

MONITORING TURBIDITY IN ASPROKREMMOS DAM IN CYPRUS USING EARTH OBSERVATION AND SMART BUOY PLATFORM

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ABSTRACT

This paper presents the methodology and some results obtained from an existing running project between the Cyprus University of Technology and Water Development Department in Cyprus for monitoring the water quality in dams in Cyprus. In the framework of this project, an autonomous, low cost energy efficient floating sensor platform (buoy) was installed in the outlet of Asprokremmos Dam in Paphos District in Cyprus. The buoy, equipped with various water quality sensors such as turbidity and temperature, served as an automatic real-time sensor acquisition tool for remote monitoring of water quality. The data acquired from the sensors are transferred via a wireless link to a remote central database and are used as additional information to satellite imagery for further calibration and testing. Based on the fact that satellite remote sensing can be applied efficiently due to the high availability of cloud free images, the authors proposed to develop a regression model that will be used for systematic monitoring of water quality from space in the near future. Results obtained from the last summer campaign will be presented.

1 INTRODUCTION

Cyprus is the third largest island in the Mediterranean, after Sicily and Sardinia, with an area of 9,251 sq.kms. It is situated at the north-eastern corner of the Mediterranean. Cyprus lies at a latitude of 34°33'-35°34' North and longitude 32°16'-34°37' East. The climate is typical Mediterranean with hot dry summers and mild wet winters, with an average precipitation 500mm per year falling mostly in the winter months. The total annual water crop is estimated around 900 million cubic meters (MCM) out of which 600 MCM is surface water and the remaining 300 MCM is

groundwater. In the last years Cyprus is suffering from water scarcity caused by repeated droughts (Charalambous, 2001; Tsiourtis, 1999; Margat and Vallée, 2000).

Since the 1960's, Cyprus embarked in a program to increase water supply by constructing dams and conveyance infrastructure. In the last 46 years the freshwater storage capacity was increased from 0.006 to 0.327 km³ being the total capacity of 108 dams varying from small ponds to major dams. During the last 15 years the recorded rainfall 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 (Cyprus has 101 dam reservoirs with a total capacity around 300 MCM), 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. It should be recognized that there are limits to the development of new dams and water transfers and that water conservation and demand management should be given more emphasis (Iacovides, 2007; Tsiourtis, 1999).

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).

Water-quality investigation includes processes of sampling, measurement, recording, and analysis. The results provide bases for further studies of water-quality modeling, decision analysis, and pollution-control-system design (Huang and Xia, 2001; Bartram and Helmer, 1996).

Traditional water quality monitoring depends on in situ measurements or sequent laboratory analysis of the samples. This kind of point sampling methods may give accurate measurements, but they are time and money consuming. Further and most importantly, they can't give the real-time spatial overview that is necessary for the global assessment and monitoring of water quality (Wang et al., 2004; Brivio et al., 2001). On the other hand remote sensing of lakes with satellites has the potential to produce a truly synoptic tool with which to monitor water quality variables such as chlorophyll a (chl a), total suspended sediment (TSS), suspended minerals (SM) and coloured dissolved organic matter (CDOM) (Allan et al., 2011; Mayo et al. 1995; Zhang et al. 2002).

This project aims to develop a monitoring tool for the synoptic water quality observation in large dams in Cyprus based on remote sensing techniques. In this paper, we describe the overall methodology been used in order to retrieve a mathematical model by applying regression analysis between in-situ water quality parameters and in-situ spectro-radiometric data. Moreover we describe how an innovative floating buoy is used as a calibration tool for the development of the algorithm for the water quality monitoring in Asprokremmos Dam in Paphos.

2 STUDY AREA (ASPROKREMMOS DAM)

Asprokremmos Dam is built at an altitude of about 100 m above sea level and is

located 16 km (10 miles) 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 last time this happened was in 2004. 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 Figure 1 and Figure 2.



Figure 1. Landsat TM image of Cyprus focus on the Study Area – Asprokremmos Dam



Figure 2. Picture of Asprokremmos Dam / Tower pumping station (Outlet Area)

3 METHODS

The overall proposed methodology includes the following steps:

- The design of a sampling station network in the area of interest - Asprokremmos Dam

- In-situ campaigns in order to retrieve in-situ spectro-radiometric data and water quality data such as in-situ turbidity measurements, acquired during the satellite overpass
- Statistical analyses for retrieving the cross-correlation of water qualitative parameters with the in-situ spectroradiometric data and the spaceborn retrieved data (find optimal band)
- Use of 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

3.1 In-situ turbidity and spectroradiometric measurements

In-situ campaigns 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. 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 GPS system was used in order to store and define the preselect 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. For the determination of water turbidity values a portable turbidity meter (Palintest Micro950) and a Secchi Disk were used. In-situ spectroradiometric data were obtained by using a field spectroradiometer GER1500 equipped with a fiber optic probe.

3.2 Smart buoy sensor platform

The data buoy, designed and implemented by SignalgeneriX Ltd, consists of a low cost, low-powered, autonomous floating sensor platform, data logger and gateway to a remote data server. It utilises 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 and has been deployed in the Asprokremmos Dam, for real time monitoring of water quality as shown in Figure 3.



Figure 3. Pictures of smart sensor platform deployed in Asprokremmos Dam

In particular, an innovative low-cost sensor, measuring suspended solids and turbidity by the optical backscatter method, has been installed in the floating platform giving us the opportunity to acquire water turbidity measurements every 2 minutes. In addition to this, water temperature, air temperature and humidity sensors have been installed on the platform.



Figure 4. Pictures of turbidity optical sensor and humidity sensor located on a floating buoy deployed in Asprokremmos Dam

4 RESULTS

4.1.1 In-situ data

In situ measurements of turbidity and spectroradiometric data are presented on Table I and Figures 5&6. As we can see 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.

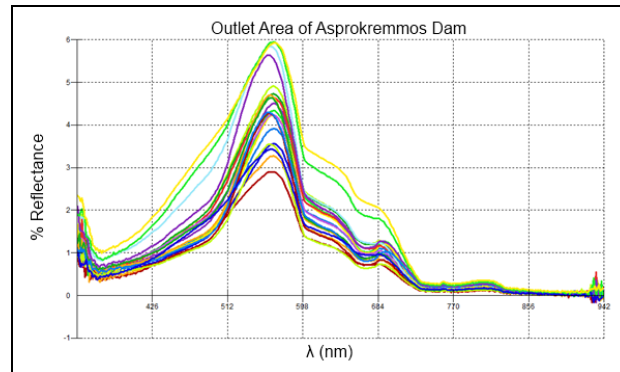


Figure 5. Spectral signatures of Outlet Area of Asprokremmos Dam acquired using a handheld field spectroradiometer GER1500

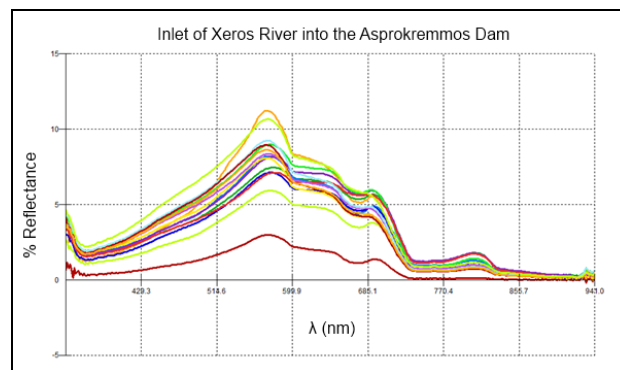


Figure 6. Spectral signatures of Inlet Area of Asprokremmos Dam acquired using a handheld field spectroradiometer GER1500

Table I. Turbidity values measured in Outlet & Inlet Area of Asprokremmos Dam

	Outlet Area	Inlet Area
Date of sampling campaign	Turbidity (NTU)	Turbidity (NTU)
31-May-10	3.53	11.95
16-Jun-10	4.14	19.70
24-Jun-10	3.61	26.30
2-Jul-10	2.45	21.90
18-Jul-10	3.10	18.88
3-Aug-10	2.26	19.28
11-Aug-10	1.65	18.88
19-Aug-10	1.62	10.50
27-Aug-10	2.60	16.20

4.1.2 Data Buoy Real time data through a Remote Monitoring Web-Platform

Real Time Data are obtained through the Wisense® Remote Monitoring Platform, which provides a fully customizable interface for controlling a deployment and accessing data from nearly everywhere in the world. The platform offers various features such as: a dashboard feature for critical parameter displaying, a historical data processing feature for embedded data analysis and trend chart displaying, a data export feature for exporting data in various file formats and a mapview feature for buoy visualization through embedded interactive Google maps. Sample sensor data acquired from Asprokremmos Dam are presented using Wisense® platform in the following figures.

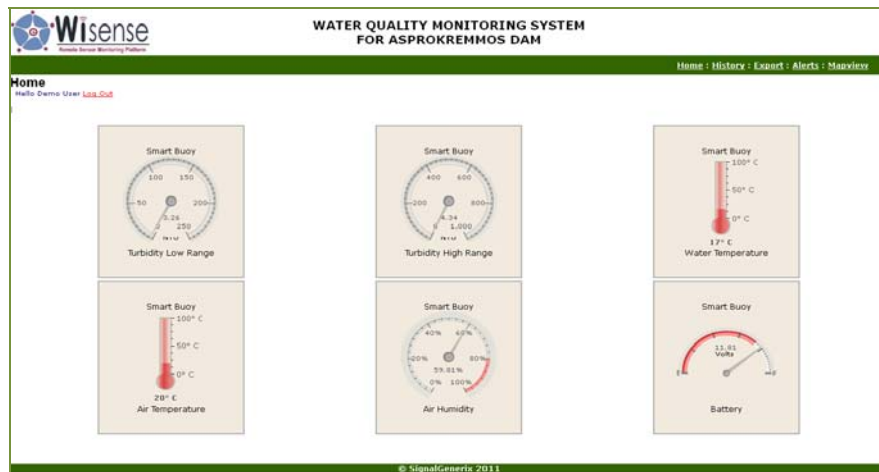


Figure 7. Real Time Water Quality parameters from Asprokremmos Dam using Wisense remote monitoring system

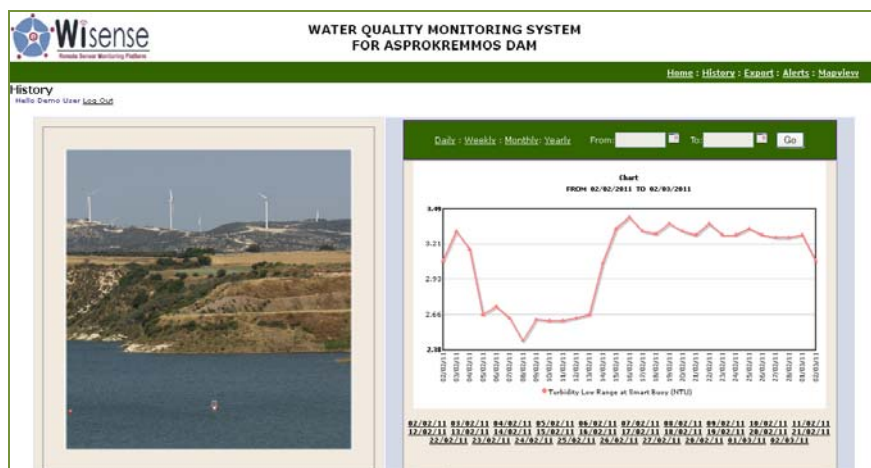


Figure 8. Turbidity range in Asprokremmos Dam for a selected period using Wisense remote monitoring Platform- diagrammatically presentation of measured values



Figure 9. Real Time Data from Asprokremmos Dam using Wisense remote monitoring Platform

5 CONCLUSIONS

Statistical analysis of the results retrieved during field campaigns acquired in Asprokremmos Dam in Paphos have indicated that turbidity measurements and reflectance values are both higher in the Inlet Area of the Dam. This is due to the fact that is the area where Xeros River flows into Asprokremmos Dam and as a result particles are carried through the river into the Dam in this Area.

Using archived satellite images, spatial variations of water quality in the inlet and outlet areas, were apparent. Such findings were in accordance with those derived by the in-situ campaigns. Higher reflectance values were indicated for the Inlet area of Asprokremmos Dam.

The development of an innovative, energy-autonomous floating sensor platform (buoy) which is installed in the Asprokremmos Dam is used to measure and transmit turbidity and temperature data wireless. This is an efficient tool that can assist further to test and calibrate our developed equation as well as to provide alerts to the Cyprus Water Development Department immediately when determined turbidity values are found to be above the desired limits. The integrated use of both autonomous smart buoy and satellite remote sensing systems is beneficial tool for water quality monitoring measurements.

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