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Water Quality Retrieval from Landsat TM Imagery

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Abstract

In this paper, the utility of Landsat TM imagery for water quality studies in East Texas is investigated. Remote sensing has an important and effective role in water quality management. Remote sensing satellites measure the amount of solar radiation reflected by surface water and the reflectance of water depend upon the concentration and character of water quality parameters. Three water quality parameters namely the total suspended solids, chlorophyll-a, and turbidity are estimated in this study. In situ water quality parameter measurements from seven ground stations and the corresponding Landsat TM data were used to estimate the water quality parameters. Regression models are used to evaluate correlation between the water quality parameters and spectral reflectance values.

Keywords: water quality; satellite images; regression model; parameter estimation

1. **Introduction**

Satellite imagery holds significant potential for enhancing regional monitoring and assessment of lake water quality. Several investigations have demonstrated that reliable empirical relationships can be developed between Landsat Thematic Mapper data and ground observations of water quality parameters such as the chlorophyll, turbidity, and total suspended sediments [1,2,3,4]. Sensors abroad satellite can measure the amount of solar radiation at various wavelengths reflected by surface water, which can be correlated to water quality parameters.

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The advantages of using satellite images for water quality parameters include a) near continuous spatial coverage of satellite imagery allows for synoptic estimates over large areas, b) the global coverage of satellite allows for the estimation of water quality in remote and inaccessible areas, c) long record of archived Landsat imagery allows estimation of historical water quality, when no ground measurements can be performed. This work deals with water quality parameter estimation for the watershed area that contains the West Mud Creek drainage area in East Texas. The optical properties or reflectance of water depend on the concentration and character of suspended sediments, phytoplankton, and dissolved organic matter. The watershed area also contains agriculture production in the form of cropland, cattle grazing, and poultry production. In addition, these areas are seeing an increase in the amount of natural gas drilling and development activity. Each of these types of development pose a potential threat to water quality, either through urban storm water runoff or other types of point or non-point discharges of pollutants. A review of the state's surface quality database revealed that there is a very little to no available water quality data within the proposed project watershed area. The principal goal of the study was to provide the information and tools needed to understand how watershed regulation and associated land use decisions are made. In this study we considered three water quality parameters namely turbidity, chlorophyll-a, and total suspended solids (TSS).

Turbidity is the cloudiness or haziness of a fluid caused by individual particles (suspended solids) that are generally invisible to the naked eye, similar to smoke in air. The measurement of turbidity is a key test of water quality. Fluids can contain suspended solid matter consisting of particles of many different sizes. While some suspended material will be large enough and heavy enough to settle rapidly to the bottom of the container if a liquid sample is left to stand (the settable solids, very small particles will settle only very slowly or not at all if the sample is regularly agitated or the particles are colloidal). These small solid particles cause the liquid to appear turbid. Turbidity in open water may be caused by growth of phytoplankton. Human activities that disturb land, such as construction, can lead to high sediment levels entering water bodies during rain storms due to storm water runoff. Areas prone to high bank erosion rates as well as urbanized areas also contribute large amounts of turbidity to nearby waters, through storm water pollution from paved surfaces such as roads, bridges and parking lots. Certain industries such as quarrying, mining and coal recovery can generate very high levels of turbidity from colloidal rock particles. In drinking water, the higher the turbidity level, the higher the risk that people may develop gastrointestinal diseases. The growth of phytoplankton and suspended solids make the water turbid. A number of researchers have demonstrated the estimation of turbidity using different satellite sensors, such as AVHRR and Landsat TM.

Chlorophyll-a is a green pigment found in almost all plants, algae, and cyanobacteria. Chlorophyll-a is an extremely important biomolecule, critical in photosynthesis, which allows plants to obtain energy from light. The intense green color of chlorophyll-a is due to its strong absorbencies in the red and blue regions of the electromagnetic spectrum, and because of these absorbencies the light it reflects and transmits appears green. Chlorophyll-a a is the most commonly used parameter for monitoring phytoplankton biomass and nutrient status, as an index of water quality. Chlorophyll-a concentrations can be used to determine a lake's trophic status. Though trophic status is not related to any water quality standard, it is a mechanism for "rating" a lake's productive state. The concentration of chlorophyll-a varies with the ratio of green to red reflectance (TM2/TM3) of Landsat TM image bandwidth values. This is consistent with the optical properties of chlorophyll-a, which has high reflectance in green and low reflectance in red. In the absence of substances that have high red reflectance, the red reflectance is relatively constant and close to that of pure water. Then the ration of green to red reflectance correlates to the concentration of chlorophyll-a [1].

Total Suspended Solids is a water quality measurement usually abbreviated TSS. It is listed as a conventional pollutant in the U.S Clean Water Act. This parameter was at one time called non-filterable residue (NFR), a term that refers to the identical measurement: the dry-weight of particles trapped by a filter, typically of a specified pore size. Higher TSS (>1000 mg L-1) may greatly affect water use by limiting light penetration and can limit reservoir life through sedimentation of suspended matter. TSS levels and fluctuations influence aquatic life, from phytoplankton to fish. TSS, especially when the individual particles are small (<63μm), carry many substances that are harmful or toxic. As a result, suspended particles are often the primary carrier of these pollutants to lakes and to coastal zones of oceans where they settle. In rivers, lakes and coastal zones these fine particles are a food source for filter feeders which are part of the food chain, leading to bio magnification of chemical pollutants in fish and, ultimately, in man. In deep lakes, however, deposition of fine particles effectively removes pollutants from the overlying water by burying them in the bottom sediments of the lake. The correlation between TSS and different spectral bands can be given with ratios, logarithmic transformations and some combinations of TM bands. For example, TSS TM1, TSS TM2 + TM3, etc. [4]. A significant amount of sediment is transported by rivers during runoff events. This is one of the causes why turbidity increases at the river mouth in the days after rainfall. The correlation analysis showed that in areas affected by river runoff, red reflectance (TM3) correlates positively with turbidity (Hellweger et al, 2004). Like TSS, the correlation between turbidity and different bands can be given with ratios, logarithmic transformations and some combinations of TM bands.

2. Methodology

2.1 Selection of Ground Data

Water quality data were collected by ANRA from the proposed Lake Columbia Water Supply Reservoir, which has a watershed containing 384 square miles. The watershed contains a large area within the West Mud Creek drainage which is in a rapidly urbanizing area of the City of Tyler. The water in the Mud Creek is proposed to be impounded to form Lake Columbia. A rough outline and location of Lake Columbia is shown in Figure 1[5]. Tables 1 and 2 show the water quality parameter measurements, reflectance values at seven ground stations where measurements were made,

Table 1. Water quality parameters and reflectance values

Stations	**Latitude**	**Longitude**	**B1**	**B2**	**B3**	**B4**	**B5**	**B7**	**Chl**	**TSS**	**Tur bidity**
16586	320945.98N	951016.34W	53	22	22	30	53	25	2.63	5.3	10.2
10538	320717.86N	951225.57W	56	24	24	42	67	29	ND	8.5	18.1
17103	320617.08N	950958.76W	52	23	24	36	64	29	ND	9.7	16.3
10536	320138.25N	951012.76W	57	26	27	32	66	32	ND	9.8	18.9
14477	315837.70N	950938.85W	55	24	26	35	65	31	ND	16	25.8
AN001	320934.92N	950951.98W	57	24	27	45	84	35	1.96	12	22.2
10539	320956.67N	951659.70W	53	21	21	39	48	20	ND	15	23.8

Table 2. Water quality parameters and reflectance values

Stations	**Latitude**	**Longitude**	**B1**	**B2**	**B3**	**B4**	**B5**	**B7**	**Chl**	**TSS**	**Tur bidity**
16586	320945.98N	951016.34W	66	32	24	127	87	30	3.18	4.5	37
10538	320717.86N	951225.57W	70	33	30	102	91	33	ND	9.5	18.8
17103	320617.08N	950958.76W	67	29	20	128	81	23	ND	13	37.4
10536	320138.25N	951012.76W	76	39	36	101	104	45	ND	18	38.1
14477	315837.70N	950938.85W	65	29	21	115	82	25	ND	6	53.6
AN001	320934.92N	950951.98W	69	35	25	154	110	39	ND	18	48.5
10539	320956.67N	951659.70W	67	29	24	102	79	27	ND	14	33

2.2 Satellite data

The image used in this study is extracted from Landsat 5 Thematic Mapper (TM) from which bandwidth values were extracted. The Landsat 5 TM has acquired images of the Earth nearly continuously from March 1984 to the present with a 16-day repeat cycle. Landsat TM records data in seven spectral bands. The image file consists of several spectral bands. The resolution is 30 meters for bands 1-5, and 7. Band 6 resolution is a collected 120 meters, but is resampled to 30 meters. These bands are broken down into portions of the visible, infrared, and thermal infrared regions of the electromagnetic spectrum. From these various bands, a great deal of information about the land cover can be displayed and analyzed.

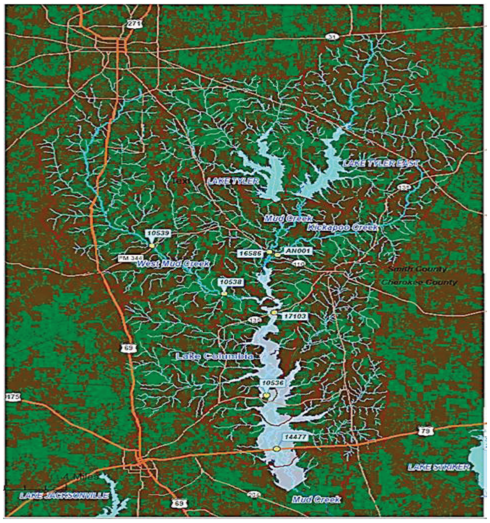

Figure 1. Lake Columbia location

2.3 Regression Model

We used simple regression model as shown in Equation (1), for estimating chlorophyll, turbidity, total suspended solids. Reflectance values and ratios of reflectance values were used as independent variables. The regression coefficient is given by Equation (2) [6].

$$\hat{y} = mx + b$$

where,

$$m = \frac{n\sum_{i=1}^{n} x_i y_i - \left(\sum_{i=1}^{n} x_i\right)\left(\sum_{i=1}^{n} y_i\right)}{n\sum_{i=1}^{n} x_i^2 - \left(\sum_{i=1}^{n} x_i\right)^2} \tag{1}$$

$$b = \bar{y} - m\bar{x}$$

$$r = \frac{n\sum_{i=1}^{n}(x_i y_i) - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{\sqrt{\left[n\sum_{i=1}^{n}(x_i^2) - \left(\sum_{i=1}^{n} x_i\right)^2\right]\left[n\sum_{i=1}^{n}(y_i^2) - \left(\sum_{i=1}^{n} y_i\right)^2\right]}} \tag{2}$$

3. Results and Discussions:

We developed four models for estimating chlorophyll using red, green, ratio of green to red, and log values of the ratio as independent variables, respectively. The models are shown in Table 3. Models 4 and 5 were developed to estimate TSS values, and Models 7-9 were used to estimate turbidity. The regression models are shown in Figures 2- 4.

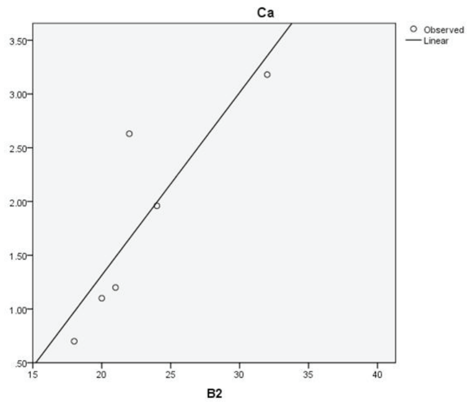

Figure 2 Regression model for chlorophyll and band2 reflectance values.

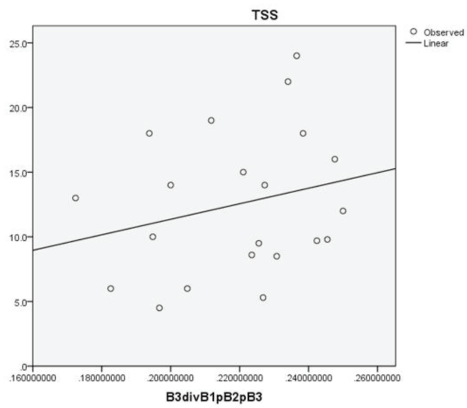

Figure 3. Regression model for TSS and normalized band3 reflectance values.

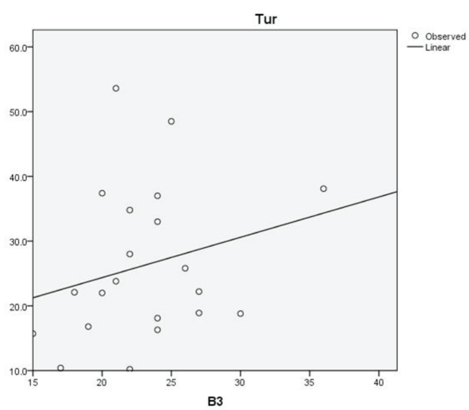

Figure 4. Regression model for turbidity and band3 reflectance values.

It can be seen from Table 3 that the model with the green band value showed the highest correlation with chlorophyll content. Normalized reflectance values in red band were correlated with turbidity.

Table 3. Correlation coefficients for various models

Model No.	Variables	R	Std. Error of the Estimate
1	Chlorophyll-a and Log(B2/B3) (Log(Green/Red))	0.112	1.07467
2	Chlorophyll-a and B2/B3 (Green/Red)	0.156	1.06835
3	Chlorophyll-a and B3 (Red)	0.734	0.73443
4	Chlorophyll-a and B2 (Green)	0.864	0.54441
5	Total Suspended Solids and B3/(B1+B2+B3)	0.244	5.4979
6	Total Suspended Solids and B3	0.147	5.6073
7	Turbidity and B3/(B1+B2+B3)	0.461	10.7484
8	Turbidity and B3	0.247	11.7382
9	Ln(Turbidity) and B3	0.171	-

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