Estimation of water quality distribution in freshing reservoir by satellite images

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Abstract

Kojima Lake in Okayama prefecture is a freshing reservoir constructed adjacent to the oldest reclaimed land in Japan. This lake has a serious water quality problem because two urban rivers are flowing into it. In the present study, unsupervised classification was performed at intervals of several years using Landsat MSS data in the past 15 years. After geometric correction of these data, MSS data corresponding geographically to the field observation data were extracted and subjected to the multivariate analysis. Water quality distribution in the lake was estimated using the regression equation obtained as a result. In addition, two-dimensional and three-dimensional numerical simulations were performed and compared with the distribution obtained from the satellite images. Behavior of the reservoir flows is complicated and water quality distribution varies greatly with the flows. Here, I report the results of analysis on three factors, field observation, numerical simulation and satellite images.

Keyword: freshing reservoir , water quality problem, Remote sensing technique, satellite images, numerical simulations

Observation of Kojima Lake water area based on Landsat satellite images

In the previous study, we examined Kojima Lake together with reclaimed farmlands in its hinder land as the study area after geometric correction. In this study, water area alone was cut out for analysis in the attempt to elucidate clearer flow patterns. The authors cut out the water area of Kojima Lake from the Landsat satellite images observed and presented the images in the combination of 3 bands, band 1 (blue), band 2 (green) and band 4 (near infrared) to visualize flow patters in the lake as much as possible. Figs. 1 and 2 show typical examples. It can be seen that the flow patterns in the lake vary completely depending on the conditions such as inflow condition from rivers, outflow condition through sluices, direction and velocity of the wind, and condition of density stratification.

Figs. 3 and 4 show the results of unsupervised classification of the satellite image data of the surface of Kojima Lake. In other words, here, the spectral data of the images are classified into 6 classes. This classification is not reflecting any physical phenomenon but simply a statistical analysis of optical intensities of electromagnetic waves of blue (band 1), green (band 2) and near infrared (band 4) reflected from the water surface. Therefore, this classification is reliable to a certain degree as flow patterns but expression in the same color does not necessarily indicate the same water quality.

From these images, the following points can be estimated; ① the inflow pattern from Sasagase River is relatively clear, ② seasonal variations seem to be captured fairly clearly and ③ the stagnant area of Yatsuhama is often covered with high-reflecting matter particularly in summer. The behavior of water in Kojima Lake is very complicated but we consider that its flow pattern can be grasped more accurately by accumulating observation of satellite images densely.

Comparison with the analysis of the lake flow by numerical simulation

Fig. 5 shows the result of 3-dimensional numerical simulation. The bottom of the lake becomes the deepest just before the control gate and a deep channel leading to the trough exists. Simulation was performed assuming that deep pits were present near the inlet of Sasagase River and on the left of the closing dam. Calculation was started assuming that salt water was accumulated to the level of sill of the sluice and that the lower layer than this level was sea water and the upper layer was fresh water. Taking 44 hours as one cycle, calculation was performed on the assumption that the flow equal to the volume flowing into the lake from Sasagase River, Kurashiki River and District 7 reservoir was discharged through the sluice between 42^{nd} and 44^{th} hours. Fig. 5 shows the final result. The process in the initial stage is the accumulation of water flowing from Sasagase River in the lake and the lower salt layer did not change greatly. Water in the surface layer also shows backward flow by damming up. When discharge is started by opening the sluice, water flows down by a sharp pulling towards the sluice and the lower salt layer is also carried away.

Fig. 1 Observation on May 9, 1990

Fig. 2 Observation on August 24, 2000

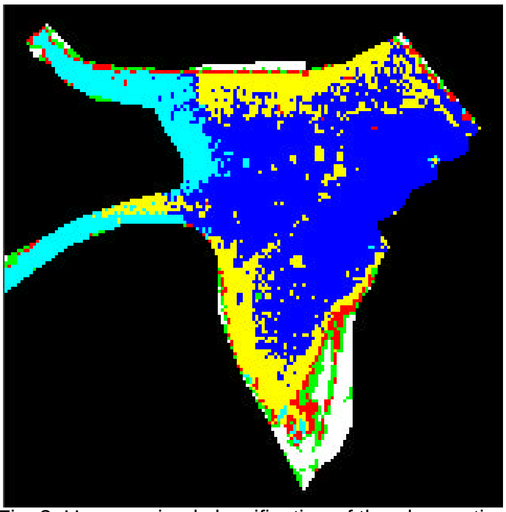

Fig. 3 Unsupervised classification of the observation on May 9, 1990

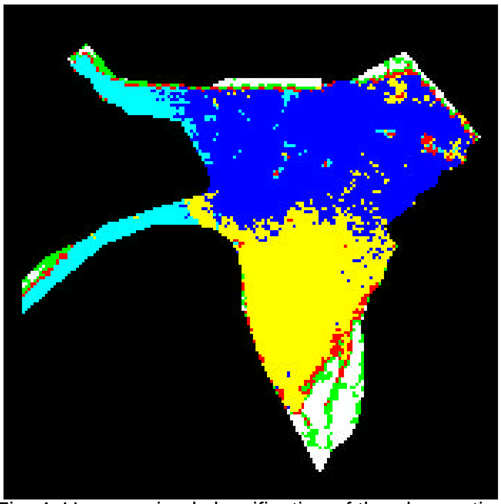

Fig. 4 Unsupervised classification of the observation on August 24, 2000

In this situation, it is understood that the salt concentration in the lake decreases. Inflows from rivers are accumulated until the lake water is discharged and, thus, flow patters become very complicated.

Fig. 6 shows the result of 2-dimentional flow simulation. In this simulation, the fluid present in the freshing lake in the beginning was represented in red, water flowing in from Sasagase River and Kurashiki River in blue and the areas consisting of their mixtures in sky blue, green, yellow, etc. to show how inflow water spread on the lake surface. The boundary conditions were set such that a fixed flow rates were given to Sasagase River and Kurashiki River and the amount of water equivalent to the inflow rate discharged from the sluice gate. Influence of wind, large inflow such as in flood, or discharge due to the range of tide or influence of sluice operation were not taken into consideration.

Complicated flows in the Kojima Lake can be imagined from Figs. 5 and 6.

Prospect in future

High-performance computers have been developed and satellite image processing software are acquiring multiple functions at unbelievable speed.

Figs. 3 and 4 show unsupervised classification of the water area in Kojima Lake by extracting water

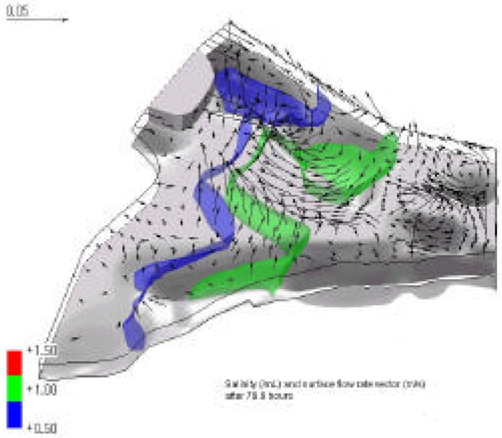

Fig. 5 Result of simulation of 3-dimensional density flow in Kojima Lake

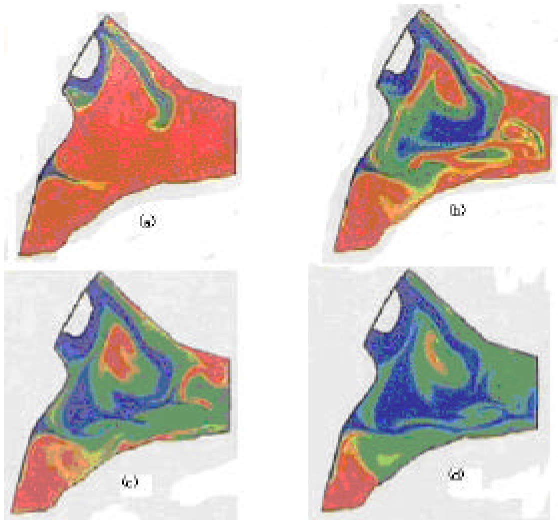

Fig. 6 Simulation of surface flow in Kojima Lake
(dispersion of inflow water from rivers)

area in the attempt of classifying lake water into groups of areas showing uniform spectral properties.

It is possible to locate the field sites where water quality data were measured on Figs. 1 and 2 or Figs. 3 and 4 if we could know their accurate locations in the latitude-longitude system or UTM system. By accumulating such data, we can estimate water quality from the spectral value by a simple multivariance analysis.

By deriving an accurate a regression equation for estimation of water quality, permits more detailed and more accurate estimation of water quality distribution in the water area than that shown in Fig. 3 and 4.

A drainage control system with high precision will be completed by linking the result of observation of lake water by satellite image analysis and flow pattern determined by numerical simulation and observation and piling up measurement data for water quality. While flow simu lation showed detailed results, those obtained by satellite image analysis were rather rough. Additional comparison with the water quality data and detained positional data will give us results of higher precision. At present when performance of computers has progressed greatly and measurement data in various fields are available, it is necessary to carry out studies in various cases comprehensively in this field.

Finally, we used numerical data for topographical maps from CD-ROM published by the National Geographical Agency (?). Landsat TM satellite image data were those offered for researchers at low prices from the National Space Development Agency of Japan. We used a satellite image processing software, DRDAS Imagine produced by ERDAS for satellite image processing. We express our thanks to all those concerned.