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MONITORING AND DETERMINATION OF IRRIGATION DEMAND IN CYPRUS

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ABSTRACT

This technical paper describes and interprets the main results of an original research project, which integrates technological tools for developing a complete system for monitoring and determining irrigation demand on a systematic basis in Cyprus. More specifically, the main contribution of this paper consists in the estimation of evapotranspiration (ET) in Cyprus and furthermore in the undertaking of the required measures for a sustainable irrigation water management in the future. The determination of ET is a very difficult procedure, since it combines various meteorological and field parameters, while quite many different estimation models have been indicated in the literature. In this case study, a wireless sensor network is proposed to act as a monitoring tool for providing measurements of the necessary parameters (meteorological, climatic and other auxiliary data required to be included in the irrigation demand models) while reflectance is being determined directly from the satellite images. Geographic Information Systems (GIS) have been used to create a database for the collected data. Taking in to account the great importance of irrigation water as a principal driver in rural development, as well as the increasing demand for irrigation water, the investigation of ways for irrigation water management is extremely valuable, especially in water-scarce areas.

KEYWORDS: agricultural extension, evapotranspiration, irrigation, precision agriculture, remote sensing, waterware software.

1. INTRODUCTION

Optimal use of irrigation water plays a significant role in increasing land productivity (Ahmad *et al*., 2009; Hongjun *et al*., 2008) and feeding the earth's growing population (Cai *et al*., 2003).. At the same time, the irrigation water global demand is increasing following the expand of the irrigated land. Recent figures point to the fact that Irrigated areas have increased rapidly, over the last 30 years, and more than 70% of diverted water goes to the agricultural sector (Bjornlund *et al*., 2009). According to Michailidis *et al*., 2009, one of the main components of the water balance is the water loss via evapotranspiration (ET), which is proportional – among others – to the vegetation cover of a region.

Contemporary tools of precision agriculture, remote sensing (RS) and GIS techniques have played a vital role in applications regarding water management and identification of irrigated area (Nahry *et al*., 2011) and classification of the vegetation coverage. In light of precision agriculture, RS and GIS techniques have played a vital role in applications regarding water management and irrigation (Nahry *et al*., 2011). However, despite these theoretical advances, access to and use of RS data by end users require considerable technical knowledge over computing and RS, which is still a challenge (Moreenthaler *et al*., 2003). Additionally, a cost of applying precision agriculture is much higher than traditional one and thus any related investing decision has to be followed by strong potentials.

The main objective of this technical paper is to present the main results of an original research project, which describes and applies a procedure for monitoring and improving the performance of on-demand irrigation networks. In particular, the application of the procedure is based on the integration of RS techniques and simulation modeling of irrigation water in Cyprus, which is facing severe droughts throughout the year. Multi-spectral satellite images are used to infer crop potential ET, which is a main input for water balance simulations. The need for estimating ET in Cyprus, is imposed in order to determine the exact quantity of irrigated water needed for each specific crops. The over use of water for irrigation has resulted in strong stressing for the water resources in the country. The determination of ET for irrigation purposes will be used as a vital tool for supporting the decision-making process in the management of water resources, on a technocratic level, and on the other hand will have a positive effect on the rest of water resources of Cyprus. Intended purpose is to estimate potential ET using remotely sensed data (satellite imagery) and ground meteorological data (wireless sensor network). This data will be transformed into ET maps using GIS. Final goal is to provide policy makers with accurate data, regarding irrigation management, for determining irrigation demand in Cyprus.

2. LITERATURE REVIEW

A consistent effort has been made in the field of agricultural research to improve the understanding of physical processes involved in an irrigation system (Feddes *et al*., 1988; Menenti, 1989; Michailidis and Mattas, 2007). With the water resources shortage being a basic issue for many countries, management of the available water resources is one of the greatest challenges of the 21st century. The agricultural sector is one of the major consumers of water, accounting for more than 70% of the world's fresh water (Michailidis *et al*., 2011). Thus, the use of irrigation water plays a significant part in increasing land productivity (Ahmad *et al*., 2008). According to Azzali *et al.* (2001), the spreading of modeling techniques using distributed parameters has largely encouraged the use of input data from remote sensing with the support of GIS systems for manipulating large data sets in irrigation water management, while Menteti *et al*. (1989), D'Urso *et al.* (1992), Bastiaanssen (2000), Ambast *et al*. (2006) and Papadavid *et al.* (2011) have indicated the potentiality of multispectral satellite images for the appraisal of irrigation management. Estimation of crop water parameters using remote sensing techniques is an expanding research field and development trends have been progressing since 1970s (Jackson *et al*., 1977; Seguin and Itier, 1983). Since then, remote sensing has played an increasing role in the field of hydrology and especially water management. The integration of remotely sensed data with auxiliary ground truth data for obtaining better results is common in literature. (Bastiaanssen *et al*., 1998; Bastiaanssen *et al*., 2003; Ambast *et al*., 2006; Minaccapili *et al*., 2008). It is considered that the resolution in time and space of remotely sensed data is vital in water management (Schultz *et al*., 2001). The rationalistic use of surface water and the monitoring of consumptive use of water by applying remote sensing techniques has been a topic of great interest for irrigation water policy makers (Tasumi *et al*., 2003).

The use of remote sensed data is very useful for the deployment of water strategies because it can offer a huge amount of information in short time, compared to conventional methods. Besides convenience and time reducing, remotely sensed data lessens the costs for data acquisition, especially when the area is extended (Thiruvengadachari *et al*., 1997). Ambast *et al*. (2006) have shown that the application of remote sensing data in irrigation is of high importance because it supports management of irrigation and is a powerful tool in the hands of policy makers. The potentiality of remote sensing techniques in irrigation and water resource management has been widely acknowledged. It has been found that research in ETc is directed towards energy balance algorithms that use remote sensing directly to calculate input parameters and, by combining empirical relationships to physical models, to estimate the energy budget components (Courault *et al*., 2005; Bastiaanssen, 2005; Minaccapili *et al*., 2008; Papadavid *et al*., 2010). All the remote sensing models of this category are characterized by several approximations and need detailed experimental validations. Multispectral images are used to infer ETc, which is the main input for water balance methods-models.

3. RESOURCES AND METHODOLOGY

Case study

The Paphos district area has been selected as our case study since it is the main area of agricultural production (Figure 1) in the country. The irrigation supply of the Paphos area is provided from: Asprokremmos Dam reservoir, 24 boreholes drilled in the gravel aquifers of the major river beds Dhiarizos, Xeropotamos and Ezousas rivers and the coastal calcarenite aquifer. The irrigated area near the Asprokremmos dam will be used as a pilot study in this project.

Figure 1. Case study selected

Resources

For estimating ET using *FAO Penman-Monteith* method, auxiliary meteorological data where used. Air temperature, atmospheric pressure, wind velocity and other data where collected from an automatic weather station, located nearby our case study (Figure 2). The auxiliary meteorological data will be the base for validating the data collected from the wireless sensors network which is installed in the fields of interest (Figure 4).

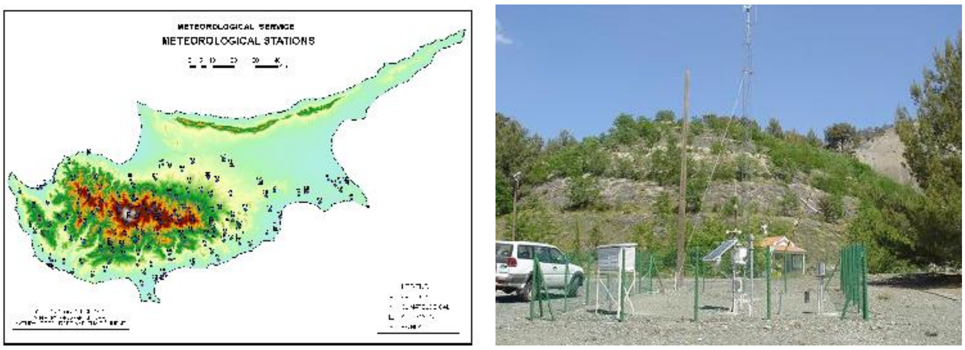

Figure 2. Map of the meteorological stations in Cyprus and an automatic weather station

Furthermore, multi-spectral, ASTER and Landsat 7 ETM+ satellite images, for the past two years have being used. For the pre-processing and processing of the satellite images the ERDAS IMAGINE software (www.erdas.com) was used. Sun-photometer and spectro-radiometer measurements were also taken in situ.

Figure 3. Spectro-photometer and Sun-photometer measurements in situ

More specific a five-channel handheld Microtops II sun-photometer (www.slarlight.com) operated from 380 to 1020 nm is used (Figure 3). The sun-photometer will be used to derive the Aerosol Optical Thickness and the water vapour concentrations during the satellite overpass so as to assist the effective removal of atmospheric effects. The GER1500 field spectro-radiometer (www.spectravista.com) is also used in this research project. The GER1500 field spectro-radiometers is a light-weight with high performance spectral reflectance's accuracy, covering the ultraviolet, visible and near-infrared wavelengths from 350 nm to 1050 nm. GER 1500 uses a diffraction grating with a silicon diode array which has 512 discrete detectors and provides the capability to read 512 spectral bands. The instrument is very rapid scanning, acquiring spectra in milliseconds. The spectro-radiometer is used to derive the spectral reflectance values of various crops in the selected agricultural fields and to support the derivation of reflectance values from medium and high resolution images.

The Wireless Sensor Network (WSN) is consisting of a number of approximately twenty wireless nodes placed in our case study (Figure 4). The WSN acts as a wide area distributed data collection system deployed to collect and reliably transmit soil and air environmental data to a remote base-station hosted at Cyprus University of Technology (at the RS Laboratory) (Hadjimitsis *et al*., 2008). The sensors are deployed using ad-hoc multi-hop communication protocol and transmit their data to a gateway which is responsible to collect, save and forward them to a remote database through a GPRS connection. The solar powered gateway is equipped with various meteorology sensors required to assist the indeed research project such as rain, wind, barometric pressure, temperature etc, which give additional information to the system. The gateway also hosts a GPS sensor for identifying the exact position of the WSN an event-driven smart camera for acquiring real-time pictures of the area and also a GPRS modem for communicating with the remote server. In the future a multi-parameter decision system running on the remote server would be able to process the sensor data and produce valuable information about watering different vegetables and create early notifications and suggestions which are then distributed to farmers and water management authorities. The system would be able to process multi parameter data collected from different sensors such as soil moisture, soil temperature leaves wetness and temperature, humidity, rainfall, wind speed and direction and ambient light.

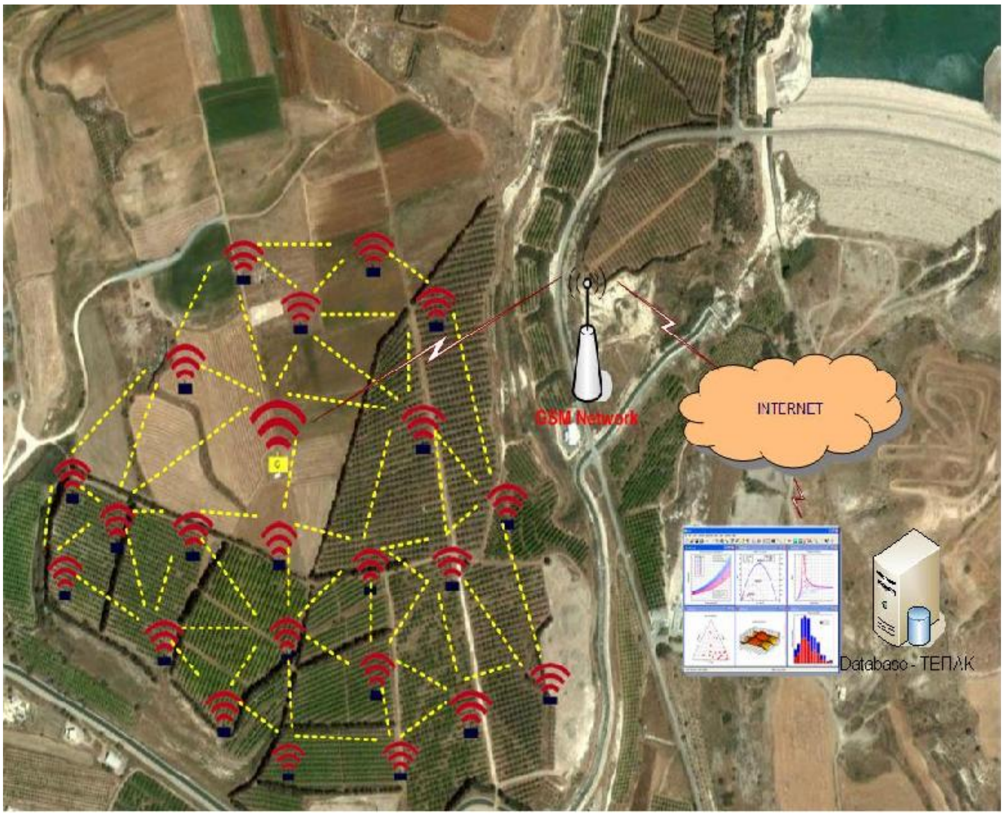

Figure 4. The Wireless Sensor Network in the AOI

Methodology

Pre-processing and processing of the satellite images, includes geometric correction (second order polynomial transformation), georeferenced of the image using ground control points (WGS 84/UTM), radiometric correction in order to obtain the same comparable units for each image, and finally atmospheric correction by employing the darkest pixel method (histogram minimum method), to get the true reflectance of each pixel of the image (Hadjimitsis *et al.*, 2003). Finally Liang's equation (Liang 2000) for deriving albedo was employed in this research for ASTER images. For Landsat images, weighted coefficients and irradiance were used for calculating albedo for each image (Zoran and Stefan 2006).

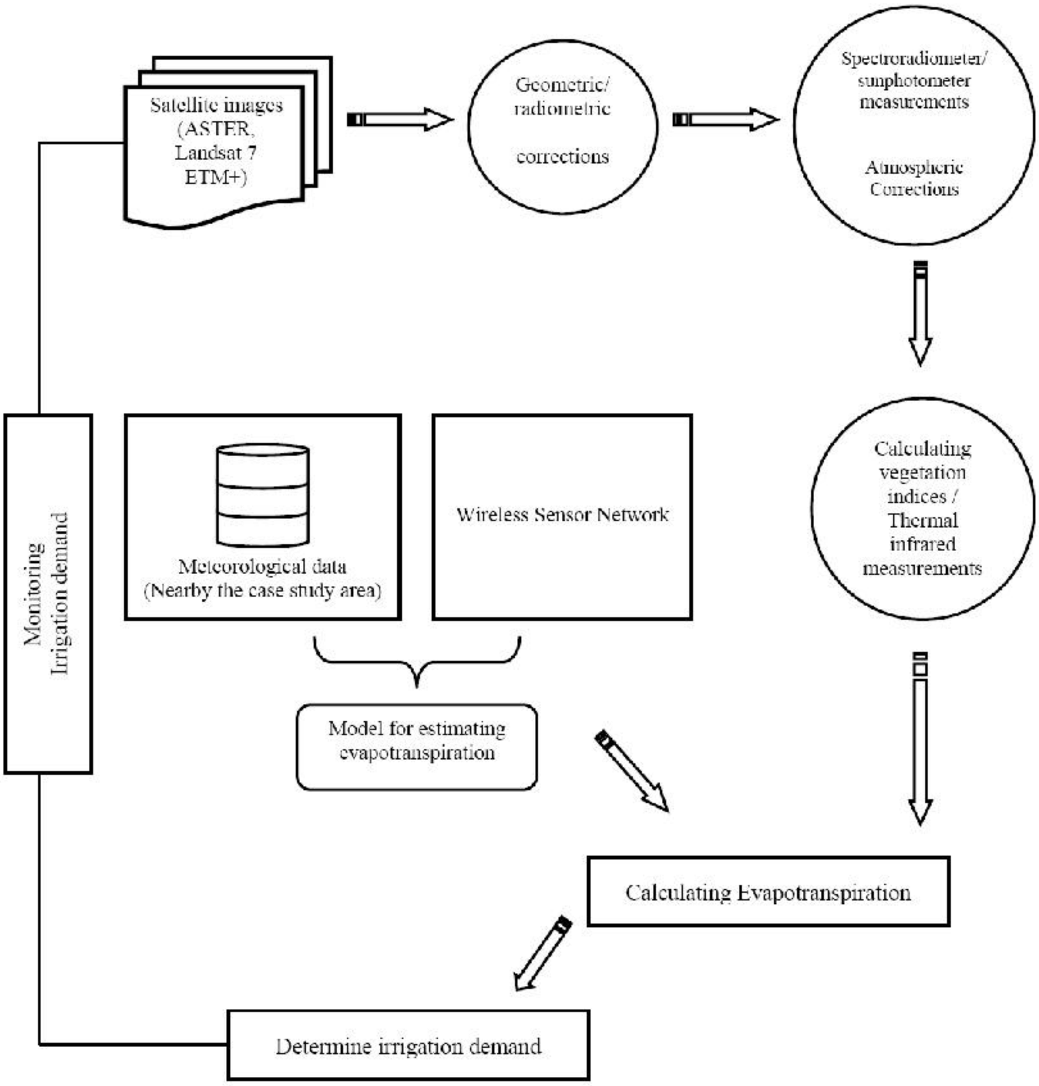

Figure 5. Methodological framework

In order to estimate ET, the one step FAO Penman-Monteith adapted to satellite data method was applied. The specific equation which is widely used to estimate ETp, under assumptions, relies on the direct application of the Penman-Monteith equation with canopy parameters estimated from satellite imagery. For estimating ET meteorological and satellite data have been used. Air temperature, atmospheric pressure, wind speed and other meteorological data were collected through the wireless sensor network which has been deployed in the fields of the study area. Satellite data, such as LAI and albedo maps (Figure 6), have been derived from satellite imagery using simplified methods (D'Urso *et al.*, 1995).

$$ET_p = \frac{86400}{\lambda}\left[\frac{s(1-0.4e^{-0.5LAI})(1-a)(K^{\downarrow}+L^{*})+c_p p_a(e_s-e_a)U/124}{s+\gamma(1+U/0.62LAI)}\right]$$

where: $K^{\downarrow}$ is the incoming solar radiation and U the wind speed; the other variables, namely L^{*} (net longwave radiation), c_p (air specific heat), ρ_a (air density), (e_s-e_a) (vapour pressure deficit), λ (latent heat of vaporisation of water) and γ (thermodynamic psychrometric constant) are calculated from air temperature and humidity at 2.0 m reference height. This equation is valid under conditions of high solar irradiance (typical summer condition in Mediterranean climate) and for LAI>0.5, which is the case of Cyprus. The height of the crops was defined from direct observations.

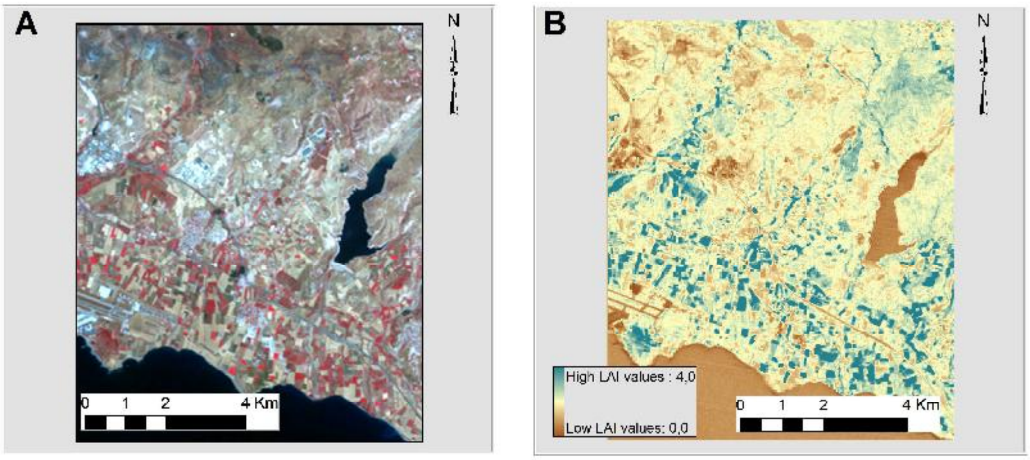

Figure 6. Example of satellite imagery (ASTER) transformance to thematic maps (here LAI map)

4. RESULTS

The final results have been tabulated and shown in Table 1 and graphically in Figure 7. Atmospheric correction has been found to be very critical for estimating ET. Approximately an error of 5% less than the calculated 'ETp' mean was recorded due to atmospheric effects. Figure 8 shows a presentation of ET on a satellite image for the area of interest. It is obvious that ETp is increasing during summer months.

Table 1. Results of FAO Penman-Monteith application for estimating ETp

No	Date of Satellite image	Satellite	ETp mean	ETp max	ETp min
1	17-12-2007	ASTER	2.33	2.36	2.29
2	24-12-2007	ASTER	2.34	2.38	2.27
3	26-02-2008	ASTER	2.25	2.27	2.22
4	28-07-2008	LANDSAT 7 ETM+	2.78	2.85	2.74
5	13-08-2008	LANDSAT 7 ETM+	2.84	2.88	2.77
6	29-08-2008	LANDSAT 7 ETM+	3.03	3.07	2.99
7	04-12-2008	ASTER	2.65	2.69	2.60

The results have provided strong evidence to support what theory illustrates: low values during winter time and high values during summer time while middle values for autumn and spring are counted. The highest values are derived in august while the lowest values in december. These results can be used in irrigation scheduling for providing the farmers with the right water requirements for their crops. Of course this procedure is a dynamic one and depends also on the meteorological data of the area. That's why the wireless sensor have been very assisting in the methodology as it was providing real time data. It has to be mentioned that the wireless sensor network is very accurate in providing meteorological data and it is calibrated every month from specialist of the cyprus university of technology.

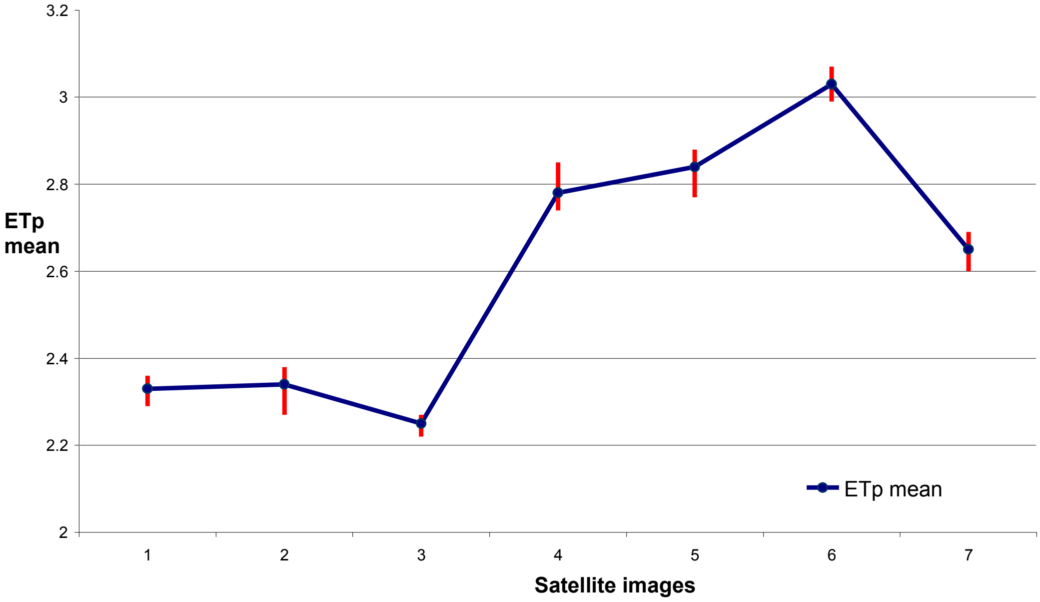

Figure 7. ETp mean diagram for each date, with their variations

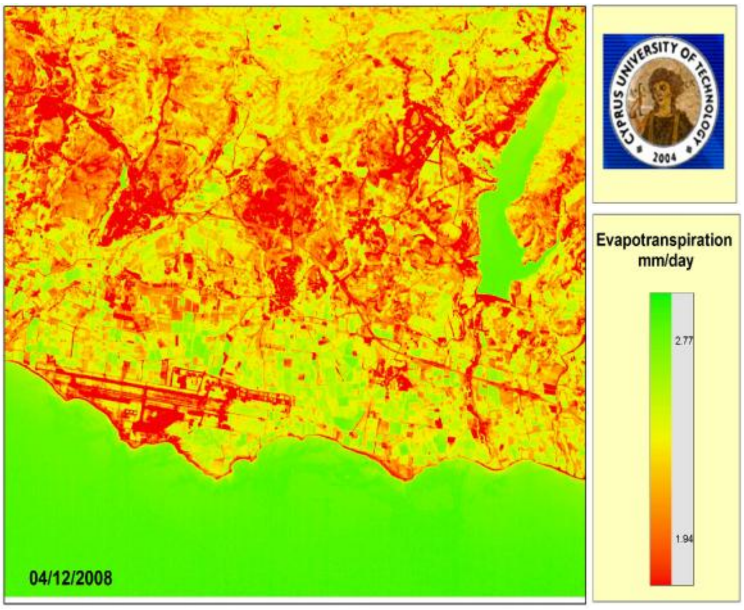

Figure 8. Map showing the ETp as calculated for ASTER images using GIS software

5. CONCLUSIONS

This technical paper presents some first results of the application of FAO Penman-Monteith method in the estimation of ET. For this purpose auxiliary meteorological data have been used from a wireless sensor network along with satellite images (Landsat 7 ETM+ and Aster) for providing crop canopy parameters. For more accuracy results spectro-radiometer and sun-photometer measurements have been also used. These promising results show how RS data can be used in order to calculate ETp. The main goal of this paper was to provide a novel structural tool to agricultural extension services for the monitoring and determination of irrigation demand in Cyprus. On the other hand, the application described has international relevance to several other local areas where irrigated agriculture is an important component of rural development. Actually, it is not a unique application. There are many other similar ones in several other areas, in both developed and developing countries, that rely on irrigated agriculture to some degree (Nahry *et al*., 2011; Mouratidis *et al*., 2010). Besides, most irrigators internationally express concerns about their weakness to estimate ET and furthermore to undertake the required measures for a sustainable irrigation water management in the future. In addition, they often express the need for information to support irrigation water efficiency improvements and the desire to make optimal use of available and limited natural resources. Thus, the application presented here could well have resonance in many other countries well beyond Cyprus. Future work consists of further validation of the results, not only using Penman-Monteith method for other cultivations but other acceptable methods and models for estimating ET.

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