THE USE OF AIRBORNE HYPER-SPECTRAL REMOTE SENSING FOR ENVIRONMENTAL RELATED TOPICS IN THE VICINITY OF THE GREATER CAPE TOWN AREA, SOUTH AFRICA

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ABSTRACT:

A hyper-spectral airborne campaign was conducted in August 2005 in Cape Town, South Africa, by Elbit Systems Electro-optics - Elop Ltd. together with the City of Cape Town Disaster Management Department, Environmental Planning Department and the Scientific Services Department. It was part of a larger campaign aimed at various applications, which covered about 800 sq km in South Africa. The goal of this study was to explore the ability of hyper-spectral remote sensing for monitoring the trophic state of inland water bodies around the city, based on concentration of chlorophyll-a and total suspended solids concentration. The sensor that was used in this campaign is AISA-ES, a hyper-spectral airborne imager with a spectral range spanning 400-2370 nm. Two levels of ground-truthing were carried out simultaneously over two water bodies - Zeekoevlei, the largest (2.56 sq km) freshwater lake in Cape Town, South Africa and the adjacent Cape Flats Wastewater Treatment Works. First, spectral readings were taken in the field for atmospheric calibration, and second, water samples were taken from various locations in both water bodies for laboratory analysis. Reflectance spectra were investigated and algorithms for estimation of water quality based on concentration of chlorophyll-*a*, and total suspended matter were applied. Quantitative thematic maps of the spatial distribution of these water constituents were created. This approach can be used for a cost-effective, on-line monitoring of the water bodies in the vicinity of the city of Cape Town.

1. INTRODUCTION

There are a number of water bodies in the City of Cape Town area which suffer from moderate to severe eutrophication and concomitant "blue-green" algal proliferation. Some of these water bodies are used for recreation (e.g. Zeekoevlei) while others support non-contact activities such as bird watching (e.g. Cape Flats Wastewater Treatment Works (WWTW)). Conventional methods to analyse the water quality are quite expensive, and moreover, time elapses between the sampling and the results. An effective supplementary technology for monitoring water

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quality in ponds and reservoirs could be remote measurements of water reflectance that depends on the concentrations of water constituents, absorbing and scattering light.

Braude *et al*., (1995) used SPOT images for the classification of clean water and wastewater reservoirs. Oron and Gitelson (1996) used the algorithms, developed for inland waters (Gitelson *et al*., 1994; Yacobi *et al*., 1995), for the qualitative estimation of chlorophyll-a (Chl) and Total Suspended Matter (TSM) in the Revivim Mashabei Sade wastewater system, Israel. High spectral resolution spectrometric data were used to select the most suitable spectral bands for remote sensing of "optically active" constituent concentrations (Gitelson *et al*., 1997). Reflectance value was calculated at 720 nm above a base line from 670 to 800 nm for Chl assessment. Reflectance around 570 nm correlated closely with TSM concentration. That was the first reported study on the quantitative remote assessment of wastewater quality. Stark (1997) used, developed further and validated the algorithms for quantitative estimation of constituent concentrations in waste water reservoirs.

Aim

The purpose of this study was to demonstrate the ability of hyper-spectral remote sensing for monitoring environmental issues in an urban area such as the City of Cape Town, South Africa (SA) and more specifically as a tool for monitoring water quality of inland water bodies.

2. SITE BACKGROUND

Water Bodies

Zeekoevlei (34°04'S; 18°31'E) is a hypertrophic water body and the largest freshwater water body on the Cape Flats (2.56 km2). The Big and Little Lotus Rivers (18 and 4 km in length, respectively) which empty into Zeekoevlei in the north drain a catchment approximately 80 km^2 in size (Figure 1). Zeekoevlei is "U"-shaped with Zeekoevlei is "U"-shaped with a central peninsula dividing it into northern and southern basins. It is utilized for recreational purposes such as fishing, sailing and canoeing. The outlet from Zeekoevlei is controlled by a weir in the south-western corner and a 3 km artificial channel (the Zeekoe "River"/Canal) downstream of the weir connects it to the sea. Polluted urban runoff from the entire catchment and nutrient enriched runoff from the Philippi Horticultural Area (PHA) have resulted in excessive nutrient loading in Zeekoevlei (catchment sources account for 28% of total annual phosphorus loading). Vast quantities of these nutrients are stored in the lake's sediments (25% of total annual phosphorus load), (Southern Waters, 2000).

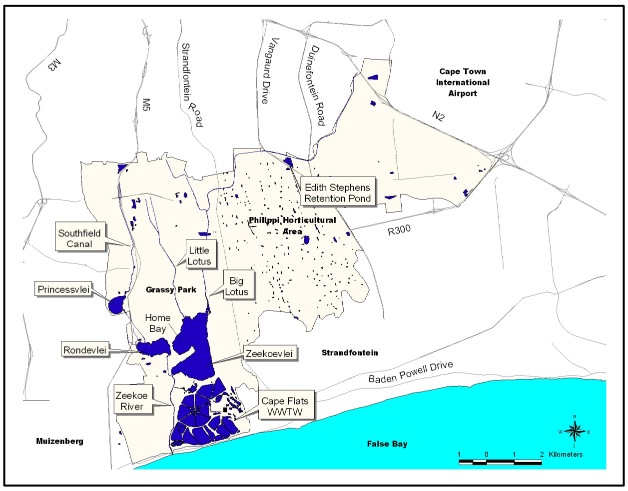

Figure 1. Map of the Zeekoe Catchment illustrating main aquatic features and other locality details (Haskins, C.A. 2006).

The Cape Flats WWTW treats 150 megalitres domestic sewage per day. It is the largest of 21 sewage works which operate within the City of Cape Town municipal area. Management of the works is occasionally complicated during the hot summer months by the presence of phytoplankton blooms in certain ponds, and the high nutrient levels in the sewage effluent are also ideal for the proliferation of nuisance macrophytes (e.g. water hyacinth). The final effluent is discharged into the Zeekoe Canal which has its outlet in False Bay.

3. METHODS

The study had four main stages: (a) Airborne and ground data acquisition, (b) Pre-processing (various types of corrections and calibrations), (c) Processing, and (d) Post-processing (image and index-mosaicing to larger area maps).

Data acquisition

Ground Analytical Measurements. Surface grab samples were collected from the water bodies on the date of the flight and delivered to the laboratory for analysis. Among the many parameters characterizing water quality, only Chl concentration and TSM were selected. Measurements of these constituents were carried out according to the standard methods for the examination of water and wastewater by Clesceri *et al*., (1989). The above water quality variables constituted the ground-truth for the remote sensing assessment.

Ground Radiometric Measurements were collected using an ASD hand-held spectro-radiometer with a spectral range of 350-2500nm. Measurements were performed on August 16th 2005, at several target locations that were chosen in advance and used for atmospheric calibration of airborne data. All measurements were accompanied by a GPS measurement, a photograph and by textual description.

Airborne Data was collected using the airborne hyper-spectral imager – AISA-ES. Characteristics of the flights over all the regions are summarized in Table 1

No. of flight lines	10
Flight altitude	25000ft
No. of spectral bands	180
Spectral range	403-2363nm
Spatial resolution	4m
Date of acquisition	Aug 16th 2005

Table 1. Characteristics of the airborne data

Pre-processing

Raw airborne data was first pre-processed in several steps, in order to enable analysis and interpretation. Generally, radiometric corrections and atmospheric corrections were applied to all raw data. Following radiometric calibration, the data was converted into reflectance using the "empirical line" method. The calibration targets that were used for this specific project were clear sea water, a road and sand dune spectra.

Processing

Processing was undertaken on data from Zeekoevlei, the adjacent Cape Flats WWTW. The NIR band at 851nm, in which water reflectance uniquely approaches zero, was used to exclude all non-water features leaving only water bodies for analysis. After masking-out irrelevant data, spectral indices were calculated to map water quality parameters. These parameters are the following:
(i) TSM - The reflectance value of the peak around 550nm (i.e. the green spectral range).
(ii) Chl - calculation of the height above base line was based on Stark. 1997, reading

$$h_{b2} = \rho_{b2} - \rho_{b1} - \left(\frac{\lambda_{b2} - \lambda_{b1}}{\lambda_{b3} - \lambda_{b1}} \right) \cdot \left(\rho_{b3} - \rho_{b1} \right) \qquad (1)$$

Where, h_{b2} is the height of the chlorophyll reflectance peak above its local baseline in the NIR range (b_2),
ρ_{b1} is the reflectance value at the beginning of the chlorophyll reflectance peak towards the shorter wavelengths (b_1),
ρ_{b2} is the reflectance value at the chlorophyll reflectance peak (b_2),
ρ_{b3} is the reflectance value at the end of the chlorophyll reflectance peak, towards the longer wavelengths (b_3),
λ_{bi} is the wavelength in nanometers at the corresponding spectral bands (i being bands 1, 2 and 3 respectively).

Due to the difference in the trophic state of the two water bodies, slight changes were made in the chlorophyll algorithm to adjust it to the right water status.

Post-processing (Final Products)

In order to avoid degradation of spectral information in an image (by spatial re- sampling and mixing), all interpretation of imagery was done prior to geo-rectification. To be able to apply geo-rectification, the attitudes of the aircraft (i.e. roll, pitch and yaw) and its x, y and z coordinates (geographical position) during the flight were used. With this data, motion-correction and geo-rectification could be performed. The process of mosaicing was used to "stitch" all the strips together based on its geographical coordinates. This enabled the union of image-mosaics and map-mosaics within a Geographical Information System (GIS) for further analysis

4. RESULTS AND DISCUSSION

The ten flight lines produced a mosaic covering an area of 60 km^2. The following types of products were generated for this data: Geo-rectified image-mosaics of the region and Geo-rectified index map-mosaics of the region. Following the interpretation, quantitative analysis of the results of water constituents was made. Ground truth measurements of TSM and Chl were used to create respective thematic maps (Figure 3 and Figure 4). The relationships were defined by crossing ground analytical measurements with spectral index results. Table 2 summarizes the correlation determination coefficients (R^2) for the mapped water constituents TSM and Chl.

The two adjacent water bodies (Zeekoevlei and the Cape Flats WWTW) differed in their trophic was also expressed in their spectral behaviour. Hence, different algorithms for chlorophyll concentration were used for these two water bodies. Overall a good agreement was observed for all constituents between the airborne data and the ground analytical measurements.

Task	**Samples**	**R^2**
Zeekoevlei - Chl	4	0.82
Cape Flats WWTW - Chl	5	0.71
Zeekoevlei & Cape Flats WWTW -TSS	10	0.87

Table 2. Coefficients of correlation with ground truth data

The above results confirmed a few key points in the understanding of the status of Zeekoevlei. This water body is well mixed due to moderate to strong prevailing winds and the hydraulic residence time is relatively long (~ 0.28 yr) due to the presence of an artificial weir in the south-western corner. Nutrient concentrations are exceptionally high and algae have ample time to proliferate under these favourable conditions. This has been confirmed by monthly water quality monitoring (grab samples) of this water body which demonstrates consistently high Chl and TSM concentrations and high availability of nitrogen and phosphorus.

It is also known that there are two areas where "sludge" (a composite of sediments and decomposed algal cells) tends to be deposited i.e. the protected Home Bay area and in the southern portion of the water body. Due to prevailing environmental conditions in these two areas and the release of nutrients from the sediments it is suspected that algal growth may be greater over these areas than in the rest of the water body.

In addition, there is a significant contribution of bio available phosphorus in water that seeps from the Cape Flats WWTW into Zeekoevlei along the south / south eastern shoreline. The hyper-spectral study illustrated these phenomena in Home Bay and in the southern portion of the vlei (refers to Figure 4 which depicted areas of high chlorophyll-*a* concentration in yellow).

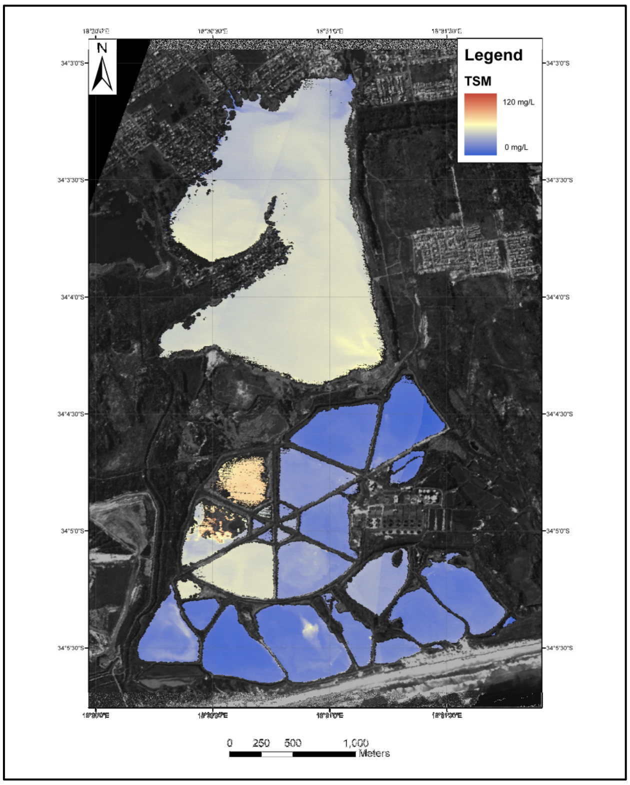

Figure 3. Zeekoevlei and Cape Flats WWTW - TSM Map.

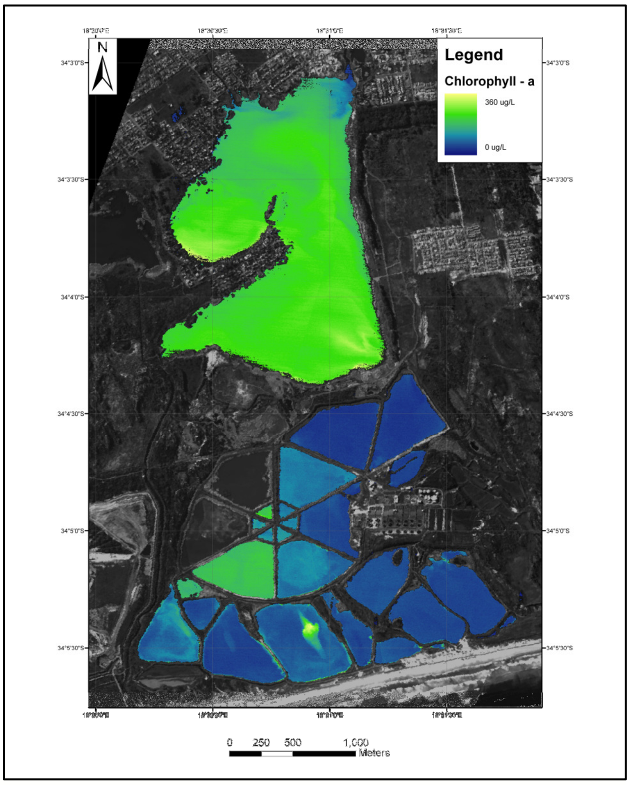

Figure 4. Zeekoevlei and Cape Flats WWTW - Chl Map.

Areas of lower algal activity are depicted in blue e.g. near the inlets of the Big and Little Lotus Rivers which enter the water body in the north. The rest of the water body showed relatively uniform coloration – probably since it is well mixed.

The Cape Flats WWTW has a relatively high flushing rate in the ponds, giving the algae less opportunity to develop before water is discharged at the final effluent outlet point. In spite of this, there are, in fact, algal bloom problems which arise particularly in the hot summer months. The hyper-spectral study took place during August 2005 (winter in SA) when temperatures where still quite low and this might account for the fact that not much algal activity was evident.

An interesting feature to note is the apparent bloom development in one of the large ponds located close to the sea. This pond once had an island which was heavily utilized by birds (e.g. cormorants). Guano deposited on the island probably leached into the pond and therefore represented a rich source of phosphorus for algal growth. The island has apparently virtually disintegrated into the water leaving the guano deposits in shallow water as a continuing source of nutrients. The algae growth sustained by this ongoing nutrient source is clear in the hyper-spectral imagery.

5. CONCLUSIONS

Within the framework of environment related topics in an urban area, the use of airborne hyper-spectral remote sensing proved to be an important and reliable tool, and a successful contributor of Value Added Data (VAD) for monitoring various aspects of water quality. The city's monthly monitoring programme of surface water bodies and rivers yields a wealth of water quality data which is specific to a particular isolated spatial location. The value of this technology is that it is capable of generating a "continuous" water quality layer of information which is relevant to the entire water surface. Such outputs enhance long-term monitoring for eutrophication of inland water bodies and coastal waters.

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