Remote Sensing of Coastal Areas in Cyprus Using In-Situ Spectroradiometric Data and Water Quality Data: The "SAT-COAST" Project

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Abstract. This paper seeks to test how remote sensing techniques can become a powerful tool for monitoring coastal water quality in Cyprus. It aims to present the first results derived from a running project funded by the Research Promotion Foundation of Cyprus developed by the Department of Civil Engineering & Geomatics, Remote Sensing Laboratory, Cyprus University of Technology in corporation with the Department of Fisheries and Marine Research in Cyprus. For the purposes of 'SAT-COAST' project, a running field sampling campaign program started during 2011. During sampling campaigns spectroradiometric field measurements are collected using a handheld GER1500 field spectroradiometer equipped with a fiber optic probe in order to retrieve the spectral signature of the examined coastal areas which are situated in Limassol district. Indeed, this will assist the development of an efficient model for monitoring purposes using satellite imagery. At the same time, both surface and 10 meters below sea level (using a Niskin Sampling Bottle) water samples are collected. A number of physicochemical measurements are determined on site when collecting samples for laboratory analyses of nutrients and metals. These in situ measurements include pH, electrical conductivity, dissolved oxygen concentration and temperature. In all, this paper presents the spectral signatures examination at the case study of Limassol district and compares them to previous measurements at the coastal area of Pafos district. Moreover, a preliminary environmental impact assessment was carried out using 10 Landsat TM & ETM+ satellite images in order to examine the coastal area of Larnaca district were a desalination plant exists.

Keywords. Coastal water, remote sensing, field spectroscopy, optical properties, monitoring tool, Cyprus.

1. Introduction

Since the 1980s satellite RS represents an opportunity for synoptic and multi-temporal viewing of water quality [1]. Satellite images are valuable tools for environmental assessment since daily or weekly data are available, depended on satellite overpass frequency, rather than monthly as done by traditional sampling campaigns. Moreover, the low price availability of satellite images enables the extend use of remote sensing for monitoring water quality in coastal areas. Finally, the use of satellite imagery offers the advantage of providing spatially continuous data, rather than information relating only to sampling points [2], [3], [4], [5].

The colour of the ocean, i.e., the spectral water-leaving radiance, Lw(k), is the combined result of the properties of various coloured constituents in the surface ocean, namely water molecules, phytoplankton, detritus, coloured dissolved organic matter (CDOM), suspended sediments, and bottom reflectance (if the water is optically shallow). The use of satellite remote sensing have been recommended to acquire more reliable information about the extent of the cyanobacterial blooms than the conventional monitoring programs provide [6], [7], [8], [9].

Summarizing, the objective of this project is to focus on the development of a water quality monitoring tool for coastal areas using satellite imagery, based on field spectroscopy measurements and optical properties of the water. Such techniques can be applied in coastal areas providing with more data and helping to examine larger areas and as a result detect and solve pollution problems. Coupling satellite observations with predictive models will provide better management of the coastal areas for mitigation in areas of public health, invasive species, fisheries management and water resources. Therefore, the development and improvement of satellite remote sensing technologies and applications for water quality observations rely on the needs of sustainable water strategies and new policies for water management [10].

2. Methodology

2.1. Study areas

Three different coastal areas were selected in order to examine the coastal water quality in Cyprus. The first study area is Vrisoudia bay, in Paphos district which is a city located on the side of the island of Cyprus (Figure 1a). The second study area is positioned in Limassol district which is located on the southern part of the island of Cyprus. Three different sampling stations were selected as shown in Figure 1b, where 1 is the Old Harbour; 2 is the Vassilikos and 3 is the Zugi Harbour. The third study area is the area of Larnaca's Desalination Plant which is located in Larnaca district which is placed on the south-east side of Cyprus (Figure 1c).

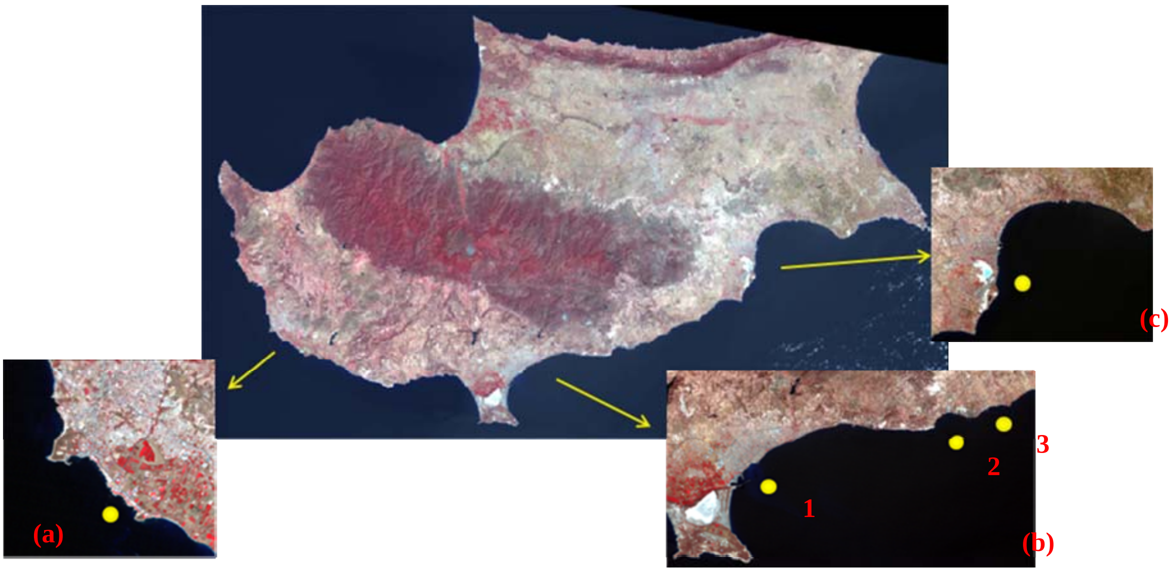

Figure 1: The study areas.

2.2. Resources & data

A power-engine boat was used to support the in-situ campaigns in the coastal area of Limassol. A Global Position System Garmin GPS72 was also used.

Physico-chemical water quality parameters: 1) Laboratory analysis of water samples collected during the sampling campaigns such as Suspended Solids, chl-a and 2) Field measurements of water quality parameters such as pH, D.O., Conductivity, Temperature, Salinity.

In-situ spectroradiometric measurements were made using a handheld spectroradiometer GER1500 equipped with a fiber optic probe. Spectral signatures of the water were collected at several depth below water surface, as mentioned, at 0.0m (water surface); 0.10m (10cm below water surface), 0.30m, 0.50m and 1.00m.

10 Landsat TM/ETM+ images were analysed in order to retrieve the mean in-band reflectance for the case study of Larnaca district area where the desalination exists. The image processing was performed using the Erdas Imagine 2011.

Figure 2: Sampling campaign in Limassol district.

2.3. Procedure

The method is briefly presented below:

1) Collection of water samples during the satellite overpass
2) Collection of spectro-radiometric measurements over the satellite wavelengths during the satellite overpass
3) Correlation of water quality parameters (suspended solids & chl-a) against spectro-radiometric measurements. Retrieval of the band with the highest correlation for every coastal water quality parameter.
4) Pre-processing of satellite images in order to correlate water quality parameters against the at-satellite reflectance after atmospheric correction.
5) Use of the retrieved equations to monitor the coastal water quality parameters.

3. Results

All the in situ spectroradiometric measurements were collected using the handheld GER1500 spectroradiometer equipped with a fibre optic probe. Spectroradiometric measurements were collected for several depths below the sea surface. For the case of Vrisoudia bay in Paphos district spectral signatures were collected at 0,10m - 0,20m - 0,50m and 1,00m below the sea surface and for Limassol district, sampling stations Zugi – Vasilikos and Old Harbour at 0,0m (sea surface), 0,10m – 0,30m - 0,50m and 1,00m below the sea surface. Higher concentration of SS was found for the water samples collected from Vrisoudia Bay, Paphos district compared to water samples collected in Limassol district. As it can be noticed, the reflectance values are reduced gradually to the depth both for Paphos and Limassol, but the reflectance values are higher for Paphos, areas where higher SS values observed (Figure 3, Figure 4). For the case study of Limassol district, slightly lower reflectance values were observed for the sampling station of Zugi compare to the stations of Vasilikos and Old Harbour for all the sampling campaigns.

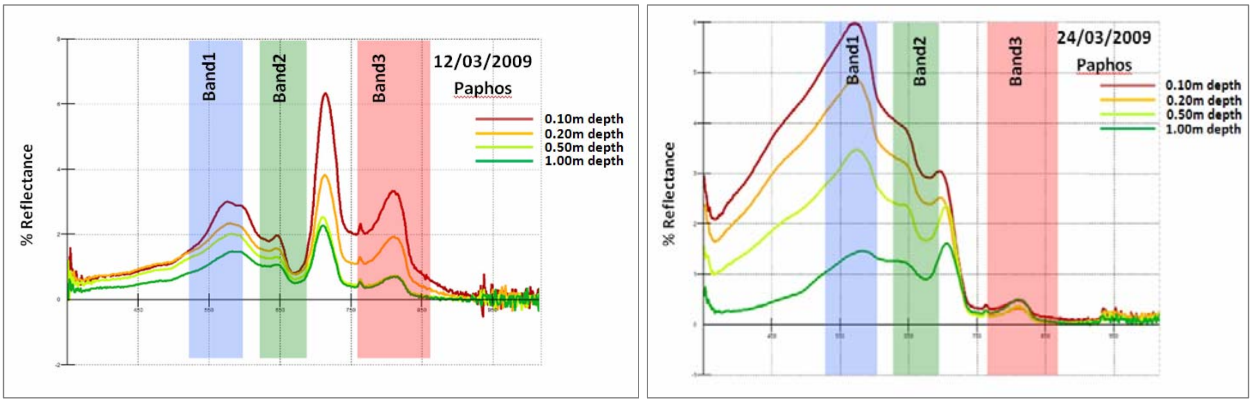

Figure 3: Spectral Signatures referring to Vrisoudia Bay, Paphos district.

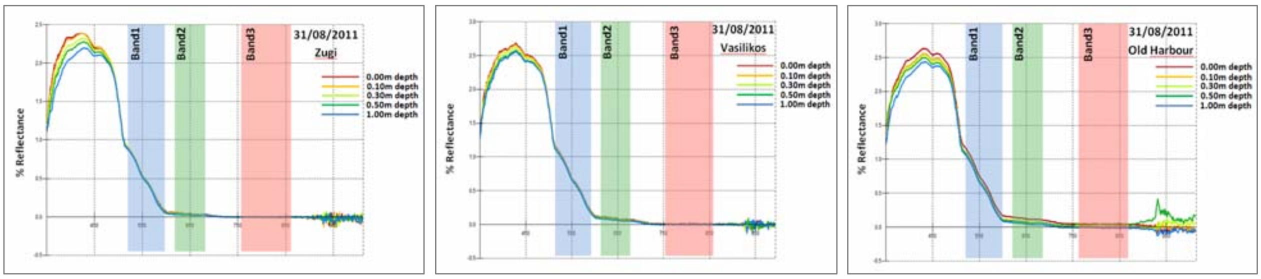

Figure 4: Spectral signatures referring to Zugi-Vasilikos-Old Harbour, Limassol district.

For the case study of Larnaca's district 10 Landsat images were pre-processed, including atmospheric and geometric correction. In order to process raw satellite images commercial computer software was used, in particular Erdas Imagine 2011. As it is shown in Figure 5 the point where the brine discharged is point 3. The calculation of mean in-band reflectance values for Band1 of Landsat after the atmospheric correction has shown that the reflactance values are higher for points 1-5 in comparison to points 6-15 and the maximum value is found for point 3. It is also obvious from results shown in Table 1 that the reflectance values slightly increesed from points 10 to 6 and 15 to 11.

Figure 5: Landsat ETM+ referring to Larnaca district – Desalination plant area.

Table1. % Reflectance Values Band 1 Landsat for Larnaca District (points 1-15 as it is shown in Figure 5) and for Limassol District (3 sampling stations).

Larnaca District						
1	6	11		2,162	1,151	1,097
2	7	12		2,402	1,120	1,084
3	8	13		2,484	1,118	1,036
4	9	14		2,238	1,106	1,032
5	10	15		1,962	1,071	0,961

Limassol District	
Zugi	1,444
Vasilikos	1,376
Old Harbour	1,425

4. Conclusions

This research demonstrates that, up to now, the reflectance values ranged from 1,5 % to 6,3 % for the coastal area of Paphos and up to 1,0 % to 2,5 % for Limassol district. The correlations that have been performed between turbidity and spectro-radiometric measurements have indicated that there is a strong correlation between water quality parameters such as SS and Turbidity and in-situ spectroradiometric measurements. It has been found after correlating the SS and Turbidity with the water reflectance obtained using the GER 1500 that high correlation was occurred for ASTER band 2 and band 3 respectively (r^2>0.80).

Satellite remote sensing information has been found to be useful for monitoring and qualitative evaluation of the coastal water quality conditions in beaches in the coastal areas of Cyprus. More sampling campaigns, during the satellite overpass, are planned in order to collect in-situ spectro-radiometric measurements and water samples for laboratory analyses. This will permit the most effective and reliable assessment of the coastal water quality in coastal areas in Cyprus and will be very helpful for the implementation of the Water Framework Directive 2000/60/EC. Our future work is to test further the developed methodology in coastal areas near to desalination plants located both in Paphos and Larnaca. In-situ spectroradiometric data will be collected in those areas.

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