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ASSESSMENT OF PHYSICOCHEMICAL WATER QUALITY PARAMETERS IN FRESHWATER FISHPONDS USING SENSOR-BASED MONITORING

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Abstract
Maintaining appropriate physicochemical conditions is essential for freshwater aquaculture because water quality directly influences fish health, growth, survival, and pond productivity. Sensor-based monitoring provides a practical approach for evaluating changing aquatic conditions through repeated measurements of key environmental parameters. A quantitative, observational, secondary-data-based study was conducted using 591 freshwater fish-pond observations representing 11 fish categories. The analysis focused on pH, temperature, and turbidity. Descriptive statistics were calculated to summarize overall conditions, species-wise differences were assessed using the Kruskal–Wallis test, and Spearman correlation analysis was performed to examine relationships among the physicochemical parameters. The findings demonstrated clear variability in pH, temperature, and turbidity across the fish categories. Pangas showed comparatively higher pH conditions, while koi had lower pH levels. Prawn was associated with higher temperatures, whereas tilapia showed lower thermal conditions. Greater turbidity was observed in magur and karpio. Species-wise differences were statistically significant for all three parameters. Correlation analysis showed weak negative relationships of pH with temperature and turbidity, while temperature had a moderate positive association with turbidity. The study confirms that physicochemical water conditions vary considerably across freshwater fish categories and that these parameters are interrelated. Sensor-based monitoring can support timely assessment of pond conditions and strengthen practical water-quality management in freshwater aquaculture.

Keywords: *Freshwater aquaculture; pH; temperature; turbidity; sensor-based monitoring*

1. Introduction

Fresh water aquaculture is a significant source of animal protein in food production, it is an accessible source of livelihood for rural people and it plays a key role in food security. Water quality is one of the most important factors affecting freshwater fish culture in terms of its productivity and sustainability as fish are always in contact with the water. Water changes may affect feeding, metabolism, growth, disease resistance, survival and productivity. It is therefore necessary to monitor frequently for proper aquaculture management. The application of Internet of Things (IoT) systems has been growing over the past few years, and they are now used for monitoring and controlling freshwater fish-farming environments (Anani et al., 2022). The ability to monitor in real-time has also been facilitated by the installation of low-cost sensor networks, especially in smaller fish farms in rural areas where less frequent laboratory assessments can be challenging (David & Mdodo, 2025).

pH, temperature and turbidity are the most important major physicochemical indicators of pond water quality. pH is a measure of the acidity or alkalinity of water and may affect biological reactions, and the availability or toxicity of dissolved substances. Temperature has an impact on fish metabolism and multiple chemical and biological processes in ponds; and turbidity indicates suspended materials that can impact light penetration, productivity, feeding efficiency, and habitat quality. The use of multisensor systems to detect changes of freshwater pond conditions is increasing (Mutiara et al., 2026). The use of IoT-based systems can offer real-time data and facilitate prompt decision-making in water management (Echubu et al., 2025), and the monitoring of water quality variables using sensors is a key component of sustainable aquatic environments as it allows for regular assessment (Kuppusamy et al., 2025).

Conventional monitoring of water quality typically relies on discrete sampling over time and can miss the dynamic response of water quality to environmental changes. This can be overcome by implementing IoT-based monitoring systems that can collect data frequently and automatically (Eso et al., 2024). Advancements in access to water-quality data for aquaculture have been enhanced by the use of web-based platforms and microprocessors like Arduino (Cacho et al., 2025). Wireless sensor networks also offer the potential for continuous and earlier monitoring of pond conditions as they change as opposed to periodic manual monitoring (Boonsong et al., 2020).

Although these advances have been made, most of the literature has focused on the design and technical performance of the monitoring system and not much detailed statistical evaluation has been conducted of the recorded physicochemical observations. Despite the development of advanced IoT systems for pond management and environmental protection, there is a need to focus more on interpreting data monitored by these systems from an aquaculture management perspective (Kumar et al., 2024). Some systems have also targeted individual parameters, like TDS, which has shown the feasibility of real-time monitoring, but offers poor integrated assessment of multiple water-quality parameters (Zafi et al., 2024).

There are some newer technological advances such as embedded deep-learning methods for pond monitoring using visual data (Chumchu et al., 2026) and the use of Arduino based multisensors for aquaculture applications (Calajate et al., 2024). The total dissolved solids (TDS), electrical conductivity (EC), and temperature sensors have also been used in prototype systems for catfish culture (Riswanto et al., 2026). But little attention has been paid to the distribution, variability, species-level differences and relationship between parameters commonly measured like turbidity, temperature, and pH. Such monitoring data can be statistically analyzed to give valuable information about the environmental conditions experienced by various groups of fresh water fish.

Water quality continues to play a key role in the success of freshwater aquaculture, with poor conditions potentially impacting fish health and production (Bastian et al., 2025). Systematic monitoring is thus essential to identify changes in the environment and to help make timely management decisions. This is important in intensive and recirculating aquaculture systems, where physicochemical changes might occur quickly (Lindholm-Lehto, 2023). Automatic telemonitoring systems that use sensors can continuously collect data like temperature, dissolved oxygen, pH, and total dissolved solids (Ayu et al., 2026), and aquatic resource management can be guided by sensor networks that continuously provide environmental data (Khatei et al., 2025).

In this study pH, temperature and turbidity measurements from the freshwater fish-pond monitoring data are evaluated, differences between the fish groups are compared, relationship between the parameters are checked and pond water conditions are assessed. To provide a practical physicochemical evaluation for better monitoring of water quality and sustainable management of freshwater aquaculture.

Research Objectives
1.To assess the distribution and variability of pH, temperature, and turbidity in freshwater fish-pond water.
2.To compare physicochemical water-quality parameters across different freshwater fish species/categories represented in the dataset.
3.To examine relationships among pH, temperature, and turbidity and evaluate the overall suitability of recorded water conditions for freshwater aquaculture.

2. Materials and Methods
2.1 Study Design
The design of the study was quantitative, observation, secondary data in order to evaluate the Physico Chemical Water Quality condition of the freshwater fish pond. An existing data set of measurements recorded for the various freshwater fish species/categories was analysed retrospectively. No field sampling, experimental manipulation or direct intervention took place in the present study.

2.2 Data Source
The data used was the Realtime Pond Water Dataset for Fish Farming from Kaggle which is available publicly (Mukul, 2021). Physicochemical observations for freshwater fish farming monitored such as: pH, temperature, turbidity and fish species/category. This was applied to the present study to assess the general water-quality conditions, differences between the fish categories and relationships between the measured physicochemical parameters.

2.4 Data Selection and Preparation
The data set was pre-screened for missing data, duplicate observations, inconsistent data entries, and implausible numerical data. The completeness and validity of pH, temperature and turbidity measurements were checked and all acceptable measurements were used for further analysis. Also, the fish-species/category labels were revised for uniformity of records and categorising the data was undertaken as required for species-wise comparison of the physicochemical parameters.

2.5 Water Quality Parameters
The following three physicochemical parameters were analyzed: Turbidity, pH, and temperature. Acidic or alkaline nature of pond water was determined by using pH and it affects the physiology of fishes and chemical processes in the pond. Temperature was evaluated since it affects fish metabolism, growth, feeding and other biological processes, and turbidity was evaluated as an indicator of suspended matter and water clarity which may affect the light penetration, feeding and habitat conditions. These parameters collectively gave a general idea of pond-water conditions pertinent to the management of freshwater aquaculture.

2.6 Statistical Analysis
The physicochemical parameters are summarised by descriptive statistics such as mean, standard deviation, median, minimum, maximum and interquartile range where applicable. Distribution of pH, temperature and turbidity were explored and then species-wise comparisons were made to determine the differences between the various categories of freshwater fishes. The relationship between pH, temperature and turbidity parameters was investigated using the correlation analysis. A p value of < 0.05 was used to determine statistical significance.

3. Results
3.1 Distribution of Observations Across Fish Categories

In total, 11 freshwater fish categories had 591 water-quality records that were analyzed. Note that the percentages of observations varied among the fish groups, indicating different representation of the included species. The frequency and the percentage are given in figure 1.

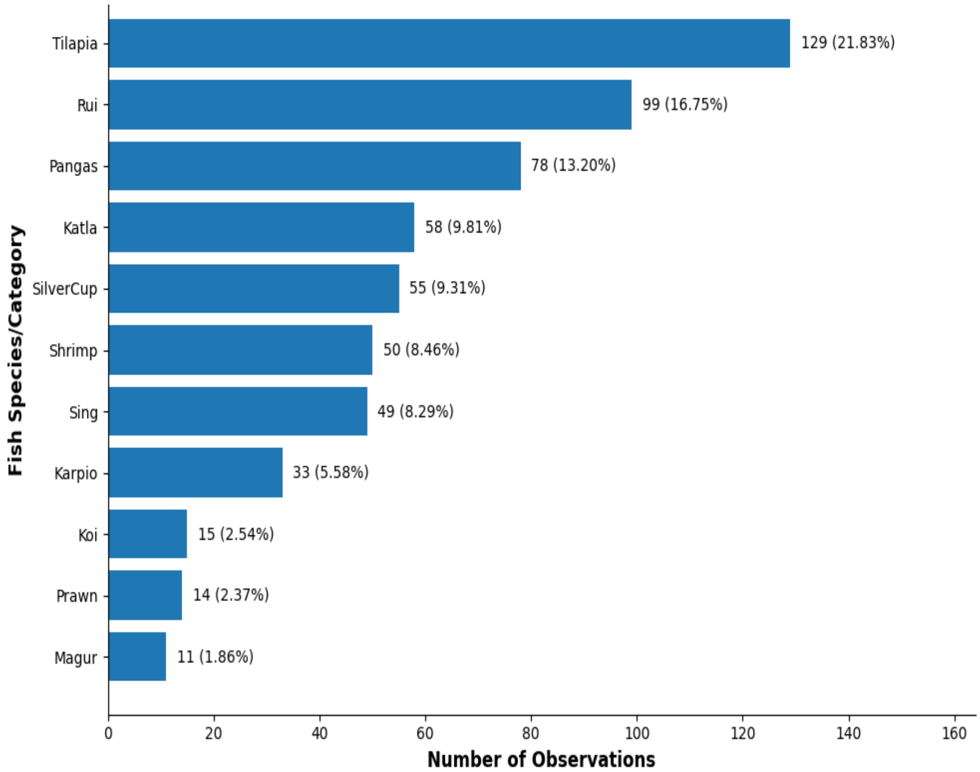

Figure 1. Distribution of Fish Categories

Tilapia was the most abundant species followed by rui and pangas. SilverCup, shrimp and sing had moderate representations while koi, prawn and magur had the smallest representations. The overall trend does show differences between the number of observations of the various fish categories.

3.2 Overall Physicochemical Characteristics of Pond Water

Descriptive analysis revealed that levels of pH, temperature and turbidity were different and significant throughout the observation period. The pH values were generally within a moderate range with the temperatures being more variable. However, the turbidity showed more scatter towards the higher values, with a positive skewness in some of the measurements. The general descriptive statistics are reported in Table 1.

Table 1. Descriptive Statistics of Physicochemical Water-Quality Parameters

Parameter	Mean	SD	Median	Q1	Q3	IQR	Minimum	Maximum
pH	7.53	0.81	7.50	6.99	8.20	1.21	5.50	9.00
Temperature	21.79	4.54	21.06	17.94	24.00	6.06	4.00	35.00
Turbidity	4.43	2.17	3.57	3.48	4.00	0.52	1.00	15.80

3.3 Species-Wise Variation in Physicochemical Water Quality

The results of species-wise analysis indicated significant variation in the physico-chemical parameters of the various categories of fishes. Pangas exhibited higher pH conditions and koi exhibited lower pH conditions in comparison. Prawn was correlated with higher temperature conditions, tilapia with comparatively lower temperatures. Magur and karpio showed higher turbidity level and pangas, tilapia and katla showed lower turbidity level. The results of Kruskal – Willi's testing indicated that there was a significant difference among the fish categories for all three physicochemical parameters. Species-wise results are presented in detail in Table 2 and depicted in Figure 2.

Table 2. Species-Wise Physicochemical Water-Quality Characteristics and Kruskal–Wallis Comparison

Fish species/category	pH, Mean ± SD	Temperature, Mean ± SD	Turbidity, Mean ± SD
Karpio	7.24 ± 0.17	19.36 ± 9.11	7.68 ± 1.48
Katla	7.72 ± 0.52	23.10 ± 3.36	3.74 ± 0.29
Koi	6.67 ± 0.87	26.00 ± 4.54	4.62 ± 0.83
Magur	7.24 ± 0.11	25.18 ± 3.06	7.71 ± 0.36
Pangas	8.48 ± 0.56	20.99 ± 5.01	3.64 ± 0.86
Prawn	7.89 ± 0.32	28.93 ± 1.82	6.31 ± 1.43
Rui	7.06 ± 0.68	22.43 ± 3.37	3.75 ± 0.77
Shrimp	7.15 ± 0.41	22.14 ± 2.70	6.83 ± 5.22
SilverCup	6.83 ± 0.70	22.19 ± 2.91	3.88 ± 0.85
Sing	7.33 ± 0.51	23.71 ± 3.83	4.58 ± 1.46
Tilapia	7.92 ± 0.78	19.22 ± 3.21	3.66 ± 0.59
Kruskal–Wallis H	258.567	214.866	331.087
p-value	<0.001	<0.001	<0.001

The graphical comparison is an overview of the differences in magnitude of the three physicochemical indicators between the fish categories. The relative patterns of pH, temperature and turbidity can be seen together in Figure 2.

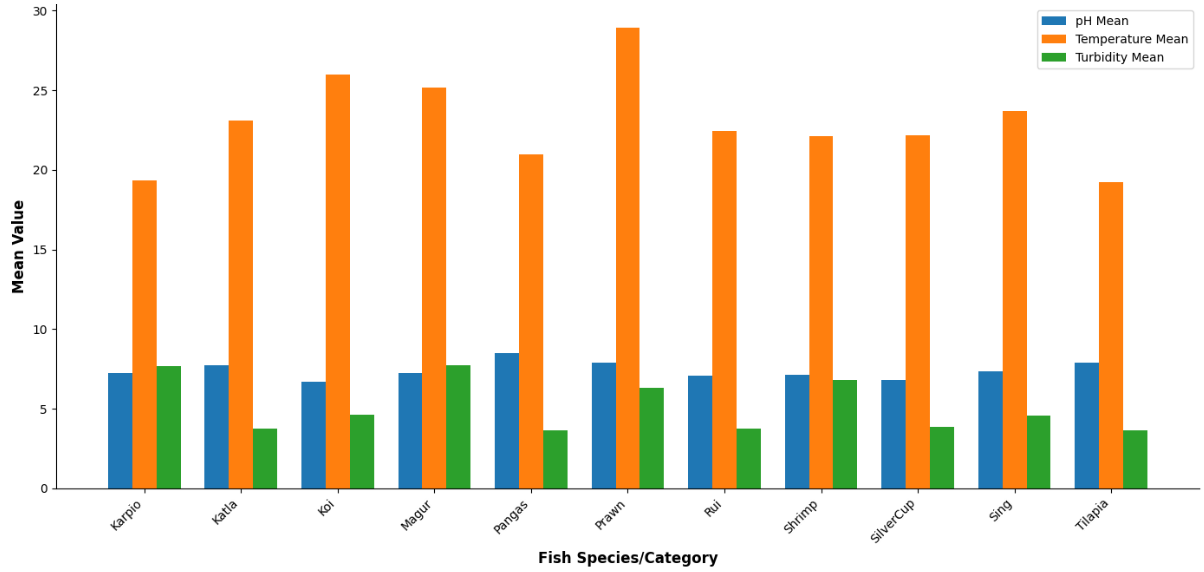

Figure 2. Mean Physicochemical Parameters Across Fish Species

The temperature was the most spread out of the three indicators, and the pH was relatively compact in most categories. Turbidity had more variation within some groups, indicating the varying conditions of water clarity in the fish environment being monitored.

3.4 Correlation Among Physicochemical Water-Quality Parameters

The results of the correlation analysis revealed that the three physicochemical indicators had statistically significant correlation. A negative correlation occurred between pH and temperature and turbidity, and a positive correlation occurred between temperature and turbidity. The direction and relative strength of these relationships is provided in Figure 3.

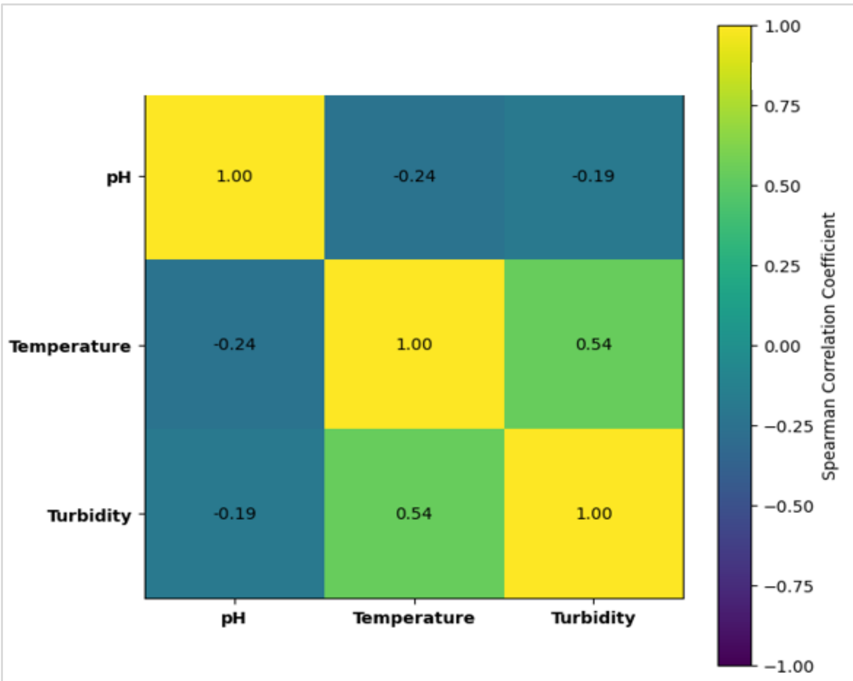

Figure 3. Correlation Among Water-Quality Parameters

The heatmap shows that temperature and turbidity were more closely related than pH was to the other parameters. In general, the relationship between the change in thermal conditions and the change in water clarity appeared to be stronger than the relationship between the change in acidity or alkalinity and the change in water clarity.

4. Discussion

The present results indicate significant difference in the physicochemical parameter with different categories of freshwater fishes. The general trend in the pH curves was in a rather moderate range, however, the species-wise difference became apparent suggesting that aquatic conditions were not uniform throughout the observations. Pangas was associated with relatively high pH while koi was associated with low pH. There was also significant differences in temperature among fish groups, with prawn being associated with the warmer temperature and tilapia the cooler temperature. These differences might be due to differences in pond environment, season, stocking practices, feeding intensity, or otherwise related to pond management. Turbidity exhibited very distinct trends and had higher turbidity in magur and karpio and less in several other categories. This variation is significant as too much suspended material may affect light penetration, feeding visibility and habitat quality. The results of the Kruskal–Wallis test for all three parameters are also significant, which further confirms that the differences observed among the species were not random.
The results of the correlation give further insight on the interactions between the measured parameters. The negative, but weak, relationship of pH with temperature and turbidity indicate that as temperature and turbidity increased, there was a slight decrease in pH. By comparison, the moderate positive correlation between temperature and turbidity was more clearly defined, indicating that higher temperatures in the ponds generally were associated with higher turbidity. This connection can be as a result of either greater biological activity or a disturbance of the sediment, plankton development or greater decomposition in the warmer conditions. However, these relationships should be considered as associations and not direct causal effects as this is an observational study.
The present results are similar to those reported in previous studies that stressed the need for ongoing monitoring of several water-quality parameters instead of monitoring that is limited to selected parameters. Even though water quality sensors are not a new technology, they have proven to enhance the monitoring of water quality changes and the detection of environmental fluctuations that might not be detected during periodic sampling (Rose et al., 2021). The same focus on advanced monitoring of lentic water systems has pointed to the need to integrate both physicochemical and biological monitoring for effective protection and management of freshwater resources (Bustos-Terrones et al., 2025).
The variability of the pH, temperature and turbidity observed also shows that there is potential to adapt low cost sensors technologies for general use in aquatic monitoring. An analysis of IoT-enabled water-quality sensors reveals that, while low-cost sensing systems can provide frequent and practical water-quality measurements, they must be considered in terms of calibration, accuracy and data quality (De Camargo et al., 2023). More particularly, in aquaculture, intelligent monitoring frameworks have been suggested to assist with the timely management of water conditions and lower risks due to the deterioration of the environment (Yamuna et al., 2023). The current results also support the fact that the interacting environmental factors are the key determinants of water quality management in aquaculture, and not just a single factor (Hambalia et al., 2024). Also, prior studies on smart aquaponics highlight that the quality of data collected by sensors is critical to the accuracy of subsequent analyses and decision-making, underscoring the need for proper screening and understanding of monitoring data (Eneh et al., 2023).
The results are useful for the management of freshwater aquaculture. Frequent checks for pH, temperature, and turbidity will help detect any changes in pond conditions that could lead to a larger environmental issue. Species-wise differences also indicate that uniform management thresholds are not necessarily indicative of the conditions for all fish species. The pond environment and the biological needs of species being cultured should therefore be taken into consideration in monitoring programs. Additional evidence of the moderate relationship between turbidity and temperature suggest that simultaneous assessment of multiple indicators might prove more valuable than

individual assessment of parameters.
There are several restrictions to be taken into consideration. The study was secondary and so was limited to the variables that were available in the source. Dissolved oxygen, ammonia, nitrate, conductivity and total dissolved solids were not measured. It was also not possible to assess seasonally or longitudinally because of the limited information on time. Also, duplicate observations were kept since they might be repetitions of a valid observation; however, no verification of the source of the duplicate observation could be made. The sensor calibration, sampling frequency, pond management and local environment conditions were also not provided to correct for.
Future work should include more physicochemical and biological indicators, in addition to a series of measurements taken at different times of day and night to study the variation during the day. Longitudinal monitoring can help to determine how turbidity, temperature and pH change over time, and if this change occurs before fish growth, survival and productivity change. In addition, future studies should also incorporate sensor-calibration data, pond specific management parameters, and field testing to enhance the interpretation and use of sensor-based water-quality monitoring in freshwater aquaculture.

5. Conclusion

The water quality of freshwater fish ponds was evaluated and measured by the pH, temperature and turbidity of the water of the ponds during various categories of fishes. The results obtained revealed significant differences in all three parameters, suggesting that the pond-water conditions were not similar for all the fish groups represented. Pangas was correlated with relatively high pH and koi was correlated with low pH. There was a higher temperature associated with prawn and lower temperature with tilapia. The turbidity also fluctuated significantly, with magur and karpio having comparatively higher values than a few other categories. These differences between species were all statistically significant, and thus meaningful differences in the physicochemical environment between the fish groups exist. The correlation analysis also revealed that the temperature and turbidity showed a weak negative correlation with the pH while the temperature and turbidity showed a moderate positive correlation. This indicates that an increase in suspended material concentrations in the pond was associated with warmer conditions. The results, overall, show the practicality of the approach of using more than one water-quality indicator and not interpreting them individually. Using sensors can help identify undesirable shifts on time and enhance freshwater pond management. Monitoring for dissolved oxygen, ammonia, conductivity, nutrients and for time would however provide a more comprehensive evaluation. Future studies should thus include the continuous monitoring of multiple sensors along with fish growth, survival and productivity to enhance sustainable aquaculture management.

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