one (0,0.1,0,2 ... 1) [22]. The fuzzy logic computational process requires the two inputs, including: the estimated value of NH3 and the estimated value of dissolved oxygen. In this research, the Mamdani [23] inference type and the membership function in a trapezoid are employed. The membership function for unionized ammonia is written as NH3Low from 0.0 to 0.2, the membership function for NH3Med is from 0.2 to 0.6 while for NH3High is from >= 0.5, illustrated in Figure 5(a).



(a) (b)

Figure 5. (a) NH3 Membership (b) Oxygen solubility Membership

Meanwhile, the DOLow membership function starts from 0 - 4, DOMed starts from 2 - 8 and DOHigh starting from >= 8 is illustrated in Figure 5(b). Meanwhile, the water quality decisions are depicted in Figure 6. The decisions, obtained from processing the unionized ammonia value with the oxygen solubility value, consist of WQSafe with values ranging from 0.0 to 0.3, WQModerate with values ranging from 0.3 to 0.6, and finally WQToxic with values ranging from 0.5 >= 1.

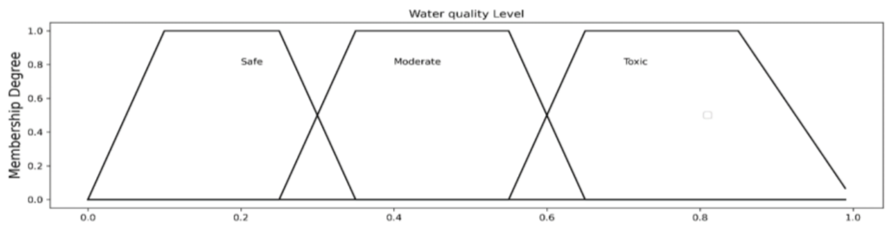


Figure 6. Water Quality Membership

The inference system process applies the rules as illustrated in Table 2. The processing results from the system are in the form of decision information that determines the water quality levels.

Table 2. Fuzzy Rules

Rule Number	NH3 Level	Oxygen solubility Level	Water Quality Level
1	Low	Low	Moderate
2	Low	Medium	Moderate
3	Low	High	Safe
4	Medium	Low	Moderate
5	Medium	Medium	Moderate
6	Medium	High	Safe
7	High	Low	Moderate
8	High	Medium	Toxic
9	High	High	Toxic

3. Results and Discussion

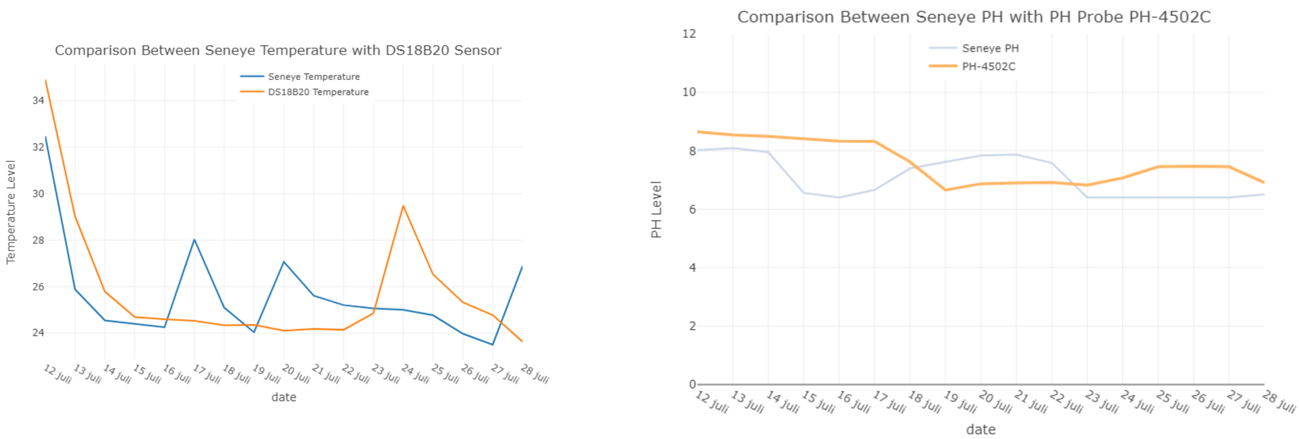
3.1 Sensor Measurement Results

These experimental studies employed analytical-grade and food-grade chemicals. Chemicals used to lower the pH ranged from 5.5 to 6.5 in water using the chemical of H3PO4 [24],, to increase the pH using Potassium Hydroxide

KOH [25] and to increase the value of ammonia in water using the chemical of NH4OH. Figure 7(a) indicates that the lowest temperature is around 24 Celsius and the highest temperature is 34 Celsius, and the average temperature is 25 Celsius. On July 12th, an experiment was conducted by changing the water as much as 95% of the total ± 100-liter water in the container by using hot water gradually until achieving the highest water temperature of 30 Celsius.

As additional information, this research was conducted before July 12th(July 8th). At that time, an experiment was also performed by adding hot water to the pool of water. Figure 7(a) presents the temperature comparison of the DS18B20 with the Seneye Sensor. It was recorded that the temperature value read by the DS18B20 sensor is worth 31 celcius, while the Seneye sensor is worth 27.5 celsius (July 12th). This result occured because the water heater was turning on to monitor the data change. From July 12th in the evening to July 13th in the morning, the water heater was turned off, illustrated in the picture indicating a decreasing temperature in the pool. On July 13th to July 15th there was an increase in temperature from 24.5 Celsius to 26.5 because NH4OH was gradually added approximately 2 x 5 ml into 100 liters of water; thereby chaning the water to be warm at that moment.

Figure 7(b) compares the pH value of the Seneye sensor with the PH-4502C sensor used in this study. The error between the two values is insignificant; indicating that the pH value obtained from the PH-4502C sensor is almost similar to that obtained from the Seneye sensor.

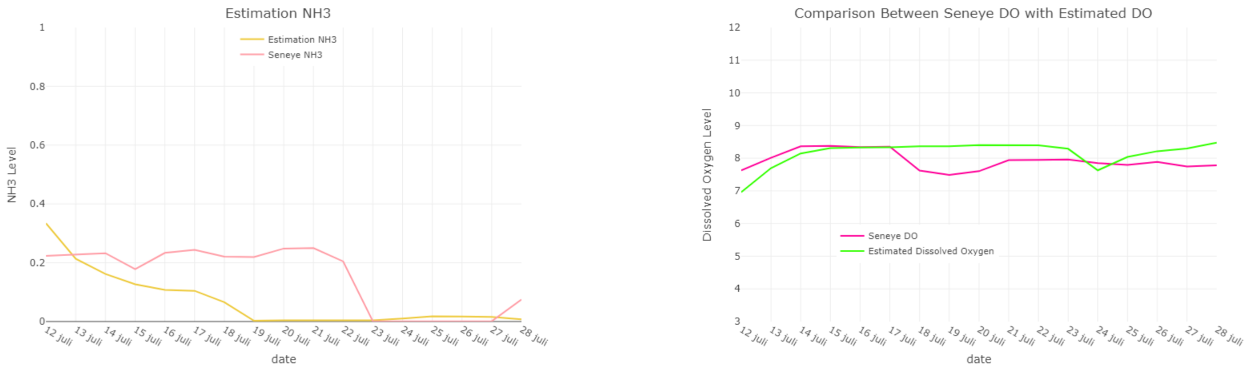


(a) (b)

Figure 7. (a) Temperature level and (b) Comparison ph value between Seneye with PH-4502c

3.2 Estimation of NH3 and Dissolved Oxygen

Furthermore Figure 8(a) presentsthe results of the estimated value of NH3 estimation using Equation 1 from the Emerson. The lowest value starts from 0.0, and the maximum value reaches to 1.0(July 12th) when NH4OH was added to reach 0.35 mg/L of amonia level. On the next day,(July 13th) the ammonia level decreased after changing the water of 95% from the total 100 litre water. In another day, until the data is stored on database, the ammonia is in the lowest points because temperature and ph are in optimal value.



(a) (b)

Figure 8. (a) NH3 Estimation and (b) Oxygen solubility Estimation

Thus, the increasing pH value of the water increases the estimated value of NH3. Figure 8(b) presents the information on the estimated oxygen solubility value, indicating a decreasing graph on 12th July due to the addition of hot water. On 16 July at 3:00 pm, the estimated oxygen solubility value decreased because the water heater was turned

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on for approximately 4 hours. The estimated value of oxygen solubility gradually increased after the temperature in normal water was around 24-25 Celsius after the water heater was turned off.

3.3 Water Quality Classification based on Fuzzy Logic

The estimated value of NH3 and the of Dissolved Oxygen solubility obtained from the numerical computations described in section 2 are then processed by using fuzzy logic as two input values determining whether the water quality is safe, moderate, or toxic. As illustrated in Figure 9 on July 12th, the estimated value of unionized ammonia was around 0.3341, and the estimated value of oxygen solubility was around 6.9606. These two values were utilized as input values to classify water quality by using fuzzy logic. The obtained results ranged from 0.78, including the category of toxic water on July 12th.

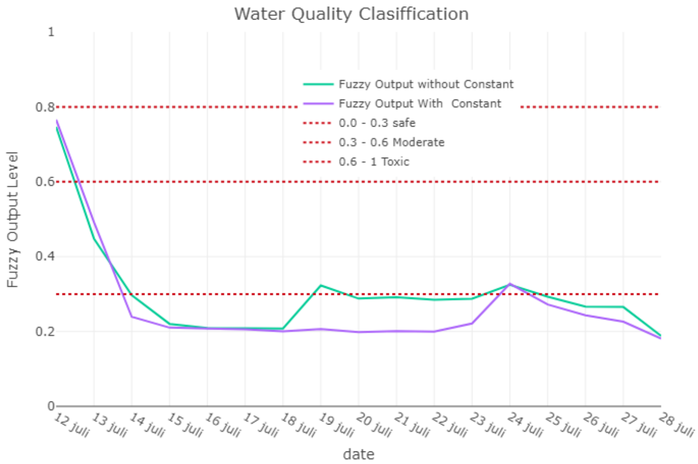

Figure 9. Water Quality Level

3.4 Validation

This research started on July 12th, 05:44 AM, and finalized on July 28th, 02:14 pm. Data collection was conducted every 12 minutes, reaching 120 samples in one day and 1920 data samples until 16 days, further averaged daily. The root means square error (RMSE) and mean absolute error (MAE) formulas are used as described in section 2 to compare the actual value of oxygen solubility obtained by Seneye with ph-4502c,.

Table 3. Comparison Oxygen Solubility Between Seneye with Estimation Dissolved Oxygen

Date	Seneye Oxygen solubility	Estimate Dissolved Oxygen
12-Jul-21	7.625	6.960683333
13-Jul-21	8.010416667	7.694472917
14-Jul-21	8.363829787	8.145689362
15-Jul-21	8.377083333	8.3112125
16-Jul-21	8.342553191	8.32543617
17-Jul-21	8.35	8.335822917
18-Jul-21	7.620833333	8.365116667
19-Jul-21	7.4875	8.362485417
20-Jul-21	7.602083333	8.401933333
21-Jul-21	7.941666667	8.389710417
22-Jul-21	7.947916667	8.39583125
23-Jul-21	7.960416667	8.289147917
24-Jul-21	7.852083333	7.62890625
25-Jul-21	7.791666667	8.0384125
26-Jul-21	7.883333333	8.214058333
27-Jul-21	7.744680851	8.297921277
28-Jul-21	7.782857143	8.476534286
RMSE		0.489275627
MAE		0.410996447

Table 3 explains that the accuracy of the estimated results (prediction) of oxygen solubility with the actual value of oxygen solubility obtained from Seneye indicates that a significant error is inevitable if the constant is not added. To avoid mistakes, the addition of constants is highly recommended to minimize a high error. The addition of the constant value could offset the actual yield of dissolved oxygenconducted by finding the best value one by one with a more negligible difference than the actual value of oxygen solubility from the Seneye sensor.

Another comparison as presented in Table 4 indicates the actual value of NH3 obtained from seneye compared to the estimated value obtained from the Emerson formula (NH3 estimate). The addition of the constant value is highly recommended to minimize the high error between the actual value of oxygen solubility (Seneye NH3) with the estimated value of oxygen solubility (Emerson Formula).

Table 4. Comparison Seneye NH3 with Estimation NH3 with and Without Constant = a(b+(EstimationNH3-c))*

Date	Seneye NH3	Estimation NH3	Estimation NH3 with Constant =a*(b+(EstimationNH3-c))
12-Jul-21	0.223166667	0.334191667	0.282981171
13-Jul-21	0.2271875	0.213329167	0.222280233
14-Jul-21	0.232510638	0.161761702	0.196381435
15-Jul-21	0.178229167	0.126802083	0.178823618
16-Jul-21	0.233574468	0.1078	0.169280176
17-Jul-21	0.24375	0.104504167	0.167624905
18-Jul-21	0.22075	0.065829167	0.148201107
19-Jul-21	0.219645833	0.002589583	0.116440205
20-Jul-21	0.248229167	0.00401875	0.117157977
21-Jul-21	0.2496875	0.004366667	0.117332712
22-Jul-21	0.204520833	0.004477083	0.117388167
23-Jul-21	0.001	0.003927083	0.117111939
24-Jul-21	0.001	0.009954167	0.12013893
25-Jul-21	0.001	0.017989583	0.124174568
26-Jul-21	0.001	0.0172375	0.123796848
27-Jul-21	0.001	0.015897872	0.123124045
28-Jul-21	0.074942857	0.0076	0.118956593
RMSE		0.130997947	0.09324831
MAE		0.100057694	0.083266944

3.5 Summary Findings

From the obtained analysis in the study, the results of the study classify water quality into three parts of safe, moderate, and toxic. Water quality classification is obtained from the two inputs: the estimation of NH3 using the Emerson formula and the estimation of oxygen solubility by applying the Benson-Krause formula, processed by applying fuzzy logic. In this finding, Seneye classifies water as non-toxic by using the word “free ammonia”, similar to unionized ammonia in the language of aquatic science. Comparison of the actual and the estimated value of NH3 with and without using constants results in a huge error; meanwhile, if the estimated value of NH3 obtained from the experiment is added to the value of the constant a*(b+(estimationNH3-c), where a = 0.9996942 b = 1.2017176 and c = 1.199157, then the error gap is not too high. Since this study does not use an ammonia sensor, adding the constant value becomes a priority to achieve an estimated value of NH3 similar to the value of the NH3 result from Seneye. The experimental results obtained in the analysis confirm that the water quality that does not use the constant is in the moderate water quality position, indicating that the water quality is not suitable for fish. Meanwhile the constant in the Emerson formula indicates that the position of water quality is at a safe point. The finding of this study concluded that the addition of constants in the Emerson formula is advisable to reduce water quality which was previously in a moderate position to a safe position.

4. Conclusions

In this study, an experiment was conducted to discover the classification of water quality based on the Emerson formula to obtain the estimated value of NH3 and the Benson-Krause formula to obtain the estimated oxygen solubility value. The estimated value of NH3 and the estimated oxygen solubility is validated by applying the marketed Seneye multi-sensors to measure the accuracy between the actual and predicted values by using the RMSE and MAE and to evaluate performances. Furthermore, the two results from the formula are utilized as two inputs by using fuzzy logic, including: safe, moderate, and toxic water. The two findings emerged as the experimental results of this research, confirming the water quality without the addition of constants and the water quality with the addition of constants (in estimating the value of NH3 and dissolved oxygen). From these findings, the addition of constants could transform the

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initially moderate water quality to a safe position. This experiment further indicates significant benefits for small-scale freshwater fish farming or aquaculture in order to seek water quality classification. In sum, that the results of this study are expected to provide beneficial information for researchers, professionals, aquacultures in the field of IoT and fisheries technology.

Acknowledgments
This research is funded by Hibah Internal Penelitian Dasar dan Terapan Universitas Telkom 2021.

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