Satellite Remote Sensing for water quality assessment and monitoring-an overview on current concepts, deficits and future tasks

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Abstract: - The aim of this study is to give an overview of the current state of monitoring water quality issues and the application experience with the approaches provided by using satellite remote sensing as an effective monitoring tool for such studies. It is pointed out that the current in-situ techniques must be replaced by satellite remote sensing techniques due to their cost effectiveness and benefits of providing synoptic coverage of the area under investigation. Today satellite remote sensing can provide much needed information-for example, on some aspects of water quality where access is difficult or where a large area needs to be surveyed and the cost of a ground survey would be too high. Satellite Remote Sensing was found to be a valuable tool of assessing multi-temporal changes, spatial variations and synoptic coverage of water quality as described in this paper by citing the example of the Cyprus Island in which a Landsat TM or ETM image covers almost the entire island. Indeed, the benefit of using only one snapshot and assessing water quality for all the inland water bodies is highlighted.

Key-Words: - water quality, satellite remote sensing, spatial variations and synoptic coverage

1 Introduction

This paper provides the basics advantages provided by the use of satellite remote sensing in general by briefly stating and presenting the remote sensing cycle (collection of data and pre-processing); an overview of the benefits and deficits found by the use of satellite remote sensing for monitoring water quality in inland waters; and finally a case study from the use of satellite remote sensing for assessing spatial and temporal variations as well for determining turbidity levels from imaging data at Kourris Dam in Cyprus is presented.

2 Satellite Remote Sensing

Landsat Thematic Mapper (TM) and MSS, SPOT satellite images are widely used for deriving information about the earth's land. Moreover, the operational availability of high-resolution satellite imagery such as Quickbird and IKONOS opens up new possibilities for investigating and monitoring natural resources. Compared with traditional survey techniques, satellite remote sensing is accurate, timely and cost-effective. These data offer a number of advantages:

- Provide synoptic coverage and therefore give an extensive view of vast areas at the same time. They allow the analysis of land use over large areas - thousands of hectares or more in a single image.
- Images can be acquired for the same area at a high rate of repetition (two to three times a month), thus permitting selection of the most appropriate seasonal data.
- Satellite images are recorded in various wavelengths, visible and non-visible, which provide accurate information on ground conditions.
- They can be obtained for any part of the world without encountering administrative restrictions.
- Satellite images can be acquired over the same area at a high rate of resolution, thus permitting selection of the most appropriate seasonal data

In their raw form, as received from imaging sensors mounted on satellite platforms, remotely sensed data generally contain flaws or deficiencies [11]. The correction of deficiencies and the removal of flaws present in the data are termed *pre-processing*. Pre-processing refers to those operations that are proceeding to the main analysis, and include mainly *geometric* and *radiometric* corrections (see Figure 1).

3 Benefits: Use of satellite remote sensing for monitoring water quality

Monitoring water quality typically involves costly and time consuming in-situ boat surveys in which water samples are taken and returned to a laboratory for testing of water quality indicators e.g. chlorophyll-a (an indicator of algae) and suspended solids. This method allows accurate measurement within a water body but only at discrete points [1].

Satellite remote sensing has been a valuable tool in providing a complete and synoptic geographical coverage of water quality in fresh water systems. The principal benefit of satellite remote sensing for inland water quality monitoring is the production of synoptic views without the need of costly in-situ sampling.

The potential of using satellite remote sensing techniques to monitor water quality in developing countries, where the substantial costs of in-situ monitoring makes the management and monitoring impossible, has been shown by the study performed by Choubey (1994) in the Tawa reservoir in Central India [2]. Choubey (1994) mentions, "There is no government private agency to monitor water quality of the Taw reservoir (Central India) covering large areas. It is apparent that a timely low cost method providing information on water quality to various users of the reservoir water is important. Conventional methods involved tedious and expensive in-situ and laboratory studies. Satellite-borne sensors have capabilities of providing repetitive, low costs, multi-spectra, timely, reliable information over areas…" (p.122) [2].

In addition, spectral analysis of remotely sensed images give an indication of the physical properties in water bodies, the algal distribution and accurate estimates of the overall trophic status without the need for costly ground truth sampling. Remote sensing techniques may also be used to design or improve in-situ sampling monitoring programmes by locating appropriate sampling points [3]. A further benefit is the capability of establishing spectral statistical relationships of satellite data with water quality parameters, enabling characterization of the water quality of the inland water bodies under investigation

4 Deficits: Use of satellite remote sensing for monitoring water quality

- The availability of cloud-free images is the major obstacle in humid tropical countries-satellite imaging.

- Failure to account for atmospheric effects when working with multi-spectral imagery can potentially lead to erroneous assessments of water quality.
- Atmospheric effects are both large and variable when low-reflectance targets are monitored [5, 6, 8 and 9]. Hadjimitsis *et al*. (2000) has shown that uncorrected at-satellite reflectance values for the Queen Mary reservoir (UK) in a 12-image time series contained from 81 % to 99 % atmospheric contribution in the visible and near infrared bands [9]. It is therefore essential that atmospheric effects be taken into account before attempts are made to estimate ground conditions [13]. An example of the severe atmospheric effects interaction in low reflectance targets is shown in Figure 2 for Asprokremmos Dam in Paphos, Cyprus (Landsat TM image).

5 Monitoring water quality

5.1 Introduction

The strength of remote sensing techniques lies in their ability to provide both *spatial* and *temporal* views of surface water quality parameters that is typically not possible from *in situ* measurements as shown by Hadjimitsis *et al*. (2006) [6].

Remote sensing makes it possible to monitor the landscape effectively and efficiently, identifying water bodies with significant water quality problems. These water quality parameters, often, can be quantified using remote sensing techniques allowing better and more effective management plans to be formulated to reduce movement of substances from watersheds to water bodies thus reducing the effects of the pollutant on water quality.

5.2 Statistical analysis: correlating image against water quality data

Several studies reported in the literature regarding the use of satellite remote sensing for monitoring and assessing water's turbidity such as [7, 10, and 12]. Remote sensing data were correlated with *in situ* observations of water quality parameters such as turbidity, chlorophyll-a and suspended solids [13]. Statistical analysis has been performed to correlate image data against water quality parameters. Indeed, linear region and multiple linear regressions were most widely applied as shown by various researchers [10, 12, and 13].

6 Case Study: Kourris Dam in Limassol (Cyprus)

In order to meet the required standards the Cyprus Water Development Department takes periodically in-situ samples in all dams, rivers and reservoirs, especially in the summer period in which the presence of algae is a considerable nuisance. The only tools that have been available to monitor water quality are based on direct physical sampling, which requires considerable resource.

A single Landsat TM image of Cyprus (see Figure 3) covers almost the entire island and this permits the assessment of all the dams and reservoirs simultaneously [9]. Indeed, by selecting areas of interest near the outlet in every dam, a synoptic assessment of the water quality in every dam was achieved as shown by Hadjimitsis *et.al*. (2000) [9]. Table 1 show that the Evretou Dam had higher mean Digital Numbers (DNs) in TM bands 1 and 2 than the other dams. This suggests that the water quality was worse in the Evretou Dam than the other dams.

Table 1. Average and standard deviations of digital numbers for selected areas of interest in dams in Cyprus (Image: Landsat-5 TM 11-9-1998 path/row=176/36) [9].

DAM	Mean (st.dev) DN in TM Band 1
Asprokremmos	15.2 (2.4)
Evretou	17.1 (1.6)
Polemidia	4.9 (2.3)
Kalavassos	13 (2.6)
Germasogia	9.5 (1.9)

6.1 Determine spatial variations of water quality across the Kourris Dam

The in-situ measurements of turbidity values in Kourris Dam, indicates that the turbidity in the inlet of the dam is higher than the outlet. This can be easily found by selecting two areas of interests, one near the inlet and the other near the outlet as shown below (see Table 2). It is apparent that the high reflectance values are observed near the inlet with high spatial variability (high standard deviation) and lower reflectance values appear near the outlet

Table 2. At-satellite reflectance at inlet and outlet of Kourris Dam

LANDSAT TM IMAGE: 11-MAY-2000 KOURRIS DAM	At-satellite Reflectance-before AC (%) Inlet	At-satellite Reflectance Before AC (%) Outlet
Landsat TM-Band 1	9.2 %	8.8 %
Landsat TM-Band 2	7.4 %	6.5 %
Landsat TM-Band 3	4.8 %	4.7 %
Landsat TM-Band 4	2.7 %	2.6 %

6.2 Determine temporal variations of water quality across the Kourris Dam

The average at-satellite reflectance values (before atmospheric correction=AC) and the target reflectance at ground level (after AC) for an area of interest in Kourris Dam near the outlet was selected. The target reflectances (after correction) represent potentially useful information about the state of water. High reflectance values correspond to more turbid water as shown by [4 and 5]. For example, in Landsat TM band 1, the target reflectance for the image acquired on 30-01-2001 was higher than the others acquired on 11-05-2000 (spring to summer period) and 11-9-1998 (autumn period).

6.3 Statistical analysis between water quality parameter and image data

Water samples were collected at Kourris Dam using a powerboat at the outlet of the Kourris Dam. The water sampling coincides with the Landsat TM-5 and ETM+ 7 satellite overpass: 20/4/2004, 6/5/2004, 30/5/2004 and 7/6/2004 [Figure 3]. These image data have been pre-processed as according the steps shown in Figure 1.

An area of interest at the outlet of Kourris Dam has been selected (50 x 50 pixels). The mean reflectance of each TM band 1, 2, 3 and 4 was found. Then reflectance data were correlated against turbidity values. The greatest correlation coefficient (r^2=0.87) was found when a linear regression was applied for correlating TM band 3 against turbidity values. The equation found from the regression analysis can be further tested with more data and can be used for future monitoring assessment of water quality.

7 Conclusions

Satellite remote sensing has been found to be useful for monitoring and qualitative evaluation of water quality in several inland waters as shown by the literature and by the investigated case study. In particular, satellite remote sensing techniques were used to image spatial variations in water quality across inland waters, to monitor temporal changes of water quality between scenes and finally to provide a synoptic qualitative assessment of the water quality in all the water bodies in large regions. Despite some of the deficits of the use of earth observation such as cloud and atmospheric effects, space technology has been proved an ideal tool for any local or governmental body for managing water resources and assessing their water quality on a systematic basis.

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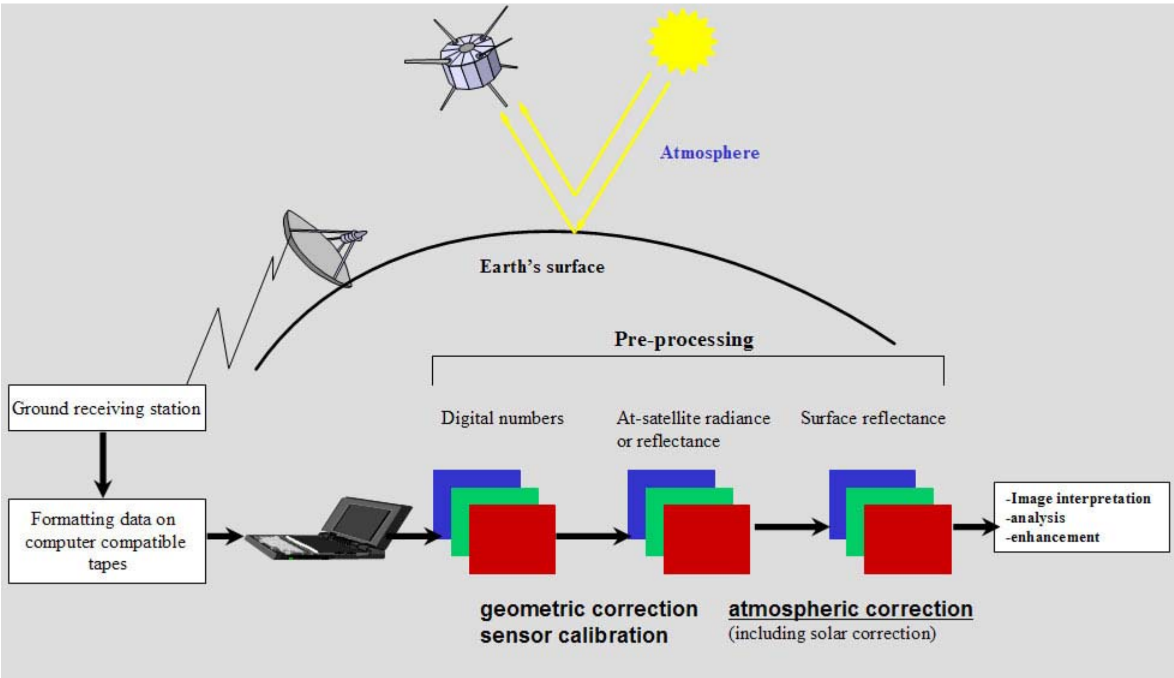

Figure 1. Passive collection of image data and pre-processing steps [5].

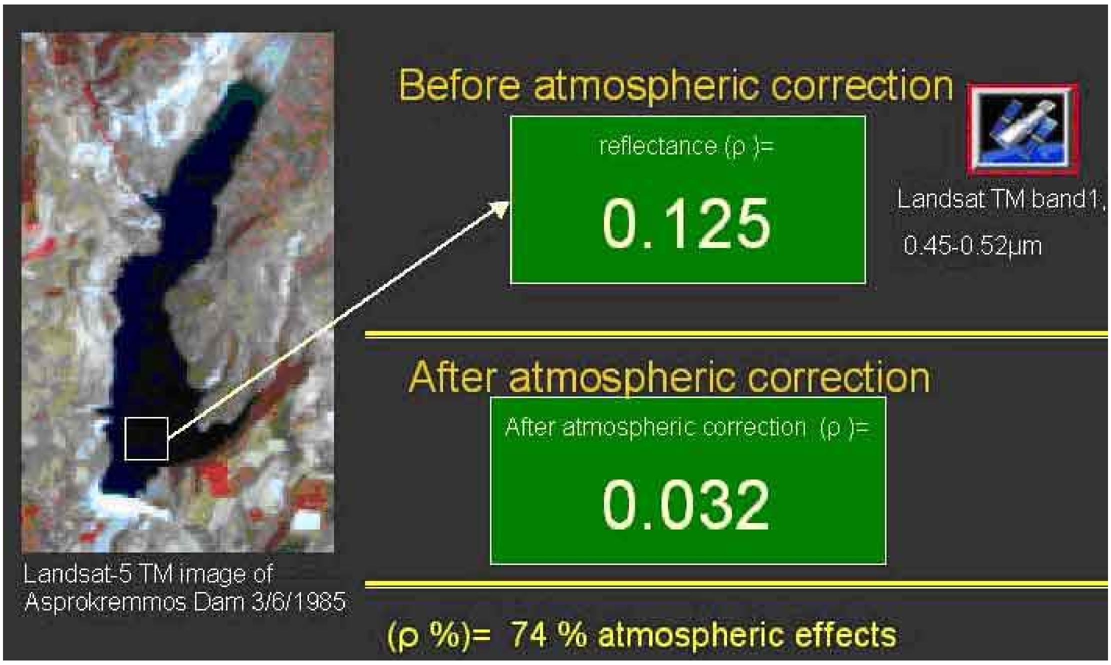

Figure 2. An atmospheric correction example for a dark target (dam) using Landsat TM band 2 data showing reflectance values before and after correction (Asprokremmos Dam, Paphos-Cyprus) [5].

Figure 3. Landsat TM image (after geometric correction) of Cyprus (image covers almost the entire island) [5].