Monitoring Surface Water Quality in Coastal Area of Penang

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Abstract—The water quality parameter total suspended solids in the coastal area of Penang Island, Malaysia have been studied using Landsat TM data. The aim of this study was to test the feasibility of using satellite data for mapping and monitoring water quality parameter total suspended solids (TSS) by using remote sensing and digital processing techniques. The model used in this study is based on the reflectance model which is a function of the inherent optical properties (IOP) of water and this in turn can be related to the concentration of its constituents. The digital numbers for each band corresponding to the sea-truth locations were extracted and then converted into radiance and reflectance values. The reflectance values were used for calibration of the water quality algorithm. The efficiency of the proposed algorithm was investigated based on the observations of correlation coefficient (R) and root-mean-square deviations (RMS) using the sea truth data. The proposed algorithm is considered superior to other tested algorithms based on the values of the correlation coefficient, R=0.93 and root-mean square error, RMS=9 mg/l. The calibrated TSS algorithm was used to generate the water quality maps. The water quality image was geometrically corrected and image smoothing was performed on the map to remove random noise. The generated map was color-coded for visual interpretation.

Keywords—water quality; landsat TM; TSS

I. INTRODUCTION

Currently the Penang coastal areas have been under heavy pressure those from sea transportation, fisheries, oil industries, and including from sewerage system which carry raw sewage to discharge into the estuary. The present of these activities carry a large portion of possibility in the damaging the environmental as well as in degradation of coastal water quality in the affected areas, leading to the need an integrated management using environmental information system that is comprehensive and multi-disciplinary in nature.

Water quality not only refers to chemical and biological characteristics of water, but as well physical characteristics. The physical characteristics consists of turbidity, color and temperature [1]. Monitoring of water quality is an essential in order to handle many problems regarding water quality.

Monitoring coastal water quality using conventional sampling method can be precise, but is time consuming and requires high operating cost. Remote sensing technique can overcome the problems. Coastal water quality monitoring by using remote sensing data provides synoptic view of study area and better estimates of spatial distribution at relatively cheaper cost [2].

Landsat MSS data have been used in a range of coastal water quality assessment activities. The knowledge on this topic is well documented [3, 4].

The sediment, backscattering and the absorption characteristics can be related to its concentration although other factors such as the sediment's size and color are also important in this study. Hence, an algorithm can be developed from the optical model coastal water [5]. The TSM map was developed using the proposed algorithm. In addition, the TSS map was also geographically corrected and color-coded for visual interpretation.

The main objective of this study is to demonstrate the potential application of Landsat TM Satellite digital image to the survey and monitoring of water quality in coastal areas affected by several activities, and including the sewerage system. The main emphasis was placed on the development of an algorithm retrieval of TSS from remote sensing data where in the field.

II. STUDY AREA

Penang Island, is located in the northern part of Malaysia, within latitudes 5° 12’N to 5° 30’ N and longitudes 100° 09’ E to 100° 26 E (Figure 1). Capital city in Penang is located in the east region of Penang Island, which is George Town. In addition, it is also the most populated island in the country, with an estimated population of 720,000.
III. MATERIAL AND METHOD

The Landsat TM image satellites were used in order to analysis this study. The bottles were used to store the collected samples during the satellite overpass the study area. A hand-held GPS was used to establish the position of each sampling location. The sampling locations were selected to cover a wide range of TSS concentrations and to be representative of the study areas. The water samples were filtered through 0.45 µm nuclepore ultracellulose membrane filters to determine the concentration of TSS. The measured TSS concentrations in the estuaries ranged from 50 mg/l to 150 mg/l.

Landsat data products are stored in GeoTiff file format Folder and have the following properties:

- Pixel Size – 30 for the Visible and NIR/SWIR spectral range
- Map projection – UTM
- Ellipsoid - WGS84
- Output format - GeoTIFF

The satellite image containing separate image files for each of the 8 bands, a metadata file and ground control points file. Bands 1 to 3 were then imported into PCIDSK raster maps using PCI Geomatica Software V10.3.

A. Geometric Correction

The data processing begins by geometric correction to equalize the position of the image by means of a position on the map. The satellite image was then geometrically corrected by second order polynomial equation using the nearest neighbor method.

B. Radiometric Correction

In radiometric correction DNs values were converted into irradiance values a using the equation [6].

\[ \lambda = \frac{L_{\lambda} - L_{\text{MIN}_{\lambda}}}{Q_{\text{cal max}} - Q_{\text{cal min}}} \left( Q_{\text{cal}} - Q_{\text{cal min}} \right) + L_{\text{MIN}_{\lambda}} \]  

where \( L_{\lambda} \) is the Spectral radiance at the sensor’s aperture [W/ (m²srµm)]; \( Q_{\text{cal}} \) is the quantized calibrated pixel value [DN]; \( L_{\text{MIN}_{\lambda}} \) is minimum quantized calibrated pixel value corresponding to \( L_{\text{MIN}_{\lambda}} \) [DN]; \( L_{\text{MAX}_{\lambda}} \) is the maximum quantized calibrated pixel value corresponding to \( L_{\text{MAX}_{\lambda}} \) [DN]; \( L_{\text{MIN}_{\lambda}} \) is the spectral radiance at the sensor scaled to \( Q_{\text{cal}} \); and \( L_{\text{MAX}_{\lambda}} \) is the spectral radiance at the sensor scaled to \( Q_{\text{cal max}} \).

The top of the atmosphere (TOA) reflectance is obtained by converting the radiance recorded at the sensor to reflectance using the equation [6].

\[ \rho_{\lambda} = \frac{\pi L_{\lambda} \cdot d^2}{\text{ESUN}_{\lambda} \cdot \cos(\theta_0)} \]  

where \( \rho_{\lambda} \) = Planetary TOA reflectance; \( \pi \) = Mathematical constant(3.14159); \( L_{\lambda} \) = Spectral radiance at the sensor’s aperture [W/ (m²srµm)]; \( d \) = Earth-Sun distance [astronomical units]; \( \text{ESUN}_{\lambda} \) = Mean exoatmospheric solar irradiance [W/m²µm]; \( \theta_0 \) = Solar zenith angle [degrees].

C. Atmospheric Correction

A simple atmospheric correction, namely darkest pixel technique was performed in this study. This is a very simple correction, based on dark pixels subtracting method [7].

D. Optical Model of Water

A physical model relating radiance from the water column to the concentrations of the water’s constituents provides the most effective way to analyze remotely sensed data for water quality studies. Remote sensing reflectance, \( R_{rs} \), is related to the irradiance reflectance just beneath the water surface, \( R_{ird} \) and is calculated as:

\[ R_{rs} = \frac{(1 - \rho)(1 - \sigma)R_{ird}}{n^2(1 - x)Q} \]  

where \( \rho \) = internal Fresnel reflectance; \( \sigma \) =air-water fresnel reflection at the interface; \( x \) = water-air reflection; \( n \) = refractive index (1.34); \( Q \) = \( \pi \). Equation (3), according [8] can written as

\[ R_{rs} = 0.182 \frac{R_{ird}}{Q} \]  

The inherent optical properties are determined by the contents of the water. The contributions of the individual components to the overall properties are strictly additive [9] For a case involving three water quality components, e.g. chlorophyll, C, suspended sediment, P, and yellow substance, Y, the simultaneous equations using three channels ( \( \lambda_1 \) and \( \lambda_2 \) ) can be expressed as:
The method applied here relies on the concept of forward and inverse modeling, leading to analytical methods (Figure 2) [10].

### E. Regression Algorithm

TSS concentrations can be obtained by solving the simultaneous equations (5) and (6) to get the series of terms in R1 and R2.

\[
R(\lambda_1) = R_1 = \frac{c[0.5b_w(\lambda_1) + b_w'(\lambda_1)C + b_w(\lambda_1)P]}{Q[a_u(\lambda_1) + a_u'(\lambda_1)C + a_u(\lambda_1)P + a_u'(\lambda_1)Y]}
\]

(5)

\[
R(\lambda_2) = R_2 = \frac{c[0.5b_w(\lambda_2) + b_w'(\lambda_2)C + b_w(\lambda_2)P]}{Q[a_u(\lambda_2) + a_u'(\lambda_2)C + a_u(\lambda_2)P + a_u'(\lambda_2)Y]}
\]

(6)

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\[
P = \frac{1 - a_wR}{0.165b_{bw}} - \frac{0.33b_{bw}}{0.165b_{bw}} = \frac{a_p}{a_0 + a_p} + \frac{a_p}{a_0 + a_p}R
\]

(7)

where \(b_{bw}\) = backscattering coefficient; \(a_w\) = absorption coefficient; \(a_p^s\) = sediment specific absorption coefficient; \(P\) = suspended sediment.

We have to know two parameters (the backscattering and absorption coefficients) to solve Equation (7). But these parameters were not available from this study area. So we used regression technique to solve the equation. Using Equation (7), we can simplify the regression model as shown by Equation (8) for TSS measurements.

\[
P = \frac{1 + a_pR}{a_0 + a_p}
\]

(8)

where \(a_0, a_1\) and \(a_2\) were the algorithm coefficients that can be solved empirically. Figure 2 shows the flowchart of the research.

![Flow chart for data processing of the image](image_url)

**IV. RESULTS AND DISCUSSIONS**

A Landsat TM image of the coastal area, taken by Landsat TM on 12 March 2007 was available for use in this study (Figure 2). The Landsat TM obtains data used only three spectral bands: band 1, 0.45-0.52 μm; band 2, 0.52-0.6 μm; band 3, 0.63-0.69 μm.

All image-processing tasks were carried out using PCI Geomatica version 10.3 digital image processing software at the School Of Physics, Universiti Sains Malaysia (USM).

The digital numbers (DN) for each band corresponding to the sea-truth locations were determined. The satellite image was then geometrically corrected by second order polynomial equation.

The DN’s values extracted using the window size of 3 by 3 was used due to the higher correlation coefficient (R) with the sea-truth data. The extracted DN values were converted into irradiance values and then converted into reflectance values using equations (1) and (2). The Spectral Reflectance is then corrected for atmospheric effects using ATCOR2 in the PCI Geomatica version 10.3. In this study, Landsat TM signals were used as independent variables in our calibration regression analysis.

A simple atmospheric correction, namely darkest pixel technique was performed in this study. This is a very simple correction, based on 2 assumptions:

- The first assumption is that in the darkest water pixel of the image there is total light absorption and the radiation light recorded by this pixel comes from the atmospheric path radiance.
- Secondly it is assumed that the atmospheric path radiance is uniform all over the image. The radiation of the darkest water pixel (assumed to represent the atmosphere) is subtracted from the whole image. The darkest pixel is found by searching for the lowest values over water for all wavelengths. The pixel with the lowest value for each band was selected as the darkest pixel.

The plot of the relationship between the reflectance \(\rho_\lambda\) for each channel and the TSS values is shows positive correlations between these two parameters in all bands. In this study, reflectance \(\rho_\lambda\) values were use as independent variables in our calibration regression analyses.
The proposed algorithm produced the correlation coefficient of 0.93 between the predicted and the measured TSS values and RMS value of 9 mg/l. A map of the water quality suspended solids parameter was then generated using the calibrated proposed algorithm. Then the generated suspended solids map was geometrically corrected using the cubic convolution method to produce a smoother map. The generated map was filtered using 3 by 3 pixels averaged to remove random noise and then color-coded for visual interpretation as shown in Figure 3.

From the produced output TSS map, the distribution concentration in the estuaries within the study areas are generally higher compare to other area. Generally the Prai, Pinang, Juru and Muda River discharged high TSS (red circles). The map indicate TSS concentration are generally more than 100 mg/l in the vicinity of the river mouth. The other source of TSS was the dynamics of the shallow water areas, which resulted in resuspension of bottom sediments. Other environmental data sources were not available to provide additional information to the generated TSS patterns.

V. CONCLUSION

The algorithm developed from optical model of water can be used in the TSS mapping. The TSS algorithm produces high R and low RMS values. A high correlation coefficient was obtained with the proposed algorithm. It is possible to produce an accurate TSS map by using the Landsat imagery over the Penang Island, Malaysia. Further studies have to be conducted to improve the results.

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REFERENCES


