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MEASURING WATER QUALITY USING STATISTICAL ANALYSIS AT SUNGAI PAHANG, MALAYSIA

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Abstract – Water is very important for the economy of the country. However, there are many water issues occurring around the world because of the humans do not appreciate it. Improper disposal of waste causes the water pollution happens. The purpose of this study is to identify the variation of water quality by applying the control chart for individuals and time series control chart for auto correlation data. The appropriate ARIMA model is identified for the auto correlation data and the residuals from the model are used to construct the time series control chart. This study also aims to compare the water quality level among the stations at Kuala Mai by using ANOVA and Kruskal-Wallis test and to compare the water quality parameters for each station with National Water Quality Standards for Malaysia. This study involves eight water quality parameters which are temperature, pH, dissolved oxygen, conductivity, ammonia, phosphate, nitrate, and total suspended solid and there are five stations for each parameter. The investigated river in this study is Sungai Mai which is located at Pahang. The control charts indicate that 13 water quality parameters are out of control. All five stations for both ammonia and phosphate are in statistical control among the eight parameters. ANOVA and Kruskal-Wallis test indicate that there are no significant differences in water quality among the stations for each parameter. Based on National Water Quality Standards for Malaysia, the water quality of Kuala Mai is classified as Class IIA/B and there are 3 parameters exceed the National Water Quality Standards limit.

Keywords: water quality, control chart, National Water Quality Standards Malaysia

I. INTRODUCTION

Water is very important for the economy of the country. In agriculture, water is used for irrigation of crops. For the animal husbandry, human uses water on animal because animals need water to survive. Water is also used in many industries. Food industries always use the method of simmering, boiling or steaming to make the product. Hence, they need water to cook the food or make the beverages. Chemical industries also require water as a solvent to dissolve the compound. Besides, water is used in dam for generate electricity. Human also uses the water in daily life like cooking, dish washing, bathing and others.

There are many developing countries facing the water issues, such as Chinese reported faces five main water issues [1]. They are water shortage, flooding disaster, water pollution, over-exploitation of groundwater and poor water resources management. Besides, expanding agriculture and rapid industrialization also increase the demand of the fresh and clean water. Global warming is one of the factors that cause the shortage of water. In Bangladesh historically, their water source was contaminated with bacteria [2]. In Kenya, human activities like deforestation and also soil degradation leads to the water pollution and the government is unable to develop the water treatment. Hence, the people don't have sufficient clean water for drinking purpose. Improper way of disposal of toxic chemicals and heavy metals from manufacturing or industrial areas and the fertilizer, pesticides, animal wastes and salts from evaporated irrigation water from agriculture may cause the river water is contaminated.

As shown in Table 1 at Appendix 1, National Water Quality Standards (NWQS) is applied to the surface water and classify the water quality parameters into six water use classes. The goal of this standard is to improve the water quality in order to meet the standards of the better water class than actual. In this study, there are six water quality parameters are considered and the measurement reading form five stations will be classified the water quality based on NWQS.

Appendix 1

Table1.1. Water Use Classes in the National Water Quality Standards

Class	Uses
I	Conservation of natural environment Water supply 1 - practically no treatment necessary. Fishery 1 - very sensitive aquatic species
IIA	Water Supply II - conventional treatment required Fishery II - sensitive aquatic species
IIB	Recreational use with body contact
III	Water Supply III - extensive treatment required Fishery III - common, of economic value, and tolerant species livestock drinking
IV	Irrigation
V	None of the above

Table1.2. National Water Quality Standards for Malaysia

Parameter	Unit	Class					
		I	IIA	IIB	III	IV	V
Ammoniacal Nitrogen	mg/l	0.1	0.3	0.3	0.9	2.7	> 2.7
Dissolved Oxygen	mg/l	7	5 - 7	5 – 7	3 - 5	< 3	< 1
pH	-	6.5 - 8.5	6 - 9	6 - 9	5 - 9	5 - 9	-
Total Suspended Solid	mg/l	25	50	50	150	300	300
P	mg/l	Natural levels or absent	0.2	0.2	0.1	-	Level above IV
NO_3	mg/l	Natural levels or absent	7	7	-	5	Level above IV

II. SIGNIFICANCE OF THE SYSTEM

Monitoring the water quality is very expensive and time consuming. However, it is very important for us to monitor the water quality because human health and livelihood are depending on these clean and reliable water supplies. Assessment on the water quality helps us to determine whether or not the ways that we did to protect or to clean the water are effective. Moreover, it also helps the law makers and water managers measure the effectiveness of the water policies. They have to formulate a new policy to improve the water quality continuously to ensure that everybody will be supplied with health and good water quality.

The water quality of river becomes a big issue in Malaysia. Hence, it is necessary to investigate each parameter of water quality by using statistical methods. Moreover, the water pollution will become more serious if the locations of the source of pollution are not determined. Therefore, this study was design and conducted to identify the variation of water quality by applying control chart. This study also aims to compare the water quality level among the stations at Kuala Mai and to compare the water quality parameters for each station with National Water Quality Standards.

III. REVIEW OF THE LITERATURE

Research on water quality changes in the river by using Shewhart control charts and functional data analysis through global quality index. Their results showed that Shewhart control charts are effective in identifying and eliminating the unusual values in the analysis of quality of water [3]. Meanwhile, [4] did a study on microbiological quality control of purified water and used the Shewhart control chart in the study and results showed that there are two regions were in the out of control state, and [5] had done a study on spring monitoring in karst terranes by applying the control chart. They used combination of Shewhart control chart and CUSUM control chart in monitoring the quality of water in the presence of springs. The application of Shewhart and CUSUM control chart has been applied on monitoring sewage treatment plants [6]. Shewhart-CUSUM control charts also widely used in various field such as monitoring the groundwater [7], monitoring water supply in south-western Australia [8]*, detect the unusual variation in emissions data [9], dynamic mass balancing for wastewater treatment [10], controlling the water quality of the Mandurim River [11] and to identify and follow up the continuous changes in the system state when the researchers added the new data into the system [12].

Analysis of variance (ANOVA) is widely used to compare the similarities of mean from more than two different groups, such that the effect of the fertilizer source on ground and surface water quality in drainage from turfgrass [13], treatment block interactions effects [14], the effects of multiple low-head dams on fish, macroinvertebrates, habitat, and water quality in the Fox River, Illinois [15]. In order to use Anova, the data should be followed normality assumption, while Kruskal-Wallis can be used as alternative technique without knowing the distribution of the data. Kruskal-Wallis has been used to test for analyse the surface runoff water quality [16], studied on Chromosome aberration (CA) and micronucleus (MN) frequencies in *Allium cepa* cells exposed to petroleum polluted water [17], to determine the differences of rainwater quality parameter among the station. Therefore this study will consider the control chart, analysis of variance and Kruskal-Wallis test to investigate and analyse the water quality at Sungai Pahang.

IV. METHODOLOGY

A. Data Description

There are five stations and eight water quality parameters involved in this study. The eight water quality parameters are water temperature, dissolved oxygen, pH, conductivity, ammonia, phosphate, nitrate and total suspended solid. The samples were collected from each station and there is only one subgroup for each sample so it is an individual data.

B. Control Chart

One of the assumptions that needed to fulfil when using a control chart: the underlying distribution of the quality characteristics is normal. The test that can be used to assess the normality assumption is Anderson-Darling test. Anderson-Darling test is a test that used to measure how well the data follow a specific distribution. If the data is not normal, Box-Cox transformation is applied. The second assumption is the observations are independent and identically distributed. The scatter diagram is used to test for autocorrelation or independence of the measurements before constructing the control chart.

There is one control chart that applied to the data with individual observation called Individual X-Moving Range chart (IX-MR chart). Individual chart (I-chart) is used to track the process level and moving range chart (MR chart) is used to track process variation. The data are plotted according to the time order in this chart [18]. Shewhart control chart for individuals is used because the data in this study is individual measurement. Moreover, Shewhart control charts seem to be the best for the purpose of checking the statistical control of a process [19]. For constructing the I- chart, the center line is set in the average value of the process.

$$\bar{x} = \frac{\sum x}{n} \qquad (1)$$

The upper control limit is set three standard deviation above the center line and lower control limit is set three standard deviation below the center line. Process variability is estimated by using the moving range of two successive observations. The moving range is

$$MR_i = \left| x_i - x_{i-1} \right| \qquad (2)$$

The standard deviation of the process is estimated from the moving range of size 2 as $\overline{MR}/d_2$, where d_2 is the mean of the distribution of the relative range. The value of $d_2$can be read from the table of factors for constructing variables control charts [20]. Hence, the center line and control limits of the individuals control chart are

$$\mathrm{UCL} = \bar{x} + 3\frac{\overline{MR}}{d_2}$$

$\mathrm{CL} = \bar{x}$ (3)
$\mathrm{LCL} = \bar{x} - 3\frac{\overline{MR}}{d_2}$

For the moving average chart, the center line is the average of the moving range of the two observations.

$\overline{MR} = \frac{\sum MR}{n-1}$ (4)

The parameters of the moving range chart are
$\mathrm{UCL} = D_4\overline{MR}$
$\mathrm{CL} = \overline{MR}$(5)
$\mathrm{LCL} = D_3\overline{MR}$

where D_3 and D_4 are the constraints that provide 3σ limits for a given sample size. The value of $D_3$and D_4 can be read from the table of factors for constructing variables control charts [20].

C. Time Series Control Chart

Time series control chart is used for the data with autocorrelation. It is a typical control chart that applied to the residuals the data that fitted by a time series model. The most commonly used time series model is ARIMA model. The general form of the ARIMA *(p, d, q)* is

$\Phi_p(B)\nabla^d x_t = \Theta_q(B)\varepsilon_t$ (6)

where

$\Phi_p(B) = 1 - \phi_1 B - \phi_2 B^2 - \cdots - \phi_p B^p$ (7)

is autoregressive polynomial of p-th order,

$\Theta_q(B) = 1 - \theta_1 B - \theta_2 B^2 - \cdots - \theta_q B^q$ (8)

is moving average polynomial of q-th order and

$\nabla^d = (1 - B)^d$ (9)

where

ϕ = parameter estimate of the autoregressive component
θ = parameter estimate of the moving average component
∇ = backward difference
B = backward shift operator
ε_t= white noise

Let consider the model:

$x_t = \xi + \phi x_{t-1} + \varepsilon_t$ (10)

where ξ and ϕ ($-1 < \phi < 1$) are unknown constants and ε_t is normally and independently distributed with zero mean and standard deviation σ. Equation 3.16 is a first-order autoregressive model. The first-order moving average model is as below:

$x_t = \mu + \varepsilon_t - \theta\varepsilon_{t-1}$ (11)

So, the first procedure is identification of the time series model and estimation of the parameters. Then, construct the typical control chart for the residuals of the selected model.

D. ANOVA and Kruskal-Wallis Test

The ANOVA procedure stands for analysis of variance. It is used to compare the means between groups and to determine if these means are statistically significantly different with one another. In this study, ANOVA is used to compare the water quality parameter level within stations. The goal of ANOVA is to determine the amount of variability in groups of data and to see whether the variability is smaller within groups than between groups. For the hypothesis testing of equality of treatment means, the test statistic is

$F_0 = \frac{SS_{\mathrm{Treatments}}/(a-1)}{SS_E/(N-a)} = \frac{MS_{\mathrm{Treatment}}}{MS_E}$ (12)

Kruskal-Wallis test is a nonparametric statistical test that used to determine if there are significant differences between two or more groups of an independent variable on a continuous or ordinal dependent variable. It is used when the assumptions of one-way ANOVA are not met. It makes only general assumptions related to the distribution's source and it can be applied to the data that is not normally distributed which means it does not depend on the distribution shape of the population [21]. In this study, Kruskal-Wallis test is used to compare the water quality parameter within the stations. The H statistic is calculated as follow:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{C} \frac{R_i^2}{n_i} - 3(N+1) \qquad (13)$$

where N = sum of sample sizes for all samples
C = number of the samples
n_i = size of the i^{th} sample
R_i = sum of the rank in i^{th} sample

V. RESULTS AND DISCUSSIONS

A. Assumptions of Control Chart

The Anderson-Darling test indicates that there are 26 out of total 40 stations following the normal distribution. For the other stations with non-normal data, the Box-Cox transformation is applied. After applying the transformation to the non-normal data, the independence assumption of constructing control chart is checked by using the scatterplot. The scatterplots indicate that the autocorrelation exists in most of the stations. There are 34 out of 40 stations are dependent and time series control chart is used for these stations. The other 6 stations which are independent will be applied with Shewhart control chart for individuals. However, for all of the stations of conductivity, ammonia, phosphate, nitrate and total suspended solid, Shewhart control chart is applied due to the fewer observations of these stations. The minimum observation that required to build a reasonable ARIMA model is 50 observations. Hence, time series control chart is not used although existence of autocorrelation in these stations. Only 5 stations of pH and 4 stations of dissolved oxygen are using residuals of the suitable model to construct Shewhart control chart for individuals while 41 stations are using original data to construct Shewhart control chart for individuals.

B. Time Series Modelling

There are 9 stations undergoing the fitting of ARIMA model. They are station 1, 2, 3, 4, 5 of pH and station 2, 3, 4, 5 of dissolved oxygen. The Augmented Dickey-Fuller test indicates that the null hypothesis, according to which the time series is not stationary, cannot be rejected at 5% of significant level for all of the stations involved of these two parameters. Hence, these stations are needed to undergo the differencing procedure to achieve the stationarity of the data. The appropriate model for each station is summarized in Table 3. All the parameters of these models are estimated and the Ljung-Box test indicates that there is no existence of autocorrelation in these data. Hence, the residuals of these models for each station can be used for constructing the typical control chart.

Table 3: The appropriate model for each station

Parameter	Station no.	Model
pH	1	ARIMA (1,2,0)
	2	ARIMA (1,2,0)
	3	SARIMA(1,0,0)(1,1,1)$_{12}$
	4	ARIMA(2,2,0)
	5	SARIMA(1,0,0)(1,1,1)$_{12}$
Dissolved oxygen	2	ARIMA (1,1,1)
	3	ARIMA (1,1,2)
	4	ARIMA (1,1,5)
	5	ARIMA (1,1,1)

C. Shewhart Control Chart for Individuals

For both station 1 and station 2 of temperature, there are 1 point out of control limit in I-chart and 4 points out of control limit in MR chart. The I-chart of station 3 gives 2 points out of upper control limit while there are 4 points out of the control limit in MR chart of station 3. For the station 4 of temperature, there are 5 points out of upper control limit and 3 points out of lower control limit in I-chart. The MR chart of station 4 gives 2 points out of control limit. For the station 5, there are total 12 points out of control limits in I-chart. There are 3 points out of the upper control limit in MR chart. For all the stations of the temperature, the processes are out of control.

For the station 1 of pH, there is 1 point out of the control limit for both I chart and MR chart. The I-chart of station 2 gives no point out of the control limit but there is 1 point out of the control limit in MR chart. For the station 3 of pH, there is no any point are out of control limit in both I-chart and MR chart. For both I chart and MR chart in station 4, there is 1 point falling beyond the 3σ control limit. The I-chart and MR chart in station 5 gives no point are out of the control limit. There are 3 stations out of control which are station 1, 2 and 4 while only station 3 and station 5 are in the statistical control.

For the station 1 of dissolved oxygen, there is one point falling beyond the lower control limit in I chart. For the MR chart of station 1, it gives 3 points are out the control limit. For the station 2, there is no point falling beyond the control limit in both I-chart and MR chart but there are 2 out of 3 consecutive points fall beyond the 2σ limit in MR chart. For the station 3 of dissolved oxygen, the I chart gives no point out of the control limit but MR chart gives 1 point out of the upper control limit. There is no point fall beyond the control limits for both I-chart and MR chart of station 4. For the station 5, both I-chart and MR chart recorded no point falls beyond the control limits. Only station 4 and 5 are in the statistical control while station 1, 2 and 3 are out of the control. For all stations of conductivity, ammonia and phosphate, both I-chart and MR chart show no point are out of the control limits. For both nitrate and total suspended solid, only MR chart of station 4 recorded 1 point out of the control limit.

D. ANOVA and Kruskal-Wallis Test

The results of normality test for all parameters indicates that conductivity is the only one water quality parameter that is normally distributed (p=0.554). The other water quality parameters like temperature, pH, dissolved oxygen, ammonia, phosphate, nitrate and total suspended solid are not normally distributed (p<0.005). For parameter ammonia and phosphate, Box-Cox transformation is applied to the data to make it become normal. One-way ANOVA test is applied and the results show that there are no significant differences (p>0.05) among the stations for these three parameters. The other five parameters are highly not normal and the transformation does not have any effect on these parameters. Hence, Kruskal-Wallis test is used to analyse these non-normal parameters. Kruskal-Wallis test shows that there are no significant differences (p>0.05) among the stations for temperature, pH, dissolved oxygen, nitrate and total suspended solid.

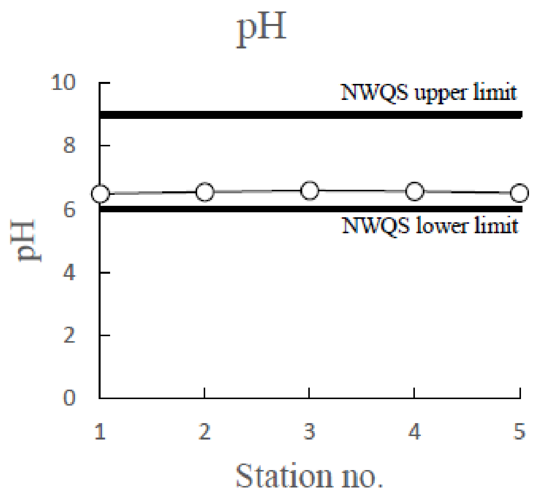
E. National Water Quality Standards Malaysia

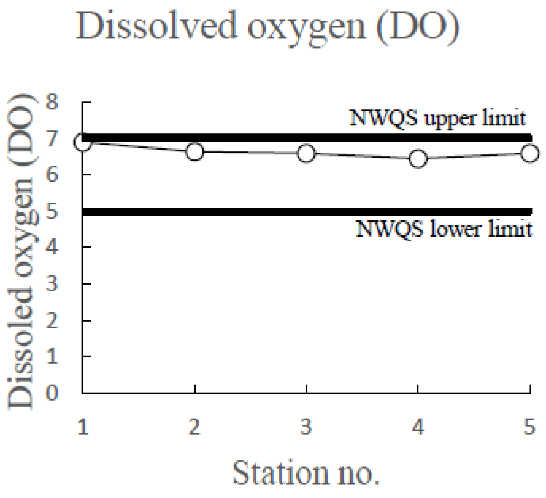
Table 4 shows the six water quality parameter concentrations. The pH values range from 6.49 to 6.58. The mean pH value recorded is 6.54. All the stations sampled are classified as Class IIA/B according to NWQS classification. For the dissolved oxygen (DO), its concentration varies from 6.44 mg/L to 6.90 mg/L with a mean value of 6.63 mg/L. Based on the NWQS classification, all stations are classified as Class IIA/B. The ammonia of the water sampled range from 0.86 mg/L to 0.91 mg/L. The mean value is recorded as 0.89 mg/L which indicated that all the stations are classified as Class III based on the NWQS classification. The mean concentration of phosphate in the study area is recorded as 0.31 mg/L. According to the NWQS classification, all stations are categorised as Class IIA/B. The nitrate concentration varies from 0.09 mg/L to 0.14 mg/L. The average value of nitrate concentration is recorded as 0.11 mg/L and this indicates that all stations are classified as Class IV, based on the NWQS classification. The total suspended solid (TSS) concentration varies from 157.88 mg/L to 188 mg/L. The average value of the TSS concentration is recorded as 169.5 mg/L. According to the NWQS classification, all stations are categorised as Class III.

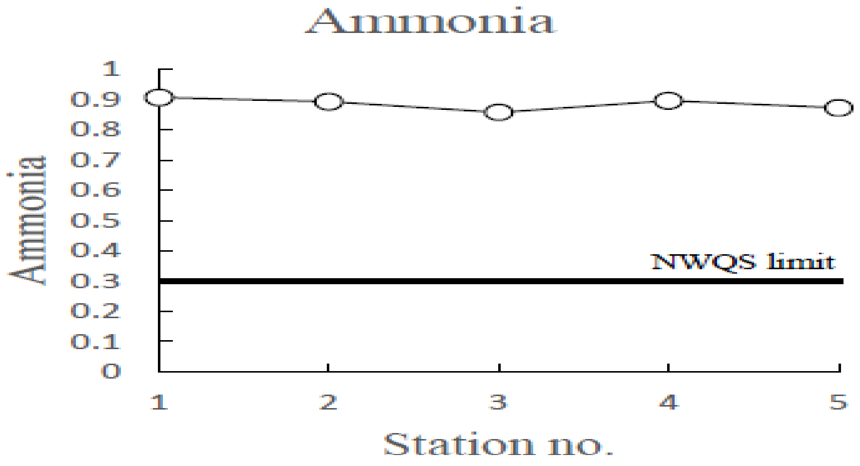
Table 4: Water quality parameter concentrations

Station No.	pH	DO	Ammonia	Phosphate	Nitrate	TSS
1	6.49	6.90	0.91	0.34	0.11	164.63
2	6.54	6.64	0.89	0.25	0.10	164.38
3	6.58	6.59	0.86	0.38	0.09	172.63
4	6.56	6.44	0.90	0.29	0.09	157.88
5	6.51	6.59	0.87	0.30	0.14	188.00
Average	6.54	6.63	0.89	0.31	0.11	169.50
NWQS Class	IIA/B	IIA/B	III	IIA/B	IV	III

The water quality of Kuala Mai is classified as Class IIA/B since most of the water quality parameters are in the range of this class. The NWQS limits of Class IIA/B are used for all six water quality parameters. The results of all the stations of the water quality parameters are shown in Figure 1. For water quality parameter pH, the value of the lower limit and upper limit of the NWQS for Class IIA/B are 6 and 9. The lower and upper limits for the dissolved oxygen (DO) are 5 mg/L and 7 mg/L. From the graph, all of the stations are in the NWQS limits. For the ammonia and phosphate, the NWQS limits for Class IIA/B are 0.3 mg/L and 0.2 mg/L. Based on the graphs, all of the stations for ammonia and phosphate exceed the limits of the National Water Quality Standards. The NWQS limit for nitrate is 7 mg/L. The graph shows that all the stations are less than 1 mg/L which are under the limit. For the total suspended solid, the limit of the National Water Quality Standards for Class IIA/B is 50 mg/L. Based on the graph, all five stations exceed the limit.







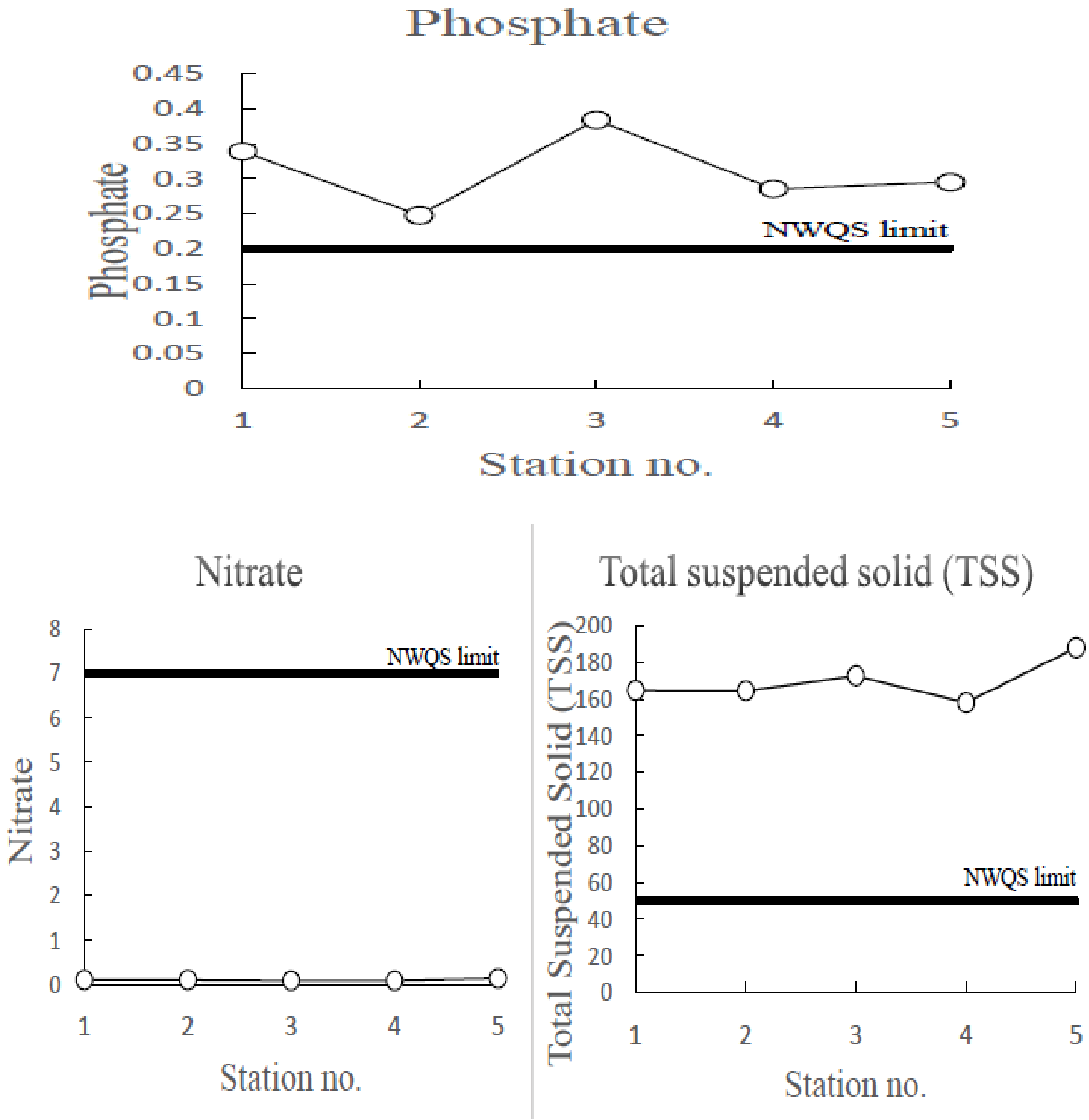


Figure1. Water quality parameter concentrations at 5 stations

VI. CONCLUSIONS

For all the stations of the temperature, the processes are out of control. For the pH, there are 3 stations out of control which are station 1, 2 and 4 but only station 3 and station 5 are in the statistical control. For dissolved oxygen, station 1, 2 and 3 are out of the control but only station 4 and 5 are in the statistical control. For conductivity, ammonia and phosphate, all the stations are in the statistical control. For nitrate and total suspended solid, there are 4 stations which are station 1, 2, 3, and 5 are in statistical control and only station 4 is out of control. The corrective action is needed. The results of ANOVA and Kruskal-Wallis tests show that there are no significant differences among the stations for each parameter. If the river water is polluted or the value of the water quality parameter is abnormal, the source of pollution can be concluded that is located at station 1 of Kuala Mai or before station 1. The water quality of Kuala Mai is classified as Class IIA/B based on National Water Quality Standards. All of the stations for pH, dissolved oxygen and nitrate are in the National Water Quality Standards limits. For ammonia, phosphate and total suspended solid, all of the stations exceed the National Water Quality Standards Malaysia limits.

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