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Mapping Water Quality of Yongdam Reservoir Using Landsat ETM Imagery

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Abstract : Chlorophyll-a concentration maps of Yongdam reservoir in September and October, 2001 were produced using Landsat ETM imagery and the in-situ water quality measurement data. In-situ water samples were collected on 16th September and 18th October during the satellite overpass. The correlations between the DN values of the imagery and the values of chlorophyll-a concentration were analyzed. The visible bands(band 1, 2, 3) and the near infrared band(band 4) data of September image showed the correlation coefficient values higher than 0.9. The October image showed correlation coefficient values of about 0.7 due to the low variations of chlorophyll-a concentration. Regression models between the DN values of the Landsat ETM image and the chlorophyll-a concentration have been developed for each image. The developed regression models were then applied to each image, and finally the chlorophyll-a distribution maps of Yongdam reservoir were produced. The produced maps showed the spatial distribution of the chlorophyll-a in Yongdam reservoir in a synoptic way so that the tropic state could be easily monitored and analysed in the spatial domain.

Key Words : Water Quality, Chlorophyll-a, Landsat ETM, Correlation, Regression.

1. Introduction

Yongdam Dam was constructed to meet the increasing demand for water resources in south-western part of Korea, and also to reduce the natural hazard by flooding. Yongdam reservoir was formed by the construction of the Dam in the upper stream of Kum river. The size of the catchment area is about 930 km^2, and the storage capability is 81,500 million m^3.

The conventional water quality measurements by in-situ water sampling provide only site specific temporal water quality information but not the synoptic geographic coverage of water quality distribution. To circumvent these limitations of the point sampling approach for water quality monitoring, research in water quality monitoring has increasingly involved remotely sensed multispectral imagery(Lillesand *et al.*, 1983, Verdin, 1985, Novo *et al.* 1989, Quibell, 1992, Serwan, 1993, Yacobi *et al.*, 1995).

There have been two approaches for the exploiting satellite imagery in water quality assessment. The one is to do supervised classification using the trophic state information derived from the water sampling. This approach categorize the water quality into several group

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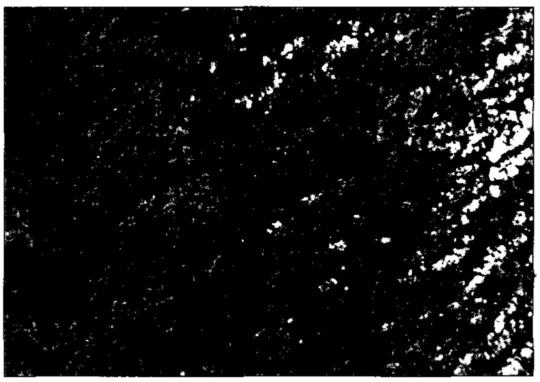
- eutrophic, mesotrophic, oligotrophic, etc. And then using these categories as classes for classification and the DN values of the water sample points as training data, the trophic state map of water covered area can be produced. A trophic state map of Daechung reservoir was generated by this classification approach(Kim and Kim, 1996). The other is to make use of the correlation between the brightness values of satellite image and the concurrently acquired water quality measurements (Yacobi *et al.*, 1996, Kim *et al.*, 1996). A set of water quality predictive regression equations are derived from the correlation. The equations are then used to characterize water quality conditions for all surface water appearing in a image. In this study, using this approach, water quality maps of Yongdam reservoir were generated from the Landsat ETM image.

2. Data Collection

In order to produce a spatial distribution map of water quality in a quantitative way from satellite image, as many as surface truth data are needed. Also, the acquisition process of those surface truth data should be synchronized with the satellite image acquisition. First of all, we surveyed the Landsat 7 satellite's schedule for path 115 which covered the Yongdam reservoir. Among the candidates, 16th September and 18th October were targeted for the collecting water samples for the water quality analysis. The water samples were collected at 27 points of interest on 16th September and 24 points on 18th October using GPS equipped boat by Kum River Water Quality Research Laboratory. The Landsat ETM image of Yongdam reservoir area captured on 16th September and 18th October were shown in (a) and (b) of Fig. 1 respectively. There exist some clouds in October image but not in Yongdam reservoir area. The water samples collected were analysed in-situ and in the laboratory with temperature(°C), turbidity(NTU), chlorophyll-a(mg/m^3), etc. Yongdam reservoir showed the chlorophyll-a concentration range about 5 mg/m^3 to 300 mg/m^3 in September, and the concentration range about 10 mg/m^3 to 20 mg/m^3 in October.

The DN values of each band for the water sampled points were extracted after applying the 3 by 3 average filter to the image in order to compensate the positional errors in GPS positioning of sampling points and the satellite image's geometric error. Table 1 shows the DN values of the visible(band 1, 2, 3) and near infrared(band 4) data of Landsat ETM image. In this study, only the

(a)



(b)

Fig. 1. (a) Landsat ETM image of Yongdam reservoir acquired on 16th September, 2001.
(b) Landsat ETM image of Yongdam reservoir acquired on 18th October, 2001.

Table 1. Landsat ETM DN values and the chlorophyll-a concentration of each water sampling point.

Sampling Point	16th September, 2001					18th October, 2001				
	Band				Chl-a (mg/m^3)	Band				Chl-a (mg/m^3)
	1	2	3	4		1	2	3	4	
Y1	30.3	39.6	25.8	11.7	5.4	53.8	33.4	24.4	16.6	15.5
Y2	59.3	38.1	25.7	11.1	9.5	53.0	32.9	24.1	14.9	16.2
Y3	58.2	38.8	25.8	11.3	9.2	52.9	33.1	23.2	15.6	15.2
Y4	59.0	38.7	26.1	10.6	11.8	53.6	34.0	24.6	15.3	12.7
Y5	58.9	39.8	26.1	11.0	13.0	53.8	34.3	23.7	15.1	12.6
Y6	58.9	39.6	26.8	11.6	8.9	53.9	34.3	24.6	16.2	11.8
Y7	58.0	39.1	26.3	10.9	10.8	52.8	33.6	25.0	15.8	11.8
Y8	58.3	39.4	26.2	10.9	11.8	53.1	33.2	25.0	15.9	13.7
Y9	59.1	40.8	26.1	11.2	10.9	53.7	33.6	24.2	16.1	13.3
Y10	59.2	41.0	26.9	11.8	12.2	52.6	33.0	23.8	15.6	11.1
Y11	59.2	41.0	26.9	11.2	15.5	53.4	34.1	23.7	15.8	12.9
Y12	58.8	40.6	26.7	10.3	13.9	53.2	37.9	24.4	15.3	15.0
Y13	59.0	41.0	26.3	11.0	14.5	53.4	34.0	23.2	15.3	14.3
Y14	60.1	42.2	27.4	11.1	15.3	52.7	33.8	23.9	15.0	18.3
Y15	61.2	43.0	28.7	10.9	17.0	53.1	35.6	25.3	16.1	19.0
Y16	61.7	43.8	28.9	11.1	13.3	53.7	35.2	25.2	14.6	16.2
Y17	60.9	43.0	28.1	11.1	12.9	53.9	35.9	24.2	15.6	10.9
Y18	61.1	43.3	28.0	11.6	24.3	54.4	35.6	25.1	15.8	15.8
Y19	60.8	43.8	29.0	11.8	20.5	53.9	36.3	26.1	17.4	18.0
Y20	61.3	43.8	28.8	12.2	18.7	54.9	37.3	25.9	16.7	19.9
Y21	60.8	42.0	28.2	11.9	32.5	56.1	38.9	26.8	17.3	18.8
Y22	60.3	42.3	28.2	12.7	19.6	55.4	39.0	26.6	16.8	20.5
Y23	60.2	42.0	28.6	12.1	63.5	57.0	41.7	28.7	17.6	20.7
Y24	61.6	45.2	30.8	12.9	45.4	60.2	48.0	34.4	18.2	13.5
Y25	61.6	46.9	32.0	12.3	52.3					
Y26	63.0	48.6	34.6	13.8	121.0					
Y27	70.3	61.2	52.8	24.0	306.9					

visible and infrared band data of ETM image were used for the analysis. The concentration values of chlorophyll-a in each sampling point were also shown in the last column of the table.

3. Water Quality Mapping

In order to produce a spatial distribution maps of water quality, The relations between the DN values of each band and the chlorophyll-a concentration were analysed. The analysis results of September data and October data were shown in Fig. 2 and Fig. 3 respectively. As shown, the visible(band 1, 2, 3) and near infrared(band 4) data shows very high correlation coefficients(> 0.9) in September data. However, in October, the correlation coefficients were about 0.7 due to the low variations of chlorophyll concentration of which the differences can not be discriminated by the satellite sensor.

The DN values of all bands were increased as the chlorophyll concentration increase. Especially, due to the energy absorption characteristics of the water in near infrared wavelength, the near infrared band data showed very high correlation with the chlorophyll-a concentration. Near infrared energy is mostly absorbed

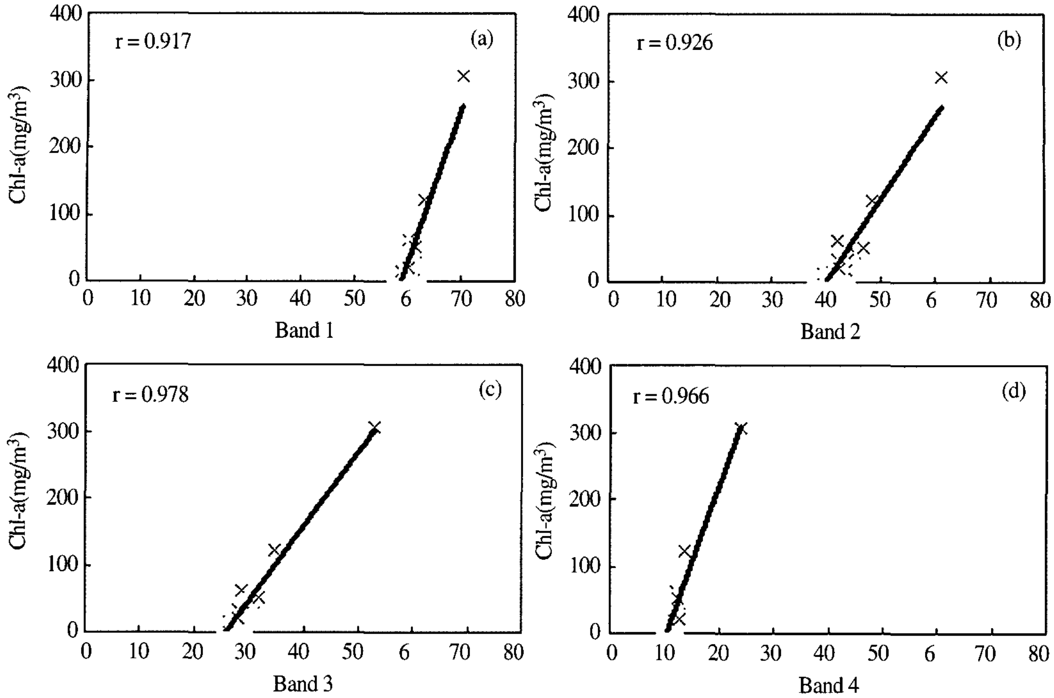


Fig. 2. The relation between the DN values of each band and the concentration of chlorophyll-a(16th September, 2001).

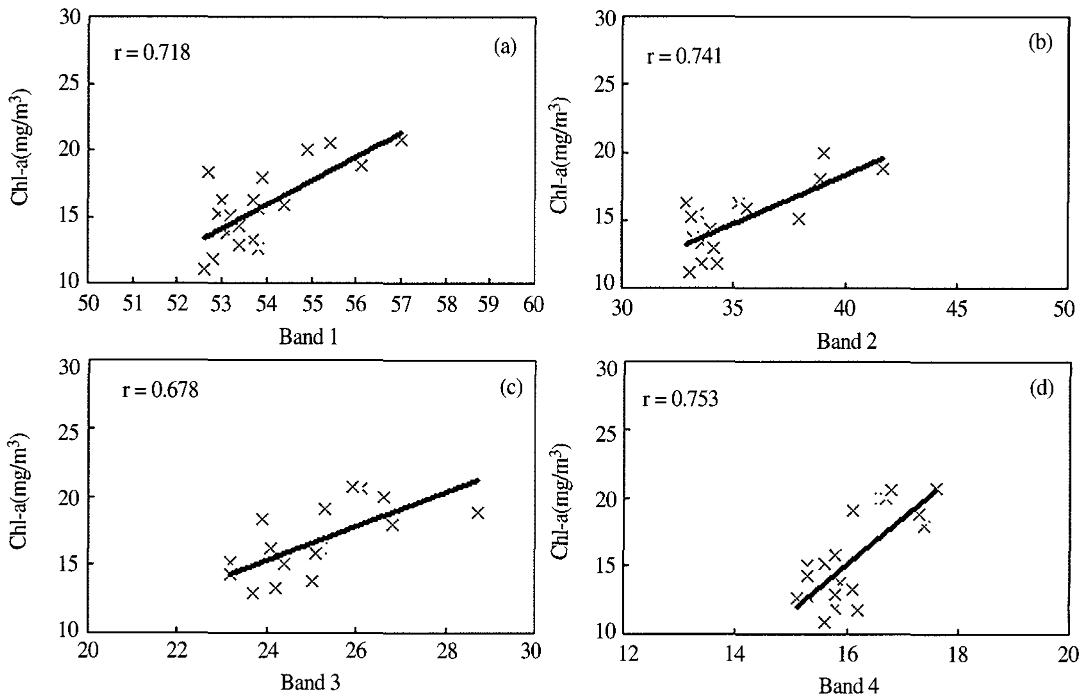


Fig. 3. Relation between the DN values of each band and the concentration of chlorophyll-a(18th October, 2001).

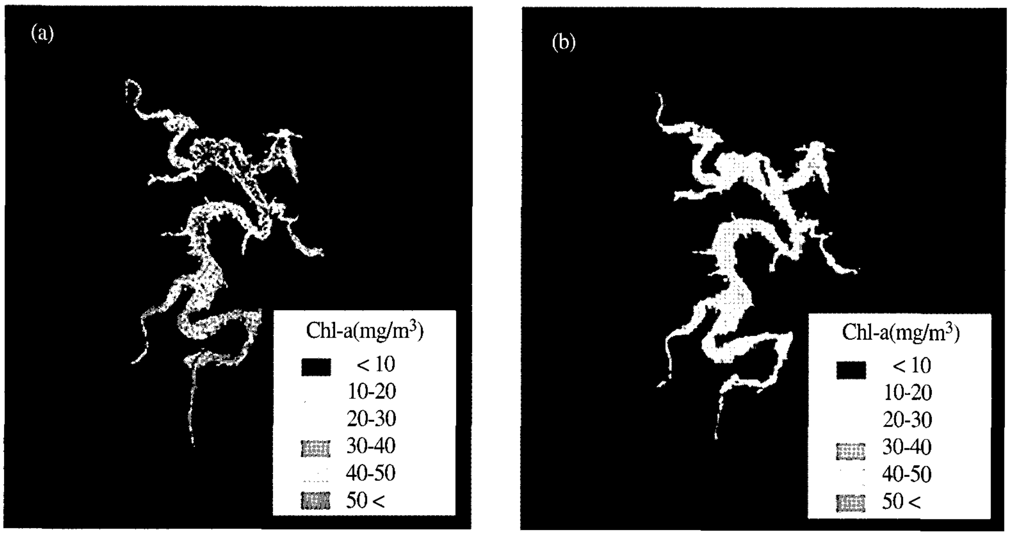


Fig. 4. The finally generated chlorophyll-a distribution maps of Yongdam reservoir.
(a) Map of 16th September, 2001. (b) Map of 18th October, 2001.

by the water body. It is well known that most algae are suspended near the water surface because they need the light energy to survive(Kim *et al.*, 1996). Therefore, the reflectance of near infrared band energy in water body is very sensitive to the concentration of algae. Yacobi *et al.*(1995) reported that most reflected energy in near infrared wavelength is due to the scattering by the algae when the concentration of the chlorophyll is more than 20 mg/m^3. The reflective energy of the blue band(band 1) is decreased with the increase of the chlorophyll concentration while the green band's reflective energy is increased. However, the blue band reflectance is also known to be sensitive to the depth of water(Lepley *et al.*, 1975). Therefore, in this study the green band(band 2) and the near infrared band(band 4) were selected to decide the regression model for chlorophyll-a. The following regression model was found for the September data where R^2 value was 0.95.

$$\text{Chlorophyll-a}(mg/m^3) = -324.2 + 3.617*\text{Band2} + 16.996*\text{Band4} \quad (1)$$

The regression model for the October data was also calculated and shown in equation (2) where R^2 value was very low as 0.55 due to the low variations in chlorophyll-a concentration as mentioned in the previous section.

$$\text{Chlorophyll-a}(mg/m^3) = -32.9 + 0.474*\text{Band2} + 1.974*\text{Band4} \quad (2)$$

Finally, Yongdam reservoir area was extracted using the near infrared band data, and then these regression models were applied. The result water quality maps are shown in Fig 4. The chlorophyll-a distribution map of 16th September, 2001 is shown in (a) and the map of 18th October, 2001 is shown in (b).

4. Conclusions

In this study, the relations between the DN values of Landsat ETM image and the chlorophyll-a concentration were analysed. The visible(band 1,2,3) and near infrared(band 4) data shows very high correlation coefficients(> 0.9) in September. However, in October, the correlation coefficients were about 0.7 due to the low variations of chlorophyll concentration.

And then the regression models were derived which predict the chlorophyll-a concentration from the DN values of band 2 and band 4 data of Landsat ETM imagery. The R2 value of the regression model for 16th September was 0.95 and that of the regression mode for October was 0.55. Using the derived regression models, the chlorophyll-a distribution maps were generated.

Further studies on the atmospheric effect and the sensor calibration are required for more quantitative analysis of the water quality using satellite imagery. Another topic being explored currently is the applicability of the regression model derived from the September data to the image acquired on October without surface truth data.

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