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Integrated remote sensing and GIS approach for water quality analysis of Kwan Phayao Lake Thailand

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Abstract

Kwan Phayao is the largest water source in the northern region of Thailand, and it is surrounded by agricultural activities and community lifestyles which have effects on changes of water quality in each area at each period of time. The purpose of this study was to apply the technology of geographic information system (GIS) in combination with satellite data images. The GIS was used together with the field survey to inspect and measure the water quality in order to find out the relationship between the satellite images and the spectral reflectance as indicators of the water quality by using the satellite for reducing the expense and period of the field survey. In the study, the field survey was performed at 3 measuring points (K10, K14, and K19) at the area of Kwan Phayao in 2010, 2015, 2017, 2019, and 2021. During the study period, the LANDSAT 5 and LANDSAT 8 satellites had relationship with various parameters used in the survey such as total dissolved solids (TDS) (temperature, conductivity, and pH both in winter and the dry season, but with low relationship in the rainy season. The application of the satellite images in this study can lead to the guidelines for planning the follow up of the water quality inspection in every area in Kwan Phayao and other water sources in a quick, accurate, and economic way for sustainable resource management.

Key word: Water Quality, Season, Remote sensing GIS, Kwan Phayao

1. INTRODUCTION

Kwan Phayao is the largest water source in the northern region and it is on the third rank of the country. Its area covers more than 20 km^2 (Phayao Provincial Office, 2020) in Muang District, Phayao Province. Kwan Phayao is important for consumption and various activities around it. Its surroundings include rural and urban areas with residences, shops, government agencies, and hospitals etc. due to expansion of urbanization and different activities changes. These factors have effects on Kwan Phayao in terms of water quality problems, deterioration of its environment and area (Kasetsart University, 2004). Regarding particularly the water quality in 2010, Pollution Control Department considered Kwan Phayao as the water source with deteriorate water quality which consequently reduces the interestingness of tourist attractions at Kwan Phayao.

With this problem, the related agencies have installed water quality meters, but the number of these meters are insufficient and do not cover various activities in the area (Pollution Control Department, 2018). As a result, the point sources of pollution cannot be clearly identified, the surveys are not frequently performed, and the analyses of the survey and measurement in the laboratories cost

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high expense and time. The present study emphasized on collecting the existing survey data and the new data from surveying different pollution point sources. These collected data were used together with the data from remote sensing technology by using satellites to survey natural resources in water quality, land use, and land cover (Wang and Yang, 2019) around Kwan Phayao in order to relieve and solve the problems in long term. The capacity of the satellite data allowed water inspections in an accurate, convenient, and continuous way, and the data at all points of the area in Kwan Phayao and Ing River Basin were obtained and compared with the census by satellite. The water quality data were displayed in the form of the online mapping system derived from semi-automatically processing the satellite images at near real time to monitor water quality changes from the multiple-temporal satellite function (Ye and Sun, 2022). The series of these data in longer than 40 years are available with free access (Viana et al. 2019) to reduce the problems of water uses in various activities which affect water quality. This participatory technology development (PTD) enables perception of problems in all aspects, verifiability of the related sectors for public benefits, cost reduction in the dimensions of time and survey expense, and increase of effectiveness in the area management. Although these issues are supported by international research; in Thailand, they are not developed and applied sufficiently and only some parameters are used (Wanichsathian, 2006). Particularly, the areas of Kwan Phayao and Ing River Basin are not supported by research studies to be the model areas which use technology with participation of all sectors. In addition, new knowledge can be created in using economical technology to support spatial decisions in setting guidelines systematically for sustainable management of natural resources in order to balance the future uses of water resources in the areas. The objectives of the present study were to collect the spatial data in term of water quality at Kwan Phayao in order to study the water environmental factors with effects on changes of water quality at Kwan Phayao. The satellite images were used in the study to find the relationship as well as to follow up, assess, and compare the water quality in several periods at Kwan Phayao.

2. METHODOLOFY

In the literature review and documentary study, the primary data were collected for the analysis in 2 parts: in situ survey on water quality, and use of satellite images.

The first part of water quality survey at the Kwan Phayao area included 9 parameters: depth, dissolved oxygen (DO), pH, temperature, conductivity, chlorophyll-a (Chl-a), transparency, total dissolved solids (TDS), and biochemical oxygen demand (BOD) together with coordination system at the points of the water quality survey and the survey date.

The second part of satellite images used the images from LANDSAT 5 and LANDSAT 8 satellites. The data of LANDSAT 5 with thematic mapping (TM) were recorded with reflectance of 7 bands: blue, green, red, near infrared, 2 middle infrared (2), and thermal infrared (Table 1) in 1984 – 2013. On the other hand, the data of LANDSAT 8 were recorded by 2 signal receivers of operational land imager (OLI) and thermal infrared sensor (TIRS) with 11 bands: cirrus, coastal aerosol, blue, green, red, near infrared, shortwave infrared (2), thermal infrared (2), and panchromatic (Table 2) in 2013 – present (United States Geological Survey, 2021).

Table 1 LANDSAT 5 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

ID	Bands	Wavelength (μm)	Resolution (meters)	Sensor
1	Blue:B	0.45-0.52	30	TM
2	Green:G	0.52-0.60	30	TM
3	Red:R	0.63-0.69	30	TM
4	Near Infrared: NIR	0.77-0.90	30	TM
5	Short-wave Infrared: SWIR	1.55-1.75	30	TM
6	Thermal Infrared: TIR	10.40-12.50	120	TM
7	Short-wave Infrared: SWIR	2.09-2.35	30	TM

Table 2 LANDSAT 8 LANDSAT 5 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS)

ID	Bands	Wavelength (μm)	Resolution (meters)	Sensor
1	Coastal aerosol: CA	0.43-0.45	30	OLI
2	Blue: B	0.45-0.51	30	OLI
3	Green: G	0.53-0.59	30	OLI
4	Red: R	0.64-0.67	30	OLI
5	Near Infrared: NIR	0.85-0.88	30	OLI
6	Short-wave Infrared: SWIR	1.57-1.65	30	OLI
7	Short-wave Infrared: SWIR	2.11-2.29	30	OLI
8	Panchromatic: Pan	0.50-0.68	15	OLI
9	Cirrus: CI	1.36-1.38	30	OLI
10	Thermal Infrared1: TIR1	10.6-11.19	100	TIR
11	Thermal Infrared2: TIR2	11.50-12.51	100	TIRS

As the LANDSAT revisit was in every 16 days, the field survey had to collect the water quality data consistently to the recorded satellite images so the data had to be analyzed in a short time. Meanwhile, if the study area at Kwan Phayao was covered with clouds on the survey date, the data could not be analyzed. Therefore, the inspection had to be performed in 2 parts. Firstly, the image data conformed to the exact survey dates or close to the survey dates (the difference between the survey date and the satellite image records were set at about ±5 days). Secondly, the recorded images were examined on whether the study area was covered by the clouds. The images must be recorded without cloud coverage at the corresponding periods of the survey.

After the data collection, the data from the survey of water quality inspection and the satellite images were analyzed to find the relationship. The location coordinates of the survey points from the global positioning system (GPS) were compared with the coordinates from the

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survey at Kwan Phayao and spectral reflectance at the pixels of each band recorded by the satellite at the same positions. Then, the GIS instructions were used to extract the reflectance values of each band from both satellites and these values were compared with the values from survey in pairs (the reflectance values from the satellites and the values of the parameter measurement in the fieldwork). Next, the linear regression was performed to find the relationship between both datasets (R^2), and these results were analyzed according to seasons before disseminating the findings to related agencies for later applying them in water quality management.

3. RESULTS

The study results presented the linear relationship between the data from the in situ survey and the satellite images. The in-situ data on water quality were 9 parameters: *depth, dissolved oxygen (DO), pH, temperature, conductivity, chlorophyll-a (Chl-a), transparency, total dissolved solids (TDS), and biochemical oxygen demand (BOD).* The survey was performed at 21 coordinate points in the UTM zone47 WGS1984 system (KP1, KP2……KP14, KP14/2……KP19, and KP20) (Table 3) during January 2010 – May 2021 in 43 times in total. The data were analyzed for screening the satellite images at the same time of the in situ survey (Table 4). The images were appropriate (without cloud or little cloud in the area of Kwan Phayao). The interval of the survey and the image record was not more than 5 days in 11 periods during 2010 – 2021 (in a chronological order from past to present). The image data of LANDSAT 5 were recorded in 1 period whereas the image data of LANDSAT 8 were recorded in 10 periods. The survey periods in a chronological order were 1) 13 March 2010 (Table 4, No. 3), 2) 24 January 2015 (Table 4, No. 18), 3) 26 September 2015 (Table 4, No. 26), 4) 31 October 2015 (Table 4, No. 27), 5) 30 November 2015 (Table 4, No. 28), 6) 15 December 2015 (Table 4, No. 29), 7) 21 April 2017 (Table 4, No. 32), 8) 17 January 2019 (Table 4, No. 37), 9) 28 April 2019 (Table 4, No. 41), 10) 3 May 2021 (Table 4, No. 41), and 11) 19 May 2021 (Table 4, No. 43). In seasonal division, the satellite image data were in 3 seasons: 5 dry seasons (March to May), 2 rainy seasons (September to October), and 4 winters (November to January).

The values from the water quality survey (14 parameters) were compared with the satellite reflectance in each band to determine the linear relationship in winters (Table 5), dry seasons (Table 6), and rainy seasons (Table 7). There were 3 survey points with comparable values: K10, K14, and K19. It was found that the correlations were fairly different and scattering. Regarding the seasonal explanation, in winter, temperature and chlorophyll-a (Chl-a) highly correlated with the satellite reflectance and bands in several periods and several bands (Table 5) at the mean of 0.66 and 0.72 (Table 8). In the dry season, many parameters were more than 0.5, and the highest values were in transparency and pH at the mean of 0.69 and 0.63 respectively (Table 9). In the rainy seasons, the parameters with the highest values were dissolved oxygen (DO) and total dissolved solids (TDS) at the mean of 0.64 and 0.62 respectively (Table 10). In overall of all season (annually), chlorophyll-a (Chl-a) and total dissolved solids (TDS) had the highest relationship with the satellite reflectance and bands at the mean of 0.62 and 0.61 respectively (Table 11).

Table 3 Water quality survey point and location coordinates (X,Y)

No.	Locations	coordinates X	coordinates Y
KP 1	Ing River (inlet)	591215	2123266

No.	Locations	coordinates X	coordinates Y
KP 2	Ban San Nong Niew	591065	2122387
KP 3	North of Phayao Hospital	591517	2122399
KP 4	Ban San Pa Muang	590516	2121235
KP 5	Middle of Kwan Phayao Lake	591335	2121286
KP 6	Phayao Hospital	592128	2121439
KP 7	Ban San Wiang Mai	590644	2120288
KP 8	Middle of Kwan Phayao Lake	591600	2120400
KP 9	Middle of Kwan Phayao Lake	592543	2120322
KP10	Water supply / Wat Sri Khom Kham	593246	2120544
KP11	North of Ban San Kwan	591028	2119341
KP12	Middle of Kwan Phayao Lake	591872	2119213
KP13	Middle of Kwan Phayao Lake	593101	2119238
KP14	Phayao City	593624	2120067
KP14/ 2	Lower of Phayao City	594075	2119260
KP15	Lower of Ban San Kwan	591818	2118107
KP16	Between Ban Rong Hai and Ban San Kwan	592555	2117813
KP17	Ban Rong Hai	593370	2118255
KP18	Ban Mae Tam	594355	2118266
KP19	Fisheries Research and Development Center, Phayao Provinc	594780	2118842
KP20	Ing River (outlet)	596077	2118756

Fig. 1 Showing water quality survey points in Kwan Phayao Lake.

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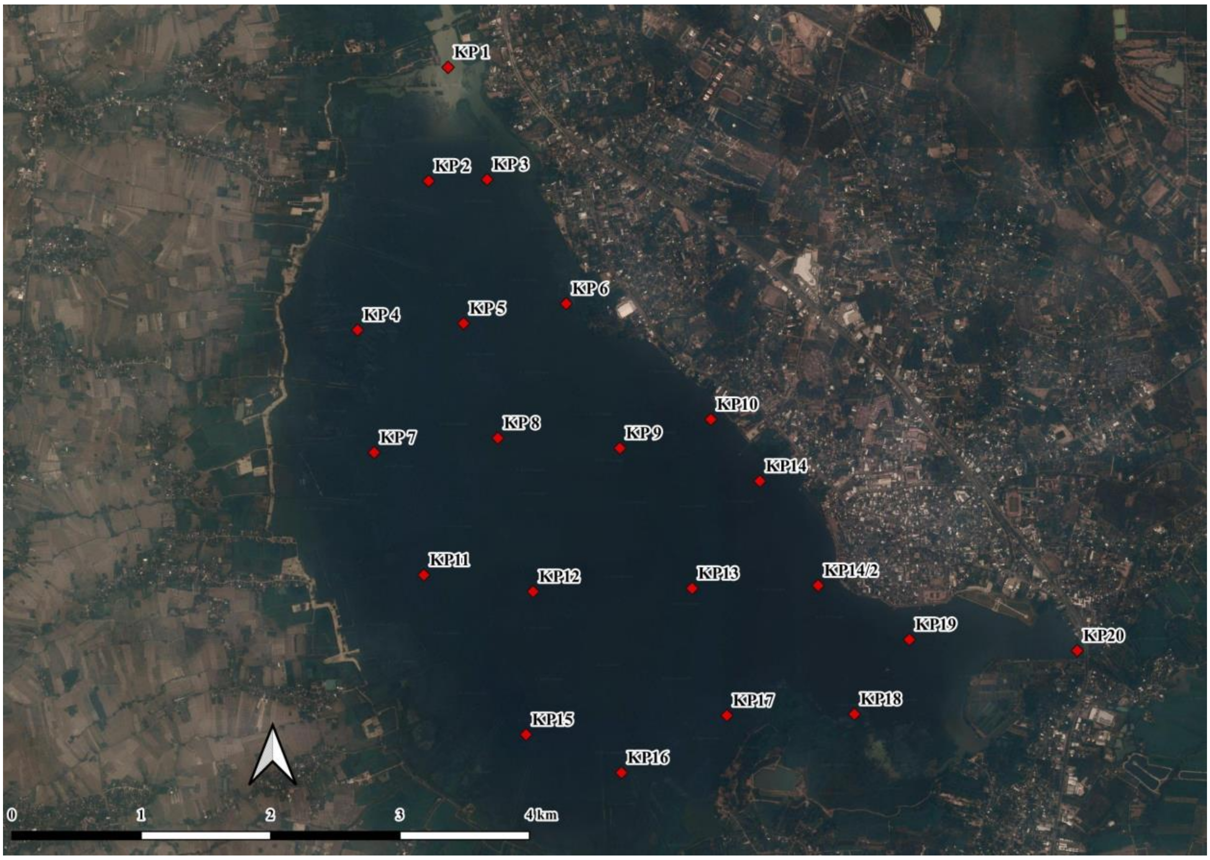

Table 4 The relationship of the date of the field water quality survey. and date of recording of satellite data.

No.	Date of field survey	Satellites in geostationary orbit		Difference (Days)	Season
		LANDSAT 5	LANDSAT 8		
1	8-Jan-10	29-Jan-10	-	21	N/A
2	23-Feb-10	14-Feb-10	-	9	N/A
3	13-Mar-10	18-Mar-10	-	5	Dry Season
4	28-Apr-10	-	-		N/A
5	22-May-10	5-May-10	-	17	N/A
6	20-Jun-10	-	-		N/A
7	17-Jul-10	cloudy	-		N/A
8	11-Apr-12	-	-		N/A
9	21-May-12	-	-		N/A
10	20-Jun-12	-	-		N/A
11	18-Jul-12	-	-		N/A
12	22-Aug-12	-	-		N/A
13	24-Sep-12	-	-		N/A

14	24-Oct-12	-	-		N/A
15	21-Nov-12	-	-		N/A
16	25-Dec-12	-	-		N/A
17	24-Jan-13	-	-		N/A
18	24-Jan-15	-	27-Jan-15	3	Winter
19	28-Feb-15	-	cloudy	0	N/A
20	28-Mar-15	-	16-Mar-15	12	N/A
21	25-Apr-15	-	1-Apr-15	24	N/A
22	25-May-15	-	5-Mar-15	20	N/A
23	30-Jun-15	-	20-Jun-15	10	N/A
24	27-Jul-15	-	cloudy	-	N/A
25	30-Aug-15	-	cloudy	-	N/A
26	26-Sep-15	-	24-Sep-15	2	Rainy Season
27	31-Oct-15	-	26-Oct-15	5	Rainy Season
28	30-Nov-15	-	27-Nov-15	3	Winter
29	15-Dec-15	-	13-Dec-15	2	Winter
30	13-Dec-16	-	31-Dec-16	18	N/A
31	17-Feb-17	-	1-Feb-17	16	N/A
32	21-Apr-17	-	22-Apr-17	1	Dry Season
33	2-Jun-17	-	25-Jun-17	17	N/A
34	20-Feb-17	-	มีเมฆ		N/A
35	13-Oct-17	-	31-Oct-17	18	N/A
36	10-Jan-19	-	22-Jan-19	11	N/A
37	17-Jan-19	-	22-Jan-19	3	หนาว
38	30-Jan-19	-	22-Jan-19	0	N/A
39	11-Apr-19	-	มีเมฆ	-	N/A
40	20-Apr-19	-	28-Apr-19	0	N/A
41	28-Apr-19	-	28-Apr-19	0	Dry Season
42	3-May-21	-	1-Apr-21	2	Dry Season
43	18-May-21	-	19-May-21	1	Dry Season
Total Correspondence		4	22		

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Note N/A means that the statistical relationship is not taken into account due to the difference between the survey date and the recording date (distance intervals) too much, or in the image, there was a cloud obscuring the ground survey point, making it impossible to determine the true reflection value.

Table 5 Relationship of satellite sensors and parameters from winter observations.

	B1				B2				B3				B4			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	0.27	0.27	0.01	-	0.33	0.29	0.03	-	0.36	0.62	0.03	-	0.41	0.56	0.25	-
DO	0.44	0.72	0.11	0.00	0.38	0.74	0.07	0.00	0.35	0.96	0.07	0.00	0.29	0.93	0.01	0.00
pH	0.97	0.55	0.09	0.14	0.94	0.58	0.05	0.12	0.92	0.86	0.05	0.15	0.89	0.82	0.02	0.12
Temp	0.93	0.92	0.23	0.99	0.89	0.93	0.30	0.98	0.87	1.00	0.30	0.99	0.83	-	0.64	0.98
conductivity	0.05	0.22	0.05	0.99	0.03	0.24	0.09	0.98	0.02	0.56	0.09	0.99	0.01	0.50	0.37	0.98
Chl-a	1.00	0.55	0.97	-	1.00	0.58	0.94	-	1.00	0.86	0.94	-	1.00	0.82	0.69	-
Transparency	0.17	0.78	0.37	-	0.12	0.80	0.30	-	0.10	0.98	0.29	-	0.07	0.96	0.05	-
TDS	0.21	0.94	0.04	0.99	0.16	0.95	0.08	0.98	0.14	0.99	0.08	0.99	0.10	1.00	0.35	0.98
BOD	0.00	0.02	-	-	0.01	0.03	-	-	0.02	0.23	-	-	0.04	0.18	-	-

	B5				B6				B7				B8			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	0.20	0.23	0.77	-	0.05	0.16	0.36	-	0.05	0.12	0.39	-	0.41	0.71	0.00	-
DO	0.97	0.67	1.00	0.00	1.00	0.59	0.78	0.00	0.99	0.53	0.81	0.00	0.30	0.99	0.23	0.01
pH	0.46	0.50	0.99	0.13	0.68	0.41	0.74	0.13	0.69	0.35	0.77	0.14	0.90	0.92	0.19	0.18
Temp	0.55	0.89	0.39	0.99	0.76	0.83	0.06	0.99	0.77	0.78	0.07	0.99	0.84	0.97	0.12	1.00
conductivity	0.90	0.18	0.66	0.99	0.72	0.12	0.24	0.99	0.71	0.08	0.27	0.99	0.01	0.66	0.00	1.00

Chl-a	1.00	0.50	0.28	-	1.00	0.41	0.70	-	1.00	0.35	0.67	-	1.00	0.92	1.00	-
Transparency	0.98	0.73	0.93	-	0.87	0.65	0.97	-	0.87	0.59	0.98	-	0.08	1.00	0.52	-
TDS	0.99	0.91	0.68	0.99	0.90	0.86	0.26	0.99	0.90	0.81	0.29	0.99	0.10	0.96	0.00	1.00
BOD	0.67	0.01	-	-	0.45	0.00	-	-	0.44	0.00	-	-	0.04	0.32	-	-

	B9				B10				B11			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	0.87	0.34	0.58	-	0.25	0.01	0.97	-	0.64	0.01	0.20	-
DO	0.00	0.02	0.94	0.86	0.46	0.13	0.93	0.03	0.11	0.13	0.62	0.00
pH	0.44	0.11	0.91	0.55	0.97	0.04	0.95	0.03	0.71	0.04	0.58	0.08
Temp	0.35	0.01	0.20	0.06	0.94	0.36	0.70	0.91	0.63	0.36	0.00	0.96
conductivity	0.18	0.39	0.46	0.06	0.06	0.02	0.91	0.91	0.02	0.02	0.11	0.96
Chl-a	1.00	0.11	0.48	-	1.00	0.04	0.06	-	1.00	0.04	0.85	-
Transparency	0.06	0.01	1.00	-	0.18	0.18	0.71	-	0.00	0.18	0.88	-
TDS	0.04	0.02	0.48	0.06	0.22	0.40	0.92	0.91	0.01	0.40	0.12	0.96
BOD	0.43	0.73	-	-	0.00	0.23	-	-	0.18	0.23	-	-

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Table 6 Relationship of satellite sensors and parameters from dry season observations.

	B1				B2				B3				B4			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	1.00	-	-	-	0.03	-	-	-	0.25	-	-	-	0.25	-	-	-
DO	0.25	0.64	0.95	0.29	0.89	0.39	0.71	0.26	1.00	0.09	0.53	0.22	0.25	0.08	0.58	0.28
pH	0.12	0.58	0.96	0.98	0.97	0.33	0.98	0.99	0.97	0.05	0.90	1.00	0.41	0.05	0.93	0.98
Temp	0.05	0.88	0.85	0.29	0.85	0.67	0.54	0.27	0.54	0.30	0.36	0.22	0.91	0.30	0.41	0.28
conductivity	0.23	0.89	0.95	0.13	0.90	0.69	0.69	0.14	1.00	0.32	0.52	0.18	0.27	0.31	0.57	0.13
Chl-a	0.46	-	-	0.80	0.71	-	-	0.81	0.95	-	-	0.85	0.09	-	-	0.80
Transparency	-	1.00	-	0.44	-	0.92	-	0.46	-	0.61	-	0.51	-	0.61	-	0.44
TDS	-	0.86	0.92	0.19	-	0.65	1.00	0.21	-	0.28	0.94	0.25	-	0.28	0.96	0.19
BOD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	B5				B6				B7				B8			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	0.25	-	-	-	0.25	-	-	-	0.25	-	-	-	-	-	-	-
DO	0.25	0.65	0.53	0.60	1.00	0.56	0.56	0.92	0.25	0.53	0.56	0.90	-	0.20	0.54	0.26
pH	0.41	0.58	0.90	0.80	0.97	0.49	0.92	0.02	0.41	0.47	0.92	0.01	-	0.15	0.90	0.99
Temp	0.91	0.88	0.36	0.60	0.54	0.82	0.39	0.92	0.91	0.79	0.38	0.90	-	0.47	0.36	0.26

conductivity	0.27	0.89	0.52	0.00	1.00	0.83	0.55	0.64	0.27	0.81	0.54	0.68	-	0.48	0.52	0.15
Chl-a	0.09	-	-	0.49	0.95	-	-	0.04	0.09	-	-	0.05	-	-	-	0.82
Transparency	-	1.00		0.15	-	0.98	-	0.29	-	0.98	-	0.32	-	0.77	-	0.47
TDS	-	0.86	0.94	0.01	-	0.80	0.96	0.56	-	0.77	0.95	0.60	-	0.44	0.94	0.21
BOD	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

	B9				B10				B11			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	-	-	-	-	-	-	-	-	-	-	-	-
DO	-	0.23	0.96	0.03	-	0.83	0.92	0.01	-	0.19	0.77	0.01
pH	-	0.18	0.65	0.68	-	0.78	0.57	0.91	-	0.14	0.35	0.90
Temp	-	0.50	1.00	0.03	-	0.98	0.99	0.01	-	0.45	0.90	0.01
conductivity	-	0.51	0.96	0.80	-	0.98	0.93	0.53	-	0.47	0.78	0.54
Chl-a	-	-	-	0.93	-	-	-	1.00	-	-	-	1.00
Transparency	-	0.79	-	0.99	-	0.97	-	0.85	-	0.76	-	0.86
TDS	-	0.47	0.57	0.86	-	0.97	0.49	0.61	-	0.43	0.28	0.62
BOD	-	-	-	-	-	-	-	-	-	-	-	-

Table 7 Relationship of satellite sensors and parameters from rainy season observations.

	B1				B2				B3				B4			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19

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	B5				B6				B7				B8			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19
Depth	0.74	0.44	0.44	0.11	0.55	0.13	0.53	0.98	0.74	0.44	0.44	0.11	0.55	0.13	0.53	0.98
DO	0.61	0.99	0.87	0.91	0.79	0.93	0.80	0.51	0.61	0.99	0.87	0.91	0.79	0.93	0.80	0.51
pH	0.39	0.94	0.70	0.98	0.60	0.99	0.61	0.37	0.39	0.94	0.70	0.98	0.60	0.99	0.61	0.37
Temp	0.01	0.99	0.17	0.79	0.10	0.82	0.11	0.68	0.01	0.99	0.17	0.79	0.10	0.82	0.11	0.68
conductivity	0.30	0.44	0.07	0.80	0.13	0.78	0.13	0.00	0.30	0.44	0.07	0.80	0.13	0.78	0.13	0.00
Chl-a	0.65	0.67	0.34	0.29	0.44	0.33	0.43	0.99	0.65	0.67	0.34	0.29	0.44	0.33	0.43	0.99
Ammonia	0.13	0.02	0.40	0.25	0.30	0.22	0.31	0.27	0.13	0.02	0.40	0.25	0.30	0.22	0.31	0.27
Nitrite	0.66	0.60	0.90	0.92	0.84	0.90	0.85	0.04	0.66	0.60	0.90	0.92	0.84	0.90	0.85	0.04
Nitrate	-	0.59	-	0.91	-	0.89	-	0.04	-	0.59	-	0.91	-	0.89	-	0.04
Phosphate	0.74	0.44	0.44	0.11	0.55	0.13	0.53	0.98	0.74	0.44	0.44	0.11	0.55	0.13	0.53	0.98
Alkalinity	0.61	0.99	0.87	0.91	0.79	0.93	0.80	0.51	0.61	0.99	0.87	0.91	0.79	0.93	0.80	0.51
Transparency	0.39	0.94	0.70	0.98	0.60	0.99	0.61	0.37	0.39	0.94	0.70	0.98	0.60	0.99	0.61	0.37
TDS	0.01	0.99	0.17	0.79	0.10	0.82	0.11	0.68	0.01	0.99	0.17	0.79	0.10	0.82	0.11	0.68
BOD	0.30	0.44	0.07	0.80	0.13	0.78	0.13	0.00	0.30	0.44	0.07	0.80	0.13	0.78	0.13	0.00

Depth	0.76	0.35	0.73	0.31	0.51	0.08	0.52	0.11	0.76	0.35	0.73	0.31	0.51	0.08	0.52	0.11
DO	0.58	0.09	0.61	0.11	0.82	0.36	0.81	0.91	0.58	0.09	0.61	0.11	0.82	0.36	0.81	0.91
pH	0.37	0.19	0.40	0.22	0.64	0.51	0.63	0.97	0.37	0.19	0.40	0.22	0.64	0.51	0.63	0.97
Temp	0.01	0.02	0.01	0.03	0.12	0.21	0.12	0.79	0.01	0.02	0.01	0.03	0.12	0.21	0.12	0.79
conductivity	0.32	0.76	0.29	0.79	0.11	0.97	0.12	0.81	0.32	0.76	0.29	0.79	0.11	0.97	0.12	0.81
Chl-a	0.67	0.15	0.64	0.12	0.41	0.00	0.42	0.29	0.67	0.15	0.64	0.12	0.41	0.00	0.42	0.29
Ammonia	0.12	0.99	0.14	0.99	0.34	0.83	0.33	0.26	0.12	0.99	0.14	0.99	0.34	0.83	0.33	0.26
Nitrite	0.64	0.60	0.67	0.64	0.86	0.89	0.86	0.92	0.64	0.60	0.67	0.64	0.86	0.89	0.86	0.92
Nitrate	-	0.62	-	0.66	-	0.90	-	0.91	-	0.62	-	0.66	-	0.90	-	0.91
Phosphate	0.76	0.35	0.73	0.31	0.51	0.08	0.52	0.11	0.76	0.35	0.73	0.31	0.51	0.08	0.52	0.11
Alkalinity	0.58	0.09	0.61	0.11	0.82	0.36	0.81	0.91	0.58	0.09	0.61	0.11	0.82	0.36	0.81	0.91
Transparency	0.37	0.19	0.40	0.22	0.64	0.51	0.63	0.97	0.37	0.19	0.40	0.22	0.64	0.51	0.63	0.97
TDS	0.01	0.02	0.01	0.03	0.12	0.21	0.12	0.79	0.01	0.02	0.01	0.03	0.12	0.21	0.12	0.79
BOD	0.32	0.76	0.29	0.79	0.11	0.97	0.12	0.81	0.32	0.76	0.29	0.79	0.11	0.97	0.12	0.81

	B9				B10				B11			
	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19	24-Jan-15	30-Nov-	15-Dec-	17-Jan-19

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Depth	0.99	0.73	0.58	0.60	0.31	0.49	0.99	0.73	0.58	0.60	0.31	0.49
DO	0.18	0.86	0.12	0.94	0.34	0.98	0.18	0.86	0.12	0.94	0.34	0.98
pH	0.05	0.74	0.29	0.85	0.55	0.92	0.05	0.74	0.29	0.85	0.55	0.92
Temp	0.11	0.95	0.82	0.99	0.97	1.00	0.11	0.95	0.82	0.99	0.97	1.00
conductivity	0.73	0.17	0.94	0.29	0.75	0.39	0.73	0.17	0.94	0.29	0.75	0.39
Chl-a	0.96	0.90	0.68	0.81	0.41	0.72	0.96	0.90	0.68	0.81	0.41	0.72
Ammonia	0.01	0.03	0.58	0.00	0.82	0.01	0.01	0.03	0.58	0.00	0.82	0.01
Nitrite	0.23	0.31	0.08	0.45	0.29	0.55	0.23	0.31	0.08	0.45	0.29	0.55
Nitrate	-	0.30	-	0.43	-	0.54	-	0.30	-	0.43	-	0.54
Phosphate	0.99	0.73	0.58	0.60	0.31	0.49	0.99	0.73	0.58	0.60	0.31	0.49
Alkalinity	0.18	0.86	0.12	0.94	0.34	0.98	0.18	0.86	0.12	0.94	0.34	0.98
Transparency	0.05	0.74	0.29	0.85	0.55	0.92	0.05	0.74	0.29	0.85	0.55	0.92
TDS	0.11	0.95	0.82	0.99	0.97	1.00	0.11	0.95	0.82	0.99	0.97	1.00
BOD	0.73	0.17	0.94	0.29	0.75	0.39	0.73	0.17	0.94	0.29	0.75	0.39

Table 8 Overview of statistical values between satellite sensors and winter season parameters.

parameters	Average	Maximum	Minimum	Standard Deviation
Depth (m)	0.33	0.97	0.00	0.27
DO (mg/l)	0.41	1.00	0.00	0.39
pH	0.47	0.99	0.02	0.35

parameters	Average	Maximum	Minimum	Standard Deviation
Temp (∘C)	0.66	1.00	0.00	0.36
conductivity (µs/cm)	0.43	1.00	0.00	0.39
Chl-a (µg/L)	0.72	1.00	0.04	0.33
Trans (cm)	0.53	1.00	0.00	0.38
TDS (g/L)	0.57	1.00	0.00	0.41
BOD	0.19	0.73	0.00	0.23
Statistical mean	0.48	0.96	0.01	0.33

Table 9 Overview of statistical values between satellite sensors and rainy season parameters.

parameters	Average	Maximum	Minimum	Standard Deviation
Depth (m)	0.33	1.00	0.03	0.09
DO (mg/l)	0.49	1.00	0.01	0.31
pH	0.63	1.00	0.01	0.34
Temp (∘C)	0.55	1.00	0.01	0.30
conductivity (µs/cm)	0.56	1.00	0.00	0.29
Chl-a (µg/L)	0.61	1.00	0.04	0.38
Trans (cm)	0.69	1.00	0.15	0.27
TDS (g/L)	0.61	1.00	0.01	0.30
BOD	-	-	-	-
Statistical mean	0.56	1.00	0.03	0.29

Table 10 Overview of statistical values between satellite sensors and dry season parameters.

parameters	Average	Maximum	Minimum	Standard Deviation
Depth (m)	0.50	0.99	0.08	0.26
DO (mg/l)	0.64	0.99	0.09	0.31
pH	0.59	0.99	0.05	0.28
Temp (∘C)	0.45	1.00	0.01	0.42
conductivity (µs/cm)	0.46	0.97	0.00	0.32
Chl-a (µg/L)	0.51	0.99	0.00	0.27
Trans (cm)	0.33	0.99	0.00	0.32
TDS (g/L)	0.62	0.92	0.04	0.28
BOD	-	-	-	-
Statistical mean	0.51	0.98	0.03	0.31

Table 11 An overview of the linear relationship between satellite sensors and their parameters.

parameters	Winter	Dry Season	Rainy season	Total average per parameter
Depth (m)	0.33	0.33	0.50	0.38
DO (mg/l)	0.41	0.49	0.64	0.52
pH	0.47	0.63	0.59	0.56

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Temp (∘C)	0.66	0.55	0.45	0.55
conductivity (µs/cm)	0.43	0.56	0.46	0.48
Chl-a (µg/L)	0.72	0.61	0.51	0.61
Trans (cm)	0.53	0.69	0.33	0.52
TDS (g/L)	0.57	0.61	0.62	0.60
BOD	0.19	-	0.62	0.41
Average of total season	0.48	0.56	0.52	0.52

Result Discussion and Suggestions

Regarding the use of satellite images for inspecting water quality, many research studies investigate the linear relationship and these studies can be classified into 2 main platforms: atmospheric platform such as balloon, helicopter, or airplane; and space platform such as satellite and space shuttle (Gholizadeh, 2016). The example spatial resolution was 30 x 30 m^2 in LANDSAT 8, and 4 x 4 km^2 in NOAA16. The spectral resolution was 8 bands in LANDSAT 5 whereas the orbit or revisit at the same position of LANDSAT 8 was in every 16 days (Jensen, 2007). In such period, changes of water quality can be traced fairly well. At present, the Sentinel satellite with higher spectral resolution (10 m) and quicker revisit at about 5 days is another alternative. However, don't forget that the survey date should be the same or close to the date of the satellite records. According to the literature, no more than 5 days is usually used in case that the date of the water surface survey is not the same as the date of the satellite image record.

In terms of the water quality parameters, the parameters with high values mostly used in many surveys were chlorophyll-a (Chl-a), transparency, and total dissolved solids (TDS), depending on the landscapes with water flowing into the areas and depending on the seasons Mohammed and Hamed, 2017). Usali and Ismail (2010) surveyed the water quality in Malaysia by using the parameters of dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammoniac nitrogen (NH3-N), and suspended solids (SS). Meanwhile, Gholizadeh (2016) surveyed water quality and found that the usable parameters for assessing water quality included cholorophyll-a (Chl-a), total suspended solids (TSS), turbidity-colored dissolved organic matters (CDOM), Secchi disk depth (SDD), total suspended sediments (TSS), water temperature (WT), total phosphorus (TP), sea surface salinity (SSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), and chemical oxygen demand (COD). These parameters can be grouped into 2 groups: group of transparent water due to phytoplankton and colors from organic matters; and group of water with contamination of various element particles and colors. The value conforming to the relationship in this study was the value of chlorophyll-a (Chl-a) with the highest relationship.

Regarding the relationship between the parameters and the bands of the satellite data images, the parameters with clear effects on water quality changes by remote sensing were chlorophyll-a (Chl-a). The green reflectance absorbs energy in the violet, blue, orange, and red bands so the appearance was seen only in green. To find out the change values, the band ratio is used to detect such changes. For example, the green band makes proportions to the red band or the infrared band near the read band, or the blue band and the green band etc. The band ratio between the images reduces the reflectance and irradiance in the atmosphere, and water influence in the air both in LANDSAT 5 and 7 (Yousop et al., 2011; Bonansea et al., 2015), LANDSAT 8

(Lim and Choi, 2015; Olmanson et al., 2016), and IKONOS (Nas et al., 2007). For other parameters, the band ratio is also popularly used. For example, the transparency was similarly calculated with this method (Mancino et al., 2009). Nearly all methods use the result from in situ measurement to find relationship between the reflectance of each band by using satellite detection. To confirm accuracy and precision of the satellite image application, the statistical relationship can be calculated with linear regression analysis (LRA) or multiple regression analysis (MRA). In case of images with clear visibility, the calculation is possible to find phosphorus values in water used for intensive agriculture using soil fertilizers. When such phosphorous flows into water sources, it has relationship with the quantity of chlorophyll-a. As land use for agriculture at present increasingly uses fertilizers to increase productivity, the values of phosphorous and chlorophyll-a in water sources increase as well. Consequently, water quality is poor and aquatic animals lack of air for living and eventually die, leading to problems of water pollution. Meanwhile, the reduced quantity of oxygen in water varies according to water temperature i.e. higher temperature (Gholizadeh, 2016). Therefore, the change of water surface temperature is inspected by using thermal band in the study of Vanhellemont (2020).

According to suggestions for future research, the in situ survey should be planned in accordance with the satellite revisits for taking photos, the positions should be planned with distribution and good representative conforming to characteristics of water flow and activities with effects on water quality such as community and agricultural activities. Moreover, unmanned aerial vehicle (UAV) can be applied when the satellite images are unavailable such as not-due period of revisits, images with cloud coverage or unclarity by dust and smoke, or too much vapor. The UAV enables work to be operated quickly and conveniently (Andres et al., 2018; Pyo et al., 2022). When it is used with automatic and continuous sensors, an enormous dataset can be obtained for building water models in water management with scientific data for sustainable decision support.

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