Mapping Phosphorus Concentration in Lake Mainit, Philippines Using Landsat 8 OLI and GIS Techniques

Arturo G. Cauba Jr.[1], Leslie P. Ferrer[2]

[1] Department of Geodetic Engineering, College of Engineering and Geosciences, Caraga Center for Geo-Informatics, Caraga State University, Ampayon, Butuan City 8600, Philippines - agcauba@carsu.edu.ph

[2] DAR Regional Office XIII, Libertad, Butuan City 8600, Philippines - lpferrer77@gmail.com

***Abstract*— Lake Mainit is the fourth largest lake in the Philippines and water is one of the most important natural resources for humans and other living organisms. Sensors on satellites can measure the amount of solar radiation absorbed by surface water at different wavelengths, which can be compared with parameters of water quality. This study explored the use of Landsat 8 Operational Land Imager (OLI) and Geographic Information System (GIS) techniques for assessing the Phosphorus (P) content in the lake. Water quality data of Phosphorus from Environmental Management Bureau (EMB) was utilized to correlate with spectral values. Linear forward regression results yielded significant correlation with band combination B2/B4 with an R^2 of 55% for Phosphorus (P). The model was then used to map the P content in the lake and was found out that the concentration ranges from 0.0228768 mg/L to 0.23145 mg/L. The study was effective in correlating P content and the bands of Landsat 8 OLI. In addition, GIS techniques were used in extracting spectral values of bands.**

***Keywords*— water quality, spectral values, spectral bands, satellite sensors, solar radiation**

I. Introduction

Water is a valuable natural resource necessary for the survival of humans and the protection of ecosystems [1]. Over 40% of the world’s population live in coastal regions and lake or river shores [2]. Lake water plays an important role fulfilling as many functions such as, irrigation, aquaculture and livestock usage [3]. Nowadays, Lake Ecosystem is currently threatened of which the most important include the increased nutrient load and contamination [4].

Lake Mainit’s watershed is the habitat of other rare and threatened wildlife put the lake and its surrounding area of high ecological value and considered key biodiversity areas. It is known for its rich fish resources and is reported to be the habitat of rare fish species; the *puyo* or *perch* and *gabot*. Besides being the source of livelihood of families around it, it is also a source of water essential for household use and irrigation. Increasing number of people living in the lakeshore makes more nutrients entering in the lake from wastewater, runoff from land in urban areas during rains, and from farming that can cause nutrient pollution [5]. Too much nitrogen and phosphorus in the water causes the algae to grow faster. Increases in algae can harm water quality, food resources and habitats, and decrease in oxygen that fish and other aquatic life need to survive [6].

Monitoring of water quality is important for the detection of sources of pollutants that infiltrate water resources. Monitoring includes crucial information to identify and resolve water quality challenges by detecting trends over time, comparing different water bodies. Methods for monitoring water quality include biological measurements, physicochemical examination, indexes of water quality and the use of remote sensing techniques [7]. Remotely sensed satellite images can provide high-accuracy interpolation, generating spatially explicit water quality maps more efficiently as it consumes less time, labor, and financial inputs [8]. It provides spatially synoptic and near real-time measurements that can be effectively used to detect, map, and track many pollutants such as oil and chemical spills, algal blooms, and high suspended solid concentrations. Remote sensing has been demonstrated as an effective tool in detecting and mapping pollutant spills and for providing useful input data for oil spill models, to track pollutants through space and time [9].

Landsat 8 OLI is an appropriate data for estimating and monitoring water quality parameters on a regional scale [10]. It collects data in two new spectral bands: a deep blue (coastal/aerosol) band and a cirrus cloud detection band. OLI can outperform its predecessors in measurement sensitivity due to an improved signal-to-noise ratio (SNR). These improvements have been integral to the work of water quality managers who can now use Landsat 8 to map water quality indicators in coastal and inland waters [11].

Remote Sensing method that uses Landsat 8 OLI and GIS techniques are currently being used to assess water quality parameters. Few studies have shown that it is acceptable for assessing water quality parameters [1] [10]. Therefore, Landsat 8 OLI and GIS techniques can also be used to assess P concentration in Lake Mainit. Hence, the general objective of the study is to assess the P concentration in Lake Mainit, Philippines using Landsat 8 OLI and GIS techniques. Specifically, this study aims to generate land cover map of Lake Mainit, to correlate water parameters to spectral data/band combinations and water indices in order to produce map distribution of P.

II. Study Area

Lake Mainit is the fourth largest lake in the Philippines, and is geographically located between the Provinces of Surigao del Norte and Agusan del Norte, in the Island of Mindanao, Philippines (Figure 1). It has a total area of about 17,060 hectares and its lakeshore has total length of 62.10 kilometers. The lake is rich in fish resources which is the primary livelihood source of the town's people. It is the haven of several commercial species of fish that are a source of livelihood of fishermen around the lakeshore [12].

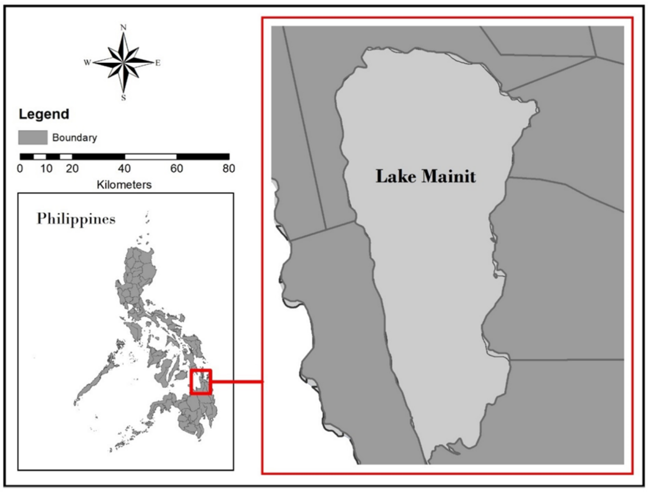

Figure 1. Map of Lake Mainit

III. Methods

The methodology of the study consists of two major activities, namely, (a) mapping the land cover of Lake Mainit, and (b) correlating the Phosphorus content and spectral data/band combinations and water indices to produce map distribution of Phosphorus concentration.

A. *Generation of Land Cover Map*

An up to date land cover map is essential for identifying the natural resources and human activities prevailing around the lake and its vicinity, as they may influence the lake's water quality. This activity consists of downloading the image data, image pre-processing procedures, training samples and ground truth data collection, image classification, and accuracy assessment.

Landsat 8 OLI satellite image is the image dataset used. It has 30-meter spatial resolution multispectral image (Figure 2).

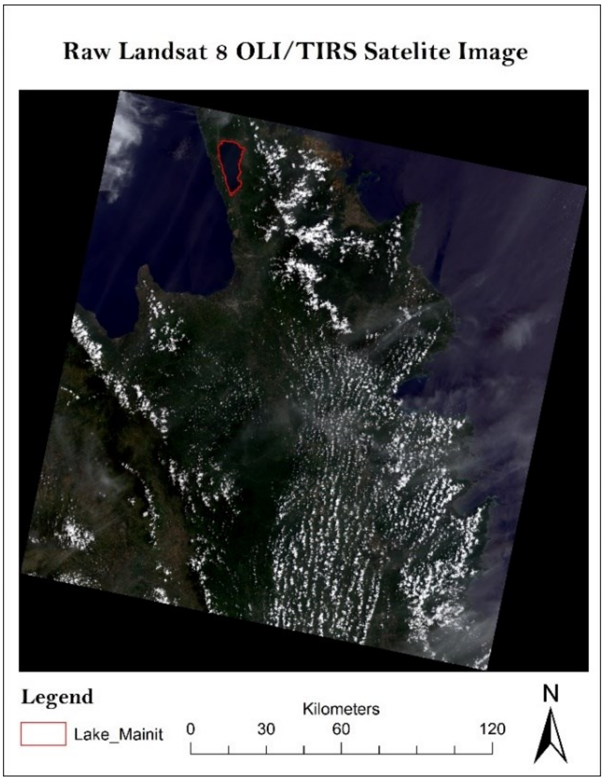

Figure 2. Landsat 8 raw image of Lake Mainit

Two pre-processing techniques were applied on the downloaded image, namely, radiometric calibration and atmospheric correction. The image was radiometrically calibrated and atmospherically corrected through dark-object subtraction method (DOS) using band minimum. DOS searches each band for the darkest pixel value, assuming that dark objects reflect no light; any value greater than zero must result from atmospheric scattering. The scattering was removed by subtracting this value from every pixel in the band [13]. After corrections were successfully made, the image was then clipped to contain only the area of interest.

In the selection of training region of interest (ROI), polygon was used to mark locations of different classes. The ROI's need not to be spatially distributed. The locations of features were visually interpreted to identify various land-cover classes present in the image with the use of different band combinations. Google Earth Pro was used to assist the identification of the land cover classes in creating ROI's and served as a guide so that the created ROI is the correct land cover class. For validation ROIs, same procedure employed in creating training ROIs was adopted. The locations of these ROIs were spatially distributed so that all areas in the classified image were represented in the accuracy assessment.

B. *Image Classification and Accuracy Assessment*

The image dataset was classified using supervised image classification. This classification uses Maximum Likelihood Classifier methods. A maximum likelihood classifier is the best option used in supervised classification classifier. In this method, it assumes the normal distribution of DN values. This classification was performed using ENVI software.

Accuracy assessment was done after the image have been classified into different land cover classes. The land cover classes were matched with their corresponding ground truth ROI. After matching the land cover classes, the confusion matrix was generated to show the accuracy of the land cover classification.

C. Correlation between P content and Spectral Data, Band Combination and Water Indices

Water's optical properties rely on water's frequency and behavior. Sensors on satellites can measure the amount of solar radiation absorbed by surface water at different wavelengths, which can be compared with parameters of water quality [14].

Phosphorus content data (Table 1) of Lake Mainit dated January 22, 2020 from Environmental Management Bureau (EMB) were utilized in this study. To explore the relationships between water quality and spectral data, Landsat 8 image with acquisition date of January 27, 2020 which has a 5-day difference from water sampling data of the EMB was used.

Table 1. Phosphorus content data obtained from EMB

Station	Latitude	Longitude	P in mg/L
1	9°23'59.2" N	125°32'39.9" E	0.006
2	9°22'27.7" N	125°33'12.3" E	0.006
3	9°22'6.8" N	125°32'41.3" E	0.005
4	9°22'12.8" N	125°30'37.9" E	0.006
5	9°22'25.2" N	125°31'35.8" E	0.005
6	9°25'29.0" N	125°30'57.3" E	0.005
7	9°28'45.9" N	125°30'34.9" E	0.006
8	9°31'5.0" N	125°33'1.6" E	0.009
9	9°29'58.6" N	125°33'39.1" E	0.010
10	9°28'5.0" N	125°33'8.1" E	0.010

The ten (10) sampling point locations were mapped and shown in Figure 3. Seven bands of Landsat 8 were used in this study, namely, Coastal Aerosol, Blue, Green, Red, Near-Infrared, SWIR1, and SWIR 2. Using the geographic locations of the monitoring stations of EMB, raster values were extracted, organized and tabulated. Three water indices were used to enhance the spectral appearance of water, Modified Normalized Difference Water Index (MNDWI) and Normalized Difference Water Index variants (NDWI1) and (NDWI2). All possible band combinations from the seven bands of Landsat 8 were explored to get more information about Phosphorus content [15].

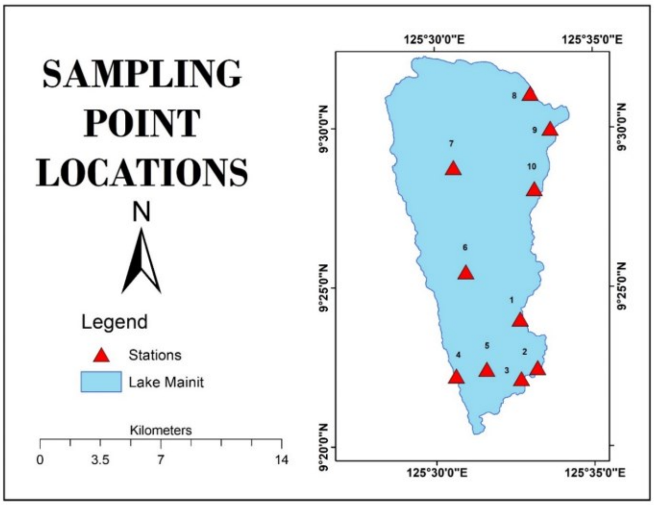

Figure 3. Map of Sampling Point Locations

All spectral values extracted from the individual band, water indices and band combination were organized and tabulated in MS excel together with the water quality data of Phosphorus. The excel file was imported to SPSS software for statistical analysis. Significant values were then found and recorded for regression. Significant values recorded after the correlation analysis were used to employ regression analysis. Linear forward regression method was used to develop empirical models in calculating P in Lake Mainit.

IV. Results and Discussion

A. Classification Accuracy and Land Cover Map

Table 2 shows the confusion matrix of the generated land cover of Lake Mainit using Maximum Likelihood Classifier. It contains the producer's and user's accuracy of every land cover class. The classification has acquired overall accuracy of 93.7198% and kappa coefficient of 0.9266%.

Table 2. Confusion matrix of the generated land cover map

		GROUND TRUTH PIXELS								
	Land Cover Class	Water	Forest	Barren	Built-up	Crop land	Grass land	Shrubs & Trees	Total	User's Accuracy (%)
CLASSIFIED PIXELS	Water	72	0	0	0	0	0	0	72	100
	Forest	0	54	0	0	0	6	0	60	90
	Barren	0	0	46	0	0	1	0	49	93.88
	Built-up	0	0	8	56	2	0	0	64	87.50
	Crop land	2	0	1	1	56	0	0	60	93.33
	Grass land	0	4	1	0	0	46	0	51	90.20
	Shrubs & Trees	0	0	0	0	0	0	58	58	100
	Total	74	58	56	57	58	53	58	414	
Producer's Accuracy (%)		97.30	93.10	82.14	98.25	96.55	86.79	100		
Overall Accuracy (%)		93.7198								
Kappa Coefficient		0.9266								

Figure 4 shows the land cover map produced after passing the required accuracy. The map shows seven different land cover classes dominating the surrounding area of the lake.

https://doi.org/10.5194/isprs-archives-XLVIII-5-2024-141-2024 | © Author(s) 2024. CC BY 4.0 License.

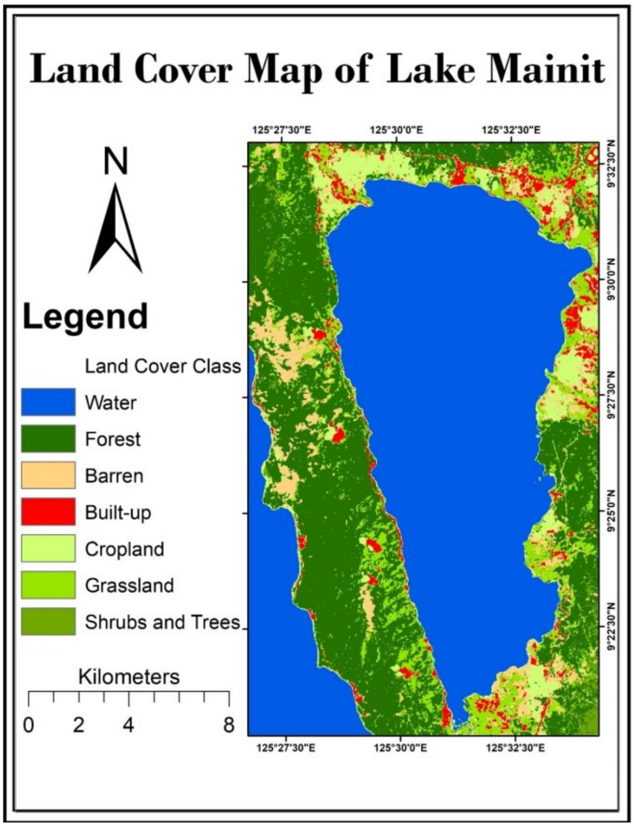

Figure 4. Land cover map of the study area

B. Correlation Analysis Result

Table 3 shows the statistics of the studied water quality parameter and spectral values of each band used in correlation analysis. After the correlation, Phosphorus showed positive strong correlations with Band 3 (Green), Band 4 (Red), Band 6 (SWIR 1) and Band 7 (SWIR 2) which is found to be significant at $p < 0.01$ level. The calculated Pearson's correlation coefficient (R) of the significant bands is shown in Table 4.

Table 3. Statistics of Phosphorus and spectral bands

Water Parameter (mg/L)	Spectral Values						
Phosphate as P	B1	B2	B3	B4	B5	B6	B7
0.006	0.041279	0.037593	0.033354	0.021059	0.031213	0.015452	0.017527
0.006	0.03969	0.037107	0.034105	0.021014	0.033244	0.015805	0.017527
0.005	0.040705	0.037328	0.033465	0.02033	0.027107	0.013774	0.016445
0.006	0.045606	0.043398	0.03735	0.026489	0.048608	0.024171	0.022847
0.005	0.043266	0.039557	0.032273	0.021588	0.021191	0.011456	0.015805
0.005	0.049204	0.045208	0.036864	0.026732	0.027284	0.016379	0.019977
0.006	0.049049	0.045164	0.038233	0.027747	0.026931	0.0166	0.02022
0.009	0.048519	0.046687	0.046445	0.034855	0.043332	0.023001	0.023112
0.010	0.047305	0.043486	0.038719	0.027593	0.037946	0.020132	0.022008
0.010	0.048321	0.045606	0.041125	0.028939	0.036555	0.020617	0.022141

Table 4. Pearson's correlation coefficients of spectral bands

Band Name	Band 3 (Green)	Band 4 (Red)	Band 6 (SWIR 1)	Band 7 (SWIR 2)
R value	0.7391	0.6688	0.6447	0.7026

Table 5 shows the statistics between the studied water parameters and spectral values of the three water indices (MDWI, NDWI1 and NDWI2) used in correlation analysis. MNDWI, NDWI1 and NDWI2 were found to be significantly uncorrelated to Phosphorus. The R value of MDWI, NDWI1 and NDWI2 are -0.247, -0.284 and -0.345.

Table 5. Statistics of Phosphorus and water indices

Water parameter (mg/L)	Spectral Values		
Phosphate as P	(MNDWI)	($NDWI_1$)	($NDWI_2$)
0.006	0.372159	0.052145	0.326347
0.006	0.380139	0.022284	0.360912
0.005	0.416834	0.104959	0.326145
0.006	0.081164	-0.167586	0.245412
0.005	0.484831	0.208903	0.307025
0.005	0.384753	0.149349	0.249756
0.006	0.399361	0.172791	0.243363
0.009	0.339711	0.035661	0.307779
0.010	0.30973	0.015189	0.295933
0.010	0.337188	0.068282	0.275244

All possible combinations were explored and 42 band combinations were made to examine. Out of all band combinations only five (5) combinations were found to be significant at $p < 0.01$ level for Phosphorus. These band combinations are B1/B4, B1/B7, B2/B4, B4/B1 and B4/B2, where B4/B2 and B4/B1 show strong positive correlation. Statistics is shown in Table 6. R values are shown in Table 7. In SPSS software, a forward regression method was applied to create an empirical model to calculate the distribution of the studied water parameter in Lake Mainit. The result of the regression showed that the model for calculating Phosphorus is based on the band combination B2/B4 (Blue/Red) band. The R-squared value for the band combination and Phosphorus distribution is 0.5509.

Table 6. Statistics of P content and band combination

Water parameter (mg/L)	Spectral Values				
Phosphate as P	B1/B4	B1/B7	B2/B4	B4/B1	B4/B2
0.006	1.96019	2.35515	1.78513	0.510156	0.560182
0.006	1.88867	2.26447	1.76577	0.529473	0.566324
0.005	2.00219	2.47516	1.83607	0.499453	0.544642
0.006	1.72168	1.99613	1.63835	0.580829	0.610372
0.005	2.00411	2.73742	1.83233	0.498975	0.545753
0.005	1.84064	2.46297	1.69118	0.543289	0.591304
0.006	1.76771	2.42576	1.6277	0.565703	0.614365
0.009	1.39202	2.09932	1.33946	0.718378	0.746569
0.010	1.71441	2.14944	1.57601	0.583291	0.634513
0.010	1.66973	2.18244	1.57591	0.5989	0.634555

Table 7. Pearson's correlation coefficients of band combination

Band Name	B1/B4	B1/B7	B2/B4	B4/B1	B4/B2
R	-0.727	-0.635	-0.742	0.697	0.717

C. Generated Map

The developed empirical model was used for calculating Phosphorus content in Lake Mainit. The generated map is shown in Figure 5. Result shows that phosphorus content has a minimum value of 0.02228768 mg/L and maximum value of 0.023145 mg/L which indicates that the concentration of Phosphorus in Lake Mainit has low level since natural levels of it usually ranges from 0.005 mg/L to 0.05 mg/L.

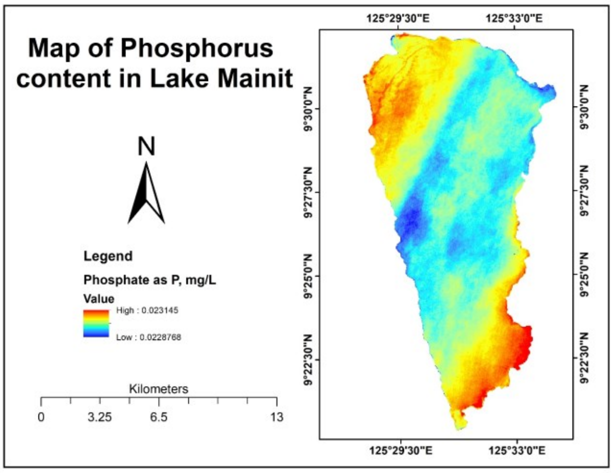

Figure 5. Map of P content in Lake Mainit

V. Conclusion and Recommendations

The main objective of the study is to map P content in Lake Mainit, Philippines using Landsat 8 OLI and GIS techniques. With the use of the satellite image, land cover map of Lake Mainit was generated and has an overall accuracy of 93.7198% and Kappa Coefficient of 0.9266.

Landsat 8 OLI also used to correlate P content with the spectral values extracted from individual band, band combinations and water indices. The results of this study showed that Phosphorus has a strong positive correlation with the individual band B3, B4, B6 and B7, band combination B2/B4, B4/B1, B4/B2 and a strong negative correlation with the band combination B1/B4 and B1/B7. Forward regression result showed that the model is based on band combination of B2/B4 with an R2 value of 55%. The model was then used to map the Phosphorus content in the lake and was found out that the concentration ranges from 0.0228768 mg/L to 0.023145 mg/L. The findings indicate that the lake is low in Phosphorus content. It is recommended to choose more sampling stations within the lake that must be spatially distributed to cover the whole Lake Mainit, and using other water parameters to correlate with band combinations and indices for assessing the nutrient pollution in the lake.

References

[1] N. Usali and M. H. Ismail, "Use of Remote Sensing and GIS in Monitoring Water Quality," Journal of Sustainable Development, vol. 3, no. 3, 2010.

[2] D. Sloggett, M. Srokosz, J. Aiken and S. Boxall, "Operational Uses of Ocean Colour Data-Perspectives for the Octopus," in Rotterdam, Netherlands, Balkema Publishers, 1995.

[3] M. S. Alam, "Assessment Of Water Quality Of Hatirjheel Lake," INTERNATIONAL JOURNAL OF TECHNOLOGY ENHANCEMENTS AND EMERGING ENGINEERING RESEARCH, vol. 2, no. 6, pp. 98-100, 2014.

[4] C. Bronmark, and L.A. Hansson, "Environment issues in lakes and ponds: current state and perspectives," Environmental Conservation, vol. 29, no. 3, pp. 290-307, 2002.

[5] M. Haseena, M. F. Malik, A. Javed, S. Arshad, N. Asif, S. Zulfiqar and J. Hanif, "Water Pollution and Human Health," Environmental Risk Assessment and Remediation, vol. 1, no. 3, 2017.

[6] "Nutrients: Phosphorus, Nitrogen," Minnesota Pollution Control Agency, 2008.

[7] K. Mosimanegape, "Integration of physicochemical assessment of water quality," Botswana, 2016.

[8] X. Wang and W. Yang, "Water quality monitoring and evaluation using remote-sensing techniques in China: A systematic review," Ecosystem Health and Suistainability, vol. 5, no. 1, pp. 47-56, 2019.

[9] S. Hafeez, et.al., Detection and Monitoring of Marine Pollution Using Remote Sensing Technologies ollution/detection-and-monitoring-of-marine-pollution-using-remote-sensing-technologies, 2018.

[10] J. Lim and M. Choi, "Assessment of water quality based on Landsat 8 operational land imager associated with human activities in Korea," Environmental Monitoring and Assessment, 2015.

[11] R. C. Trinh, C. G. Fichot, M. M. Gierach, B. Holt, N. K. Malakar, G. Hulley and J. Smith, "Application of Landsat 8 for Monitoring Impacts of Wastewater Discharge on Coastal Water Quality," Frontiers in Marine Science, 2017.

[12] E. Red, "Lake Mainit and the people thriving arount it," Inside Mindanao, 2010.

[13] A. El-Zeiny and S. El-Kafrawy, “Assessment of water pollution induced by human activities in Burullus Lake using Landsat 8 operational land imager and GIS,” *Egypt. J. Remote Sens. Sp. Sci.*, vol. 20, pp. S49–S56, Apr. 2017, doi: 10.1016/J.EJRS.2016.10.002.

[14] S. E.-K. Ahmed El-Zeiny, "Assessment of water pollution induced by human activities in Burullus," The Egyptian Journal of Remote Sensing and Space Sciences, 2017

[15] M. B. D. Campana, L. C. S. Asube, and M. V. Japitana, “Assessment of heavy metal concentration in soil using remotely sensed data,” *IEEE Reg. 10 Annu. Int. Conf. Proceedings/TENCON*, vol. 2020-November, pp. 620–625, Nov. 2020, doi: 10.1109/TENCON50793.2020.9293807.