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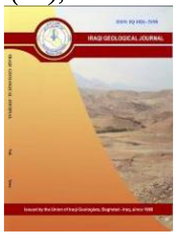

Lake Water Quality Assessment Based on Multispectral Unmanned Aerial Vehicle Images and In-Situ Testing

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Abstract

In recent years, Universiti Tun Hussein Onn Malaysia has experienced several developments in buildings and road construction. A stormwater retention pond was built as a part of the construction plan to prevent the occurrence of floods downstream of the development sites. However, poor monitoring and maintenance of the pond caused water contamination, which had bad effects on the nearby environment and lake ecosystem. Therefore, this study was conducted to assess the current water quality in the pond by using a combination between Multispectral Unmanned Aerial Vehicle images and in-situ sampling. Four water quality parameters were investigated, namely turbidity, dissolved oxygen, temperature, and pH. Aerial images were taken using a multispectral aerial mapping camera attached to UAV. The in-situ testing was performed on the same day of image capturing at 5 different locations. According to the results, it was found that the pH and water temperature were within the normal levels with maximum and minimum values of 7.34 and 6.94 for pH and 28.39°C and 28.04°C for temperature, respectively. Turbidity readings appaired with a significant variation with a maximum value of 30.9 NTU at the lake outlet and a minimum value of 18.8 NTU at the middle of the lake. Dissolved oxygen concentration was noticed to be low, with an average value of 4.3 mg/l. Water quality mapping showed the concentration distribution of each water quality parameter along the lake surface. In each map, the differences in terms of colours were found to be not significant because of the size of the lake, which is relatively small, as well as because of the small differences in terms of water quality ridings at each sampling point.

Keywords: Multispectral; Unmanned aerial vehicle; Water quality assessment; lakes; Water quality mapping

1. Introduction

Water quality is important to humans in daily activities such as domestic use, agriculture, industry, and tourism. Water pollution is caused by several factors, such as industry, commercial waste, human

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activity, and soil exploration (Owa, 2013; Awadh, S. and Al-Kilabi). Water quality can be initially measured by identifying water parameters such as dissolved oxygen (DO), pH, and turbidity (Ong et al., 2007; Awadh et al., 2019). In Malaysia, water quality is determined based on National Water Quality Standards for Malaysia (NWQS). Natural water pollution is identified from single sources such as drainage, water discharge, and roads or non-point sources such as rainwater and runoff into nearby lakes or rivers (Viman et al., 2010; Awadh and Muslim, 2014). The problems associated with lakes include algae bloom, foul smells, aquatic plants, and turbidity due to the destruction of the ecosystem in the lake's surrounding area (Skotte and Skoglund, 2022). Water quality is monitored to detect any changes, quality, and pollution in water. INWQS focuses on four parameters: DO, pH, temperature, and turbidity, identified using laboratory tests or on-situ methods (Basheer et al., 2017; Viman et al., 2010). Water quality is classified into five classes based on INWQS. Typically, Class I represents pristine water without the need for treatment, Class II represents clean water requiring conventional treatment, Class III is suitable for recreational activities, Class IV is contaminated, and Class V is polluted, making it impossible for aquatic life to survive.

Although remote sensing has developed, most decisions regarding water management are still based on traditional methods of collecting and analyzing water samples. A traditional point sample needs to provide more information to identify spatial and temporal variations in water quality, and it can be used to forecast large water bodies (Gholizadeh et al., 2016). To make accurate and timely management decisions, satellite remote sensing data must be integrated with in situ measurements (Schaeffer et al., 2013). Unmanned Aerial Vehicle (UAV) technology has developed with the advancement of technology in recent years. UAVs have numerous advantages that make them suitable for many applications today (Maddikunta et al., 2021). Using UAVs provides new opportunities for collecting water samples and measuring water quality in situ. The cost of UAVs is relatively low compared to traditional methods of monitoring water quality. They can be used in water bodies that are difficult to access with boats or dangerous for personnel (Koparan et al., 2018).

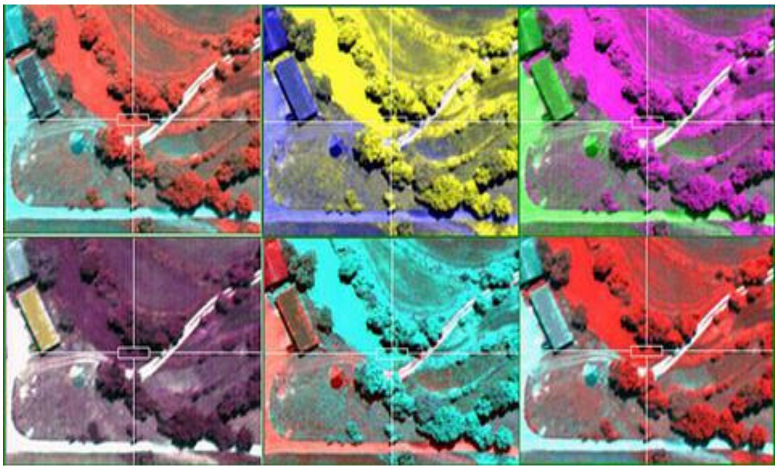

Fig.1. Images from the multispectral camera (Darwin et al., 2014)

UAVs can be equipped with multispectral cameras that are small, light, and affordable, thanks to current advances in digital camera technology. Unlike hyperspectral sensors, multispectral sensors collect imagery from multiple wavebands in the visible and near-infrared spectrums using broader wavebands. Compared to multispectral satellite cameras, these sensors are deployed at lower altitudes and display higher resolutions (Zang et al., 2012). A multispectral image is a technology discovered in the year 1800. Multispectral image technological development started in 1947 when it was developed for military purposes. It was commercialized in 1966 for the first time, and today this technology has many functions and uses. A multispectral image is produced by a multispectral camera with a precise frequency in the electromagnetic spectrum (Sun et al., 2018). The spectrum image enables the extraction of additional information on the captured image and produces images in red, green, and blue variants, known as RGB (Red, Green, and Blue). There are several divisions in the multispectral spectrum, such as RGB, Near Infrared (NIR), Mid Infrared (MIR), Far Infrared (FIR), and Thermal Infrared (Chen et al., 2014). Fig. 1 shows how images are produced from multispectral cameras using Agisoft Photoscan software.

The present study aims to assess water quality parameters in one of the UTHM lakes using multispectral UAV images and in-situ testing. A total of five water quality parameters were investigated and analyzed, including turbidity, temperature, DO, and pH. Orthophotos images were taken in two forms, including RGB and NIR and further analyzed and processed by using Agisoft Photoscan and ArcGIS software. Later, water quality parameters mapping was presented for the entire study area. In-situ testing was performed in 5 different locations and the results were presented as well.

2. Materials and Methods

2.1. Study Area

The study area is located at Universiti Tun Hussein Onn Malaysia (UTHM) campus, Parit Raja, Malaysia. The study area is an artificial lake with a total coverage area of 0.59 hectares and a total capacity of around 6000 m^3. The lake is surrounded by palm oil plantations from the north and the east directions, while the main university campus is located in the south direction, as shown in Fig. 2. The lake acts as a retention pond which was constructed to minimize the flood risk at the campus and downstream locations. Basically, the primary purpose of retention ponds is to control stormwater runoff by collecting and temporarily storing excess water during rainfall events. They help mitigate flooding by reducing the peak flow rates and releasing the water slowly over time, allowing for natural infiltration or discharge into nearby water bodies or drainage systems.

In recent years, the lake and its nearby facilities have been used for various social activities, such as fishing, jogging, and fitness training (kayaking). The lake environment is noticed to have several issues, especially in terms of water quality, such as high turbidity, high-temperature variations, low DO, and unusual pH levels. Therefore, in this study, the water quality assessment was performed for these four water quality parameters.

2.2. In-Situ Water Quality Sampling

For the purpose of water quality assessment, in-situ water quality testing was conducted at 5 different locations for the targeted water quality parameters (turbidity, temperature, DO, and pH). The in-situ testing approach provides immediate results, allowing for real-time assessment of water quality without needing laboratory analysis. This approach can be valuable in various scenarios, such as environmental monitoring, emergency response, field research, or routine water quality assessments. Fig. 2 shows the sampling locations at which point 1 is located at the inlet number 1, point 2 at the middle point of the lake, point 3 at the inlet number 2, point 4 at the furthest points toward the north direction (close to the monsoon outlet), and point 5 at the main lake outlet. Horiba U-52G Multiparameter Meter was used to perform the in-situ water quality testing. This meter has the capability to measure the needed parameters with a resolution of ±0.1 for pH, ±0.3 °C for temperature, ±1 NTU for turbidity, and ±0.2 mg/l for DO.

2.3. Data Collection Using Multispectral Unmanned Aerial Vehicle

Ahead of the data collection using UAV, ground control points (GCPs) were identified and located in the study area. GCPs are essential and one of the most important factors that must be identified to be used in georeferencing and image processing stages. In this study, marked or premarket targets were located at 3 different locations as shown in Fig. 3. The coordinates of these locations were defined through Magellan Promax's handheld GPS device (Fig. 3). After defining the GCPs, the data collection using UAV was established. An aerial mapping camera was mounted to a UAV and aerial images were captured for the entire study lake. Two different aerial images were collected, including (i) RGB image, and (ii) NIR image. Basically, RGB stands for Red, Green, and Blue, which are the primary colours used to create colours in the image. In an RGB image, each pixel is represented by three colour channels: red, green, and blue. The intensity values of these channels determine the colour of the pixel. On the other hand, an NIR image refers to an image captured in the near-infrared (NIR) portion of the electromagnetic spectrum. The NIR region lies just beyond visible red light and is characterized by wavelengths ranging from approximately 700 to 1400 nanometres. Later, the two collected images (RGB and NIR) were used to develop the lake's water quality maps.

Fig. 2. Study area and sampling locations

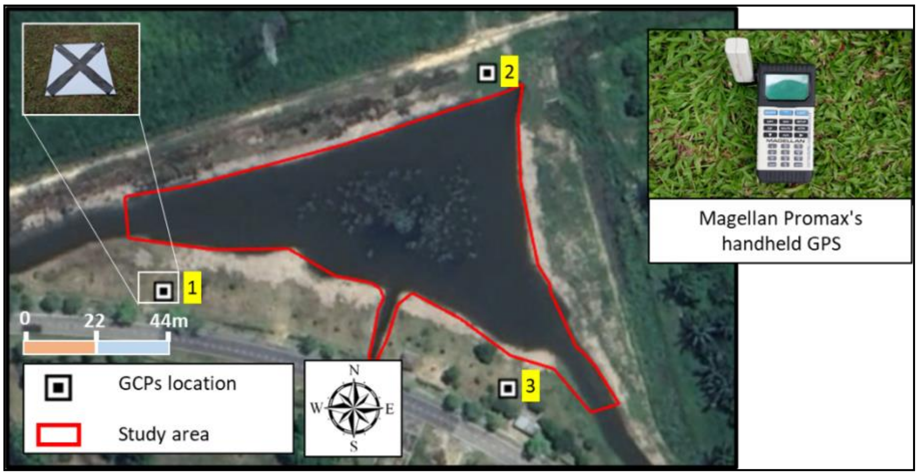

Fig. 3. Ground control points locations

2.4. Processing of UAV Data

This study involves two phases of data processing. The first one is to convert aerial images into orthophotos using Agisoft Photoscan software, and the second one is to map the water quality parameters using ArcGIS. In the first phase, the raw RGB and NIR images were processed using Agisoft Photo Scan software to convert them into orthophotos. The GCPs were used in this phase to ensure accurate georeferencing of the orthophotos. Later, the generated orthophotos were exported in TIFF format to be used in the second phase of analysis. In the second phase, the produced RGB and NIR orthophotos were processed using ArcGIS software to produce water quality mapping. The layer Stacking process was performed to determine which image would be selected for the mapping process. For RGB, images in the form of Blue were selected and used, while the image in the form of Red was selected for the NIR. Later, the sampling points locations and values were defined in the maps at which each value of every water quality parameter was represented by a unique digital number. Next, a raster calculator in ArcGIS was used to interpolate the values of each water quality parameter along the lake's surface area. Fig. 4 shows the flow chart of the data processing.

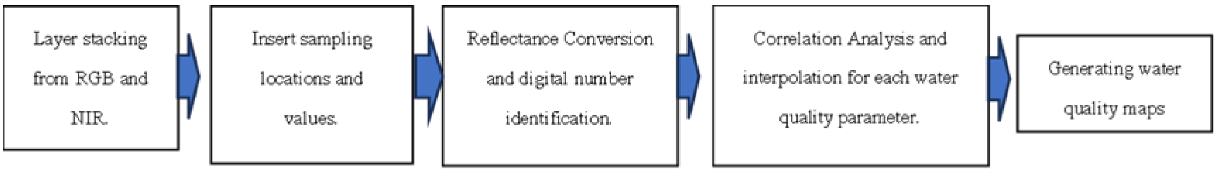

Fig. 4. Data processing flowchart

3. Results and Discussion

3.1. In-Situ Water Quality Analysis

The water quality parameters reading that were obtained from the on-situ test are illustrated in Table 1. In terms of turbidity, it can be seen that the lowest value was 18.8 NTU at point 3, which is located close to the middle point of the lake. This was due to the less water movement and low flow turbulence at that point which allowed the suspended materials to deposit to the lake ground level (Zhang and Wu, 2020). On the other hand, the highest value of turbidity was found to be 30.9 NTU at point 1, which is located at the lake outlet. This was expected due to the movement of silt and fine particles toward the lake outlet (Dejen et al., 2017). Also, flow turbulence plays a main role in increasing the turbidity at the outlet location. In general, it can be classified the lake water quality under class II according to the Malaysian NWQS.

In terms of temperature readings, it can be noticed that there are no significant changes between the measured values (Table 1). All the readings can be categorized under normal conditions according to NWQS. The highest recorded water temperature was 28.39 ºC at point 3, and the lowest reading was 28.04 ºC at point 1. These temperature values are suitable for aquatic life in the water, either fish or plants. The water temperature was noticed to be low because of the vegetation that exists inside the lake and surrounding its borders, which resulted in low ambient temperature (Aziz et al., 2017); in addition, there were no contaminates sources with high-temperature effluent that may increase the water temperature in the lake (Luo et al., 2023).

According to Malaysian NWQS, DO values can be classified under class III. The highest DO reading was 6.19 mg/l at point 2, and the lowest was 3.35 mg/l at the lake outlet. Based on the DO criterion that was developed by Malaysian NWQS, a value below 3 mg/l indicates a polluted environment and is classified under class IV. In the study area, the lowest reading was found to be 3.35

mg/l which is almost approaching class IV, which indicates that the lake experienced high pollution, especially at the outlet point. This could be due to the presence of high turbidity at that point.

In-situ pH readings ranged between 6.94 at point 4 and 7.34 at point 1. Generally, pH readings can be classified under classes II and III of the Malaysian NWQS. pH measured values indicated that the status is normal and safe for the ecosystem, fish, and plants. An acceptable value for pH in the lake was noticed because no pollution might trigger the water to become acidic such as fertilizer or other acidic material. Overall, according to the studied water quality parameters, the water quality in the lake can be considered under classes II and III of the Malaysian NWQS.

Table 1. In-situ water quality parameters results

Point	Turbidity	Temperature	Dissolved Oxygen	pH	Location	
Unit	NTU	ºC	mg/l	-	Latitude	Longitude
1	30.9	28.04	3.35	7.34	1.864666	103.084374
2	21.4	28.36	6.19	7.05	1.864726	103.084952
3	18.8	28.39	4.05	6.95	1.864577	103.084918
4	23.1	28.37	4.09	6.96	1.864897	103.085123
5	23.2	28.33	3.73	6.94	1.864409	103.085226

3.2. Results of UAV and Multispectral Images

Multispectral satellite imagery that was taken by multispectral sensors attached to UAVs has been demonstrated and approved to help in monitoring reservoirs and lakes' water quality (Bonansea et al., 2015; Su and Chou, 2015; Román et al., 2022; Tang et al., 2023). In this study, the area of concern was successfully captured by using a multispectral aerial mapping camera attached to a UAV. Two forms of images were produced, including RGB and NIR. Both images in RGB and NIR forms were used later for water quality mapping. Images in RGB form are used for mapping turbidity, DO, and pH parameters, while the image in NIR is used for mapping the temperature. Both taken photos were reprojected and aligned according to the defined ground control points (GCPs) using Agisoft Photoscan software. Fig. 5a and b shows the final orthophotos in RGB and NIR forms that were processed for the study area.

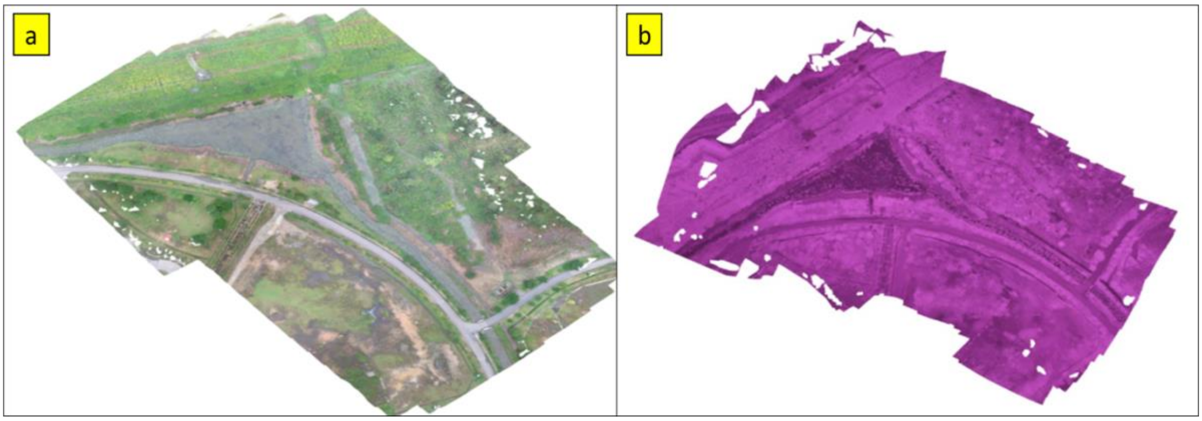

Fig.5. (a) Orthophoto in RGB form, and (b) Orthophoto in NIR form

3.3. Water Parameters Mapping

Based on the map of the turbidity value in Fig. 6a shows that the highest reading was 27.53 NTU which is shown by the colour dark orange at sampling points 3 and 5. This was due to the accumulation of silt and fine particles, these two points making the water have higher turbidity. The low turbidity value can be noticed around sampling point 4, which was 22.29 NTU, shown by the bright orange colour. This was expected due to the low flow turbulence around point 4, which allows silt and fine particles to deposit into the ground of the lake. Fig. 6b shows the map of temperature, it can be noticed that the highest value of water temperature was 28.29 ºC, shown by the dark blue colour in Fig. 6b. The lowest value of the water temperature was found to be 28.16 ºC as shown in Fig. 6b which was represented by the bright blue colour. Temperature variation along the whole lake surface area was not significant; this was because of the size of the lake, which is relatively small, also there was no effluent source with high temperature discharging into the lake.

Fig. 6c, shows the mapping of DO along the lake's surface area. The highest value of DO was noticed to be 4.67 mg/l, which was represented by dark purple colour as shown in Fig. 6c. The lowest values of DO can be seen around points 1, 2, and 4 (bright purple colour) with an average value of 4.16 mg/l as shown in Fig. 6c. Based on the pH map, the highest value of pH was noticed to be 7.31 which was represented by the dark red colour as shown in Fig. 6d. On the other hand, the lowest value of pH was found to be 6.97, which was represented by a bright red colour as shown in Fig. 6d. The high pH values were observed around points 2 and 3 close to the lake's middle point, while the low pH values were noticed to be around points 1, 4, and 5. In general, the pH scale goes from 0 to 14, with 7 being the neutral midpoint, while a pH above 7 is alkaline and becomes more alkaline as it reaches 14; a pH below 7 is acidic and becomes more acidic as it reaches 0 value (Leite et al., 2020). Therefore, the pH in the study area can be considered within the normal level of pH. Overall, the water in the lake was not polluted and according to the tested parameters, only DO jumped into Class III of Malaysian NWQS. Other parameters including pH, temperature, and turbidity, were located with Class II of the Malaysian NWQS.

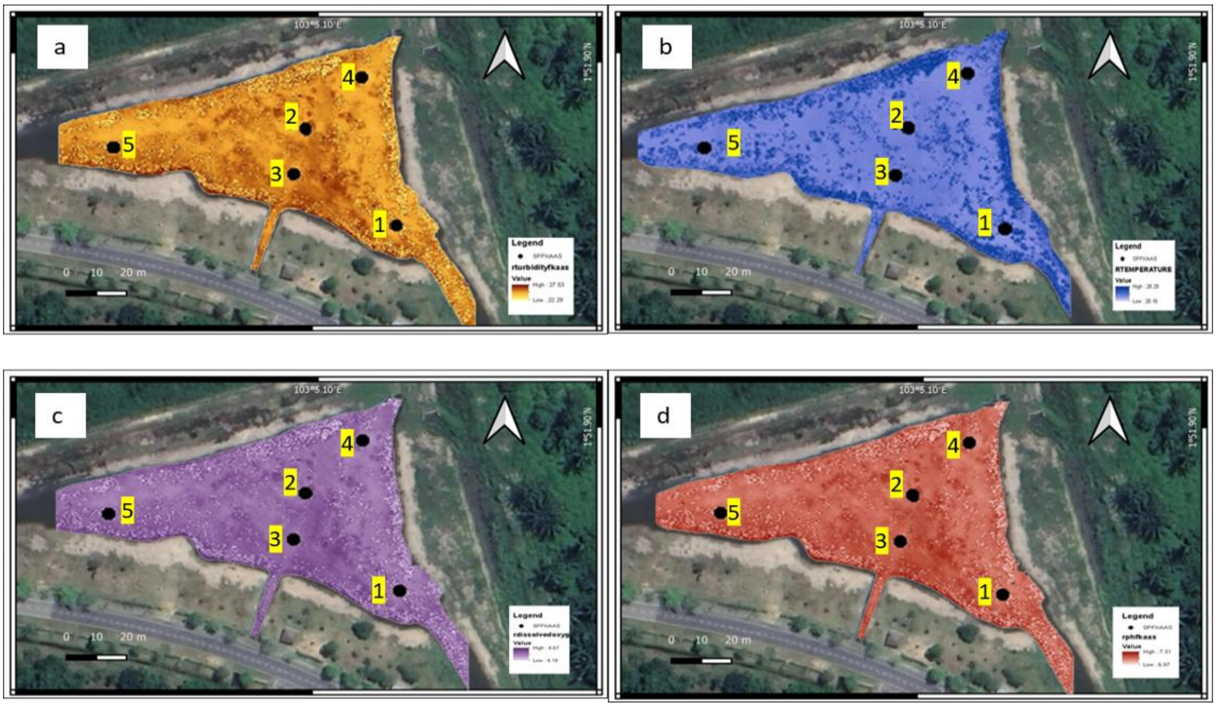

Fig.6. Water quality parameters maps (a) turbidity, (b)temperature, (c) dissolved oxygen, (d) pH.

4. Conclusions

In this study, multispectral images taken by UAV and in-situ testing were used to assess the water quality parameters in one of the Lakes that exist on the UTHM campus. Four water quality parameters were measured and analyzed at 5 different locations inside the lake, namely turbidity, temperature, DO, and pH. For the aerial images, an aerial mapping camera was mounted to a UAV, and aerial images were captured for the entire study site. According to the results, it was noticed that the water temperature and turbidity were within the normal level and the water can be considered safe for any water activities and aquatic life based on INWQS standards. Besides, the water temperature reading was found to be consistent with insignificant differences between them. On the other hand, the DO readings showed that the lake was in an unhealthy state, possibly because of the slow reaeration processes inside the lake. pH readings showed that the water was not acidic as the pH reading did not fall below 5.

The water quality mapping was produced based on the aerial images and ArchGIS processing and it was clearly shown each water quality parameter distribution along the lake surface area. Different colours were assigned to different parameters at which, orange for turbidity, blue for temperature, purple for DO, and red for pH. It is believed that the generated maps can assist in determining the distribution of the water quality parameter concentrations on the lake surface and representing the present state of the water quality. Besides, the generated maps can assist in water quality control planning and prevent pollution from getting worse.

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