Water quality control of Tasik Kejuruteraan UKM water channel using Artificial Neural Network and Neural Fuzzy Network

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Abstract. The water quality of Tasik Kejuruteraan UKM water channel is an issue that should be emphasized because excess water will be discharged to Sungai Langat where this river is the source of water supply for the residents in some part of Klang Valley area. The water quality parameters must comply with the standard assigned by Malaysian’s Department of Environment (DOE). As a first step towards proper monitoring programme, a proper analysis of the water quality should be conducted thoroughly. As such, this study composed of two parts. First, experimental investigation of the water quality of Tasik Kejuruteraan UKM water channel was carried out to assess its environmental quality. Experiment was conducted to determine the Water Quality Index of Tasik Kejuruteraan water channel based upon guidelines as stipulated by DOE. The results indicate that Tasik Kejuruteraan UKM water channel is polluted and proper water quality control should be applied. In the second part of this study, preliminary analysis of artificial neural network (ANN) and neural fuzzy network for water quality control was conducted to determine the suitability of these controllers in water treatment system. Based on the simulations conducted, neural fuzzy network shows better efficacy in the pH control scheme compared with ANN because there is no oscillation detected in the corresponding controlled variable.

1. Introduction
Malaysia is now moving towards a developed nation where many factories have been built. Most of these factories are built on the area near the river to facilitate the flow of waste materials. Problems arise when the flow of waste does not comply with the standard effluent given by Department of Environment which can cause river polluted. In addition, agricultural activity has also contributed to the pollution of the river where the chemical contained in herbicides, pesticides and fertilizers can increase the content of suspended solids. Suspended solids can prevent the light from penetrating the bottom surface of the water and can cause aquatic life affected. Cleanliness of the river plays an important role because it carries various functions to humans, especially as a source of water for commercial or domestic use [1].

Universiti Kebangsaan Malaysia (UKM) is heading towards the campus sustainability concept which is claimed to educate society a culture of sustainability. This concept covers various aspects such as a resource management system and wastewater. In the UKM Bangi campus, there are several

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sources of irrigation such as the lake at Faculty of Engineering and Built Environment UKM or called Tasik Kejuruteraan known as the focal point of this study. Water from Tasik Kejuruteraan will be discharged to Sungai Langat.

Recently, increased levels of ammonia in Sungai Langat has exceeded the minimum level of 1.5 mg/L which exceeds the requirement set by the Malaysian’s Ministry of Health [2]. Generally, ammonia is a chemical substance that contains nitrogen and hydrogen that could result from the decay of organic matter. Disposal of sewage and garbage can contribute to the production of ammonia in the wastewater.

To handle this issue, several parameters mentioned must comply with the standard assigned by Department of Environment. To overcome this issue, a proper analysis of the water quality should be conducted thoroughly. To this end, Water Quality Index (WQI) which is a single number that can be calculated easily and used for overall description of water quality can be used to provide a quick and simple methodology to assess the quality of any water bodies [3]. WQI gathers a large number of water quality parameters and expresses the aggregate of these values in a comprehensible manner such as “clean”, “slightly polluted”, and “polluted”. In Malaysia, the calculation of WQI is based on the formula provided by Department of Environment (DOE), Malaysia.

In another part of this work, a study involving the artificial intelligence to control water treatment process is also carried out. Artificial intelligence is a branch of computer science where it has a goal of making computers or machines to work, act and think like humans. Applications of artificial intelligence techniques that comprise of artificial neural network and fuzzy logic in water quality predictions and controls have been explored significantly in the past [4-7]. Artificial Neural network is a branch of artificial intelligence where it is designed based on human brain function. ANN has the ability to process information that is complex, non-linear and parallel efficiently [8]. Meanwhile, neural fuzzy network is a hybrid system between ANN and fuzzy logic. This combination has been proven to be effective in solving wide variety of control problems [9]. Neural fuzzy network train the system by fuzzy learning algorithm derived from the theory of ANN. It also has a network structure which fuzzy sets are encoded as a weight connection. In this study, the applications of these two controllers were studied in the context of water treatment controls.

2. Methodology

Tasik Kejuruteraan UKM has been selected to carry out the experimental determination of water quality. Pollution of Tasik Kejuruteraan arises from the disposal of waste from the cafeteria nearby and drainage from the engineering faculties. Figure 1 shows the research area and water source of Tasik Kejuruteraan.

![Figure 1. Research area and water source of Tasik Kejuruteraan.](image-url)
The first location is the location where the outflow of Tasik Kejuruteraan to Sungai Langat while the second and third location is the location of water sources of Tasik Kejuruteraan. The area has been chosen is the last point where the area (S5) is the outflow of Tasik Kejuruteraan to Sungai Langat. Thus, water quality control in this area should be emphasized to ensure the supply of clean water to residents is continuous. The methodology of this study is summarized in figure 1.

2.1. Sampling
Sampling should be emphasized to ensure that the samples are taken is not contaminated with outside sources. Contamination may lead to inaccurate experimental results. There are several steps that should be considered during sampling. Before sampling, sample container must be kept in clean condition to avoid impurities. For water sampling, uncapped sample container was held upside down and submerses in the water. Tip bottle upright and allow water to fill the sample container. When the container filled with the water, remove it and screw the cap. Then, the sample is sent to laboratory for analysis.

2.1.1. Ammonical nitrogen (NH₃-N). Nessler reagent set comprising nessler reagent, polyvinyl alcohol and mineral stabilizer is used for determination of ammonia nitrogen in the sample. For the preparation of the sample, 25 ml of sample are mixed with 3 drops of mineral stabilizer and polyvinyl alcohol in the conical flask and inverted. Then, 1 mL of nessler reagent is added in the mixture. 10 ml of the mixture is taken for the purpose of reading the NH₃-N contained in the sample.
2.1.2. Suspended solid (SS). 10 mL is taken from the sample for determination of the content of suspended solid. Blank sample is prepared using distilled water for calibration of the instrument spectrometer HASH DR/3600. Reading sample is run with the help of the spectrometer HASH DR/3600.

2.1.3. Dissolved oxygen (DO). Measurement for the DO is performed using DO probe in which a sample of 300mL is filled in the BOD bottle and the DO probe is used for DO reading in the sample. To obtain an accurate reading, the probe will be calibrated before the DO reading is taken.

2.1.4. Chemical oxygen demand (COD). For these experiments, COD reagents used for determination of COD values. There are two type of reagents which are low range COD reagent and high range COD reagent. The value for the low range is between 3-150 mg/L while the value of the high range is between 20-1500 mg/L. To test water quality of Tasik Kejuruteraan, low range COD reagent is used. COD reagent are mixed with 2 mL of sample and left in the reactor DBR 200 at 1500C for 2 hours. After 2 hours, the sample is cooled at room temperature and reading sample is carried out with the aid of the spectrometer.

2.1.5. Biochemical oxygen demand (BOD). BOD determination methods require the dilution process where COD determination should be determine first to obtain the total volume of sample required. Table 1 and 2 show the minimum and maximum number of samples required to obtain the appropriate number of samples.

2.1.6. pH. Determination of pH was done with the help of 827 pH meter model. The probe is inserted into the sample and reading is taken. Before the reading is taken, pH meter should be calibrated using buffer set to obtain a more precise result.
Table 1. Minimum volume of sample

| Type of sample       | BOD (mg/L) | Volume (ml) |
|----------------------|------------|-------------|
| Strong sewage        | 600        | 1           |
| Sewage               | 300        | 2           |
|                      | 200        | 3           |
|                      | 150        | 4           |
|                      | 120        | 5           |
|                      | 100        | 6           |
|                      | 75         | 8           |
|                      | 60         | 10          |
| Oxidized effluent    | 50         | 12          |
|                      | 40         | 15          |
|                      | 30         | 20          |
|                      | 20         | 30          |
|                      | 10         | 60          |
| Polluted river water | 6          | 100         |
|                      | 4          | 200         |
|                      | 2          | 300         |
Table 2. Maximum value of sample

| mg/L BOD - Sea level | Volume (ml) |
|----------------------|-------------|
| 2460                 | 1           |
| 1230                 | 2           |
| 820                  | 3           |
| 615                  | 4           |
| 492                  | 5           |
| 410                  | 6           |
| 304                  | 8           |
| 246                  | 10          |
| 205                  | 12          |
| 164                  | 15          |
| 123                  | 20          |
| 82                   | 30          |
| 41                   | 60          |
| 25                   | 100         |
| 12                   | 200         |
| 8                    | 300         |

2.2. Water Quality Index
Six parameters mentioned above are used to determine the water quality index (WQI) where its formulation is shown by equation (1). Table 3 lists the formula for the calculation of associated parameters in this WQI formulation.

\[ IKA = 0.22 S_{IDO} + 0.19 S_{BOD} + 0.16 S_{COD} + 0.15 S_{AN} + 0.16 S_{TSS} + 0.12 S_{pH} \] (1)
Table 3. Formula for calculating WQI

| Sub-indeks (SI) | Formula |
|-----------------|---------|
| **DO (% Saturation)** | |
| SIDO = 0 | $x \leq 8$ |
| SIDO = 100 | $x \geq 92$ |
| SIDO = $-0.395 + 0.03x^2 - 0.0002x^2$ | $8 < x < 92$ |
| **BOD (mg/L)** | |
| SIBOD = $100.4 - 4.23x$ | $x \leq 5$ |
| SIBOD = $108^{-0.055x} - 0.1x$ | $x > 5$ |
| **COD (mg/L)** | |
| SICOD = $-1.33x + 99.1$ | $x \leq 20$ |
| SICOD = $103e^{-0.0157x} - 0.04x$ | $x > 20$ |
| **NH₃-N (mg/L N)** | |
| SIAN = $100.5 - 105x$ | $x \leq 3$ |
| SIAN = $94e^{-0.573x} - 51x - 21$ | $0.3 < x < 4$ |
| SIAN = 0 | $x \geq 4$ |
| **SS (mg/L)** | |
| SISS = $97.5e^{-0.00676x} + 0.05x$ | $x \leq 100$ |
| SISS = $71e^{-0.0061x} - 0.15x$ | $100 < x < 1000$ |
| SISS = 0 | $x \geq 1000$ |
| **pH** | |
| SlpH = $17.2 - 17.2x + 5.02x^2$ | $x < 5.5$ |
| SlpH = $-242 + 95.5x - 6.67x^2$ | $5.5 \leq x < 7$ |
| SlpH = $-181 + 82.4x - 6.05x^2$ | $7 \leq x < 8.75$ |
| SlpH = $536 - 77x + 2.76x^2$ | $x \geq 8.75$ |

Source: Department of Environment (Malaysia)
2.3. Artificial Neural Network
To build the artificial neural network for property prediction, there are generally 7 steps that should be taken which are collections of data, build a network, network configuration, provide initial weight and bias, train the network using data, and validate network prediction and finally using the network. All seven steps are carried out by using MATLAB software version R2012 in this work.

2.4. Neural Fuzzy Network
There are several ways to build neural fuzzy network. For this study, the following four steps are followed to build the prediction model using the neural fuzzy network: upload data, plot data and clean data, generate a FIS structure, train the FIS and verify trained FIS. All four steps are carried out by using MATLAB software version R2012.

3. Results and Discussion

3.1. Pattern Parameters of Tasik Kejuruteraan UKM Water Channel
Experiment of quality Tasik Kejuruteraan UKM water channel is done 3 times a week and the sample taken at the exit point before being discharged to Sungai Langat. Figure 3 shows the pattern parameters for 16 samples.

![Figure 3. Pattern parameters for 16 samples](image)

From the experimental results in figure 3, sample 8th and 14th show the low value of COD. This is because the water samples taken during the rainy weather which is one of the factor that can cause disruption of water quality parameters changing. Samples of Tasik Kejuruteraan water channel are always at pH acidic that is in the range 6.29 to 6.89. Sample 8th until 11th, no amount of suspended solid can be detected.

By using the data from experimental results, the water quality index (WQI) can be determined. This calculation is important because it can determine the category of Tasik Kejuruteraan water channel. Equation (1) and table 3 is used for the calculation of WQI. Table 4 is the result of the WQI calculation.

From table 4, the index range red which is 0 to 59 representing Tasik Kejuruteraan water channel is contaminated and the index range yellow which is 60 to 80 representing the Tasik Kejuruteraan is
slightly polluted. So it can be concluded that Tasik Kejuruteraan UKM water channel is polluted and control of water quality index should be applied to ensure it comply the standard set by Department of Environment before being released to Sungai Langat.

Based on the average, pH, TSS and DO of 6.63, 12.92 and 6.66 respectively are in class I in which practically do not require treatment. For the parameter COD and BOD, the average values are 46.10 and 14.07 respectively. These parameters are in class III where it requires intensive treatment.

According to sub index calculations, the parameters COD and BOD are polluted where it needs control to increase the water quality index.

Table 4. Result of WQI

| Sampel | SIpH  | SICOD | SIBOD | SISS  | SIDO  | SIAN  | WQI     | Index range |
|--------|-------|-------|-------|-------|-------|-------|---------|-------------|
| 1      | 98.65 | -2.09 | -1.32 | 82.58 | 0.00  | -179.44 | -2.45   | Polluted    |
| 2      | 99.28 | 3.33  | -0.91 | 73.60 | 0.00  | 0.00   | 24.05   | Polluted    |
| 3      | 97.45 | 3.13  | -0.92 | 84.27 | 0.00  | 0.00   | 25.50   | Polluted    |
| 4      | 94.92 | 84.47 | 93.89 | 94.12 | 0.00  | -166.39| 32.84   | Polluted    |
| 5      | 98.98 | 5.85  | 85.81 | 88.49 | 0.00  | 0.00   | 43.27   | Polluted    |
| 6      | 97.90 | 3.06  | -0.96 | 90.13 | 0.00  | 0.00   | 26.48   | Polluted    |
| 7      | 98.59 | 3.94  | -0.74 | 89.76 | 0.00  | -214.37| -5.47   | Polluted    |
| 8      | 98.43 | 97.77 | 98.96 | 97.50 | 0.00  | 77.40  | 73.47   | Slightly polluted |
| 9      | 99.32 | 7.58  | 91.49 | 97.50 | 0.00  | 48.68  | 53.42   | Polluted    |
| 10     | 96.29 | -1.72 | -1.22 | 97.50 | 0.00  | -10.77 | 25.03   | Polluted    |
| 11     | 97.45 | -1.37 | -1.15 | 97.50 | 0.00  | 0.48   | 26.93   | Polluted    |
| 12     | 95.44 | -0.49 | -1.06 | 90.88 | 0.00  | 9.15   | 27.09   | Polluted    |
| 13     | 98.31 | -1.01 | -1.10 | 89.40 | 0.00  | 3.35   | 26.23   | Polluted    |
| 14     | 98.18 | 90.23 | 95.92 | 91.25 | 0.00  | 23.47  | 62.56   | Slightly polluted |
| 15     | 97.03 | 5.90  | 86.78 | 90.50 | 0.00  | 20.14  | 46.58   | Polluted    |
| 16     | 98.29 | 6.05  | 87.88 | 89.21 | 0.00  | -29.43 | 39.32   | Polluted    |

3.2. Prediction Performance of pH Control

Mathematical model for pH control system for Tasik Kejuruteraan water channel can be formulated using mass balance principle as shown in equation (2) and (3).

\[
V \frac{dx_a}{dt} = F_a C_a - (F_a + F_b)x_a
\]

\[
V \frac{dx_b}{dt} = F_b C_b - (F_a + F_b)x_b
\]

where \( V \) is the maximum volume (L), \( C \) is the concentration (mol/L) and \( F \) is the flow rate (mL/s). Subsequently, equation (4) provides pH balance relation.

\[
K_w = [H^+][OH^-]
\]
where $K_w$ is the dissociation of water ($10^{-14}$) and the pH definition stating that $\text{pH} = -\log_{10}[\text{H}^+]$. Figure 4 shows the process used in controlling pH in which component $a$ and $b$ are the acid and the alkali used to neutralize the Tasik Kejuruteraan water channel and figure 5 is a simulink model developed using the mathematical modelling.

![Figure 4. Control configuration of pH](image)

![Figure 5. Simulink model of pH control](image)

3.2.1. Neural fuzzy network controller. A pH control is performed using neural fuzzy network and Simulink models developed in two different states which are pH Tasik Kejuruteraan is in acidic and alkaline as shown in figure 6 and 7.
In neural fuzzy network, fuzzy inference system (FIS) is trained to emulate the data submitted by changing the parameters of membership functions according to the selected criteria. Type of fuzzy logic used is sugeno. Fuzzy logic rules can be categorized into two methods which are heuristic approach and data approach. Since this controller using sugeno, data approach is used as a rule of fuzzy logic as shown in table 5. According to the rules of the matrix, if the error is negative and error change is negative, then valve opening is negative where it means the valve need to be opened fast. If the error is zero and error change is zero, then valve opening is zero where it means no change in valve opening. If the error is positive and error change is positive, then valve opening is positive where it means the valve needs to be closed fast.

| Error change | Negative | Zero | Positive |
|--------------|----------|------|----------|
| Negative     | NL       | NS   | PS       |
| Zero         | NM       | ZE   | PM       |
| Positive     | NS       | PS   | PL       |

where NS = Negative Small, NM = Negative Medium, NL = Negative Large, PS = Positive Small, PM = Positive Medium, PL = Positive Large, and ZE = Zero Error

Figure 8 shows the FIS training and testing required in this controller. After FIS is trained and tested, fuzzy logic sugeno is as shown in figure 9.
Figure 8. FIS training and testing

Figure 9. Sugeno type of fuzzy logic (a) input and output variables FIS; (b) error; (c) the rate of change of error; (d) valve opening
Figure 10 and 11 are the results obtained when the neural fuzzy network is used to control the pH of Tasik Kejuruteraan water channel.

![Figure 10. Results for pH acidic](image)

![Figure 11. Results for pH alkaline](image)

The step change of 20% was applied to the neural fuzzy network control system. Referring to the figure 10, achieving a pH control system using fuzzy is successful because no oscillations can be detected. However, there is a slight overshoot of 0.002 of a set point and reach set point in less than 60 seconds. This overshoot is probably due to the concentration of alkali is added too much where it is difficult to control at first and the flow rate is high. If the flow rate used is too low, it is difficult to reach set point.

For initial set point in figure 11, the result of fuzzy neural network control achieved the set point less than a minute and this control is successful because no oscillations can be detected. After 50 minutes, an overshoot occurred from the set point of 0.0072 set and reach back to the set point less than 60 seconds.

3.2.2. Artificial neural network controller. A pH control is also carried out using artificial neural network. Narma-L2 is a type of artificial neural networks. A pH Simulink models developed in two different states which are pH Tasik Kejuruteraan is in acidic and alkaline (see figure 12).
To obtain the best structure of plant identification, the parameters involved were tested with a different value as shown in Table 6 and result in Table 7. From the results, it can be concluded that the structure II is the best structure. It has the best training regression of 0.9163 where regression training approaches one; mean the output and target values have a close relationship. In term of performance training, structure II acquire the mean square error of 0.0022. It means the difference between output and target has low error.

Table 6. ANN plant control structure

| Parameter                   | structure  | I   | II  | III | IV  |
|-----------------------------|------------|-----|-----|-----|-----|
| No of hidden layer          |            | 7   | 8   | 7   | 8   |
| Training function           |            | trainlm | trainlm | traingdx | traingdx |
| No delayed plant inputs     |            | 2   | 2   | 2   | 2   |
| No delayed plant outputs    |            | 2   | 2   | 2   | 2   |
| Maximum internal value      |            | 20  | 20  | 20  | 20  |
| Minimum interval value      |            | 5   | 5   | 5   | 5   |
The use of artificial neural network is to examine the sensitivity of the controller to change the set point or disturbance that occurred during the process. The result obtained from the simulation is shown in figure 13 and 14.

![Figure 13. Results for pH acidic](image-url)

Table 7. Result of ANN structure comparison

| Parameter                  | Structure I | Structure II | Structure III | Structure IV |
|----------------------------|-------------|--------------|---------------|--------------|
| Plant input and output     | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) |
| Training data              | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) |
| Validation data            | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) |
| Training performance       | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) |
| Training regression        | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) | ![Graph](image-url) |

Figure 13. Results for pH acidic
According to Figure 1, the step change of 20% was applied in artificial neural network. At minute 100, the control starts successfully track the set point and there was a slight swing. The control is managed to track the set point between pH set 8.0 to 8.2 and the oscillation occurs below the set point.

According to Figure 1, the step change 10% was applied in artificial neural network. Oscillation occurs at minute 30 until 40 and managed to track set point in less than 60 seconds.

3.3. Prediction Performance of Level Control

3.3.1. Mathematical modelling for level control. A mathematical model for level control is shown as in equation (5).

\[
\frac{dV}{dt} = A \frac{dH}{dt} = bV - a\sqrt{H}
\]  

(5)

where \(V\) is the total volume, \(A\) is the cross sectional area of the tank, \(b\) is the constant value related to the flowrate in the tank. Simulink model for level control is developed as shown in Figure 15.

3.3.2. Performance of level control. The purpose of this control is carried out to investigate the sensitivity of the controller to change the set point or disturbance that occurred during the process. Figure 16 represents the results obtained when the fuzzy neural network is used.
3.4. **Comparison Experimental Value with and without Control System**

Figure 17 and 18 show the comparison of experimental result with control and without control. A comparison is made to determine whether experimental result requires control or not.

Based on figure above, the blue line represents the experimental result without control of pH where the value is fluctuated. To obtain the optimum COD and BOD removal process, the optimum pH value should be achieved. Based on blue line, the pH value is difficult to achieve optimum value. So, the control system must be applied. Purple and red line represents the experimental results that have been controlled. By applying control system, the pH value is able to achieve optimum value.
4. Conclusion
In conclusion, the experimental determination of WQI for Tasik Kejuruteraan UKM water channel was successfully conducted. Based on the experimental result, Tasik Kejuruteraan is polluted and requires a suitable treatment system. In the second part of this work, neural fuzzy network and artificial neural network have been simulated to carry out effective pH and level controls. Based on the simulation results, neural fuzzy network shows the better efficacy in the water treatment controlling schemes compared with artificial neural network.

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