# Water Quality Estimation Using Spectroradiometer and SPOT Data

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**Abstract:** A field spectroradiometer SE-590 was used to measure the spectral reflectance of water body. The reflectance was calculated as the ratio of surface water radiance to the standard whiteboard radiance nearly measured at the same time. Water samples were taken simultaneously for determining their chlorophyll-a, suspended solid (SS) and transparency. The relationships between those water quality parameters and spectral reflectance were analyzed using stepwise multiple regression to derive optimal prediction models. The multiple regression was also applied to the SE-590 simulated SPOT bands. The SPOT image of the same day was also analyzed using the same method to compare the statistical results.

It showed that the multiple regression models using the SE-590 reflectance data got the best water quality prediction results. The evaluated RMS error of chlorophyll-a, SS and transparency of water quality parameters were 0.57 *u*g/l, 0.2 *m*g/l and 0.17 m, respectively, and the RMS errors were 0.36 *u*g/l, 0.49 *m*g/l and 0.42 m for SPOT data, respectively. The SE-590 simulated SPOT three bands data obtained the worst results and the RMS errors were 1.77 *u*g/l, 0.49 *m*g/l and 0.37 m, respectively.

**Key Words:** Remote sensing, Spectroradiometer, Water quality, Trophic state

## 1. Introduction

Traditionally, sparsely distributed water samples were collected to evaluate the pollution conditions of a reservoir or a river by using the Trophic State Index of Carlson (CTSI), BOD/DO ratio methods, etc. However, the water sampling sites are only a limited number of points, they can hardly give a good representation of the water surface. On the other hand, remote sensing imagery can be applied to combine the sampling data by establishing a statistical regression model for estimating water quality to the whole water surface. The physical parameters which have been applied in remote sensing include chlorophyll-a, transparency, SS, turbidity and temperature [2]. If the concentration of chlorophyll-a is greater than 12 *u*g/l and the transparency is less than 2m, the water quality would be classified as in a eutrophication stage according to the evaluation standard of EPA, USA .

In this study, we measured the water body and standard whiteboard radiance using portable SE-590 spectroradiometer (wavelength**:** 0.373~1.107 *um*). Then, we calculated the ratio for reflectance and analyzed the reflection characteristics and established the regression models corresponding to the chlorophyll-a, transparency and SS. The study area was Tekee reservoir in central Taiwan. SPOT image acquired on the same date of sampling was used. SE-590 simulated SPOT spectral bands were also used to collect spectral information of the water surface for subsequent analysis.

## 2. The Analysis Methods of Remote Sensing

### 2.1 Water Quality obtained by Remote Sensing

Each pollutant or polluting source has its own unique spectral characteristics. For example, the reflectance will raise and the spectral response curve shift to long wavelength if the SS in water increase [1]. Each pollutant has a contribution to the spectral reflectance on the remote sensing images.

The radiance of water body is affected by the following factors [3]. They are: (1) energy source, e.g. sunlight and skylight; (2) atmospheric effects, e.g. scattering and absorption; (3) surface reflection, e.g. including sunlight and skylight mirror reflection; (4) volume reflection, e.g. the integrate effects of clear water and other pollutants; (5) bottom reflection, e.g. the electromagnetic wave reflected from the bottom.

Among those five factors, volume reflection is the most critical one that contributes to the water quality assessment by remote sensing approach. Energy source is regarded as omni-effective one, which applies to all image pixels evenly. Bottom reflection would give little contribution if water depth is greater than the penetration depth of remote sensing spectrum. Furthermore, the atmospheric effect can be ignored because the SE-590 sensor is applied only about 1m on the surface water. With these conditions, statistical models can be established using water sampling data and remote sensing imagery, and estimate the water quality distribution [6].

### 2.2 Statistic Regression Analysis

The relationship of water quality parameters and multi-spectral data is given using the linear multiple regression model.

$$Y = X\beta + \Sigma \quad (1)$$

Where **Y:** water quality to be estimated, **X:** multi-spectral matrix, **Σ :** random error, **β :** regression coefficient. The least square solution of β is $(X'X)^{-}X'Y$.

252 bands of SE-590 data would take too much computer time to establish the linear multiple regression model. So, 17 bands in the spectral range between 380 to 950 *nm* were selected for a further statistical analysis.

The stepwise multiple regression model was applied to derive the optimal bands for predicting water quality. Strict statistical criteria were set for examining the parameters used for estimating the water quality [4]. They are: (1) Regression correlation coefficient is near to 1; (2) RMS is near to 0; (3) The ratio of F-test to $F_{(0.05)}$ is ≧ 4.0; (4) The statistic ti is ≧ 2.0; (5) The normalized expected total error of estimation ($C_k$) is small and the ratio of $C_k$ /( K+1) ≦1.0, k is the number of coefficients..

As a statistical regression model is selected, the multiple imagery and water sampling data can be entered to evaluate the regression and derive the optimal regression coefficients, and proceed to estimate the water quality parameters of chlorophyll-a, SS and transparency. Eventually, the estimated results were compared to the "truth" of water samples and check points to evaluate the RMS [2]. Fig. 1 is the flow chart of the water quality estimation.

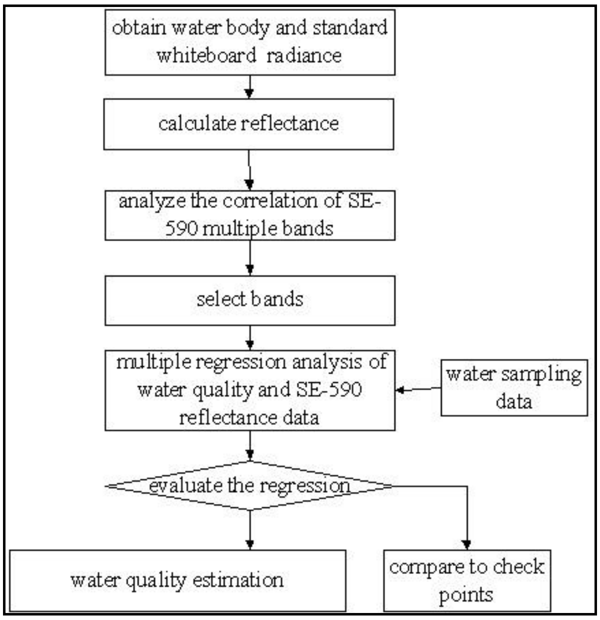


**Fig. 1. The flow chart of water quality estimation**

## 3. Results

SE-590 data, SPOT image and SE-590 simulated SPOT data were used to estimate the distribution of chlorophyll-a, SS and transparency of the water surface by applying the statistical regression models.

### 3.1 The Results of Regression Analysis

The regression analysis results of SE-590 data are given in Table 1. The regression coefficients are larger than 0.99, all the ratio of F-test to $F_{(0.05)}$ are also ≧ 4.0, and all $C_k$/K+1 ≦1.0 for chlorophyll-a, SS and transparency parameters. The SPOT image derived regression coefficients are smaller than that obtained by SE-590, especially for the transparency case which is only 0.75. However, the SE-590 simulated SPOT bands gave a better coefficient, i.e., 0.91.

The predicated RMS errors are also discussed. RMS errors of SE-590 estimated SS and transparency were smaller than those by other means. However, the simulated SPOT bands for chlorophyll-a estimation was the worst and the RMS error is 1.77 *u*g/l.

### 3.2. The Standard Error of Check points

The RMS error of check points are given in Table 2, in which the RMS errors are inferior to regression analysis results. Especially, the standard error of SE-590 estimated SS was 3.50 *m*g/l, and which was 2.96 *u*g/l for chlorophyll-a estimated by simulated SPOT bands. The measured and estimated water quality data using SE-590 simulated SPOT bands are shown in Fig. 2.

**Table 1. The regression analysis results using multiple data**

| SE-590 reflectance data | | | | | |
|---|---|---|---|---|---|
| Water quality | regression coefficient | Std. error | F-test | $F_{(0.05)}$ | $C_k/(k+1)$ |
| Chlorophyll-a | 0.9949 | 0.57 *u*g/l | 139.33 | 3.14 | 0.06 |
| Suspended solid | 0.9947 | 0.2 *m*g/l | 28.90 | 5.90 | 0.80 |
| Transparency | 0.9946 | 0.17 m | 38.30 | 4.68 | 0.78 |
| SPOT image | | | | | |
| Chlorophyll-a | 0.9273 | 0.36 *u*g/l | 24.56 | 3.41 | 0.76 |
| Suspended solid | 0.9025 | 0.49 *m*g/l | 19.02 | 3.49 | 1.0 |
| Transparency | 0.7534 | 0.42 m | 19.69 | 3.59 | 0.05 |
| SE-590 simulated SPOT bands | | | | | |
| Chlorophyll-a | 0. 9321 | 1.77 *u*g/l | 28.72 | 3.41 | 1.0 |
| Suspended solid | 0.8980 | 0.49 *m*g/l | 16.66 | 3.49 | 1.0 |
| Transparency | 0.9050 | 0.37 m | 16.59 | 3.59 | 1.0 |

Table 2. The estimated error of check points

| Check-point | Chlorophyll-a (*ug/l*) | | Suspended solid (*mg/l*) | | Transparency (m) | |
|---|---|---|---|---|---|---|
| | measured | estimated | measured | estimated | measured | estimated |
| | SE-590 reflection data | | | | | |
| 3 | 1.9 | 1.94 | 0.8 | 5.13 | 3.90 | 2.0 |
| 11 | 2.2 | 3.95 | 1.0 | 2.9 | 3.35 | 1.54 |
| 15 | 1.3 | 2.95 | 1.6 | 4.96 | 3.30 | 3.97 |
| 20 | 4.5 | 2.39 | 1.0 | 4.29 | 2.75 | 2.29 |
| 22 | 4.1 | 4.96 | 1.8 | 2.09 | 2.75 | 0.20 |
| RMS | 1.48 | | 3.50 | | 1.67 | |
| | SPOT image | | | | | |
| 3 | 1.9 | 2.22 | 0.8 | 0.02 | 3.9 | 3.95 |
| 11 | 2.2 | 2.06 | 1.0 | 0.11 | 3.35 | 3.95 |
| 15 | 1.3 | 2.95 | 1.6 | 1.14 | 3.3 | 3.31 |
| 20 | 4.5 | 2.73 | 1.0 | 0.67 | 2.8 | 3.21 |
| 22 | 4.1 | 2.33 | 1.8 | 0.68 | 2.8 | 3.42 |
| RMS | 1.35 | | 0.72 | | 0.41 | |
| | SE-590 simulated SPOT bands | | | | | |
| 3 | 1.9 | 2.3 | 0.8 | 2.6 | 3.9 | 3.7 |
| 11 | 2.2 | 7.4 | 1.0 | 3.7 | 3.35 | 3.0 |
| 15 | 1.3 | 0.1 | 1.6 | 1.5 | 3.3 | 4.2 |
| 20 | 4.5 | 4.5 | 1.0 | 2.7 | 2.75 | 3.3 |
| 22 | 4.1 | 0.2 | 1.8 | 1.3 | 2.75 | 3.7 |
| RMS | 2.96 | | 1.44 | | 0.66 | |

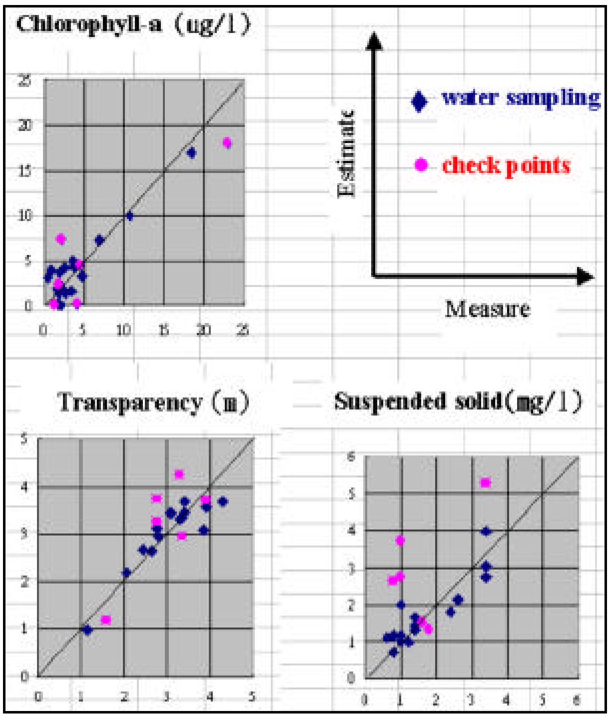


**Fig 2. The measured and estimated water quality distribution**

## 4. Conclusions and Discussion

SE-590 measured reflectance data, SPOT image and SE-590 simulated SPOT bands were used for water quality estimation. The conclusions are:

(1) The relationships between those water quality parameters and SE-590, SPOT image and SE-590 simulated SPOT bands were analyzed using stepwise multiple regression to derive optimal prediction models. The statistical criteria include high regression coefficient, low standard error, F-test, the statistic (ti) and $C_k/(K+1)$, etc. It shows that the regressions of all water quality parameters pass the basic demands for prediction models.

(2) The evaluated RMS error of chlorophyll-a, SS and transparency are 0.57 *u*g/l, 0.2 *m*g/l and 0.17 m, respectively, for SE-590 models, which were generally the best results; and the RMS errors are 0.36 *u*g/l, 0.49 *m*g/l and 0.42 m, respectively, for SPOT data. The SE-590 simulated SPOT data obtained the worst results and the RMS errors are 1.77 *u*g/l, 0.49 *m*g/l and 0.37 m, respectively.

(3) However, the RMS errors of the five check-points for SS and transparency predicted by SPOT image and simulated SPOT bands were less than those by SE-590. This may be due to the broad bandwidth and average effect of the SPOT bands.

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## 5. Acknowledgements

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