Chapter 5

Remote Sensing for Water Quality Surveillance in Inland Waters: The Case Study of Asprokremmos Dam in Cyprus

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Additional information is available at the end of the chapter

1. Introduction

Monitoring, protecting, and improving the quality of water in lakes and reservoirs is critical for targeting conservation efforts and improving the quality of the environment (Ritchie et al., 1994; Nellis et al., 1998). The standard traditional mapping and monitoring techniques of lakes have already become too expensive compared with the information achieved for environmental use (Östlund et al., 2001).

Sustainable management of freshwater resources has gained importance at regional (e.g., European Union, 2000) and global scales (United Nations, 2002, 2006; World Water Council, 2006), and 'Integrated Water Resources Management' has become the corresponding scientific paradigm (IPCC, 2007). Water resources, both in terms of quantity and quality, are critically influenced by human activity, including agriculture and land-use change, construction and management of reservoirs, pollutant emissions, and water and wastewater treatment (IPCC, 2008).

Traditional water quality monitoring typically involves costly and time consuming in-situ boat surveys in which in situ measurements or water samples are collected and returned to laboratory for testing of water quality indicators e.g. chlorophyll-a (indicator of algae) and suspended solids. This method allows accurate measurements within a water body but only at discrete points, they can't give the real-time spatial overview that is necessary for the global assessment and monitoring of water quality (Curran et al., 1987; Wang et al., 2004; Brivio et al., 2001).

The challenge of water-quality management associated with the principle of sustainable development has been of concern to many researchers and managers in the last decade. A variety of models have been developed for supporting missions of water-quality management.

Technologies are becoming more and more important for water-quality management, due to the rapid development of computational problem-solving tools and the enhancement of scientific approaches for information support (Huang & Xia, 2001).

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. Synoptic, multi-sensor satellite data products and imagery have become increasingly valuable tools for the assessment of water quality in inland and nears-shore coastal waters. Remote sensing of lakes using satellite images has the potential to produce a truly synoptic tool for the monitoring of water quality variables such as chlorophyll a (chl-a), total suspended sediment (TSS), suspended minerals (SM), turbidity, Secchi Disk Depth (SDD), particulate organic carbon and coloured dissolved organic matter (CDOM) (Allan et al., 2011; Hadjimitsis, 1999; Mayo et al., 1995; Zhang et al., 2002).

Many researchers have attempted to develop algorithms or models for monitoring water quality in different types of inland water bodies from several satellite sensors such as *Landsat MSS, TM or ETM+ data* (Baban, 1993; Mayo et al., 1995; Östlund et al., 2001; Olmanson, Bauer, & Brezonik, 2008; Lillesand et al., 1983; Wang et al., 2004), *SPOT HVR data* (Lathrop & Lillesand 1989; Chacon-Torres et al., 1992; Jensen et al., 1993; Bhatti, Suttinon, & Nasu, 2011), *MODIS data* (Chen, Hu, & Muller-Karger, 2006; Doxaran et al., 2009; Dall'Olmo et al., 2005), *NOAA AVHRR data* (Prangsma & Roozekrans, 1989; Stumpf & Pennock, 1989; Carrick et al., 1994; Woodruff et al., 1999; Ruhl et al., 2001; Chen et al., 2004), *MERIS data* (Ruiz-Verdú et al., 2008; Guanter et al., 2010; Bresciani et al., 2012), *ASTER data* (Kishino et al., 2005; Nas et al., 2009), *IRS-1C data* (Xu et al., 2010; Sheela et al., 2011), *Hyperion data* (Kutser, 2004; Wang et al., 2005; Giardino et al., 2007), *IKONOS and QuickBird data* (Sawaya et al., 2003; Ekercin, 2007; Oyama et al., 2009). Statistical techniques have been used to investigate the correlation between spectral wavebands or waveband combinations and the desired water quality parameters. Predictive equations for water quality parameters have been developed after these correlations have been determined.

This Chapter describes how remote sensing has been used to monitor water quality in large dams in Cyprus using spectroradiometric measurements and satellite imagery.

2. Monitoring turbidity in dams in Cyprus using remote sensing

2.1. Water quality monitoring in dams

The climate of Cyprus is typical Mediterranean with hot dry summers and mild wet winters, with an average precipitation 500mm per year falling mostly in the winter months. In the last years Cyprus is suffering from water scarcity caused by repeated droughts (Charalambous, 2001; Tsiourtis, 1999; Margat & Vallée, 2000).

The recorded rainfall corresponds to the long-term average of the years 1986 to 2000 gives an average rainfall which is 14% lower than the long-term average of the years 1916 to 1985. In the same period the measured inflow to the existing dams was lower than the previous years' average by 35-40%. Cyprus as a semi-arid country with a highly variable climate, it is predicted that there will be increasing water shortages with the growing water demand in the years to come (Iacovides, 2007; Tsiourtis, 1999). It is important to mention that Cyprus lies heavily on water storage in dams to satisfy its water needs. Today in Cyprus there are 108 dams varying from small ponds to major dams. The fact that the storage capacity of surface reservoirs has reached 304,7 million cubic meters (MCM) of water from a mere 6 MCM in 1960, is a truly impressive achievement when compared to other countries of the same size and level of development as Cyprus.

One of the most important challenges for the Cyprus Water Development Department is the implementation of the European Water Framework Directive (WFD; 2000/60/EC) for inland surface waters including the 108 existing reservoirs. WFD aims at achieving "good water status" and establishes a framework for the protection of all waters including inland surface waters, transitional (estuarine) waters, coastal waters and groundwater by 2015 (Mostert, 2003; Borja et al., 2004). Moreover, WFD sets new objectives for the condition of Europe's water and introduces new means and processes for achieving these objectives. Specific details are also given of the monitoring requirements for different types of water, as well as the assessment and monitoring performance quality standards that should be achieved. For these reasons, monitoring is critical to surface water status within the WFD, as it will determine its classification and the necessity for additional measures in order to achieve the objectives in the Directive (Chen et al., 2004).

Remote sensing technology can become a valuable tool for obtaining information on the processes taking place in the surface of inland water bodies. Satellite remote sensing techniques show more important advantages than traditional sampling with emphasis on the synoptic coverage; it is remarkable that only a single Landsat TM image covers almost all the 108 reservoirs existing in Cyprus; and the high frequency of image captures (Hadjimitsis, 1999; Hadjimitsis et al., 2004a; Hadjimitsis et al., 2010a). Previous studies of using satellite remote sensing in the Cyprus region emphasized the importance of using such techniques for systematic monitoring of water quality either for coastal or inland water bodies due to the good weather conditions in the island (Hadjimitsis et al., 2000; Hadjimitsis et al., 2010a). Moreover remote sensing allows the spatial and temporal assessment of various physical, biological and ecological parameters of water bodies giving the opportunity to examine a large area by applying the suitable algorithm (Hadjimitsis et al., 2006; Hadjimitsis & Clayton, 2009; Papoutsa et al., 2010). Remotely sensed images can give an indication of the physical properties in surface water bodies and can be used to design or improve in-situ sampling monitoring programs by locating appropriate the sampling stations (Dekker et al., 1995). The role of remote sensing technology is therefore under scrutiny, given its potential capacity for systematic observations at scales ranging from local to global and for the provision of data archives extending back over several decades (Rosenqvist et al., 2003). These issues also highlight a need for the exchange of information between remote sensing scientists and various organizations.

The storage of surface waters in large dams in Cyprus is of vital importance in supplying the local areas for irrigation and potable water supply purposes (Hadjimitsis et al., 2007). At the current time, the Cyprus Water Development Department takes in-situ samples in every dam which provides raw water for treatment, so as to ensure that the water meets the required abstraction standards before it passes to the water treatment works. Previous studies showed the potential of using Landsat TM and Landsat ETM+ remotely sensed data to monitor turbidity in dams in Cyprus. Indeed Hadjimitsis et al., (2007) utilized Landsat TM/ETM+ image data to determine turbidity levels in Kourris Dam, the biggest dam in Cyprus. It is important to mention that turbidity is a vital monitoring parameter for the Water Development Department, as any high concentrations of suspended solids (i.e more turbid water) may cause serious problems in water filtration processes as shown from other studies (Hadjimitsis, 1999).

Asprokremmos Dam was selected as a case study for the development of a "monitoring tool" for the assessment of Cyprus' inland water quality using remotely sensed data. The concentration of Total Suspended Solids is one of the most critical parameter for the case of Asprokremmos as the water is pumped from the 'outlet area' of the Dam (Deepest point of Asprokremmos Dam / greater distance from the area where Xeros river flows into the Dam) to the water treatment plant of Asprokremmos for pre-treatment and then to the water supply system for the final consumption. High concentrations of suspended particulate matter in reservoir waters directly affect the water treatment plants by occurring damages to the filters during the pretreatment.

During sampling campaigns in Asprokremmos Dam both Turbidity (NTU) and Secchi Disk Depth (SDD) values were determined. Turbidity measures the scattering effect that suspended solids have on light: the higher the intensity of scattered light, the higher the turbidity). Turbidity is measured in Nephelometric turbidity units (NTU) or Formazin turbidity units (FTU), depending on the method and equipment used. Turbidity measured in NTU uses nephelometric methods that depend on passing specific light of a specific wavelength through the sample. FTU is considered comparable in value to NTU and is the unit of measurement when using absorptiometric methods (spectrophotometric equipment) (Wilde & Gibs). SDD is a measure of water clarity by human eyes and all optically active substances in water affect it (Secchi depth decreases as the concentration of chl-a, CDOM, and other substances increases). Secchi Disk Transparency is a commonly used, low-cost technique that measures water clarity (Specifically, a black and white disk is lowered into the lake until it can no longer be seen). Water clarity is related to the quantity of phytoplankton in the water, although non-algal turbidity and tannic acids also can reduce water clarity (Fuller et al., 2004).

2.2. Study area

Asprokremmos Dam is built at an altitude of about 100 meters above sea level and is located 16 kilometers east of the city of Paphos. It was completed in 1982 and is the second largest reservoir in Cyprus with a capacity of 52,375,000 cubic meters. It is an earthfill dam, 55 meters high, consisting of the main embankment, spillway, tunnels and galleries and geotechnical works. Due to poor rainfall the dam rarely overflows; the latest times this happened were in 2004 and in 2011. It is considered an important wetland for endemic and migratory birds. The Xeros River that flows into the dam runs only during winter and spring. The study area is shown in Fig 1.

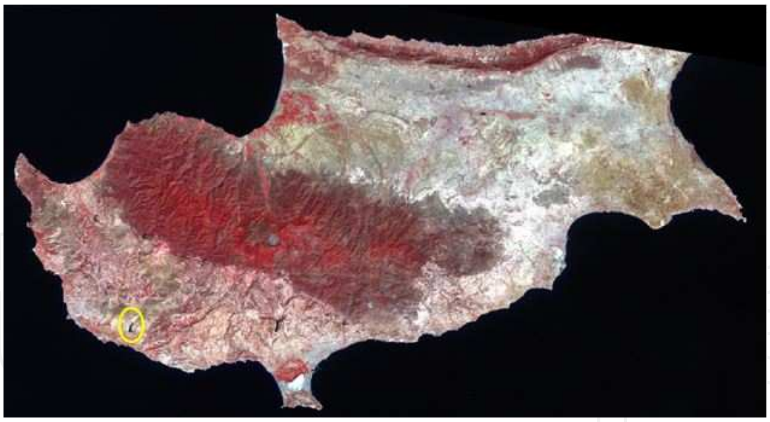

Figure 1. Landsat TM satellite image of Cyprus. Asprokremmos Dam is highlighted

2.3. Pre-processing of satellite images

Pre-processing refers to those operations that precede the main analysis and include mainly geometric and radiometric corrections (Teillet, 1986). Pre-processing steps were applied using the ERDAS Imagine software. All Landsat images were geometrically and radiometrically corrected.

Geometric correction: geometric correction was carried out using standard techniques with ground control points and a first order polynomial fit (Mather, 2004). Twenty well-defined features in the images such as road intersections, airport runway, corners of large buildings were chosen as ground control points (Hadjimitsis et al., 2006).

Radiometric correction: satellite images were converted from digital numbers to units of radiance using standard calibration values. Then the at-satellite radiance values were converted to at-satellite reflectance values using the solar irradiance at the top of the atmosphere, Sun-Earth distance correction and solar zenith angle (Mather, 2004). The next step consist the removal of atmospheric effects from satellite imagery. The objective of any atmospheric correction method is to determine the atmospheric effects. Any sensor that records electromagnetic radiation from the Earth's surface using visible or near-visible radiation will typically register a mixture of two kinds of energy. The value recorded at any pixel location on a remotely sensed image does not represent the true ground-leaving radiance at that point. Part of the brightness is due to the reflectance of the target of interest and the remainder is derived from the brightness of the atmosphere itself. The separation of contributions is not known a priori, so the objective of atmospheric correction is to quantify these two components; in this respect, the analysis can be based on the corrected target reflectance or radiance values. Many atmospheric correction methods have been proposed for use with multi-spectral satellite imagery (Hadjimitsis et al., 2004a). In this study, the darkest pixel atmospheric correction method was applied to every image (Hadjimitsis et al., 2004; Hadjimitsis et al., 2010c) since it has been found that DP is a very effective algorithm especially for the visible length. The principle of the DP approach states that most of the signal reaching a satellite sensor from a dark object is contributed by the atmosphere at Visible and Near Infra-Red (NIR) wavelength. Therefore, the pixels from dark targets are indicators of the amount of upwelling path radiance in this band. The atmospheric path radiance is added to the surface radiance of the dark target, thus giving the target radiance at the sensor.

2.4. Temporal and spatial variations in water quality across the dam

2.4.1. Temporal variations

Eleven (11) Landsat TM/ETM+ satellite images were used in order to investigate how satellite remotely sensed data can become a valuable tool to monitor and assess the *temporal variations* of water quality in Asprokremmos Dam. All the images were pre-processed including geometric and atmospheric correction steps. Atmospheric correction was achieved by applying the Darkest Pixel method for the selected area of Pafos District where Asprokremmos Dam is situated. It has been found from previous studies that the darkest pixel atmospheric correction is the most suitable for inland waters (e.g Hadjimitsis, 1999; Hadjimitsis et al., 2004b). Satellite image processing and analysis was performed using the image processing software (ERDAS Imagine). Table 1 shows the changes of the Reflectance values observed before and after applying the Darkest Pixel algorithm (ρ_λ % is the reflectance value observed before applying the AC and ρ_{DP} % is the reflectance value observed after applying the AC). It has been shown that an atmospheric correction must be taken into account in the pre-processing of satellite imagery especially where images contain dark targets such as coastal waters or inland waters (Hadjimitsis et al., 2000; 2010b; 2004b; 2009).

Acquisition Date	Band 1		Band 2		Band 3		Band 4	
	ρ_λ %	ρ_{DP} %	ρ_λ %	ρ_{DP} %	ρ_λ %	ρ_{DP} %	ρ_λ %	ρ_{DP} %
28-Apr-2004	9.45	1.88	6.79	1.50	4.30	1.15	3.60	1.41
14-May-2004	11.35	1.60	9.03	1.40	7.03	1.78	7.00	3.06
5-Oct-2004	11.42	3.10	8.76	3.11	5.43	1.82	3.67	1.37
13-Aug-2008	14.25	4.46	13.67	5.77	10.68	4.15	6.55	2.29
14-Sep-2008	13.98	3.62	13.08	5.58	10.12	4.42	5.80	1.51
17-Nov-2008	15.07	5.61	14.04	8.08	10.86	7.22	4.83	1.70
29-Jun-2009	9.88	1.37	7.88	1.35	5.14	1.51	3.86	1.31
7-Jul-2009	10.41	1.62	8.54	1.96	5.99	1.17	4.38	1.71
23-Jul-2009	9.82	0.91	8.02	1.04	5.15	1.02	3.38	2.08
1-Sep-2009	11.90	2.37	9.95	2.95	6.87	2.63	4.72	1.93
25-Sep-2009	10.85	3.08	9.92	4.73	6.39	3.80	3.19	2.73

Table 1. Mean reflectance values of Landsat Bands 1 to 4 observed in Asprokremmos Dam, before (ρ_λ %) and after (ρ_{DP} %) applying atmospheric correction.

It is obvious in Figure 2 that the maximum reflectance values for Band 2 of Landsat sensor, after applying the atmospheric correction algorithm, are observed in the winter months for all the years examined (2004, 2008 and 2009). This phenomenon is maybe caused due to the fact that in winter time we have more frequent rain events, and as a result wet deposition of atmospheric particles are observed after each precipitation event.

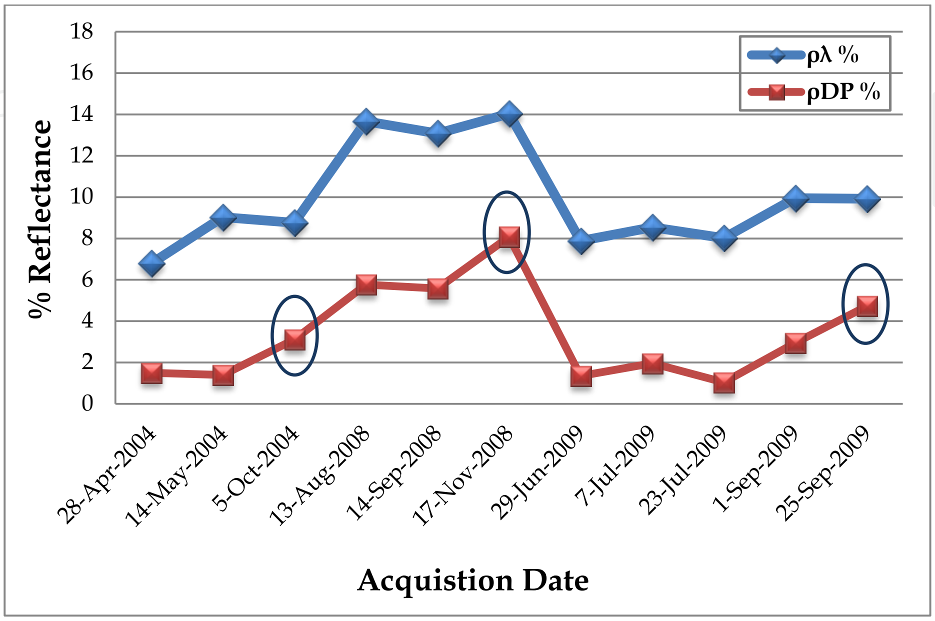

Figure 2. Temporal variations of water quality in Asprokremmos Dam for TM Band 2.

2.4.2. Spatial variations

Three archived Landsat TM images acquired on 7th July 2009, 23rd July 2009 and 25th September 2009 were analysed in order to assess the *spatial variations* of water quality in the area of Asprokremmos Dam using satellite remotely sensed imagery. The analysis included image pre-processing steps (geometric correction and atmospheric correction) and selection of two areas of the study area (Inlet & Outlet; see Fig. 3) in order to find out the variation of the reflectance in the two areas. The Inlet area is located at the outfall area of the Xeros River where water flows into the Dam and the Outlet area is the area where the water is pumped to the water treatment plant of Asprokremmos for pre-treatment and then to the water supply system for the final consumption. Satellite image processing and analysis were performed using the ERDAS Imagine image processing software and the results are presented in the next section.

The in situ measurements of turbidity have shown that for all the sampling dates the higher values of turbidity were observed for the sampling station which is positioned in the Inlet Area (see Fig. 3) which is where the Xeros River flows into the Asprokremmos Dam while the values reduced along the dam taking the lower turbidity values at the sampling stations which represent the Outlet area. The results of the mean reflectance values of *Inlet & Outlet* areas of Asprokremmos Dam which were calculated in order to find out the variation of the reflectance in the two areas are presented on Tables 2 and 3. These results are in agreement with the in-situ measurements as for all the bands, before and after atmospheric correction the mean reflectance values of the *Inlet areas* are higher than those of the *Outlet areas*.

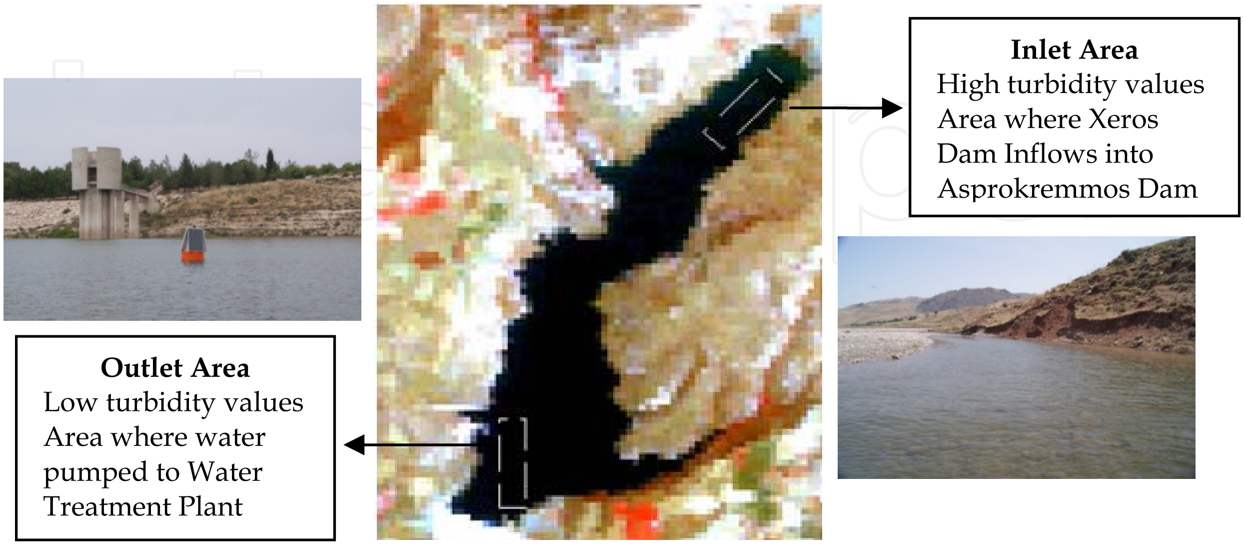

Figure 3. Landsat TM Image focused in Asprokremmos Area pointed the two study areas of the Dam; Inlet & Outlet areas.

	Band 1				Band 2			
Acquisition	ρ_λ %		ρ_{DP} %		ρ_λ %		ρ_{DP} %	
Date	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
7-Jul-09	11.57	10.43	2.78	1.65	10.76	8.61	4.18	2.03
23-Jul-09	11.15	9.85	2.24	0.94	10.75	8.12	3.76	1.13
25-Sep-09	11.40	10.83	3.64	3.06	10.90	9.84	5.71	4.66

Table 2. Spatial variation of mean reflectance values of *Inlet & Outlet areas* of the Asprokremmos Dam for bands 1 and 2 of Landsat TM multispectral scanning radiometer before and after applying the atmospheric correction.

	Band 3				Band 4			
Acquisition	ρ_λ %		ρ_{DP} %		ρ_λ %		ρ_{DP} %	
Date	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
7-Jul-09	8.26	6.03	3.44	1.21	5.34	4.41	2.66	1.74
23-Jul-09	7.78	5.19	3.64	1.06	4.27	3.48	2.96	2.17
25-Sep-09	7.82	6.37	5.24	3.79	4.23	3.29	3.77	2.82

*ρ_λ% is the percentage value of the reflectance before the atmospheric correction and ρ_{DP}% is the percentage value of the reflectance after applying the DP atmospheric correction

Table 3. Spatial variation of mean reflectance values of *Inlet & Outlet areas* of the Asprokremmos Dam for bands 3 and 4 of Landsat TM multispectral scanning radiometer before and after applying the DP atmospheric correction.

2.5. Overall methodology

The overall methodology been applied for the development of an integrated monitoring tool based on remote sensing techniques is briefly presented below (Papoutsa et al., 2011a; 2011b):

- Design an ideal sampling station network in the area of interest so as to have an adequate number of sampling stations positioned in all directions for the proper and adequate coverage of the study area
- Collect field spectroradiometric data over the satellite wavelengths during the satellite overpass
- Retrieve water quality data such as in-situ turbidity & SDD measurements Correlate water quality parameters against spectroradiometric measurements. Retrieve the band with the highest correlation for every inland water quality parameter – extract algorithm
- Correlate water quality parameters against the at-satellite reflectance after atmospheric correction
- Use the retrieved equations to monitor the inland water quality parameters
- Use data collected using the smart buoy for furthermore calibration of the retrieved algorithm due to high frequency of measurements collection (every 2 minutes)
- Use smart buoy as a monitoring tool able to trigger email or sms alerts when the measurements are outside the desired limits

2.6. In-situ turbidity and spectroradiometric measurements

In-situ campaigns in Asprokremmos Dam (Figure 4) were carried out with the collaboration of Cyprus Water Development Department and the Cyprus University of Technology (Remote Sensing Lab) using a power engine boat to collect in-situ data (Figure 5). A sampling station network has been designed in the area of Asprokremmos Dam so as to have an adequate number of sampling stations positioned in all directions for the proper and adequate coverage of the study area and a Global Position System Garmin GPS72 (Figure 6a) was used in order to store and define the preselected sampling stations during the sampling campaigns.

In-situ spectroradiometric data together with in-situ water turbidity readings were collected during the satellite overpass in order to enhance the statistical analyses for retrieving the cross-correlation of spectroradiometric data and water turbidity. A handheld GER-1500 field spectroradiometer (Figure 6b; spectral range covered by the instrument extends from 300 to 1050 nm) equipped with a fibre optic probe was used in order to retrieve the spectral signatures for certain water depths of the Asprokremmos Dam (see Figure 6c). Reflectance was calculated as a ratio of the target radiance to the reference radiance. The target radiance value is the measured value taken 10cm below water surface of the reservoir and the reference radiance value is the measured value taken on the standard Spectralon panel (Figure 6d) representing the sun radiance which reaches the earth surface-without atmospheric influence. The in-situ determination of water turbidity was achieved by using both a portable turbidity meter

(Palintest Micro950; Figure 7 b & c) and a Secchi Disk (Figure 7a). Secchi disk depth measurements were taken over the shady side of the boat (Papoutsa et al., 2011a; 2011c).

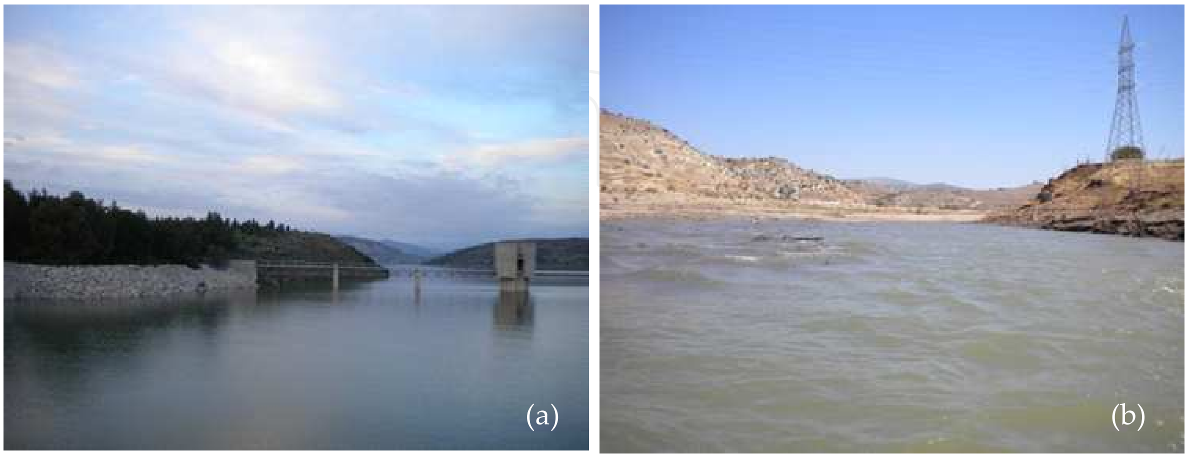

Figure 4. Picture of Asprokremmos focused in the (a) Outlet Area & (b) Inlet Area of the Dam.

Figure 5. Power-engine boat with all the required resources which was used during the sampling campaigns in Asprokremmos Dam.

Figure 6. Equipments used during field campaigns (a) Global Position System Garmin GPS72; (b) handheld GER-1500 field spectroradiometer; (c) fibre optic probe & (d) standard Spectralon panel.

Figure 7. Measuring the turbidity in Asprokremmos Dam using both (a) the Secchi Disk and (b&c) the portable turbidity meter; Palintest Micro950.

2.7. Smart buoy sensor platform

The data buoy (Figures 8a&b) consists of a low cost, low-powered, autonomous floating sensor platform, data logger and gateway to a remote data server. It utilizes an ultra compact powerful embedded system which supports the aggregation of the sensor data, their storage in a local database and transmission of the data to the secure remote storage server. The Data Buoy is highly versatile and can be easily deployed in completely isolated environments for various water monitoring and environmental applications. This robust floating platform can be easily tailored to the specific application needs by selecting different sensors, data logger, powering and communication options.

In our case the buoy has been loaded with various water quality sensors (such as thermometer, turbidity optical sensor - Figure 9a; humidity sensor – Figure 9b etc) and has been deployed in the Asprokremmos Dam, for real time monitoring of water quality (Papoutsa et al., 2011c). The buoy has been used to calibrate the retrieved regression models using the reflectance values as measured at-satellite and turbidity values as measured by the buoy.

Figure 8. Real time monitoring in Asprokremmos Dam using a Smart buoy sensor platform loaded with various water & environmental quality sensors.

Figure 9. a) Turbidity optical sensor and (b) humidity sensor located on a floating buoy deployed in Asprokremmos Dam.

3. Results

Spectroradiometric data collected during the field campaigns in two different Areas (Outlet & Inlet Areas of Asprokremmos Dam) characterized by low and high turbidity values are respectively presented in Figures 10a&10b. As we can see examining the typical spectral signatures collected during the in-situ sampling campaigns either the spectroradiometric values or the turbidity values are higher in the Inlet Area of Asprokremmos Dam comparatively to those measured in the Outlet Area of Asprokremmos Dam.

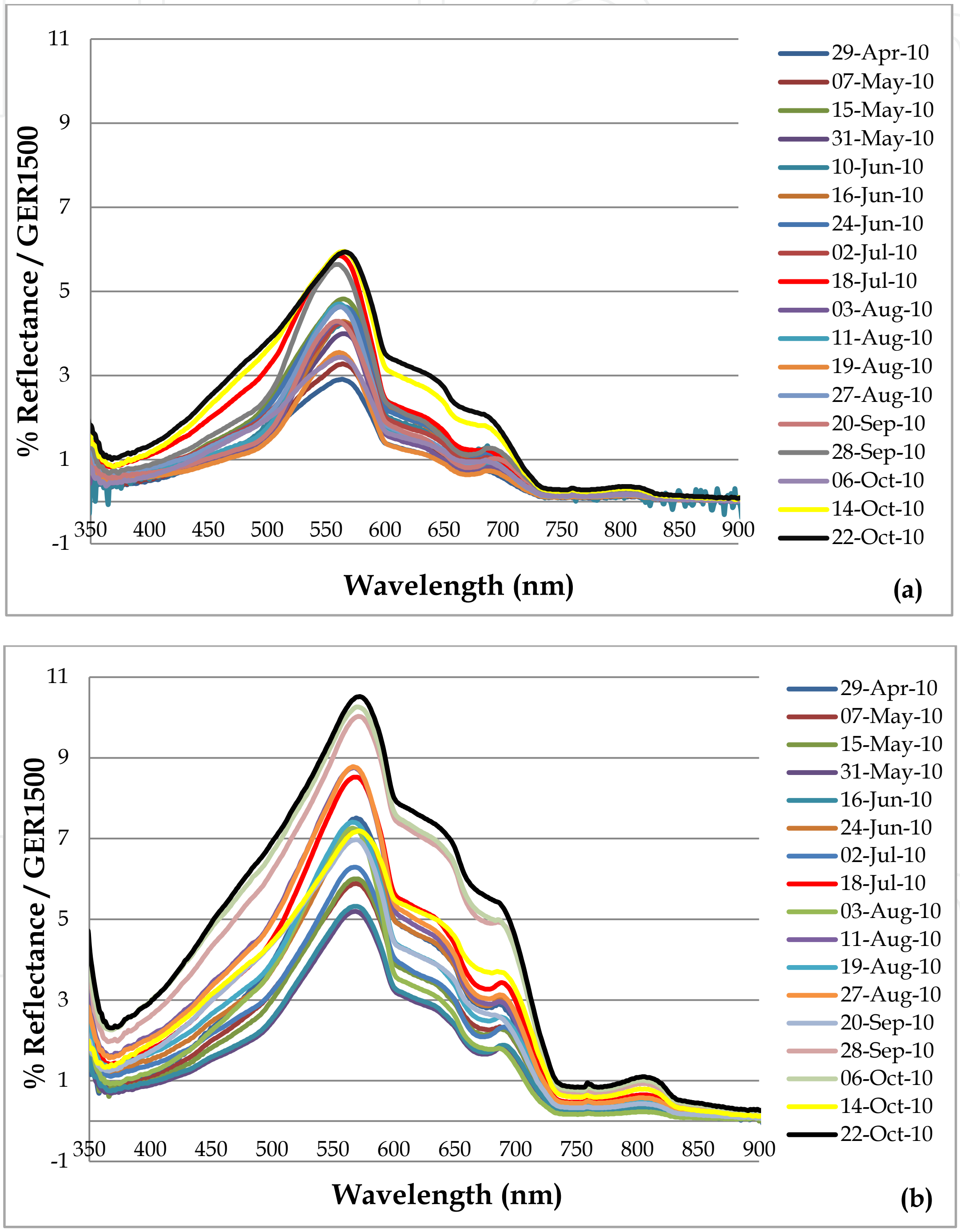

Figure 10. Typical Spectral signatures of (a) Outlet Area & (b) Inlet Area of Asprokremmos Dam acquired using a handheld field spectroradiometer GER1500.

Field spectroradiometric data acquired using the GER1500 provide reflectance data covering the UV, Visible and NIR wavelengths from 350 nm to 1050 nm, with a bandwidth sampling of 1,5nm. All in-situ reflectance data collected using the field spectroradiometer GER1500 were processed in order to get the mean 'in-band' reflectance values for the bands 1 to 4 of the Landsat TM and ETM + multispectral scanning radiometer and A1 to A62 of the Proba's CHRIS multispectral scanning radiometer. As it can be seen in Figures 11a & 11b Landsat TM has only 4 bands that correspond to the spectral region ranged from 450 to 900 nm against 51 bands (A3 to A53) of Proba / CHRIS and 300 spectral channels of GER1500 field spectroradiometer for the same spectral region.

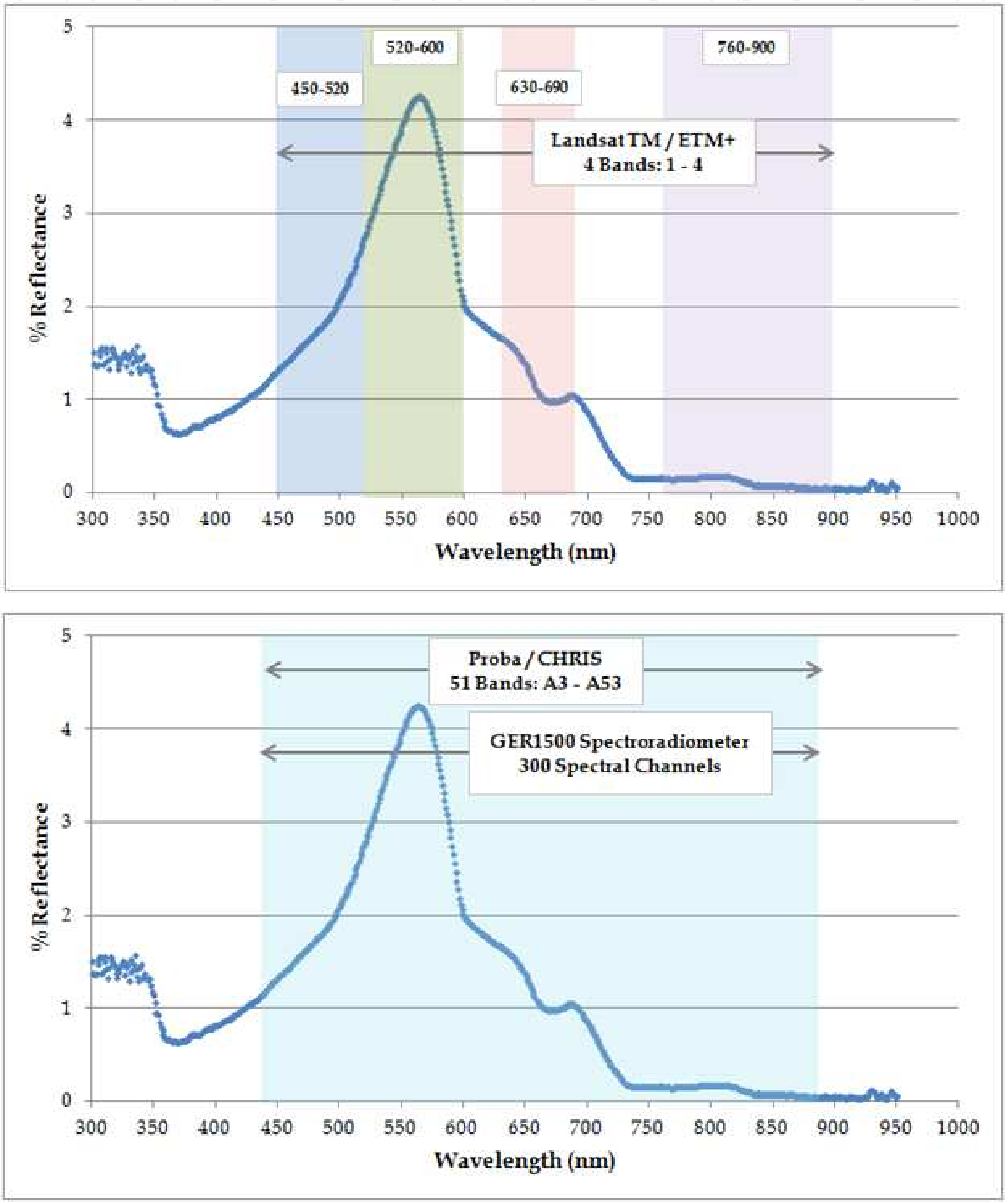

Figure 11. Corresponding Spectral Bands of (a) Landsat TM / ETM+ multispectral scanning radiometer, (b) Proba / CHRIS multispectral scanning radiometer and GER1500 field spectroradiometer of a typical water spectral signature collected during the in-situ sampling campaigns in Asprokremmos Dam – Sampling Station 2.

The mean 'in-band' reflectance value for each sampling point was correlated with the corresponding turbidity measurements collected using both the Digital Turbidity-meter and the Secchi Disk for all the bands. This was done in order to identify, the *optimal spectral regions* for monitoring the inland water quality using both Landsat and Proba sensors, and the differences between the two sensors. The methodology adopted in this study is based on the application of linear regression analysis between the mean reflectance values for each band of both the Landsat TM / ETM+ and the Proba / CHRIS (measured with the GER1500 field spectroradiometer) across the spectrum and the water turbidity values acquired at the same time at each sampling station in Asprokremmos Dam.

Although, the results depicted better correlation between the in-situ mean reflectance values and the turbidity values taken with the Digital Turbidity Meter than those when the Secchi Disk was used for both sensors (Landsat, Proba) bands. By applying the linear regression model, using the mean in-band reflectance values that correspond to Landsat TM (and ETM +) bands 1-4 as the independent variable and turbidity measurements as the dependent variable for all the combinations, the highest correlation was established between reflectance (acquired from GER1500) in *Landsat TM/ETM+ Band 3 & Band 4*. However, *Band 4* cannot be used for water reflectance measurements because the water absorption coefficient has very high value (near to 1) after 800nm (approximately) and thus, light is mostly absorbed and not reflected by water at wavelengths larger than 800nm. As a result the reflectance at *Band 4* has very low values which can be mostly attributed to measurement errors and despite the apparent high correlation; data corresponding to *Band 4* are not relevant and are not used for the purposes of this study. The very low reflectance values of water at *Band 4* do not give the opportunity for the remote sensing users to retrieve significant aspects regarding water quality. As a result for the determination of turbidity values using Landsat images the optimal band is *Band 3* with a determination coefficient R^2=0.85 (observed significance level=0.05; equation 1). The same procedure was apply for all 62 bands of Proba / CHRIS A1-A62 and the highest correlation coefficient was found between reflectance (acquired from GER1500) in *Proba / CHRIS Band A31* (Band-width range from 706,2 to 712,4 nm; λmid=709,3 nm) and turbidity with determination coefficient R^2=0.90 (observed significance level=0.05; equation 2) (Papoutsa et al., 2012).

$$y = 0{,}293x + 0{,}387 \quad R^2 = 0{,}85 \tag{1}$$

$$y = 0{,}197x + 0{,}008 \quad R^2 = 0{,}90 \tag{2}$$

Where y values are the mean in-band reflectance values for Landsat ETM+, equation (1) and Proba / CHRIS, equation (2), and x values are the turbidity values measured in *Nephelometric Turbidity Units* (NTU). The values of R^2 indicate the correlation coefficient of the two models (Papoutsa et al., 2012; Papoutsa, C., 2012).

Such outcomes can assist further the remote sensing users for the design of new satellite sensors regarding spectral characteristics for turbidity monitoring campaigns in water dams in the

Mediterranean region. Future work consists of calibration and validation campaigns of the proposed regression models based on new satellite imagery acquisitions from both sensors.

The development of regression models such as equation 1 and 2, can be used further to determine turbidity values based on the new satellite acquisitions. Indeed, the authors applied equation 1 using simultaneous measurements both from Landsat ETM+ images and ground truth measurements (spectroradiometric and turbidity). It has been found that the determined turbidity values from satellites after the application of the darkest pixel atmospheric correction, were very close to those found from field campaign. For example, for the Landsat ETM+ image acquired on 31^{st} of May 2010, determined turbidity for an area of interest near the Inlet area was 10,40 NTU (after DP atmospheric correction application) and ground truth turbidity value was 10,04 NTU.

4. Conclusions

Using archived satellite images, spatial and temporal variations of water quality in the Outlet and Intlet areas of Asprokremmos Dam were obvious. Such findings were in accordance with those derived by the in-situ campaigns. It is evident that for all samplings the highest values correspond to the Inlet area where the outfall of the Xeros River exists. It is the area where the water flows into the Dam with a result to carry down clay and suspended solids from the Xeros River resulting in increased values of turbidity accompanied with high reflectance values.

The use of an innovative, energy-autonomous floating sensor platform (buoy) which is installed in the Asprokremmos Dam is used to transfer turbidity data wireless. This can assist further to test and calibrate our developed equation as well as to provide alert to the Cyprus Water Development Department if turbidity values unusually increased.

The use of field spectroscopy assisted the retrieval and definition of the suitable spectral regions that correspond to satellite sensors, such as Landsat TM/ETM+ and Proba / CHRIS, in which turbidity can be measured and monitored in water dams in Cyprus. Finally the application of atmospheric correction such as the darkest pixel is an essential step prior to any further analysis of satellite imagery.

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