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Application of fuzzy logic in decision-making process for relocation of floating net cages in river fish farming

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ABSTRACT

BACKGROUND AND OBJECTIVES: Land-based aquaculture operations, at present, are intensively conducted to meet the ever-growing demand for food consumption. Floating net cages are one of the traditional methods commonly used by Indonesian fishermen for river fish farming. Increased human activities along the Musi River and coastline have resulted in pollution and waste in the river waters and fluctuating water quality. Yet, floating net cage owners still manually assess the water quality. This study aims to develop an early warning system for water quality and create a decision-making program as a reference for fishermen to relocate floating net cages when the river water quality deteriorates.

METHODS: The device was tested at 39 locations within a radius of approximately 3400 meters, and the distance between locations varied between 55 and 334 meters. The river was divided into three sections: the river coast, the middle section, and the other river coast. Water quality sensors were placed at a depth of 0–20 centimeters from the surface of the Musi River, with measurement durations at each location ranging from 1 to 40 minutes. Direct measurements of the Musi River's water quality were obtained by monitoring the water quality using an internet-based computer application. A decision-making Python program utilizing fuzzy logic was then executed to evaluate the suitability of the river water quality for fish cultivation. The program's input variables comprise water temperature, potential of hydrogen, and dissolved oxygen sensor data. Meanwhile, the program output recommends floating net cage owners to either "Stay in position" or "Move." Water quality warnings that exceed the upper and lower threshold limits are displayed using light-emitting diode indicators and a buzzer.

FINDINGS: Overall, the water quality values of the Musi River at the test locations generally indicated stable and suitable conditions for river fish cultivation. The average water quality values were 29.20 degrees Celsius for temperature, 3.98 milligrams per liter for dissolved oxygen, and a potential of hydrogen of 6.42. From all the data obtained during the decision-making program, 36 locations suggested that the floating net cages should "Stay in position." Meanwhile, the three remaining locations were recommended to "Move" as they exhibited poor water quality, with potential of hydrogen values below 6. Field observations indicated that these locations were situated near residential areas, factories/industries, and tributaries, which are highly susceptible to waste and pollution. The output of the decision-making program correlated with the issued warnings by the water quality warning indicators when the pH value exceeded the lower threshold limit.

CONCLUSION: The fuzzy logic method implemented in the Python program for decision-making regarding the relocation of floating net cages in river fish farming revealed the fluctuating water quality conditions of the Musi River within a specific time duration. These conditions correlated with the proximity of the water bodies to pollution sources such as residential areas, factories, and tributaries. The program's output classified the status of the floating net cages into two conditions: "Stay in position" or "Move." The decision-making application to relocate floating net cages for fish farming in rivers provides a solution for fishermen as the resulting program decisions give the same indication as the reading value of the water quality sensor.

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NUMBER OF REFERENCES	NUMBER OF FIGURES	NUMBER OF TABLES
38	9	4

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INTRODUCTION

As production from capture fisheries continues to decline, intensive fish farming has increased to meet the greater population's ever-growing demand for fisheries products (Sabilillah *et al.,* 2023; Takarina *et al.,* 2023). Aquaculture is a rapidly growing food production sector that involves the cultivation of plants or aquatic animals (Acar *et al.,* 2019). Of the total aquaculture production, 62.5 percent (%) comes from inland aquaculture (FAO, 2020). In Indonesia, rivers are a vital source of life and civilization and serve as focal points for community activities. Rivers are open water bodies that fishermen extensively utilize for cultivation purposes (Torres-Bejarano *et al.,* 2022). Various freshwater fish species are cultivated to meet the increasing demand for fish protein, mainly driven by population growth (Oyinlola, 2019; Maulana *et al.,* 2023). One commonly used method in fish farming is the floating net cage (FNC) method. FNCs are typically placed along the riverbanks, away from crowded areas. With this method, water availability, which is the main component for cultivation, is no longer a concern. However, water quality needs to be managed and given attention (Abinaya *et al.*, 2019), as the increasing human activities in modern times have led to alarming river pollution levels in Indonesia. Water quality in river ecosystems fluctuates and undergoes daily changes that are influenced by various factors. Changes in river water quality can occur due to the surrounding ecosystem, tidal cycles, temperature variations, and weather conditions. External factors such as community waste, industrial waste, agricultural runoff, vessel traffic, excessive utilization of water bodies, and other human activities that utilize the river flow can also contribute to changes in river water quality (Sulistyowati *et al.,* 2023; Ehzari *et al.,* 2022). These external factors pose risks to the survival of living organisms in and around the river. The development and survival of cultured fish depend on optimal water quality (Lekang, 2020). Pollution in one river body can spread to other river waters. Small river streams connected to larger river flows contribute to widespread water contamination. Harmful chemicals and disease-causing agents resulting from pollution can easily spread with the currents, affecting the health of fish in cultivation cages (Cardia and Lovatelli, 2016). Poor water quality also directly affects the growth and well-being of fish. Fish may experience stress, become susceptible to diseases, and even die. Mass fish mortality is generally caused by factors such as strong winds, lightning, heavy rainfall (Molato, 2022), and high pollution levels in the water bodies. Domestic and industrial wastes can also produce heavy metal pollutants in water, which are hazardous to health (Samimi and Shahriari Moghadam, 2021). Partially treated or untreated waste remains a major threat to the survival of river biodiversity (Maurya *et al.,* 2019). Industrial waste usually contains metal ions such as nickel, copper, cobalt, and timbal, each with a limit on the content levels allowed (Shourije *et al.,* 2023). For traditional fishermen in Indonesia, indicators of polluted river water are changes in the river color and an increased number of dead fish in cultivation ponds within a specific period. If the surface water changes color from its usual state or there is an unusual increase in dead fish in the FNCs, the fishermen will immediately relocate the cages to avoid greater losses. FNCs are relocated by pulling them using motorized boats to another location deemed to have better water quality than the previous one. The longer the delay in relocating the FNCs, the greater the losses incurred by the fishermen. However, there is no established measurement and assessment of water quality for river fish farming. It is advisable to regularly monitor the water quality parameters in the FNCs to ensure optimal growth and development of the fish (Boyd and Lichtkoppler, 1979; Jino Ramson *et al*., 2019). Water quality parameters need to be evaluated to ensure compliance with existing water quality standards. Thus, this research provides a solution for fishermen using FNCs in making decisions regarding the relocation of their cages when the river water quality deteriorates. This study developed a real-time water quality parameter-based assessment program using fuzzy logic as a reference for fish farmers in making decisions to relocate the FNCs, aiming to avoid greater losses due to river pollution. A Python program using fuzzy logic was employed, and real-time water quality monitoring was conducted using a personal computer with Internet of Things (IoT) technology equipped with an alarm system. The alarm system was incorporated as an early warning for the surrounding water conditions near the FNC to monitor water quality. Cage technology in aquaculture was carried out by (Kim *et al*., 2011; 2014), who developed and implemented a submersible fish cage system model that works automatically to anticipate extreme weather. The system comprised an air control system, four batteries, a backup air tank, four air pressure tanks, 12 variable ballast tanks, and a water pump. The fish cage was made of steel with 12 sides and had a diameter of 5.92 meters (m) and a depth of 2.91 m. Meanwhile, (Thangavel *et al*., 2015) designed a fish cage with an electronic system that can be automatically submerged at the desired depth. The cages were made of high-density polyethylene (HDPE) pipes equipped with control stations, nets, variable ballast frames, submersible pumps, air control systems, buoys, mooring ropes, and anchors. A study on monitoring water quality in cages by (Sung *et al*., 2014) led to the design of a remote monitoring and control device based on IoT for fish farming. The device utilized Zigbee-based sensors for temperature, dissolved oxygen (DO), potential of hydrogen (pH), and solar panel power sources. (Chen *et al*., 2016) conducted research on water quality monitoring for aquaculture industries based on a wireless sensor network (WSN) using Zigbee and Wi-Fi. The sensors included temperature, DO, pH, and water level measurements. In addition, (Kyaw and Ng, 2017) developed a control and monitoring device for water quality, which operated automatically through a mobile application or web application, and included light-emitting diode (LED) indicators. (Vishwakarma *et al*., 2018) constructed an electronic instrument for monitoring pond water with IoT-based technology. Data was wirelessly transmitted to an offshore central server using IoT. (La Madrid *et al*., 2019) developed a water quality monitoring system for tilapia fish ponds using temperature, pH, DO, and water level sensors. Arduino was used for control, and the system was equipped with a SIM900 global system mobile (GSM) module for data transmission via short message service (SMS). (Shareef and Reddy, 2019) developed a remote water quality monitoring system with an early warning system for aquaculture using temperature, pH, DO, and air humidity sensors. In short, previous researchers have also applied fuzzy logic methods for water quality parameters, such as developing an index model for classifying water quality parameters in lakes (Icaga, 2007), temperature control (Oltean and Ivanciu, 2017), real-time water quality monitoring based on IoT (Bokingkito and Caparida, 2018), and constructing a water quality analysis model for tilapia fish farming (Molato, 2022). Thus, the aim of the current study is to develop an early warning system for water quality and create a decision-making program to guide fishermen in relocating floating net cages. This study was conducted in the Musi River, South Sumatra Province, Indonesia, in 2022.

MATERIALS AND METHODS

This research was divided into several stages, including device design, fuzzy logic membership function construction, and the development of a decision-making program for the relocation of FNC. Testing was conducted at 39 locations in the Musi River of South Sumatra. The water quality measurement method divided the river into three sections: riverbank areas (coded U1-U13), the middle section (coded M1-M13), and other riverbank areas (coded D1-D13). The sensor was placed at a depth of 0–20 cm from the river surface. Real-time sensor measurements were performed with the duration at each location ranging from 1 to 40 minutes. Each measured water quality parameter at the test locations was subsequently evaluated using the developed program to assess the water conditions around the FNCs. The results of the water quality assessment serve as a reference for fishermen to determine the status of the FNCs, whether to relocate or keep them in their original positions.

Device design

The device consists of three main components: the sensor unit, the processing unit, and the monitoring and alarm unit. The sensor unit consists of six water quality sensors: temperature, DO, pH, Total Dissolved Solid (TDS), Electric Conductivity (EC), and Turbidity. All sensors used were calibrated according to standard procedures and instructions. The designed device is illustrated in Fig. 1.

This device utilized an Arduino Mega as its processing unit, supported by an ESP8266 for IoT functionality. The alarm and monitoring unit consisted of LED indicators, a buzzer, a liquid crystal display (LCD), and a monitoring application accessed via the Internet. The alarm serves as an early warning for fishermen when the water quality around the fishing area deteriorates. It provides visual and auditory alerts when the water quality reading from the sensor unit exceeds the programmed lower and upper threshold values. The water quality conditions around the fishing area can be remotely monitored through the Blynk version 1.5.4 monitoring application

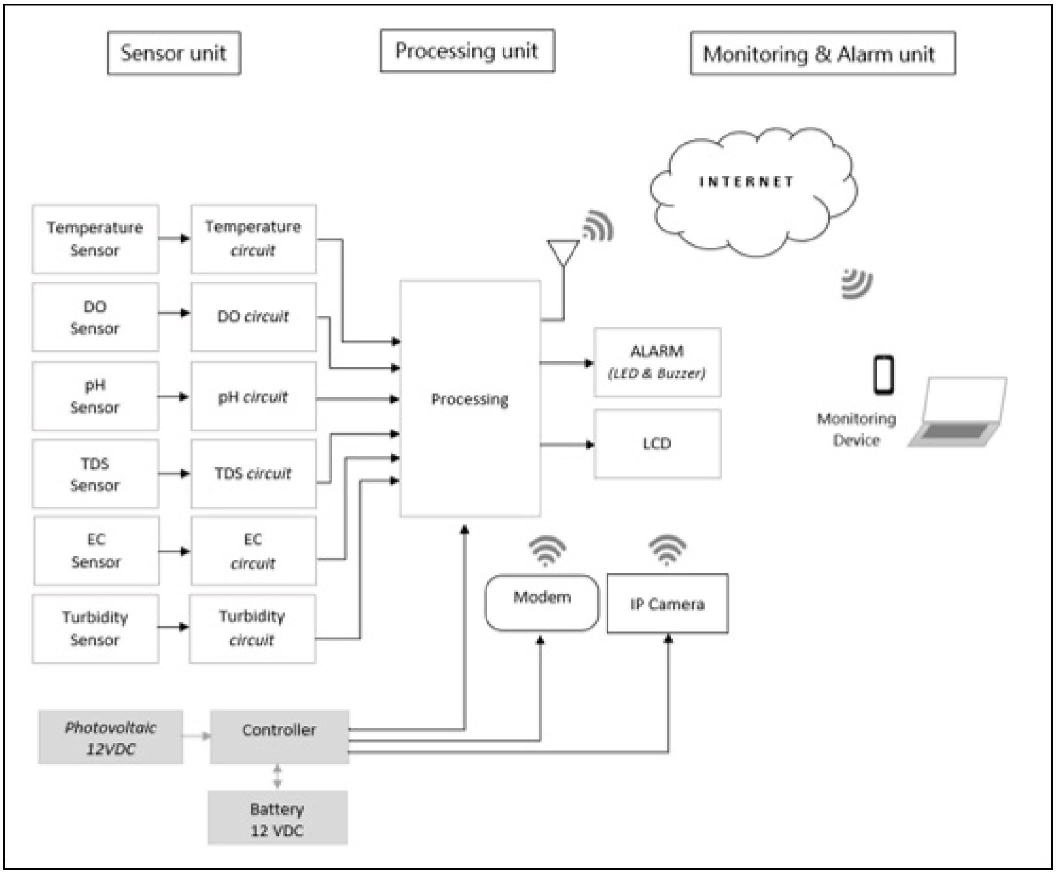


Fig. 1: Design system

using a smartphone or internet-connected personal computer (PC). This application displays real-time data from each sensor reading and can be displayed with average values and selectable time durations. Furthermore, there is an accessible database for administrators to retrieve the data.

The study area and testing location

The testing was conducted in the Musi River, South Sumatra, Indonesia. The testing location was around Karto Island, with coordinates ranging from -3.041384, 104.662513 to -3.020287, 104.640442, with a radius of approximately ±3400 m. The testing location included areas such as forests, settlements, plantations, fish ponds, ports, and community ship crossings.

Water quality alert system

Every fish has different water quality parameters according to its habitat and species. Fish living in river habitats have different water quality parameters than those living in marine environments. Suitable water quality for a fish's habitat affects its health, reproduction, and overall survival, which is essential for its growth. In the management of fisheries cultivation, water quality needs to be controlled continuously (Danh *et al*., 2020). Many factors affect water quality (Wei *et al*., 2023), such as temperature, pH, and DO, which are the primary parameters that can influence other water quality parameters or serve as indicators for them. These three parameters have also been identified as the causes of mass fish mortality (Molato, 2022). Temperature affects fish metabolism, and the surrounding environmental temperature determines the fish's body temperature (Volkoff and Rønnestad, 2020). Low levels of DO also affect fish growth and survival and may result in fish

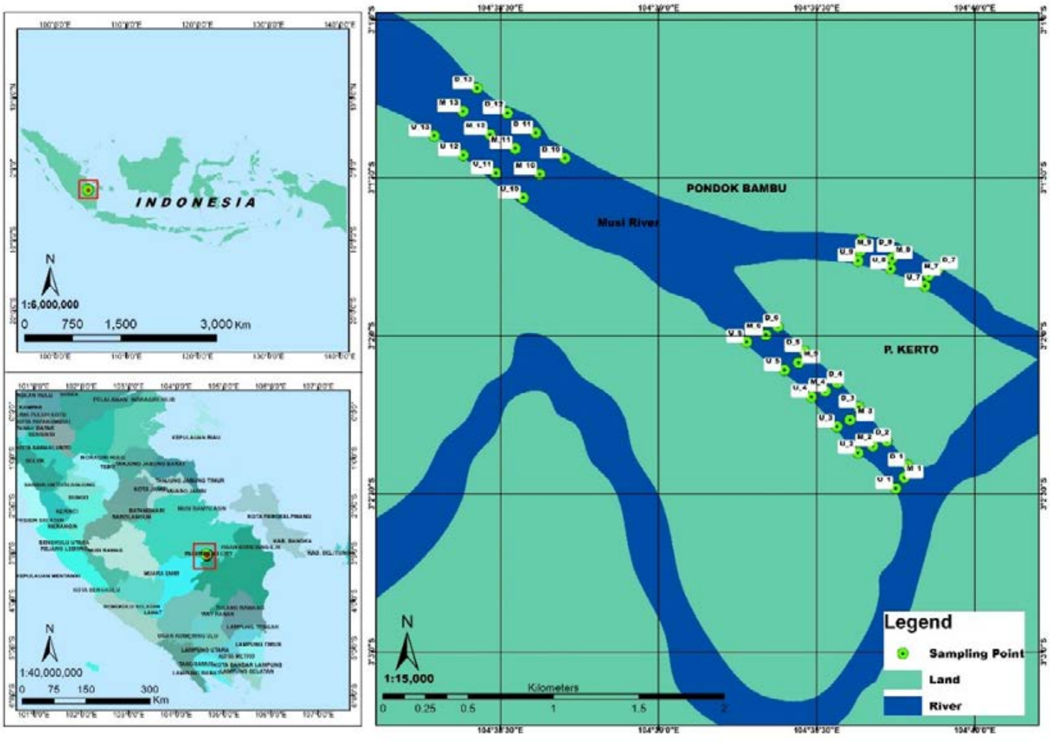


Fig. 2: Geographic location of the study area and the test location in the Musi River, South Sumatra, Indonesia

Table 1: Standard parameters for water quality in river fish cultivation (Pemerintah Republik Indonesia, 2021)

Parameter	Unit	Lower threshold value	Upper threshold value
Temperature	Degrees Celsius (°C)	27 °C	32 °C
DO	mg/L	3	>3
pH		6	9
TDS	mg/L	1.000	1.000

stress, reduced appetite, susceptibility to diseases, and death. The DO levels vary among different fish species. If the DO levels drop below 3 milligrams per liter (mg/L) within three hours, fish movement becomes sluggish, eventually leading to death if the DO falls below 1.9 mg/L (Prakoso and Chang, 2018). The pH level of water is naturally influenced by the type of rocks, soil, and contaminants discharged into the water, among other variables. Significant changes in the pH value can alter the diversity of freshwater organisms, and only a few species can survive (Abd El-Hack *et al*., 2022). Standard water quality parameters for fish cultivation in rivers have been formulated in government regulations (Pemerintah Republik Indonesia, 2021). Based on these regulatory standards, threshold values for the three main water quality parameters were established in this study, as shown in Table 1.

The upper and lower threshold values presented in Table 1 serve as references for the developed program and device. The alarm system provides early warnings for fishermen when the water quality exceeds the predetermined thresholds. The water quality alert system displays this information through a green LED indicator when the water quality surpasses the lower threshold and a red LED indicator when it exceeds the upper threshold. In addition to visual alerts, the system is equipped with a buzzer for

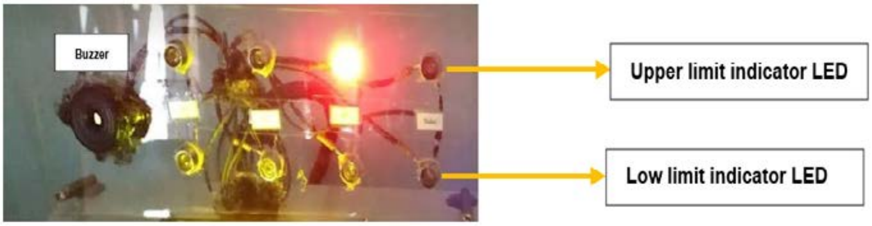


Fig. 3: LED and Buzzer water quality warning indicator

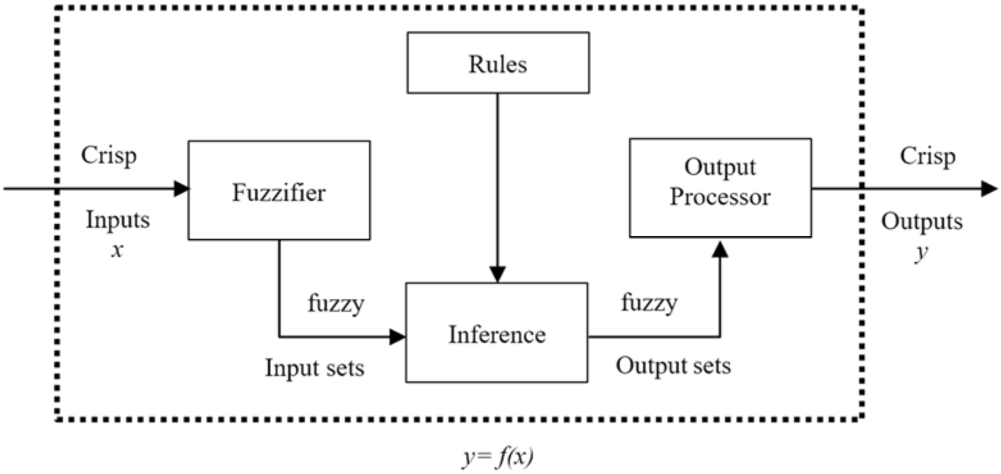


Fig. 4: Fuzzy logic system (Mendel, 2003)

audible warnings. This water quality alert system also aims to facilitate fishermen in accurately monitoring real-time water conditions around the FNC cultivation site.

Decision-making for the relocation of floating net cages based on fuzzy logic

Fuzzy logic is a type of logic that deals with uncertain or vague values that lie between true and false, ranging from 0 to 1. It resembles human thinking logic, which is different from classical logic, where everything is binary with two possible values: 0 or 1. The values of each input and output variable are determined by their membership functions (Mendel, 1995). Fuzzy logic consists of four interconnected components: fuzzifier, inference, rules, and output processing (Mendel, 2003), as illustrated in Fig. 4.

In this research, the fuzzy method was used as a decision-making tool for relocating the location of net cages, providing an alternative solution to the traditional method commonly used by fish farmers, who heavily rely on river water color and fish conditions in the ponds. The fuzzy method was implemented using the Python programming language. The fuzzy input variables consist of temperature, DO, and pH data. The standard water quality for fish cultivation in rivers has the following normal ranges: temperature ranges from 27 °C to 32 °C, pH ranges from 6 to 9, and the reference value for DO is greater than 3 mg/L. A DO value above 3 mg/L indicates a higher oxygen content level in the river, which benefits the water environment. Five membership functions were then created for each input variable based on these standard water quality parameters. Table 2 presents the developed parameter values for each input variable's membership function (MF).

Based on the temperature, pH, and DO parameters from the standard water quality for river fish

Table 2: Membership function

Inputs	Range	Name	MF Type	Parameter
Temperature	0-41	cold	gauss2mf	[2.782, 3.434, 17.7, 2.3]
		cool	gaussmf	[24, 1.7]
		normal	gaussmf	[28.5, 1.7]
		warm	gaussmf	[33, 1.7]
		hot	gauss2mf	[38.63, 2.278, 41, 0.034]
Dissolved Oxygen	0-10	very poor	gauss2mf	[0.007, 2.1, 0 0.28]
		poor	gaussmf	[2.8, 0.2]
		normal	gaussmf	[3.5, 0.2]
		good	gaussmf	[4.2, 0.2]
		very good	gauss2mf	[5, 0.28, 10, 0.007]
pH	0-14	very low	gauss2mf	[0, 0.0119, 4, 0.5535]
		low	gaussmf	[5.5, 0.5]
		normal	gaussmf	[7.5, 0.5]
		high	gaussmf	[9.5, 0.5]
		very high	gauss2mf	[11, 0.5535, 14, 0.0119]

cultivation and the constructed membership functions, a decision-making program was designed using the Python language.

```
import skfuzzy as fuzz
import numpy as np

# Temperature
temperatur = np.arange(0, 41, 1)
cold = fuzz.gauss2mf(temperatur, 2.782, 3.434, 17.7, 2.3)
cool = fuzz.gaussmf(temperatur, 24, 1.7)
normal = fuzz.gaussmf(temperatur, 28.5, 1.7)
warm = fuzz.gaussmf(temperatur, 33, 1.7)
hot = fuzz.gauss2mf(temperatur, 38.63, 2.278, 41, 0.034)

# Dissolved Oxygen
dissolved_oxygen = np.arange(0, 7, 0.1)
very_poor = fuzz.gauss2mf(dissolved_oxygen, 0, 0.007, 2.1, 0.28)
poor = fuzz.gaussmf(dissolved_oxygen, 2.8, 0.2)
normal_DO = fuzz.gaussmf(dissolved_oxygen, 3.5, 0.2)
good = fuzz.gaussmf(dissolved_oxygen, 4.2, 0.2)
very_good = fuzz.gauss2mf(dissolved_oxygen, 5, 0.28, 7, 0.007)

# pH
pH = np.arange(0, 14, 0.1)
very_low = fuzz.gauss2mf(pH, 0, 0.0119, 4, 0.5535)
low = fuzz.gaussmf(pH, 5.5, 0.5)
normal_pH = fuzz.gaussmf(pH, 7.5, 0.5)
high = fuzz.gaussmf(pH, 9.5, 0.5)
very_high = fuzz.gauss2mf(pH, 11, 0.5535, 14, 0.0119)
# Visualize the membership functions
import matplotlib.pyplot as plt

fig, (ax0, ax1, ax2) = plt.subplots(nrows=3, figsize=(8, 9))
ax0.plot(temperatur, cold, ‘b’, linewidth=1.5, label=’Cold’)
ax0.plot(temperatur, cool, ‘g’, linewidth=1.5, label=’Cool’)
ax0.plot(temperatur, normal, ‘r’, linewidth=1.5, label=’Normal’)
ax0.plot(temperatur, warm, ‘m’, linewidth=1.5, label=’Warm’)
ax0.plot(temperatur, hot, ‘y’, linewidth=1.5, label=’Hot’)
ax0.set_title(‘Temperature’)
ax0.legend()
ax1.plot(dissolved_oxygen, very_poor, ‘b’, linewidth=1.5, label=’Very Poor’)
ax1.plot(dissolved_oxygen, poor, ‘g’, linewidth=1.5, label=’Poor’)
ax1.plot(dissolved_oxygen, normal_DO, ‘r’, linewidth=1.5, label=’Normal’)
ax1.plot(dissolved_oxygen, good, ‘m’, linewidth=1.5, label=’Good’)
ax1.plot(dissolved_oxygen, very_good, ‘y’, linewidth=1.5, label=’Very Good’)
```

```
ax1.set_title('dissolved oxygen')
ax1.legend()
ax2.plot(pH, very_low, 'b', linewidth=1.5, label='Very
Poor')
ax2.plot(pH, low, 'g', linewidth=1.5, label='Poor')
ax2.plot(pH, normal_pH, 'r', linewidth=1.5,
label='Normal')
ax2.plot(pH, high, 'm', linewidth=1.5, label='Good')
ax2.plot(pH, very_high, 'y', linewidth=1.5, label='Very
Good')
ax2.set_title('pH')
ax2.legend()
def decision_making(temperature_value, dissolved_
oxygen_value, pH_value):
  if temperature_value >= 27 and temperature_value
<= 32 and dissolved_oxygen_value >= 3 and pH_value
>= 6 and pH_value <= 9:
    return "Stay_In_Position"
  else:
    return "Move"
# Get user inputs
temperature_value = float(input("Enter the
temperature: "))
dissolved_oxygen_value = float(input("Enter the
dissolved oxygen value: "))
pH_value = float(input("Enter the pH: "))

# Result
result = decision_making(temperature_value,
dissolved_oxygen_value, pH_value)
print("The Floating Net Cage should be: ", result)
```

In the running program, enter the values of the three input variables according to the water quality data read from the sensor. The result displays a decision regarding the status of the floating net cage as a fuzzy output variable for the floating net cage, consisting of two possible statuses: "Stay in position" or "Move."

RESULTS AND DISCUSSION

The field testing results indicate that the sensors are highly responsive to any changes in the river water parameters. The measurements from each sensor are displayed on the Blynk application, which can be accessed through an internet-based personal computer.

The average measurement results from all testing locations are as follows: the average temperature value is 29.50 °C, the average DO value is 3.98 mg/L, and the average pH value is 6.34.

The river water temperature during the testing ranged from 27.44 °C to 31.06 °C, which falls within the acceptable tolerance limits for river fish. The water temperature generally remained stable following the changes in the surrounding air temperature.

The measurements of DO values during testing ranged from 3.00 mg/L to 4.78 mg/L, which is above

Temperature 28.62 °C
DO (mg/L) 4
pH 6.79
Wind velocity 6.2 m/s
Voltage 14.87 V
Turbitdity (NTU) 2998.03
TDS 24.69 ppm
EC 7.65
Wind Direction 146 °

Fig. 5: Display of the water quality monitoring application

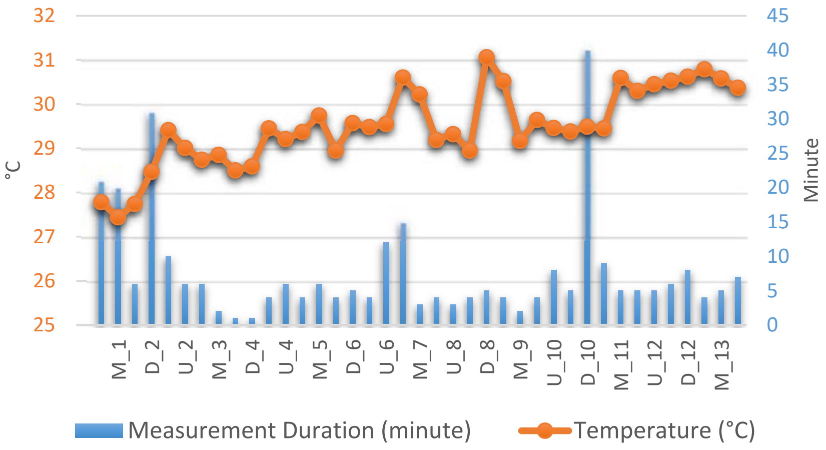


Fig. 6: River water temperature measurement results

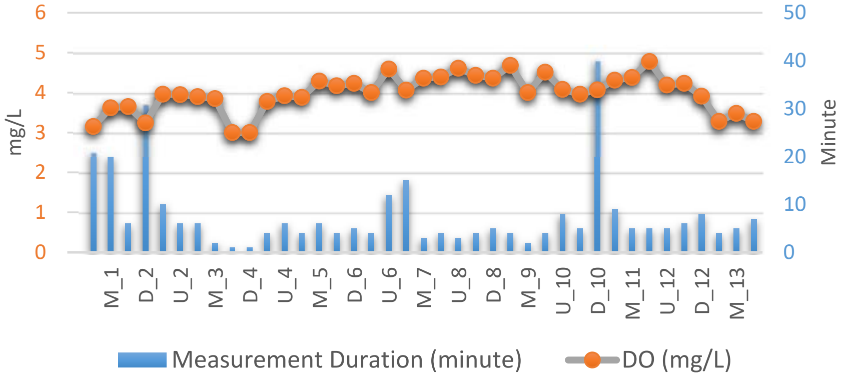


Fig. 7: River water DO measurement results

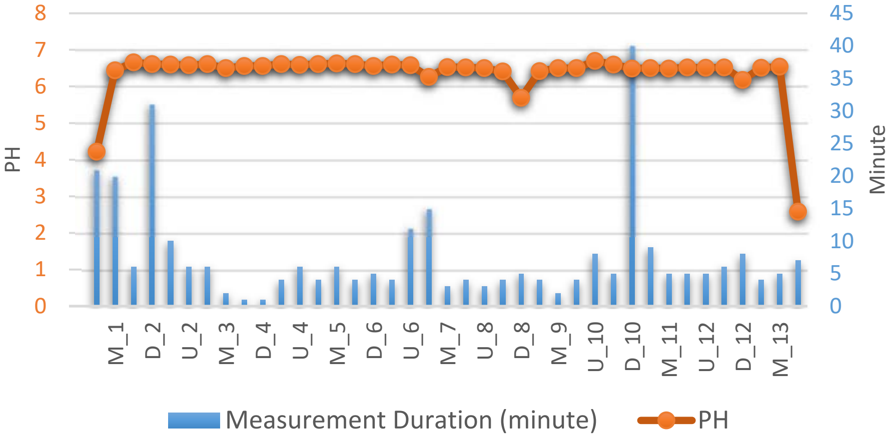
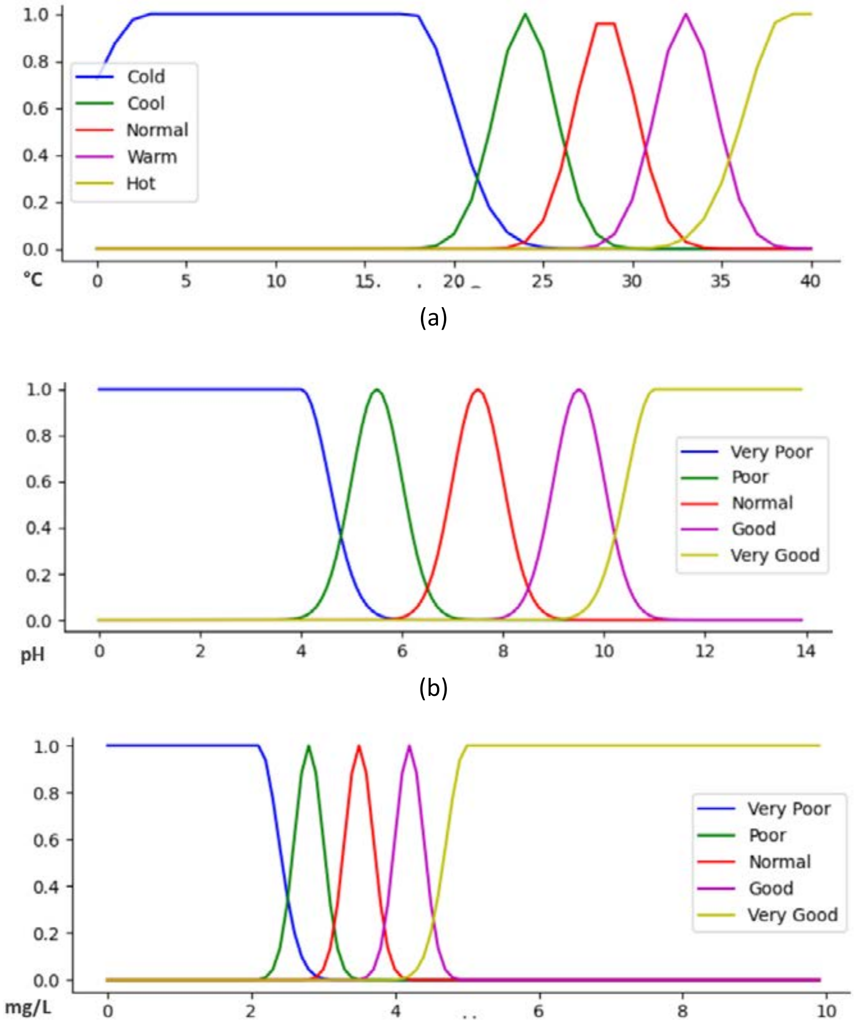


Fig. 8: River water pH measurement results

the standard threshold for river fish. Generally, the measured DO values remained stable with minimal fluctuations.

The pH measurements during testing ranged from 2.58 to 6.70, exceeding the lower threshold value of the standard range (6 to 9). There were fluctuations in the measured pH values, with certain locations experiencing a significant decrease in pH. The Python program generated a decision regarding the status of the floating net cage based on the input water parameter data from the sensor readings. The program considers the water parameter data provided and produces two possible status conditions: "Stay in position" or "Move." The status "Stay in position" is generated when all the measured input variable values in the net cage meet the predetermined standard water quality thresholds, which are a temperature range of approximately (27°C to 32°C), a pH range of (6 to 9), and a DO value above 3 mg/L. On the other hand, the status "Move" is generated when one or all of the measured output variable values in the net cage exceed the upper and lower threshold values of the predetermined standard water quality. The membership functions for the input variables temperature, pH, and DO are displayed in Fig. 9.

The measurement results of water quality and the



(a)

(b)

(c)

Fig. 9: (a) Temperature membership function. (b) pH membership function (c) DO membership function

Table 3: Measurement results of water quality and recommended status

Location Code	Coordinate	Measurement duration (minute)	Average Value			Recommended FNC Status
			Temp. (°C)	DO (mg/L)	PH	
U_1	-3.041384, 104.662513	21	27.78	3.15	4.22	Move
M_1	-3.040807, 104.662964	20	27.44	3.62	6.44	Stay in position
D_1	-3.040174, 104.663149	6	27.74	3.65	6.66	Stay in position
D_2	-3.038893, 104.662040	31	28.47	3.24	6.61	Stay in position
M_2	-3.039144, 104.661297	10	29.41	3.96	6.60	Stay in position
U_2	-3.039509, 104.660526	6	29.01	3.95	6.58	Stay in position
U_3	-3.038125, 104.659419	6	28.74	3.90	6.61	Stay in position
M_3	-3.037777, 104.660101	2	28.85	3.85	6.50	Stay in position
D_3	-3.037095, 104.660569	1	28.5	3	6.56	Stay in position
D_4	-3.035819, 104.659427	1	28.59	3	6.56	Stay in position
M_4	-3.036249, 104.658797	4	29.45	3.78	6.61	Stay in position
U_4	-3.036555, 104.658063	6	29.21	3.92	6.59	Stay in position
U_5	-3.035142, 104.656636	4	29.37	3.88	6.61	Stay in position
M_5	-3.034752, 104.657388	6	29.74	4.29	6.63	Stay in position
D_5	-3.034148, 104.657702	4	28.95	4.17	6.61	Stay in position
D_6	-3.032848, 104.656301	5	29.57	4.23	6.56	Stay in position
M_6	-3.033291, 104.655666	4	29.48	4	6.60	Stay in position
U_6	-3.033657, 104.654657	12	29.55	4.59	6.58	Stay in position
D_7	-3.029802, 104.664763	15	30.60	4.06	6.26	Stay in position
M_7	-3.030137, 104.664243	3	30.22	4.36	6.53	Stay in position
U_7	-3.030711, 104.664048	4	29.19	4.39	6.52	Stay in position
U_8	-3.029800, 104.662236	3	29.32	4.61	6.50	Stay in position
M_8	-3.029251, 104.662327	4	28.95	4.43	6.41	Stay in position
D_8	-3.028867, 104.662569	5	31.06	4.36	5.69	Move
D_9	-3.028293, 104.660743	4	30.52	4.68	6.42	Stay in position
M_9	-3.028876, 104.660646	2	29.17	4.00	6.50	Stay in position
U_9	-3.029385, 104.660524	4	29.64	4.51	6.50	Stay in position
U_10	-3.026066, 104.642879	8	29,46	4,08	6,70	Stay in position
M_10	-3.024817, 104.643743	5	29,38	3,96	6,60	Stay in position
D_10	-3.023976, 104.645068	40	29,49	4,07	6,49	Stay in position
D_11	-3.022644, 104.643542	9	29,45	4,31	6,50	Stay in position
M_11	-3.023461, 104.642456	5	30,59	4,38	6,49	Stay in position
U_11	-3.024758, 104.641437	5	30,30	4,78	6,52	Stay in position
U_12	-3.023818, 104.639707	5	30,45	4,19	6,51	Stay in position
M_12	-3.022717, 104.641116	6	30,53	4,23	6,52	Stay in position
D_12	-3.021601, 104.642045	8	30,62	3,91	6,18	Stay in position
D_13	-3.020287, 104.640442	4	30,79	3,28	6,51	Stay in position
M_13	-3.021507, 104.639701	5	30,58	3,48	6,54	Stay in position
U_13	-3.022801, 104.638177	7	30,37	3,28	2,58	Move

recommended status from each device's test location are displayed in Table 3.

The test results from all locations indicated that 36 locations possessed suitable water quality for fish cultivation. The sensor data input in the decision-making program suggested that the floating net cages should "Stay in position." However, three locations (U1, D8, U13) showed water quality unsuitable for river fish cultivation and were recommended to "Move" the floating net cages. From the three locations shown in Table 3, it can be observed that the values of temperature and DO parameters are not significantly different from the 36 locations classified as "Stay in position" and are still within the standard range of river water quality values. However, the pH values of these three locations are below 6 (lower than the standard value for river water quality). The water quality alert system performed well during the testing and aligned with the designed program. The results of the alarm system testing at location U1 are displayed in Table 4.

During the field testing, the sensors responded to every change in the river water parameters, with data updates in the application within 1 to 10

Table 4: Results of LED and buzzer indicator testing for water quality

Time	Water quality measurement			Buzzer (On/Off)	Alert Indicator			Operating LED color
	Temperature (°C)	DO (mg/L)	PH		Temperature (°C)	DO (mg/L)	PH	
11:10:00 AM	28.6	3	1.62	On	-	-	√	Blue
11:11:00 AM	28.63	3	1.65	On	-	-	√	Blue
11:12:00 AM	28.41	3	1.37	On	-	-	√	Blue
11:13:00 AM	27.43	3	0.22	On	-	-	√	Blue
11:14:00 AM	27.32	3	0.02	On	-	-	√	Blue
11:15:00 AM	28.07	3	0.24	On	-	-	√	Blue
11:16:00 AM	28.01	3	0.29	On	-	-	√	Blue
11:17:00 AM	27.83	3	0.21	On	-	-	√	Blue
11:18:00 AM	28.53	3	6.59	Off	-	-	-	None
11:19:00 AM	28.63	3	6.87	Off	-	-	-	None
11:20:00 AM	28.63	3	6.94	Off	-	-	-	None
11:21:00 AM	26.88	4.5	6.5	Off	-	-	-	None

seconds. The measured temperature values of the river water ranged from 27.44 °C to 31.06 °C, the DO values ranged from 3.00 mg/L to 4.78 mg/L, and the pH values ranged from 2.58 to 6.70. The temperature and DO values were within the allowable tolerance limits for river fish, but the measured pH values exceeded the lower threshold of the regulatory standard set at 6-9 (Pemerintah Republik Indonesia, 2021). The testing was conducted at 39 locations, and the decision-making program recommended "Stay in position" for 36 locations, as the measured water quality values were in accordance with the predetermined standards. However, three locations (U1, D8, U13) indicated poor water quality, with pH values below 6, and were recommended to "Move" the FNCs. Observations showed that these three locations were situated near residential areas, factories/industries, and tributaries, which might be contaminated by waste from surrounding activities. These conditions align with previous research by Abd El-Hack *et al*., (2022), where pH values are influenced by contaminants discharged into the water, resulting in only a few species surviving. The water quality values were within the normal range and were compliant with the existing standards compared to the data from nearby testing locations. Based on the water quality status readings, fish farmers have vital information regarding the water quality conditions around their net cages. Therefore, it is recommended that fish farmers take action and understand the characteristics of the cultivated fish species, and be aware of the duration that the fish can tolerate changes in water quality. If the water quality conditions continue to deteriorate, fish farmers can make an informed decision on relocating the floating net cages based on factors such as time, water conditions, and the specific species being cultivated. These efforts can minimize the potential losses resulting from river water pollution. Compared with previously published work, the FNCs concept proposed to be carried out horizontally on the river surface is simpler and more effective than the model proposed by (Kim *et al*., 2011; 2014; Thangavel *et al*., 2015), which moves vertically. Furthermore, applying the fuzzy logic method in this work uses three primary water quality parameter variables with data taken from direct measurements of river water compared to the previous work by (Oltean and Ivanciu, 2017), which only used one variable. Compared to the work of (Bokingkito and Caparida, 2018), fuzzy logic was built for monitoring water quality assessment in real-time using three input variables, namely temperature, pH, and turbidity, with three membership functions each. In contrast, this work implemented fuzzy logic using three input variables: temperature, DO, and pH, with five membership functions each. Furthermore, compared with the work of (Molato, 2022), fuzzy logic was built using three water parameter variables as input with three membership functions each to produce a model to analyze the overall quality of water in tilapia cultivation, monitoring equipment in the form of an LCD and equipped with a database, while in this work fuzzy logic was built to make decisions for FNC transfer with a monitoring application that displays value data and graphics and is equipped with a database.

CONCLUSION

An assessment of the water quality of the Musi River was conducted to classify the status of the floating net cage locations using a Python program. The three main parameters, water temperature, pH, and DO, were measured at 39 testing locations along the Musi River within a radius of 3400 m. All sensors responded to changes in the river water quality. The measured water quality of the Musi River fluctuated over a specific time duration. The program's decision at three testing locations (U1, D8, and U13) recommended moving the floating net cages. The average measured values for the water temperature of the Musi River were 29.20 °C, 3.98 mg/L for DO, and pH 6.42, except for these three locations where the pH values were below 6, which is below the predefined threshold. This condition correlates with the water quality alarm system, which triggers a blue LED indicator and a sounding buzzer at these three locations. Visually, there were no visible changes in the color of the river water at these three locations with poor water quality, which does not correlate with the device testing duration at each location. However, field observations revealed that all three locations were situated along the riverbanks, close to factories/tributaries (U1), and residential areas (D8, U13), which are vulnerable to waste discharge from human activities in the surrounding areas. In this research, the decision-making application for relocating the floating net cages in fish farming is user-friendly, effective in assessing water quality, and efficiently determines cage relocation decisions with accurate results. Applying the fuzzy method in this research provides certainty for fishermen in deciding to relocate the floating net cages. By referring to the program and considering other conditions, fishermen can promptly decide to move the floating net cages and avoid more significant losses. Another benefit is that the monitoring application is accessible through a personal computer or smartphone connected to the Internet. In the future, this work can inspire further research to develop an autonomous system for floating net cages whereby the cages can move automatically when the water quality around the location of the floating net cages deteriorates over a certain period.

AUTHOR CONTRIBUTIONS

Z. Nawawi, the corresponding author, has contributed in supervising the first author in collecting research data, analyzing data and interpreting the results. B.Y. Suprapto prepared test data and images and interpreted the results. R. Pramana participated in the interpretation of the results and manuscript preparation.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS	DEFINITION
%	Percent
°C	Degree Celsius
Cm	Centimeter
DO	Dissolved oxygen
EC	Electrical conductivity
Et al	And others
Fig	Figure
FNC	Floating net cage
FAO	Food and agriculture organization
Gaussmf	Gaussian membership function
Gauss2mf	Gaussian combination membership function
GSM	Global system mobile
IOT	Internet of things
LCD	Liquid crystal display
LED	Light emitting diode
LoRa	Long range
LPWAN	Low power wide area networks
m	Meter
m/s	Meters per second
MF	Membership function
mg/L	Milligrams per liter
NTU	Nephelometric turbidity unit
PC	Personal computer
pH	Potential hydrogen
ppm	Parts per million
SMS	Short message service
TDS	Total dissolved solid
Temp	Temperature
V	Voltage
VDC	Volt direct current
WSN	Wireless sensor network

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