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Unmanned Surface Vehicle (USV) for Water and Aquatic Pollution Monitoring Using IoT

Afif Najmi Haizol[1], Shaharil Mohd Shah[2]*

[1] *Faculty of Electrical and Electric Engineering*
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA
[2] *Advanced Telecommunication Research Centre (ATRC)*
Universiti Tun Hussein Onn Malaysia, 86400 Batu Pahat, Johor, MALAYSIA

*Corresponding Author: shaharil@uthm.edu.my
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Abstract

Water pollution is a very important issue because of its direct impact on human life, animals, and ecosystems. The pandemic situation made it difficult to conduct the testing in the actual water bodies such as rivers, lakes, and seas. Although the water drone in that work has been developed that can be controlled remotely, it is only able to record the water temperature. Therefore, an unmanned surface vehicle (USV) for water and aquatic pollution monitoring using IoT is proposed in this work to improve the previous work by adding a turbidity sensor, total dissolved solids (TDS) sensor and E-201-C pH electrode probe sensor. The USV was used to collect and record water quality readings in terms of turbidity in NTU, TDS in ppm and pH at three different locations in the morning, evening and night. The three locations are the lake in front of the FKEE building, the lake in front of the Development and Maintenance Office UTHM and the watershed at Taman Universiti, Parit Raja. The duration of each experiment is approximately one hour with data taken for every 15 seconds and the data are sent to ThingSpeak application to be displayed for continuous monitoring and stored in its database. The data from ThingSpeak application are then exported to Microsoft excel to plot the graphs, which also calculates the average values. These averages are mapped onto the corresponding NTU scale, TDS level and rating, and pH scale. The turbidity was generally found to be higher at night, while the TDS was highest in the morning at the lake in front of the Development and Maintenance Office UTHM and in the evening at the lake in front of the FKEE building. The pH values varied, being highest in the evening at the lake in front of the FKEE building and the lake in front of the Development and Maintenance Office UTHM, and at night at the watershed at Taman Universiti, Parit Raja. These results indicate that the USV's sensors provide reliable measurements for monitoring water and aquatic pollution. The variations in the measurements can be attributed to factors such as weather conditions, algae activity, and changes in water temperature. Therefore, it is shown that the USV provides a valuable tool for continuous monitoring of water and aquatic pollution.

1. Introduction

Water is a basic and essential natural resource, that is crucially important for the survival of living organisms [1]. Water pollution causes sea, river, lake, and groundwater ecosystems to be affected. There are several sensors for testing water quality such as pH sensors. The pH sensor is for measuring the acidity and alkalinity of water on a scale of 0 to 14. The pH value of a solution, also known as its hydrogen ion concentration index, reflects the activity of hydrogen ions [2]. If the pH of drinking water is too low, it can cause health problems [3]. In addition, a TDS sensor is a device used to measure the amount of dissolved solids in a solution, usually water [4]. After that, the turbidity sensor can also determine the quality of water that is safe to use.

An unmanned surface vehicle (USV) is a boat or ship that operates on the surface of water without a crew by using a remote-control device. Nowadays, with the rapid advancement of technology, it can be operated by smart devices such as smartphones [5]. USVs have been widely used in the twenty-first century for a range of purposes including oceanography and environmental monitoring, as well as cargo transport, and military applications. Wireless communication is becoming more common and helping people in their daily lives and tasks. With the help of IoT, it is easier to monitor and improve the sustainability of environmental resources optimally, and in this case, it is water resources. As the aquaculture industry grows rapidly and technology advances, various water qualities such as turbidity and pH become the most important factors to monitor and measure. The data will be sent to a secure IoT cloud server autonomously to be viewed on the internet using a web page which might be useful for analysis purposes [6].

The pandemic situation made it difficult to conduct the testing in the actual water bodies, such as rivers, lakes, and seas. Although the water drone has been developed that can be controlled remotely, it is only able to record the water temperature. Therefore, an unmanned surface vehicle (USV) for Water and Aquatic Pollution Monitoring using IoT is proposed in this work to improve the previous work by adding a turbidity sensor, TDS sensor. This USV is controlled by a remote-control device and uses IoT for real-time water condition monitoring which is equipped with multiple sensors to monitor those water parameters. Therefore, a suitable USV design is required to avoid any interruptions between the USV and aquatic ecosystem in the water. Moreover, the design of USV is based on the concept of a catamaran boat to achieve better stability during operation and ease of movement on the surface of the water. The use of batteries with bigger capacity is utilised so that the USV can be used longer on the water and provides more power to the motor. The data obtained from the sensors shall be sent to ThingSpeak application for continuous monitoring by authorized personnel.

2. Methodology

This section discusses the methodology applied in completing this work.

2.1 Block Diagram

Fig. 1 shows the input and output components that are connected to the ESP32 Wi-Fi module with NodeMCU-32S base module as the main controlling unit. The key component, which is the E-201-C pH electrode probe sensor, acts as the input to measure pH acidity on a scale from 0 to 14, with 0 being the most basic. Besides that, TDS sensor measures the concentration of dissolved solids in a water and Turbidity sensor is to measure the suspended solids in water from the amount of light scattered. The processed signals will then be sent to the output which is ThingSpeak application to collect the data for analysis purposes.

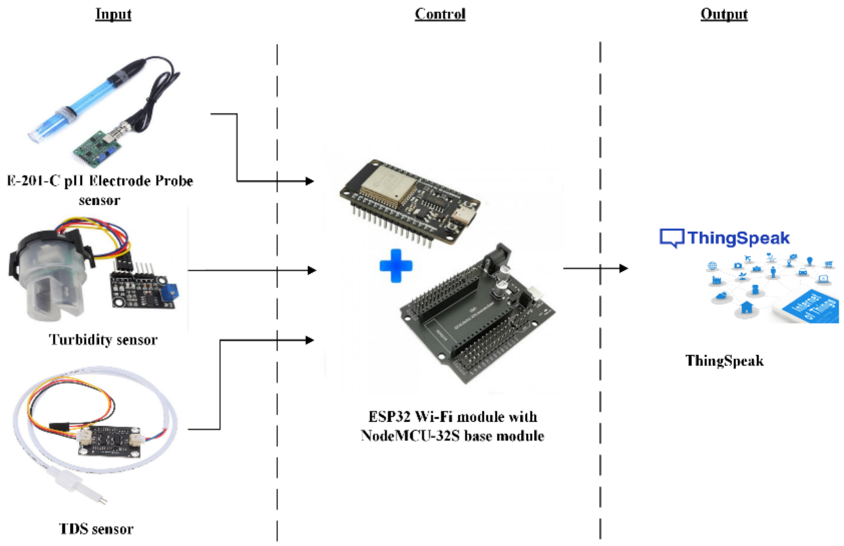

Fig. 1 *Block diagram of the unmanned surface vehicle (USV) for water and aquatic pollution monitoring using IoT*

2.2 ThingSpeak Application

ThingSpeak is an open source "Internet of Things" platform that allows users to store and retrieve data from things using HTTP over the internet or over a local area network [7]. In addition, ThingSpeak also allows users to build applications around the data collected by sensors, and features include real-time data collection, data processing, visualization, applications, and plugins. Users can enter the channel ID and view the data in row and column charts. The ThingSpeak IoT Monitor widget allows users to monitor their IoT devices connected to ThingSpeak and obtain their sensor readings on their home screen. In this work, the turbidity, TDS and pH in water to record the levels of water and aquatic pollution and the data are sent to ThingSpeak application to be displayed for continuous monitoring and stored in its database.

3. Results and Discussion

This section discusses the result obtained and analysis on the unmanned surface vehicle (USV) for Water and Aquatic Pollution Monitoring using IoT. This section is divided into the water quality parameter, final product, experimental setup, and water quality parameters at the three locations.

3.1 Water Quality Parameter

Water quality parameters refer to the chemical, physical, and biological properties of water that can be tested, measured, or monitored based on the desired parameters of concern. There are three water quality parameters used in this experiment: turbidity, TDS and potential of hydrogen (pH).

3.1.1 Turbidity

In this experiment, the turbidity values are measured in nephelometric turbidity units (NTU). Fig. 2 shows the NTU scale for three types of water: clean, cloudy and very cloudy or dirty, mapped by a group of volunteers [8].

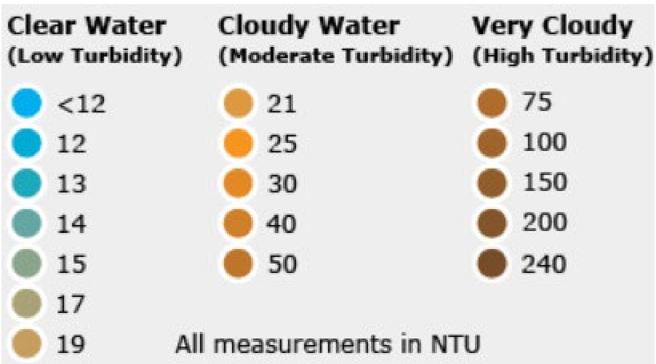

Fig. 2 *NTU scale recorded by a group of volunteers in [9]*

3.1.2 Total Dissolved Solids (TDS)

Based on this experiment, the TDS values are measured in parts per million (ppm). Table 1 shows the TDS level and rating in water in parts per million (ppm) to illustrate various water ratings [9].

Table 1 *TDS level and rating in water in parts per million (ppm) [9]*

TDS level (in ppm)	Rating
Less than 50	Considered low
Between 50 - 150	Excellent for drinking
150 - 250	Good
250 - 300	Fair
300 - 500	Poor
Above 1200	Unacceptable

3.1.3 Potential of Hydrogen (pH)

This experiment categorizes potential of hydrogen (pH) values as either acidic or alkaline. The pH scale ranges from 0 to 14, with 7 being neutral, values below 7 indicating acidity, and values above 7 indicating acidity as shown in Fig. 3 [10].

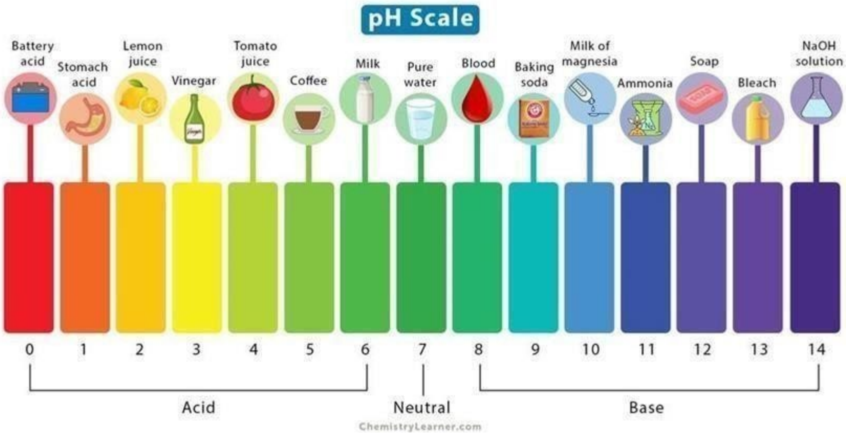

Fig. 3 *pH scale [10]*

3.2 Final Product

Fig. 5 displays the final product of unmanned surface vehicle (USV) for water and aquatic pollution monitoring using IoT. Fig. 5 (a) shows the entire USV which is made mainly from polyvinyl chloride (PVC) pipes with various diameters which are fastened using steel strips. The sensors which consist of a Turbidity sensor, TDS sensor and E-201-C pH electrode probe sensor are positioned below the junction box. A propeller powered by a brushless DC motor, a brushless motor speed controller and a metal gear analog servo are placed at the back of the USV as can be viewed in Fig. 5 (b). The use of yellow colour on the USV is a common practice due to the facts that yellow colour increases the visibility of USVs and thus, making them really stands out on the water especially in varying light and weather conditions and also for the safety of other watercrafts and the USV itself [11].

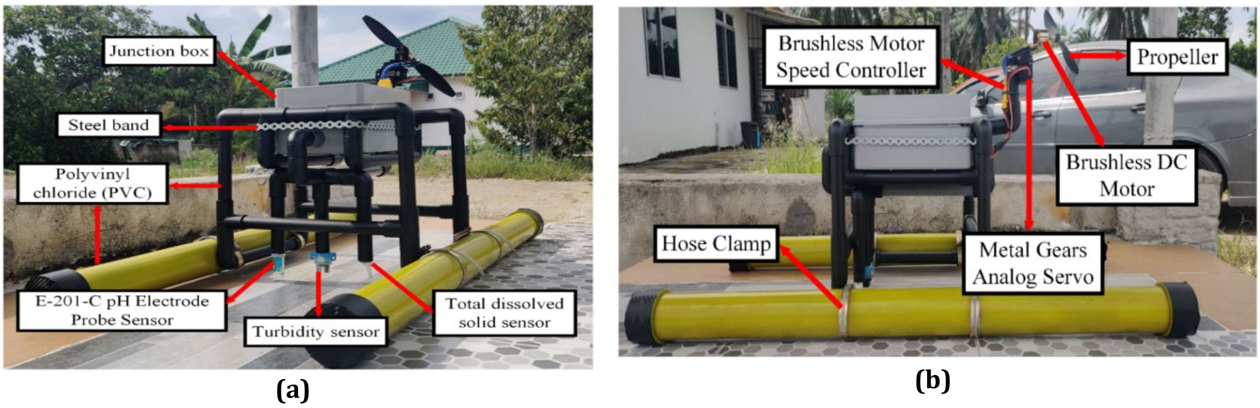

Fig. 5 *The final product of unmanned surface vehicle (USV) for water and aquatic pollution monitoring using IoT (a) Entire USV view; (b) Side view*

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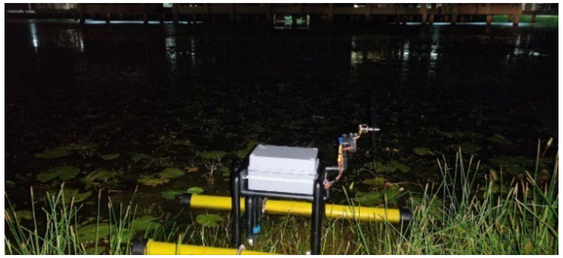
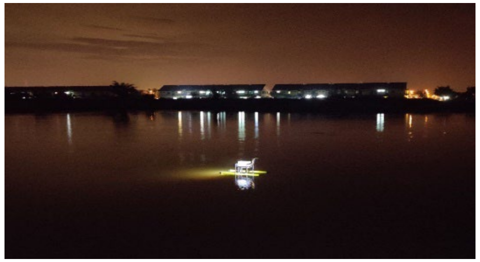
3.3 Experimental Setup

The experimental setups were prepared for measuring the turbidity, TDS and pH in water to record the levels of water and aquatic pollution. The duration of each experiment is approximately one hour with data taken for every 15 seconds and the data are sent to ThingSpeak application to be displayed for continuous monitoring and stored in its database. The data from ThingSpeak are then exported to Microsoft Excel to be plotted. Table 2 shows the experimental setups that were carried out in the morning, evening, and night at three locations: the lake in front of FKEE building, the lake in front of the Development and Maintenance Office UTHM and the watershed at Taman Universiti, Parit Raja.

Table 2 *Experimental setups for measuring the turbidity, TDS and pH in water that were carried out in the morning, evening, and night*

Time	The lake in front of FKEE building	The lake in front of the Development and Maintenance Office UTHM	The watershed at Taman Universiti, Parit Raja
Morning			
Evening			
Night			

3.4 Water Quality Parameters at the Three Locations

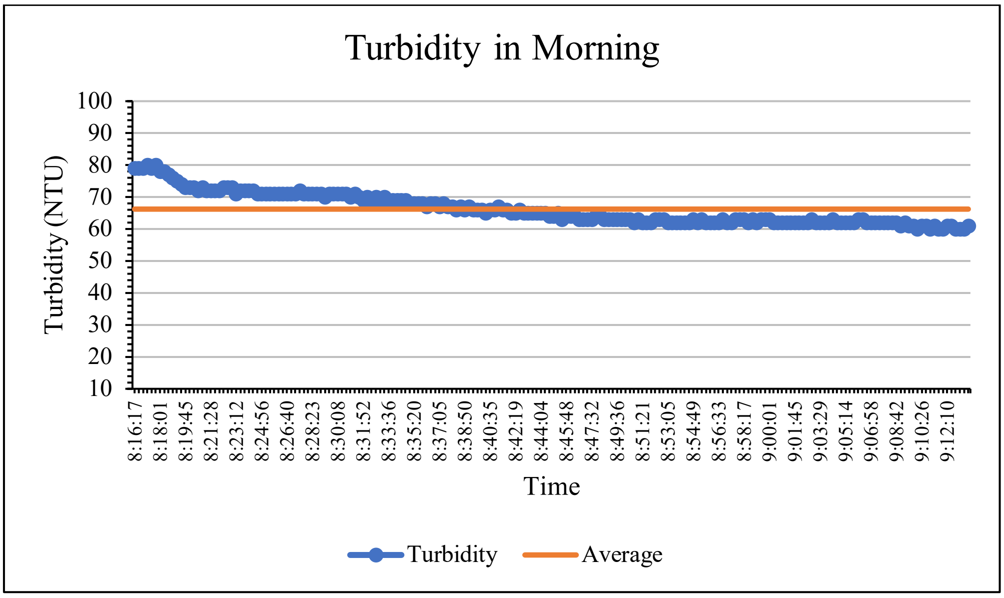
Experiments were conducted to record and monitor the level of turbidity, TDS and water pH in the morning, evening and night at three different locations, namely the lake in front of FKEE building, the lake in front of the Development and Maintenance Office UTHM and the watershed at Taman Universiti, Parit Raja.

3.4.1 The Lake in Front of FKEE Building

This section discusses the water quality measurements obtained from the Turbidity sensor, TDS sensor and E-201-C pH electrode probe sensor from the lake in front of FKEE building.

(i) Turbidity

Fig. 6 shows the turbidity values collected in the morning, evening and night which are measured in nephelometric turbidity units (NTU). The NTU scale is based on the chart in Fig. 2. Fig. 6 (a) shows the turbidity values taken in the morning from 8.16 until 9.13 am. From the figure, the turbidity ranges from 60 to 80 NTU with an average value of 66.23 NTU. Based on the NTU scale in Fig.2, the average value of turbidity shows that the water is *Cloudy*. Fig. 6 (b) displays the turbidity values taken in the evening from 16.46 until 17.45 pm. From the figure, the turbidity ranges from 26 to 92 NTU with an average value of 68.93 NTU. The average value of turbidity also shows that the water is *Cloudy*. Fig. 6 (c) depicts the turbidity values taken at night from 21.00 until 21.58 pm. From the figure, the turbidity ranges from 82 to 134 NTU with an average value of 91.79 NTU. In this case, the average value of turbidity shows that the water is *Dirty*. Table 3 compares the turbidity values in the morning, evening and night. From the table, the turbidity appears to be higher at night and lowest in the evening. Turbidity rises at night due to the influence of wind and currents on particle mixing and sedimentation in the water. Turbulence and waves caused by wind and currents can resuspend sediment and organic debris from the bottom and thus, increasing water turbidity [12].



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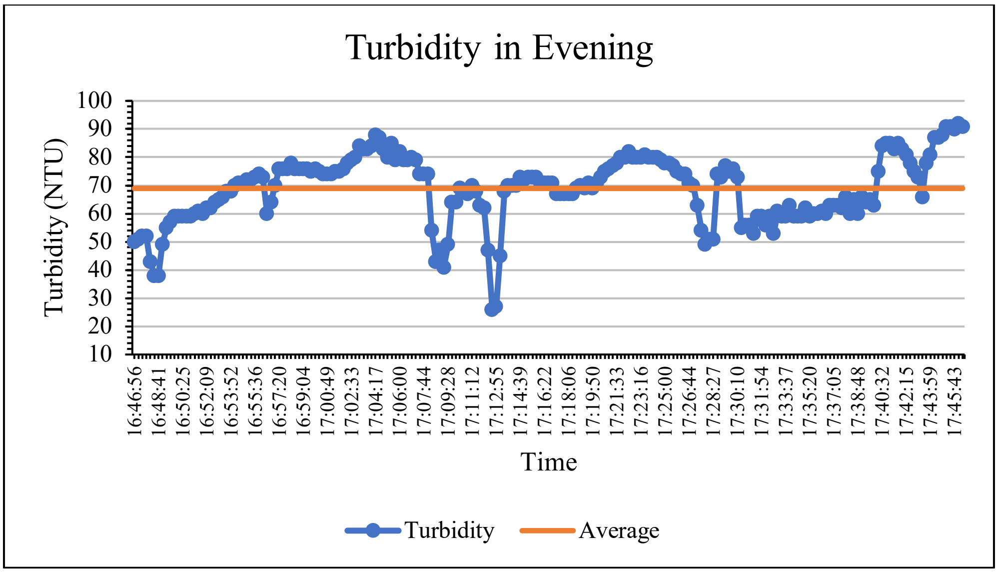

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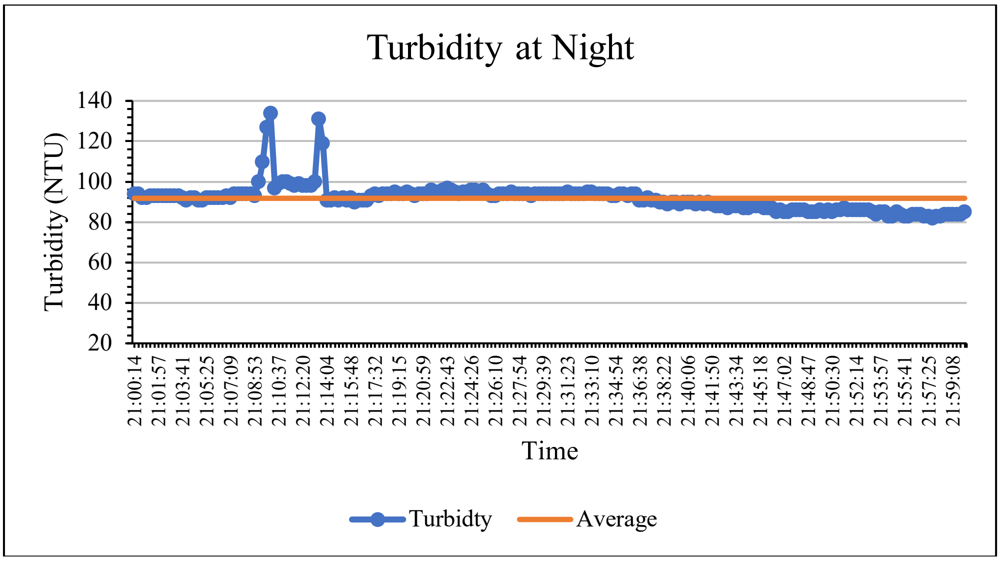


(c)

Fig. 6 *Data collected on the lake in front of FKEE building*
(a) Turbidity in morning; (b) Turbidity in evening; (c) Turbidity at night

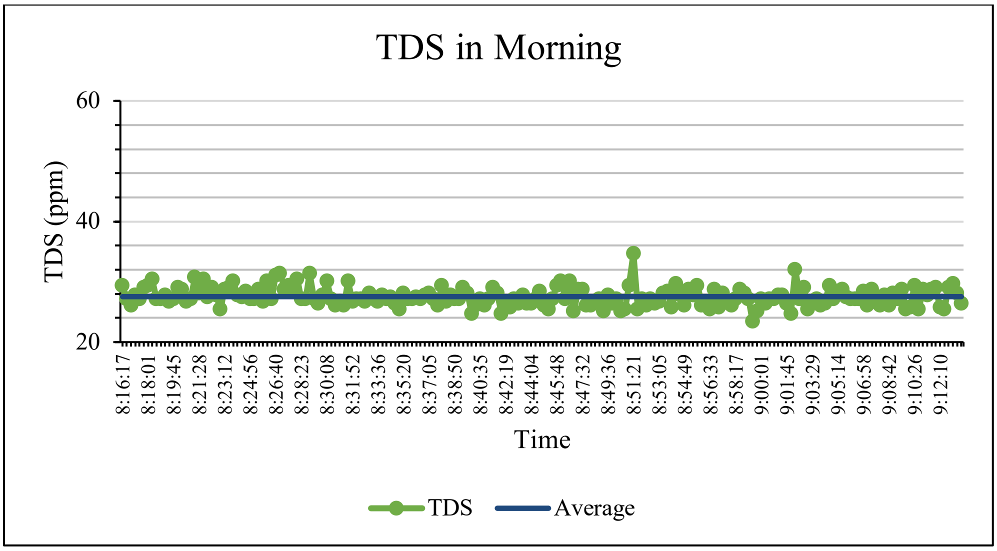
Table 3 *Minimum, maximum, and average value for turbidity at different time*

	Morning	Evening	Night
Minimum (NTU)	60	26	82
Maximum (NTU)	80	92	134
Average (NTU)	66.23	68.93	91.79
NTU Scale	*Cloudy*	*Cloudy*	*Dirty*

(ii) Total Dissolved Solids (TDS)

Fig. 7 depicts the TDS values collected in the morning, evening and night which are measured in parts per million (ppm). The TDS level and rating in water (ppm) is based on Table 1. Fig. 7 (a) displays the TDS taken in the morning from 8.16 until 9.13 am. From the figure, the TDS ranges from 23.45 to 34.73 ppm with an average value of 27.54 ppm. The average value of TDS shows that the water rating is *Considered Low* and safe to drink. Fig. 7 (b) shows the TDS values taken in the evening from 16.46 until 17.45 pm. From the figure, the TDS ranges from 28.78 to

38.67 ppm with an average value of 34.86 ppm. The average value of TDS also shows that the water rating is *Considered Low* and safe to drink. Fig. 7 (c) presents the TDS values taken at night from 21.00 until 21.58 pm. From the figure, the TDS ranges from 28.78 to 38.67 ppm with an average value of 32.71 ppm. Similarly, the average value of TDS shows that the water rating is *Considered Low* and safe to drink. Table 4 compares the TDS values in the morning, evening and night. From the table, the water quality in terms of TDS appears to be higher in the evening and night due to the hot weather compared to the morning (the experiment in the morning begins at 8.16 am). This is consistent with the fact that a hot weather condition and high-water temperatures accelerate the rate of evaporation and increase the value of dissolved solids in water. In the daytime, the heat from the sun can lead to water evaporation, which in turn results in a rise in TDS levels. Conversely, at night, as the temperature drops and evaporation reduces, there may be a decrease in TDS levels [13].



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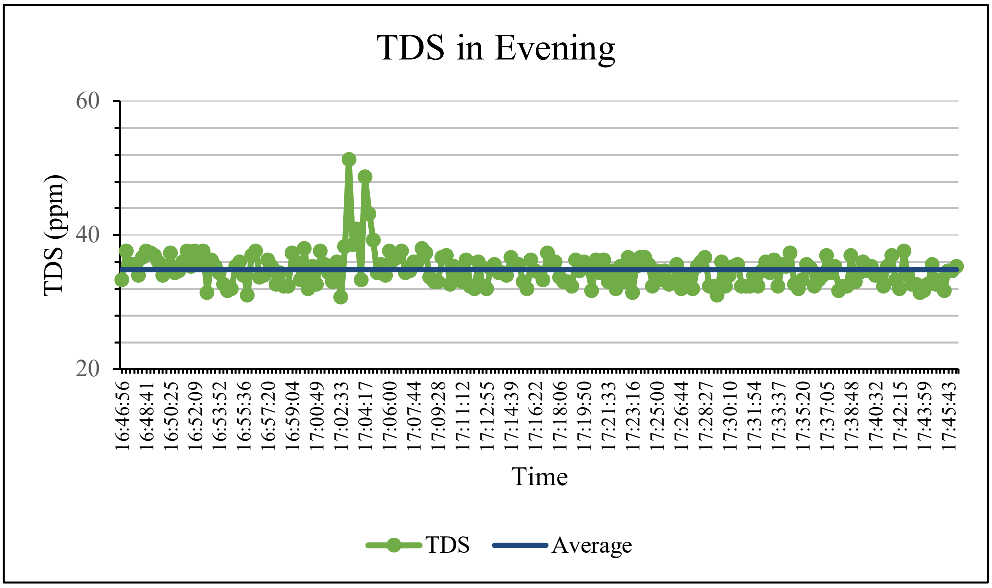

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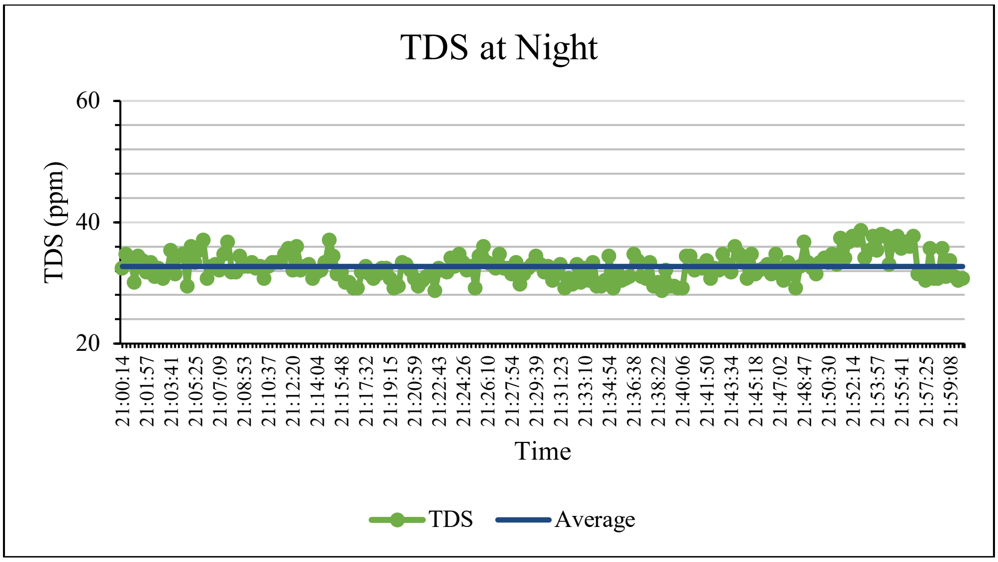


(c)

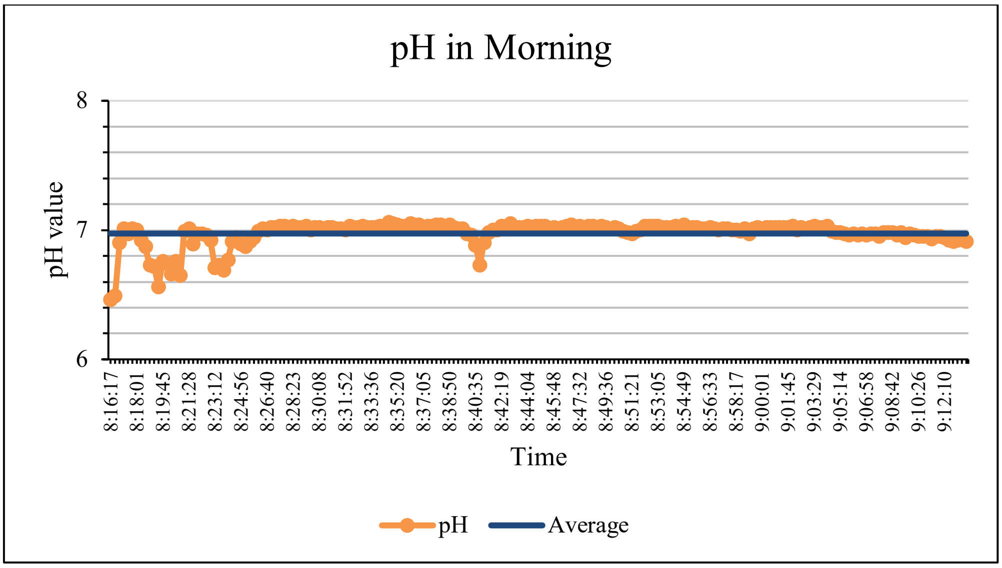
Fig. 7 *Data collected on the lake in front of FKEE building (a) TDS in morning; (b) TDS in evening; (c) TDS at night*

Table 4 *Minimum, maximum, and average value for TDS at different time*

	Morning	Evening	Night
Minimum (ppm)	23.45	30.77	28.78
Maximum (ppm)	34.75	51.36	38.67
Average (ppm)	27.54	34.86	32.71
TDS rating	*Considered Low (safe to drink)*	*Considered Low (safe to drink)*	*Considered Low (safe to drink)*

(iii) Potential of Hydrogen (pH)

Fig. 8 displays the pH values collected in the morning, evening and night which are classified as acidic or alkaline. The pH scale is based on Fig. 3. Fig. 8 (a) shows the pH values taken in the morning from 8.16 until 9.13 am. From the figure, the pH ranges from 6.46 to 7.06 with an average value of 6.97. Based on the pH scale on Fig. 3, the average pH value shows that the water is *Neutral*. Fig. 8 (b) depicts the pH values taken in the evening from 16.46 until 17.45 pm. From the figure, the pH ranges from 6.56 to 7.13 with an average value of 6.96. The average pH value also shows that the water is *Neutral*. Fig. 8 (c) presents the pH values taken at night from 21.00 until 21.58 pm. From the figure, the pH ranges from 7.13 to 7.3 with an average value of 7.22. Similarly, the average pH value shows that the water is *Neutral*. Table 5 compares the pH values in the morning, evening and night. From the table, the pH appears to be higher at night and lowest in the evening. Since there is no sunshine throughout the night, photosynthesis fully halts, raising carbon dioxide levels and generally lowering pH. However, these data show that the pH is higher at night. This is likely to be affected by other factors such as changes in temperature, changes in dissolved oxygen levels or the presence of certain minerals or chemicals [14].



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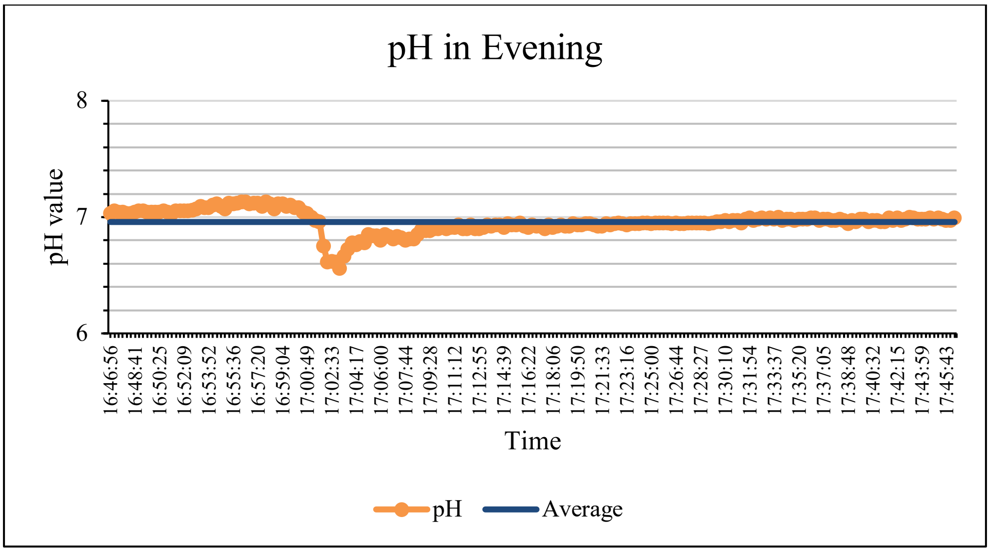

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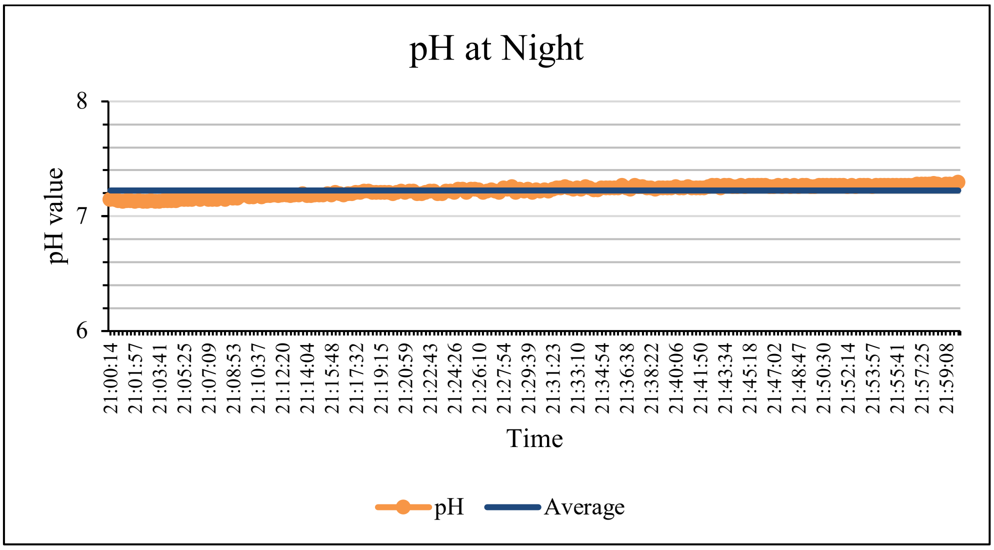


(c)

Fig. 8 *Data collected on the lake in front of FKEE building (a) pH in morning; (b) pH in evening; (c) pH at night*

Table 5 *Minimum, maximum, and average value for TDS at different time*

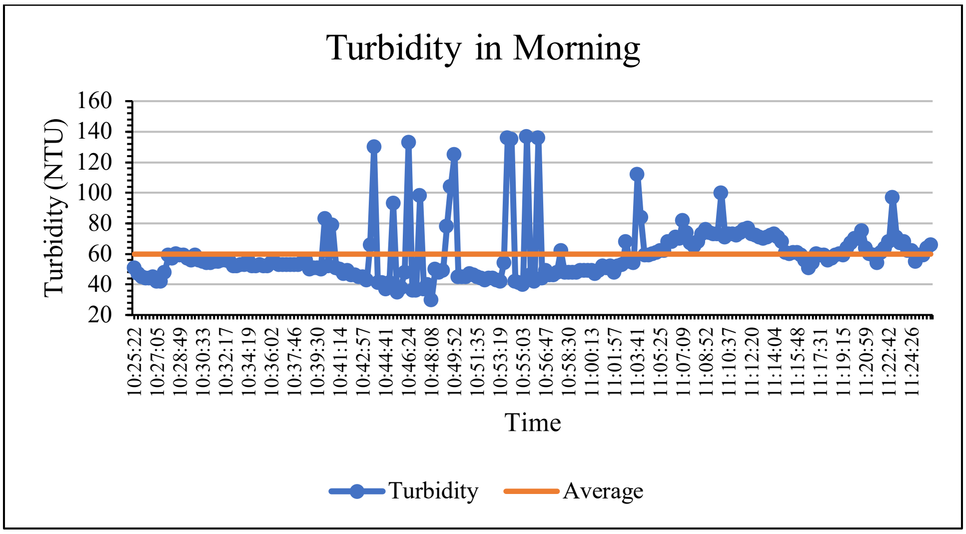
	Morning	Evening	Night
Minimum	6.46	6.56	7.13
Maximum	7.06	7.13	7.3
Average	6.97	6.96	7.22
pH scale	*Neutral*	*Neutral*	*Neutral*

3.4.2 The Lake in Front of the Development and Maintenance Office UTHM

This section discusses the water quality measurements obtained from the turbidity sensor, TDS sensor and E-201-C pH electrode probe sensor from the lake in front of the Development and Maintenance Office UTHM.

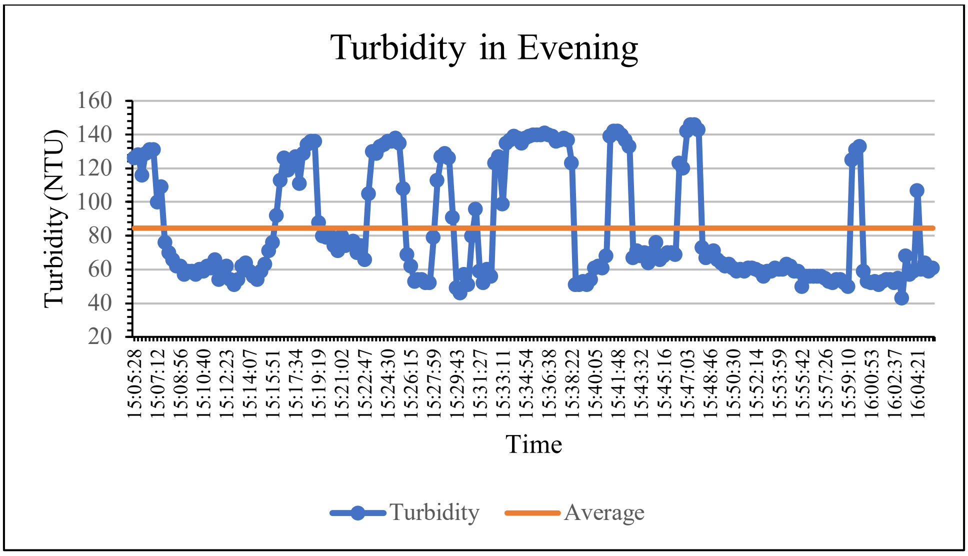
(i) Turbidity

Fig. 9 depicts the turbidity values collected in the morning, evening and night which are measured in nephelometric turbidity units (NTU). The NTU scale is based on the chart in Fig. 2. Fig. 9 (a) shows the turbidity values taken in the morning from 10.25 until 11.24 am. From the figure, the turbidity ranges from 30 to 137 NTU with an average value of 60.23 NTU. The average turbidity value, as per the NTU scale in Fig. 2, indicates that the water is *Cloudy*. Fig. 9 (b) displays the turbidity values taken in the evening from 15.05 until 16.04 pm. From the figure, the turbidity ranges from 43 to 146 NTU with an average value of 83.25 NTU. The average turbidity value also indicates that the water is *Dirty*. Fig. 9 (c) depicts the turbidity values taken at night from 20.10 until 21.09 pm. From the figure, the turbidity ranges from 166 to 174 NTU with an average value of 168.62 NTU. Likewise, the average turbidity value suggests that the water is *Dirty*. Table 6 compares the turbidity values in the morning, evening and night. From the table, the turbidity appears to be higher at night and lowest in the morning. This is consistent with the fact that the turbidity appears to be higher at night because submerged aquatic plants in the lake photosynthesize during the day and respire at night. This respiration process can release nutrients into the water, which can then lead to the growth of algae and increased turbidity [15].



(a)

Penerbit UTHM



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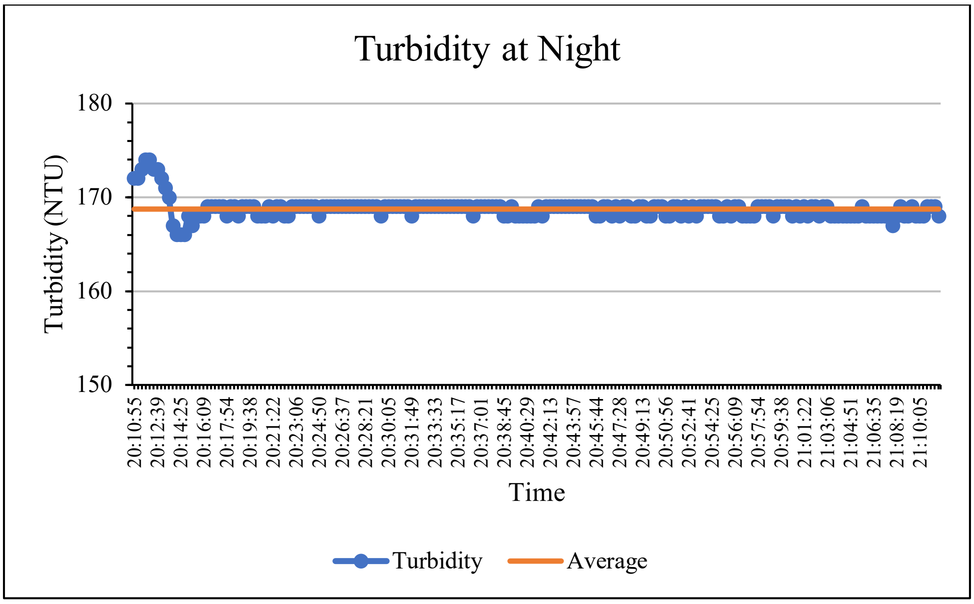


(c)

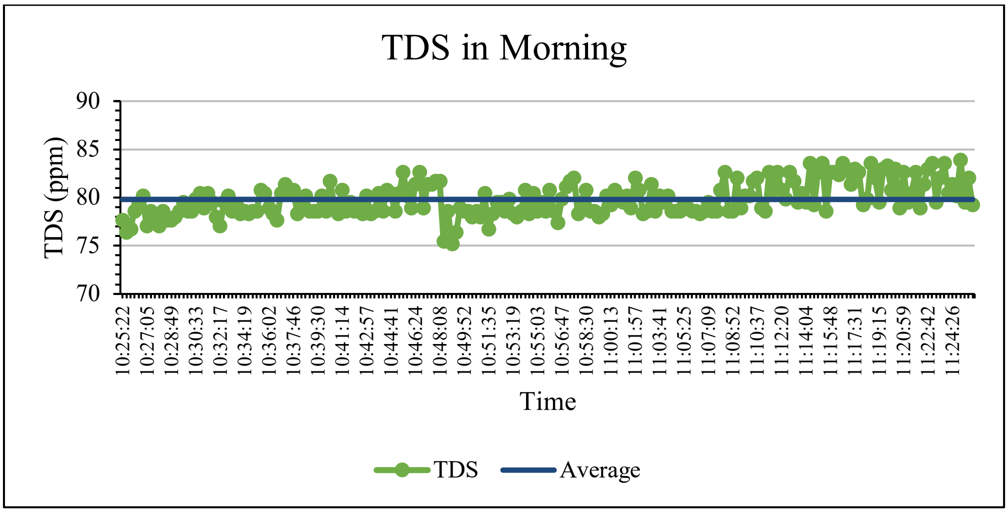
Fig. 9 *Data collected on the lake in front of the Development and Maintenance Office UTHM (a) Turbidity in morning; (b) Turbidity in evening; (c) Turbidity at night*

Table 6 *Minimum, maximum, and average value for turbidity at different time*

	Morning	Evening	Night
Minimum (NTU)	30	43	166
Maximum (NTU)	137	146	174
Average (NTU)	60.23	83.25	168.62
NTU Scale	*Cloudy*	*Dirty*	*Dirty*

(ii) Total Dissolved Solids (TDS)

Fig. 10 depicts the TDS values collected in the morning, evening and night which are measured in parts per million (ppm). The TDS level and rating in water (ppm) is based on Table 1. Fig. 10 (a) displays the TDS taken in the morning from 10.25 until 11.24 am. From the figure, the TDS ranges from 75.16 to 83.56 ppm with an average value of 79.81 ppm. The average TDS level and rating in water (ppm), as indicated in Table 1, suggests that the water quality is *Excellent* for consumption. Fig. 10 (b) shows the TDS values taken in the evening from 15.05 until 16.04 pm. From the figure, the TDS ranges from 75.47 to 81.39 ppm with an average value of 78.39 ppm. The average value of TDS also shows that the water is *Excellent* for drinking purpose. Fig. 10 (c) presents the TDS values taken at night from 20.10 until 21.09 pm. From the figure, the TDS ranges from 58.72 to 75.47 ppm with an average value of 68.41 ppm. In the same manner, the average TDS value indicates that the water is of *Excellent* quality for drinking. Table 7 compares the TDS values in the morning, evening and night. From the table, the water quality in terms of TDS appears to be higher in the morning and evening due to hot weather. This is consistent with the fact that weather condition and high-water temperatures accelerate the rate of evaporation and raise the value of dissolved solids in the water [16].



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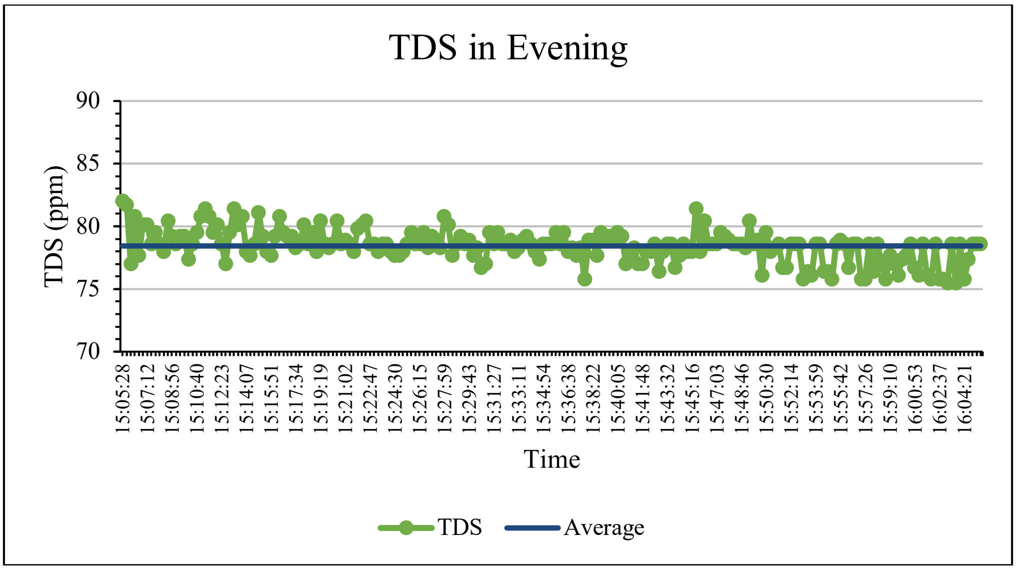

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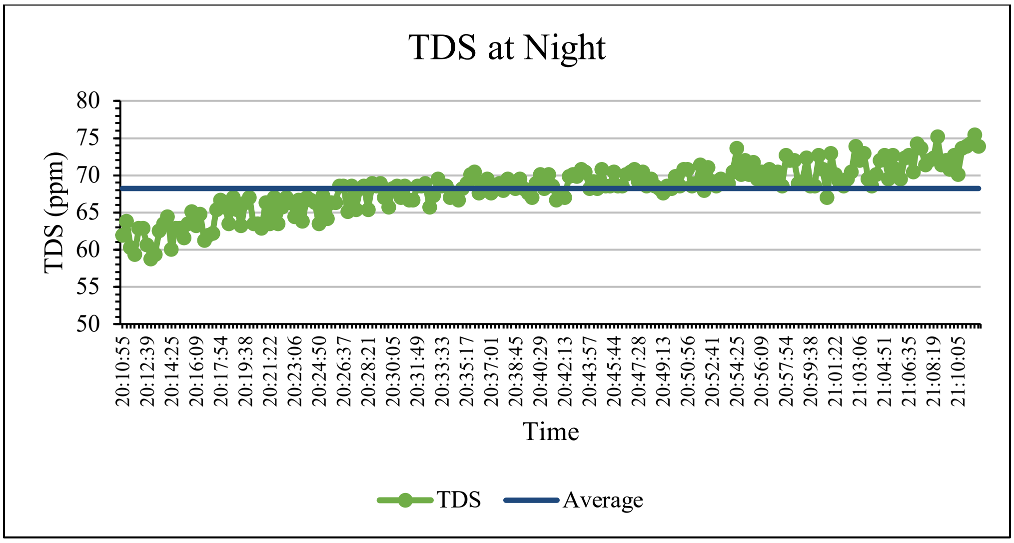

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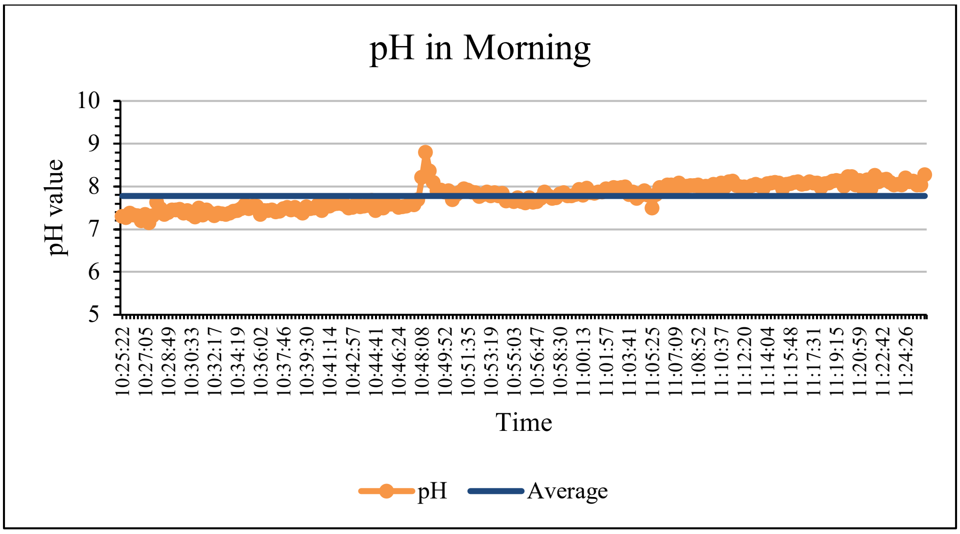
Fig. 10 *Data collected on the lake in front of the Development and Maintenance Office UTHM (a) TDS in morning; (b) TDS in evening; (c) TDS at night*

Table 7 *Minimum, maximum, and average value for TDS at different time*

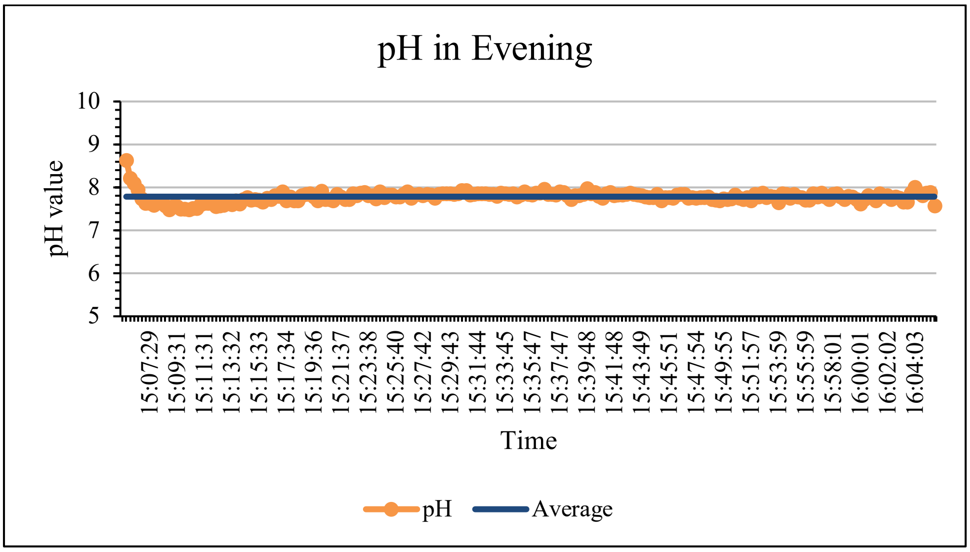
	Morning	Evening	Night
Minimum (ppm)	75.16	75.47	58.72
Maximum (ppm)	83.56	81.39	75.47
Average (ppm)	79.81	78.39	68.41
TDS rating	*Excellent*	*Excellent*	*Excellent*

(iii) Potential of Hydrogen (pH)

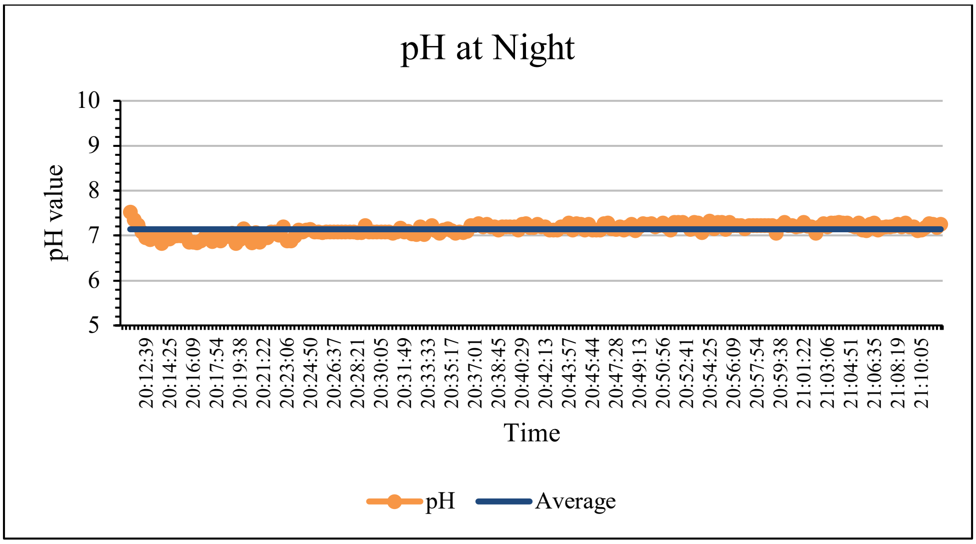
Fig. 11 displays the pH values collected in the morning, evening and night which are classified as acidic or alkaline. The pH scale is based on Figure 3. Fig. 11 (a) shows the pH values taken in the morning from 10.25 until 11.24 am. From the figure, the pH ranges from 7.16 to 8.81 with an average value of 7.78. The average pH value, as per the pH scale in Figure 3, indicates that the water is *Neutral*. Fig. 11 (b) depicts the pH values taken in the evening from 15.07 until 16.04 pm. From the figure, the pH ranges from 7.49 to 9.36 with an average value of 7.78. The average pH value also shows that the water is *Neutral*. Fig. 11 (c) presents the pH values taken at night from 20.12 until 21.09 pm. From the figure, the pH ranges from 6.82 to 7.52 with an average value of 7.14. Likewise, the mean pH value indicates that the water is *Neutral*. Table 8 compares the pH values in the morning, evening and night. From the table, the pH appears to be highest during the day and lowest at night. The variation in the pH value can be linked to the consumption of carbon dioxide by aquatic plants and algae during photosynthesis, which causes the pH to rise during the day. Then, at night, aquatic plants and algae respire, creating carbon dioxide and lowering the pH [17].



(a)



(b)



(c)

Fig. 11 *Data collected on the lake in front of the Development and Maintenance Office UTHM (a) pH in morning; (b) pH in evening; (c) pH at night*

Table 8 *Minimum, maximum, and average value for pH at different time*

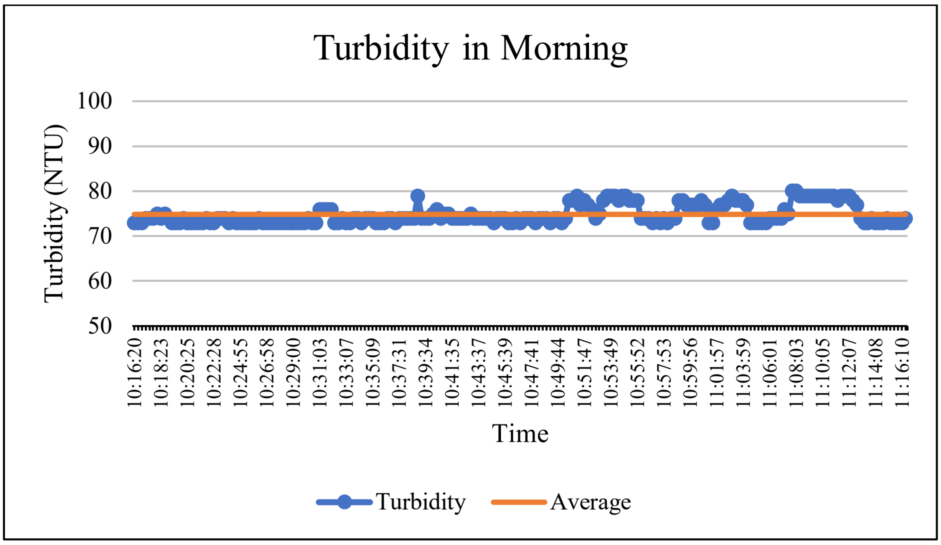
	Morning	Evening	Night
Minimum	7.16	7.49	6.82
Maximum	8.81	9.36	7.52
Average	7.78	7.78	7.14
pH scale	*Neutral*	*Neutral*	*Neutral*

3.4.3 The Watershed at Taman Universiti, Parit Raja

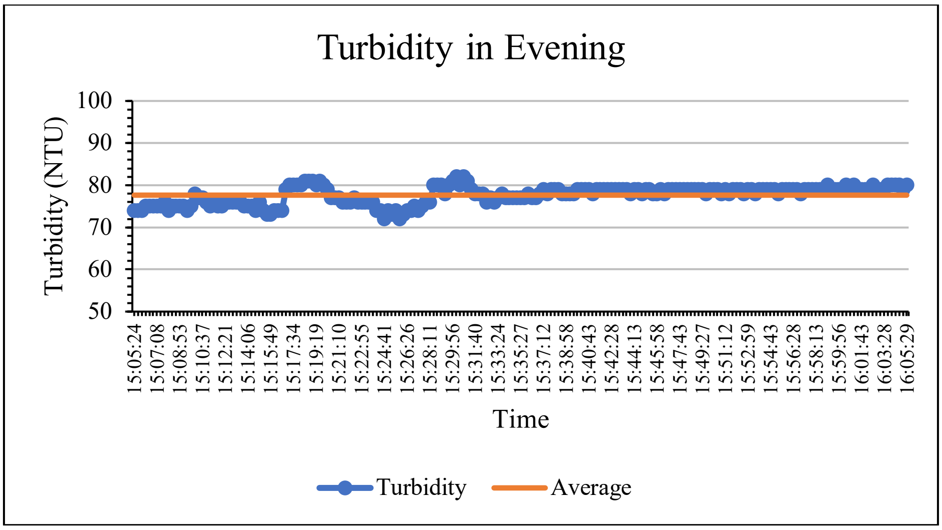
This section discusses the water quality measurements obtained from the Turbidity sensor, TDS sensor and E-201-C pH electrode probe sensor from the watershed at Taman Universiti, Parit Raja.

(i) Turbidity

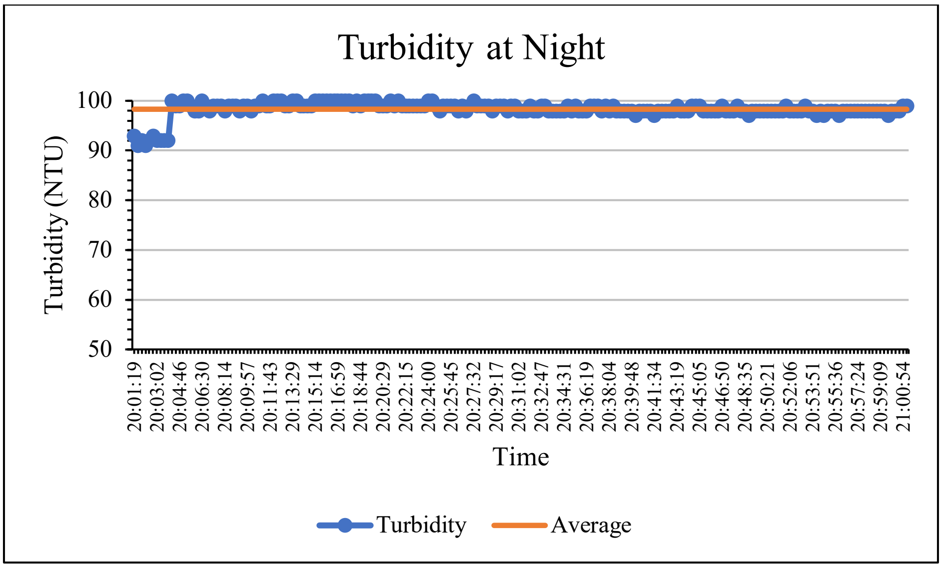
Fig. 12 depicts the turbidity values collected in the morning, evening and night which are measured in nephelometric turbidity units (NTU). The NTU scale is based on the chart in Fig. 2. Fig. 12 (a) shows the turbidity values taken in the morning from 10.16 until 11.15 am. From the figure, the turbidity ranges from 73 to 80 NTU with an average value of 74.89 NTU. The average turbidity value, according to the NTU scale in Fig. 2, suggests that the water is *Cloudy*. Fig. 12 (b) displays the turbidity values taken in the evening from 15.05 until 16.04 pm. From the figure, the turbidity ranges from 72 to 82 NTU with an average value of 77.74 NTU. The average value of turbidity shows that the water is *Dirty*. Fig. 12 (c) depicts the turbidity values taken at night from 20.01 until 20.59 pm. From the figure, the turbidity ranges from 91 to 100 NTU with an average value of 98.31 NTU. Similarly, the average turbidity value indicates that the water is *Dirty*. Table 9 compares the turbidity values in the morning, evening and night. From the table, the turbidity appears to be higher at night and lowest in the morning. The fluctuation in turbidity levels can be ascribed to a variety of biological activities. This is due to the abundance of fish and algae in the watershed, which can stir up silt and other bio-organic debris and hence, increasing turbidity [18].



(a)



(b)



(c)

Fig. 12 *Data collected on the watershed at Taman Universiti, Parit Raja (a) Turbidity in morning; (b) Turbidity in evening; (c) Turbidity at night*

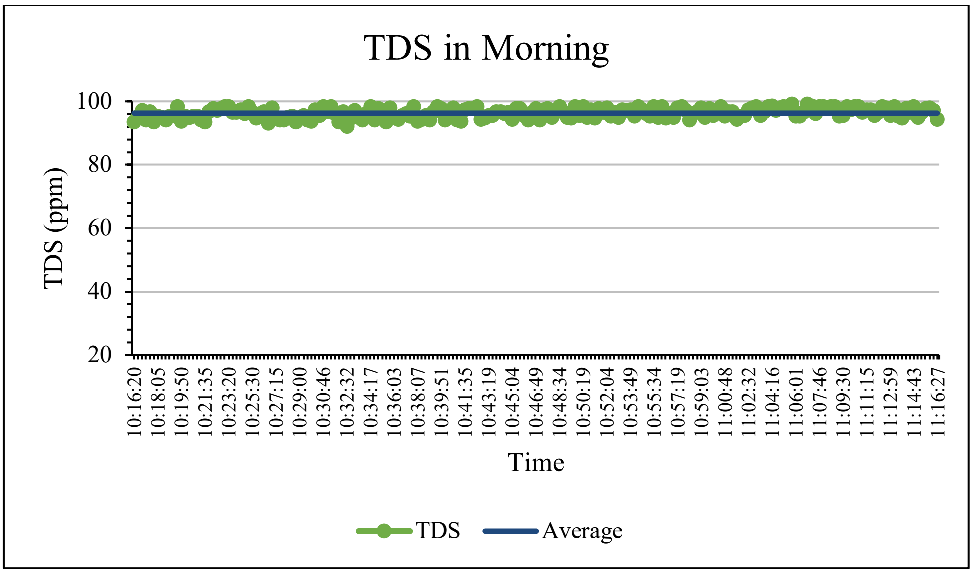
Table 9 *Minimum, maximum, and average value for turbidity at different time*

	Morning	Evening	Night
Minimum (NTU)	73	72	91
Maximum (NTU)	80	82	100
Average (NTU)	74.89	77.74	98.31
NTU Scale	*Cloudy*	*Dirty*	*Dirty*

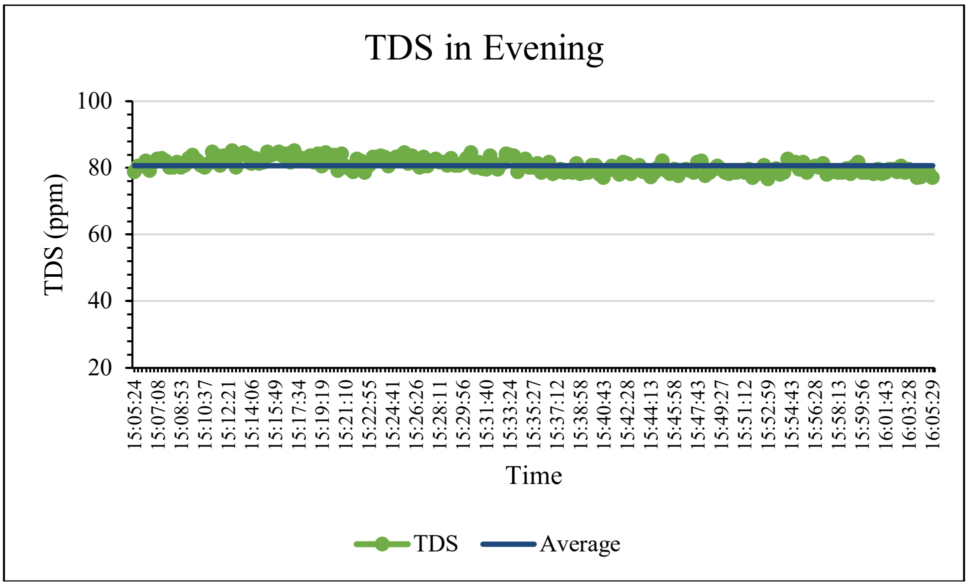
(ii) Total Dissolved Solids (TDS)

Fig. 13 depicts the TDS values collected in the morning, evening and night which are measured in parts per million (ppm). The TDS level and rating in water (ppm) is based on Table 1. Fig. 13 (a) displays the TDS taken in the morning from 10.16 until 11.15 am. From the figure, the TDS ranges from 92.19 to 99.22 ppm with an average value of 96.29 ppm. The average TDS level rating in water (ppm), as presented in Table 1, indicates that the water is of *Excellent* quality for consumption. Fig. 13 (b) shows the TDS values taken in the evening from 15.05 until

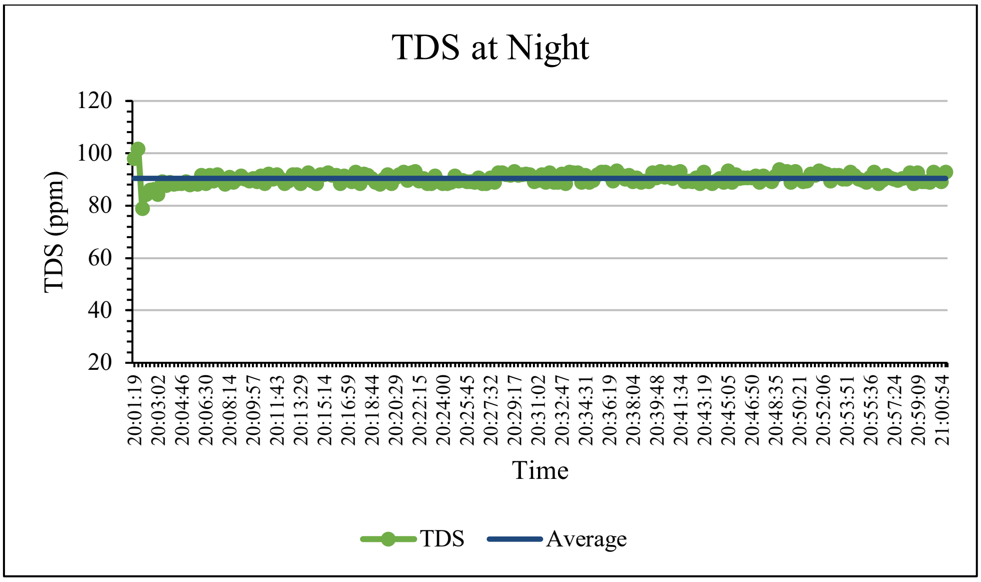
16.04 pm. From the figure, the TDS ranges from 76.72 until 85.11 ppm with an average value of 80.67 ppm. The average value of TDS also shows that the water is *Excellent* for drinking purpose. Fig. 13 (c) presents the TDS values taken at night from 20.01 until 20.59 pm. From the figure, the TDS ranges from 78.90 to 101.65 ppm with an average value of 90.43 ppm. Likewise, the average TDS value suggests that the water is of *Excellent* quality for consumption. Table 10 compares the TDS values in the morning, evening and night. From the table, the water quality in terms of TDS appears to be higher in the morning and lowest in the evening. TDS levels can be affected by various factors such as human activities, temperature and natural processes. For example, in the morning, increased human activity such as agriculture operations at the nearby palm oil plantation with discharges from industrial processes or wastewater treatment facilities, might impact TDS water levels [19].



(a)



(b)



(c)

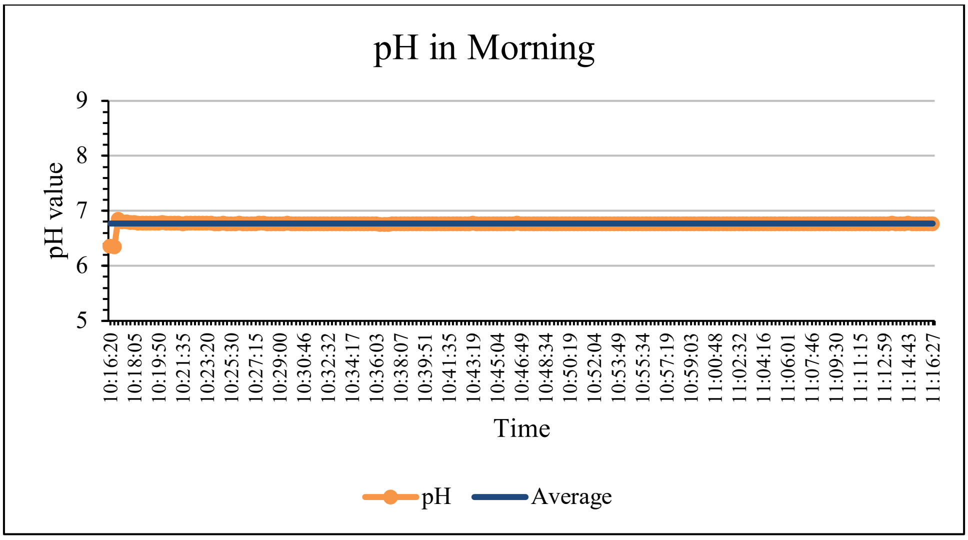
Fig. 13 *Data collected on the watershed at Taman Universiti, Parit Raja (a) TDS in morning; (b) TDS in evening; (c) TDS at night*

Table 10 *Minimum, maximum, and average value for TDS at different time*

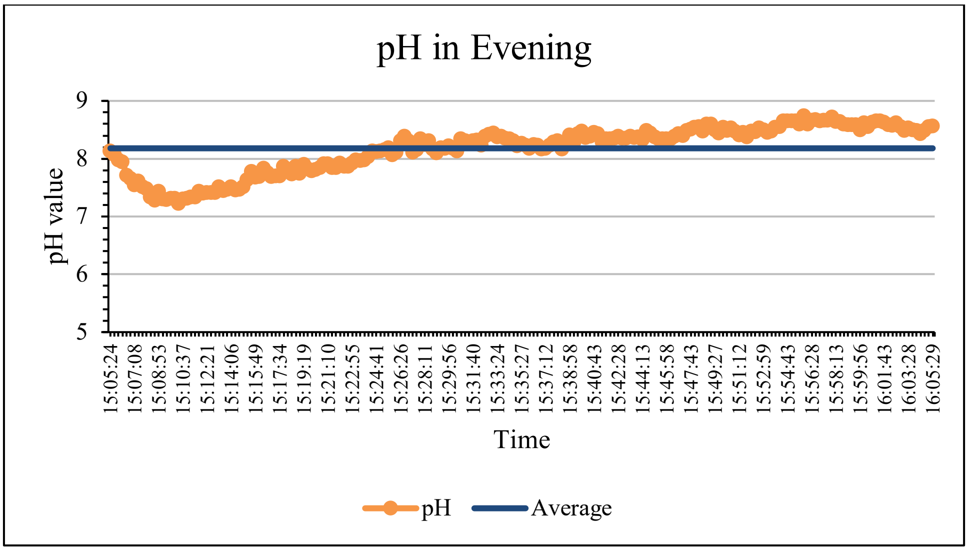
	Morning	Evening	Night
Minimum (ppm)	92.19	76.72	78.90
Maximum (ppm)	99.22	85.11	101.65
Average (ppm)	96.29	80.67	90.43
TDS rating	*Excellent*	*Excellent*	*Excellent*

(iii) Potential of Hydrogen (pH)

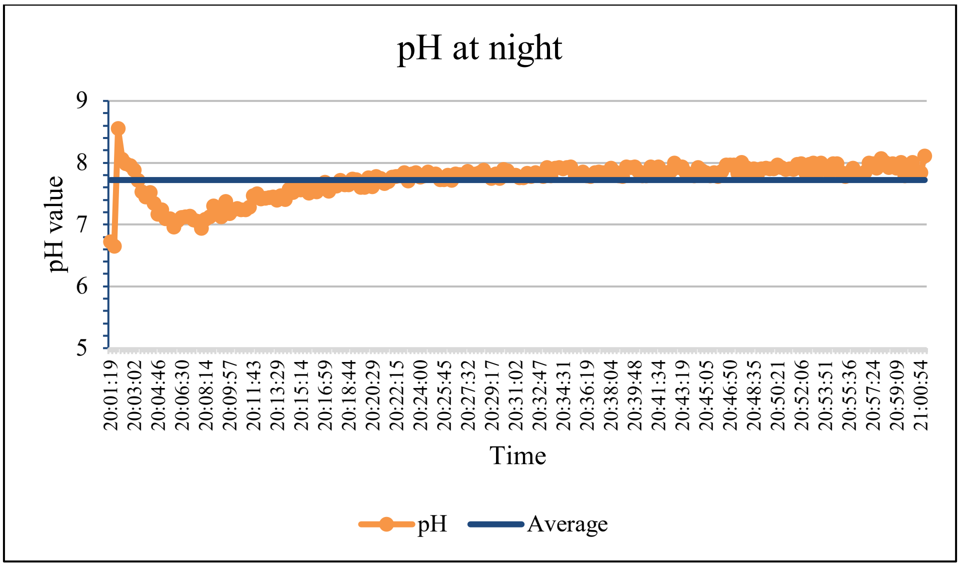
Fig. 14 displays the pH values collected in the morning, evening and night which are classified as acidic or alkaline. The pH scale is based on Fig. 3. Fig. 14 (a) shows the pH values taken in the morning from 10.16 until 11.15 am. From the figure, the pH ranges from 6.35 to 6.85 with an average value of 6.77. The average pH value, according to the pH scale in Fig. 3, suggests that the water is *Neutral*. Fig. 14 (b) depicts the pH values taken in the evening from 15.05 until 16.04 pm. From the figure, the pH ranges from 7.23 to 8.74 with an average value of 8.18. Thus, the water is also *Neutral*, as shown by the average pH value. Fig. 14 (c) presents the pH values taken at night from 20.01 until 20.59 pm. From the figure, the pH ranges from 6.93 to 8.11 with an average value of 7.72. Likewise, the average pH value shows that the water is *Neutral*. Table 11 compares the pH values in the morning, evening and night. From the table, the pH appears to be higher at evening and lowest in the morning. This is consistent with the fact that high water temperature causes more carbon dioxide to be released from the water into the air, which leads to the rising of pH value.



(a)



(b)



(c)

Fig. 14 *Data collected on the watershed at Taman Universiti, Parit Raja (a) pH in morning; (b) pH in evening; (c) pH at night*

Table 11 *Minimum, maximum, and average value for pH at different time*

	Morning	Evening	Night
Minimum	6.35	7.23	6.93
Maximum	6.85	8.74	8.11
Average	6.77	8.18	7.72
pH scale	*Neutral*	*Neutral*	*Neutral*

4. Conclusion

The unmanned surface vehicle (USV) for water and aquatic pollution monitoring using IoT has demonstrated its effectiveness in collecting and recording water quality readings in terms of turbidity, total dissolved solids, and water pH. The USV, equipped with a Turbidity sensor, TDS sensor, and E-201-C pH electrode probe sensor, was able to successfully gather data from different locations and at different times of the day. The duration of each experiment is approximately one hour with data taken for every 15 seconds and the data are sent to ThingSpeak application to be displayed for continuous monitoring and stored in its database. Microsoft Excel is used to plot the data that is exported from the ThingSpeak application. The experiments conducted at the lake in front of the FKEE building, the lake in front of the Development and Maintenance Office UTHM, and the watershed at Taman Universiti, Parit Raja showed variations in turbidity, TDS, and pH levels. These variations could be due to several factors such as weather conditions, time of the day, and human activities around these areas. Overall, this USV has demonstrated its potential as a valuable tool for continuous monitoring of water and aquatic pollution. However, further improvements and calibrations are needed to enhance the accuracy of the data collected. This technology could play a crucial role in the early detection of water pollution, contributing to the preservation of our water bodies.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Afif Najmi Haizol;* ***data collection:*** *Afif Najmi Haizol;* ***analysis and interpretation of results:*** *Afif Najmi Haizol, Shaharil Mohd Shah;* ***draft manuscript preparation:*** *Afif Najmi Haizol, Shaharil Mohd Shah. All authors reviewed the results and approved the final version of the manuscript.*

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