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WATER QUALITY ASSESSMENT AND MAPPING ON MARINE FISH CAGE SITES IN NASIPIT, AGUSAN DEL NORTE, PHILIPPINES USING REMOTE SENSING AND GIS

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ABSTRACT: Water quality serves as a critical component of an aquaculture system. This study explores the applicability of our previously developed geoinformatics-based framework for water quality modeling and mapping in mariculture environment. This study employed Remote Sensing (RS) and Geographic Information System (GIS) technologies in deriving spectral features and regression models to assess and map water quality where marine fish cages are situated. Physico-chemical parameters like temperature, pH, dissolved oxygen (DO), salinity, and turbidity were utilized to perform correlation analysis while the pixel values of the processed Landsat Operational Land Imager were employed together with the water quality parameters to perform regression analysis. Then the regression models were applied in the inverse distance weighted (IDW) interpolation method to generate water quality maps in a GIS platform. Only the recorded readings of pH and turbidity are at a good level and did pass the prescribed standard for marine water aquaculture. The five parameters showed a weak association to each other. DO yielded the highest R^2 of 100% while two regression models for turbidity garnered an R^2 of 92.7% and 88.4%, respectively. Actual value and predicted value of each parameter were validated using the t-test function. The result of the t-test analysis proved that the estimated water quality values using GIS are statistically the same with the on-site water quality values derived using the Horiba water checker. This study proved the applicability of a Geoinformatics-based WQ monitoring framework in marine waters.

1. INTRODUCTION

Water is one of the essential elements in the life cycle of all living organisms and is regarded as the most basic resource that aquaculture relies on (Zweig et al., 1999). The Municipality of Nasipit, Philippines is a coastal town and agri-fishery is one of the critical sources of income for the locals. Hence, water quality is a vital element to consider for it serves as a critical component of an aquaculture system. It is a measure of the state of water in relation to the needs of one or more species and human needs (Omer, 2019). In the water, fish perform their physiological functions such as breathing, waste excretion, feeding, reproduction, and salt balance. As a result, the value of water quality is acknowledged, as it is a deciding factor on the success or failure of an aquaculture operation (PHILMINAQ, 2019).

Cage culture, like any other aquaculture sector, necessitates good water quality (Pérez et al., 2003). Cage culture is an aquaculture processing technique that uses established water supplies while encasing the fish in a cage that allows water to flow freely between the fish and the pond, allowing for water trade and waste disposal into the surrounding water (Soltan, 2016). Despite the fact that it is frequently used to increase fish production and create jobs, the unplanned expansion of similar practices, particularly the environmental implications of nutrient loading, could come with negative consequences not only to cage culture operations, but also to the capture fisheries of such water bodies (Devi et al., 2017).

The application of Remote Sensing (RS) showed a positive response in assessing water quality; even so, Geographic Information Systems (GIS) is the one that makes it feasible to impeccably associates water quality monitoring with space and time (Ramadas & Samantaray, 2018). By integrating remote sensing data with GIS, more-comprehensive analysis of water quality has become possible (Quinn et al., 2019). Remote sensing has been utilized since the early 70's and is still widely employed in water quality assessment studies in the contemporary world (Gholizadeh et al., 2016). It gives a synoptic view of the earth surface in a sense that it provides the ability to acquire information from the spatial and temporal variations for a more-comprehensive approach of monitoring and assessment of water quality (Michelle V Japitana & Burce, 2019; Quinn et al., 2019). GIS, on the other hand, is a powerful tool for organizing and presenting spatial data in a way that allows for effectual environmental management planning. The system can be used to efficiently manage water quality and has a number of advantages for aquaculture development programs, including not only providing a visual inventory of the physical, biological, and economic characteristics of the ecosystem, but also allowing the generation of suitability maps for various uses or activities without requiring complex and time-consuming manipulations. It is a well-organized system of hardware, software and geographic data for storing, capturing, updating, manipulating, and displaying all types of geographically referenced data (Shih, 2017). In the previous works of Japitana & Burce (2019) and Japitana et al., (2019), they established a geoinformatics-based water quality mapping and modeling by utilizing Landsat 8 and regression analysis in developing models for estimating WQ parameters such as pH, dissolved oxygen (DO), total dissolved solids (TDS), total suspended solids (TSS), biological oxygen demand (BOD), turbidity, and conductivity of a river. Japitana & Burce (2019) yielded high coefficient of determination (R^2 values) in their developed WQ models but they failed to validate the models. This particular study aims to adapt the same research approach of Japitana & Burce (2019) but will integrate GIS mapping interpolations and model validation to explore further its feasibility in marine water quality assessment. Hence, this study attempts to employ a combination of remote sensing and GIS techniques and regression modeling in assessing and mapping water quality within marine fish cage sites.

2. METHODOLOGY

2.1 The Study Area

The study was conducted in the mariculture area of Nasipit, Agusan del Norte, Philippines. The Municipality of Nasipit is a third-class municipality which is located in the northwestern part of the Caraga Region as shown in Figure 1.

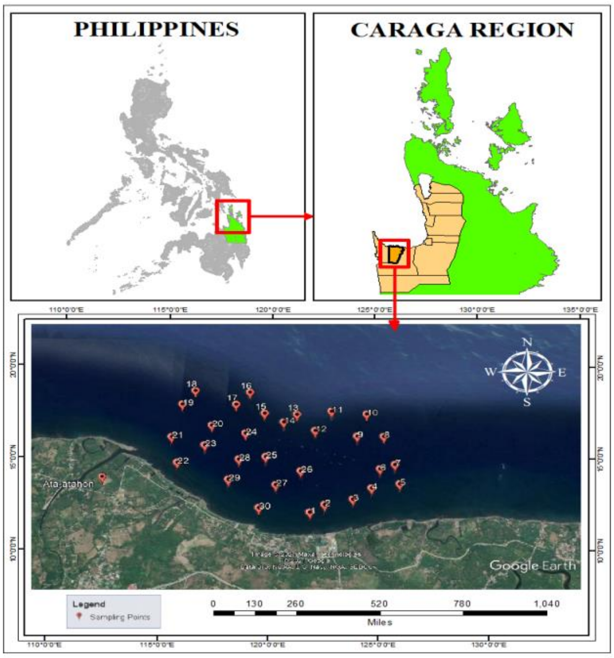

Figure 2. The Location of the Sampling Points and the Study Area.

2.2 Materials and Method

Thirty (30) random sampling points were established in the study area using a handheld GPS that will be used for model development and validation. The physico-chemical parameters considered in this study are temperature, pH, Dissolved Oxygen (DO), salinity, and turbidity and were measured using HORIBA U-50 and the on-site measurement was conducted last April 19, 2021. This study followed the selection method of Japitana & Burce (2019) in downloading Landsat 8 OLI image from USGS Earth Explorer.

This study's methodology has four components: Landsat image pre-processing, image processing, model development, and water quality mapping and validation as shown in Figure 2. Image processing was employed to generate water indices, band ratios, and principal component analysis from the pre-processed Landsat image. Feature extraction were then conducted to extract image feature values from the raw, pre-processed, and post-processed Landsat 8 bands for the training and validation points. The acquired on-site water quality data using Horiba Water Checker were then combined with the image features datasets to perform Pearson correlation and regression analysis to derive water quality regression models. Using the developed water quality models, water quality surface maps were generated by applying interpolation techniques to assess the physico-chemical condition of the study area. Lastly, model validation was done to provide evidence whether the derived water quality regression models and the generated water quality maps are significant and reliable to use.

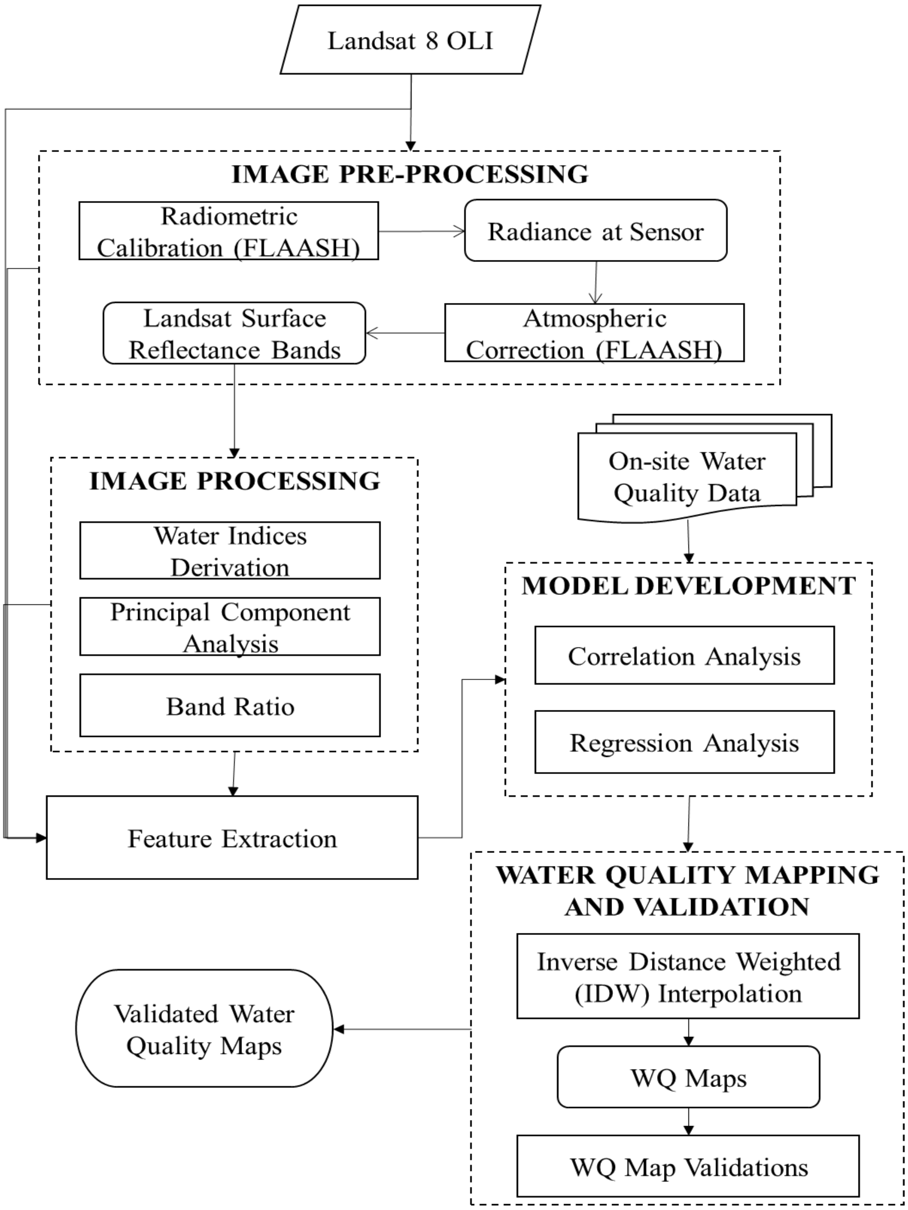

Figure 3. Methodological Framework

2.3 Model Development

The relationship between the five (5) physico-chemical parameters considered in this study were analyzed using the Pearson correlation coefficient (r) value. Pearson correlation is a tool used for measuring the degree of association between two variables. Then, the estimation of relationships between the selected parameters and the feature vector values were performed through regression analysis (Forward Method). Regression analysis is applied to assess the strength of the relationship between the variables and depict how dependent variables will vary if one or multiple independent variables vary due to factors. Regression analysis can be achieved using the equation below:

$$Y = \beta_o \pm \beta_i X_i \pm \ldots\ldots\ldots\ldots \pm \beta_{\square} X_{\square} \pm u \qquad \text{Equation 1}$$

where:

Y = Dependent variable
β_o = Intercept
β_i = Regression coefficient of x_i
$\beta_{\square}$ = Regression coefficient of $x_{\square}$
X_i to $X_{\square}$ = Independent variables

2.3 Water Quality Mapping and Validation

Water quality (WQ) Maps are generated in this study using Inverse Distance Weight (IDW) interpolation technique in a GIS platform. The procedure creates surface maps for each water quality parameter to predict the cell values of the unsampled points using the derived regression models. Only the parameters passing the water quality standards for mariculture with corresponding regression models yielding high R^2 values are included in this phase. Using the validation points, the predicted water quality levels for each WQ Maps were then compared to the actual on-site water quality values using t-test analysis.

3. RESULTS AND DISCUSSION

3.1 On-site Water Quality Data

The results of the five (5) selected physico-chemical parameters acquired on-site using Horiba is shown in Table 1. As shown in Table 1, all of the measured temperature readings did not reach the Philippines' standard limit of 25-32°C for marine waters. However, the measured temperatures are suitable for mariculture, particularly on Milkfish, which is currently the cultured species in the study area. In addition, the recorded DO readings exceeded the standard limit for marine waters but passed the optimum level of tolerance for culturing Milkfish. The measured values for pH, Salinity, and Turbidity achieved the optimum level for culturing Milkfish. Both pH and Turbidity readings passed the prescribed marine water quality limits while Salinity readings were beyond the appropriate range for marine waters.

Table 2. The Water Quality Data Collected using Horiba.

Sampling Points	Temperature °C	pH	Dissolved Oxygen mg/L	Salinity ppt	Turbidity (NTU)
1	23.47	8.68	14.43	26.73	2.31
2	23.60	8.65	14.32	27.15	1.36
3	23.52	8.56	17.16	29.47	2.72
4	23.55	8.60	11.87	27.00	2.35
5	23.77	8.89	14.02	26.28	2.94
6	23.30	8.44	13.92	25.25	2.64
7	23.42	8.49	10.44	26.88	3.80
8	23.65	8.65	16.58	25.25	5.61
9	23.88	8.32	13.12	24.82	3.71
10	23.71	8.58	13.01	26.88	2.77
11	24.29	8.97	13.93	30.09	2.38
12	24.11	8.42	16.32	27.49	8.79
13	23.67	8.58	11.81	28.59	1.35
14	23.80	8.40	11.70	27.48	1.72
15	23.83	8.47	14.30	25.92	3.77
16	24.14	8.55	12.09	27.64	8.67
17	24.06	8.50	12.61	27.95	1.07
18	23.91	8.50	16.89	26.87	0.54
19	23.83	8.59	11.72	31.41	1.70
20	23.96	8.42	12.51	27.20	2.40
21	23.58	8.54	13.17	28.27	2.38
22	24.01	8.45	10.89	26.10	3.50
23	23.95	8.54	12.91	28.14	1.88
24	23.67	8.30	14.22	27.14	2.61
25	23.73	8.30	15.26	25.72	3.77
26	24.11	8.34	16.77	31.97	4.05
27	24.44	8.56	10.90	28.62	2.50
28	24.16	8.56	14.15	30.58	3.61
29	24.19	8.54	12.04	28.71	1.00
30	24.54	8.52	11.81	29.26	1.50

3.2 Model Development Results

Table 2 shows the correlation analysis results of the five WQ parameters considered in this study. As shown in Table 2, all parameters resulted to have weak relationships since the range of the calculated (r) values very low. The results also showed that the temperature have a positive, yet weak association with pH, Salinity and Turbidity. While temperature and DO are negatively correlated. Turbidity, on the other hand, is positively correlated to DO and negatively correlated to both pH and Salinity. While DO and Salinity have negative correlation.

Table 2. Correlation Coefficient Matrix of the Physico-chemical Parameters

	Temperature	**pH**	**Dissolved Oxygen**	**Salinity**	**Turbidity**
Temperature	1.000				
pH	0.045	1.000			
Dissolved Oxygen	-0.170	-0.029	1.000		
Salinity	0.459	0.180	-0.011	1.000	
Turbidity	0.093	-0.147	0.235	-0.168	1.000

The regression models derived using the Forward Regression Analysis in SPSS software are shown in Table 3 with corresponding R^2 values. The tabulated results show that the developed models for DO and Turbidity attained the highest R^2 values. The goodness of fit of the DO regression model is remarkable with an R^2 of 100%. While, the two regression models for Turbidity yielded an R^2 of 92.7% and 88.4%, respectively. These results are consistent with the findings of Japitana & Burce (2019) which indicates that satellite-based turbidity estimation is reliable for river and marine water. Both derived models for temperature only got an R^2 of 46.3% and 58.1%, respectively. Contrary to the remarkable regression strength derived by Japitana & Burce (2019) for pH, this study garnered the lowest R^2 value of 15.8%.

Table 3. RS-based Regression Models for Selected WQ Parameters.

Model No.	**Dependent**	**Predictors and Coefficients**	**R^2 (%)**	**Standard Error of the Estimate**
1	Temperature	25.352+17.935×PC4_SR$_1$	46.3	0.226
2	Temperature	19.162+21.865×PC4_SR$_1$ +0.764×pH	58.1	0.203
3	pH	8.628-0.028×BR	15.8	0.139
4	Dissolved Oxygen	14.425-25.693×SR$_1$ B1+1.604E-5×Turbidity	100	0.000
5	Salinity	-36.490+2.690×Temperature	21.1	1.603
6	Turbidity	30.518×DO+3724.736×PC5_SR$_1$ -182.087×PC3_SR$_1$ -205.454	92.7	5.186
7	Turbidity	32.759×DO+3105.224×PC5_SR$_1$ -178.099	88.4	3.771

Legend: SR$_1$ = surface reflectance bands calibrated using post-FLAASH; B# = band number; and PC = principal component

3.3 Water Quality Maps and Validation Results

As mentioned in Section 3.1 of this paper, both pH and Turbidity readings passed the prescribed marine water quality limits and achieved the optimum level for culturing Milkfish in the study area. However, in deriving the regression models, the R^2 value for pH regression model is low. Thus, the water quality map generated for this study is for the Turbidity regression model. The Turbidity regression model with an R^2 of 92.7% was chosen with DO, Principal Component 5 and Principal Component 3 of surface reflectance bands calibrated using the post-FLAASH method (PC5_SR$_1$ and PC3_SR$_1$) served as predictors. A set of vector points were then generated to compute the predicted turbidity values using the developed regression models. Findings of this study showed that the regression models for turbidity have a reported p-value of less than 0.001, which indicates that the computed results are highly significant. The generated IDW map for Turbidity distribution in the study area is shown in Figure 2. In validating the estimated turbidity map, the t-test yielded a value of 0.687, lower than its critical value of 2.160 and has a probability value of 0.50 ($p > 0.05$). Based on this validation result, the strength of the water quality map to estimate turbidity presented strong evidence for the null hypothesis. This means that the estimated turbidity values are statistically the same as the on-site water quality values acquired by HORIBA Water Checker.

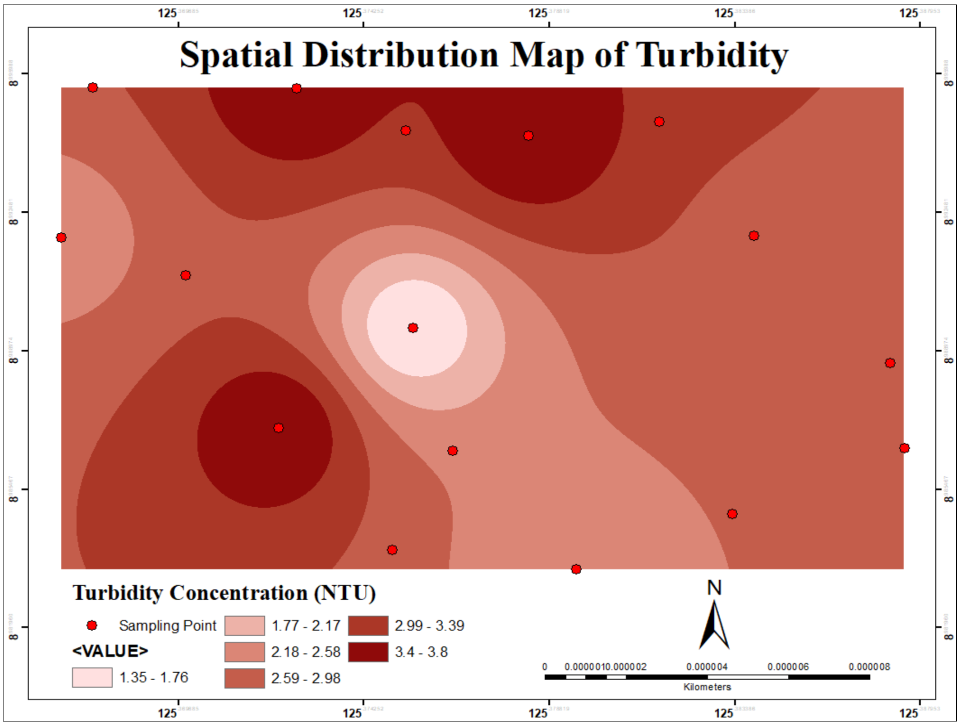

Figure 2. Turbidity Map in the Study Area

4. CONCLUSION

The findings of this study proved the applicability of a Geoinformatics-based WQ monitoring framework developed by Japitana et al., (2019) in marine waters. The study further demonstrated the practical advantage of using RS datasets in mapping and modeling WQ parameters. In this study RS-based water quality models were developed. The validated turbidity map in the study area using the regression model was statistically proven to have no significant difference between the actual on-site measurements.

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