

Integrated approach of remote sensing and micro-sensor technology for estimating evapotranspiration in Cyprus

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Abstract: The objective of this research project is to describe and apply a procedure for monitoring and improving the performance of on-demand irrigation networks, based on the integration of remote sensing techniques and simulation modeling of irrigation water in Cyprus, which is facing a severe drought in the last five years. Multi-spectral satellite images are used to infer crop potential evapotranspiration, which is the 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 crop. The overuse of water for irrigation has resulted in eliminating the water resources in the whole island. 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. The integrated method applied, consisting of Remote Sensing techniques and micro-sensor technology, has shown that it can be a useful tool in the hands of agri-policy makers for sustainable irrigation.

Keywords: remote sensing, wireless sensors, irrigation management, sustainability

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1 Introduction

The agricultural sector is one of the major consumers of water, consuming more than 70% of the world's fresh diverted water use from rivers and groundwater. Thus the use of irrigation water plays a significant part in increasing land productivity. One of the main components of the water balance is the water loss via evapotranspiration, which is proportional – among others – to the vegetation cover of a region. Unfortunately the last century, Cyprus is facing a period with very low rainfall which has caused curtailments to irrigation water schedule, which in turn has resulted in very low or no yield for the seasonal and multiannual crops. Meteorological data refers to the problem since their existence as shown in Figure 1. It is apparent that the

average rainfall, of the island through the last decade, has fallen dramatically.

The monitoring of irrigated agricultural areas in Cyprus provides important data for efficient water supply plans and for avoiding unnecessary water losses due to inefficient irrigation. From this perspective, satellite remote sensing techniques in conjunction with meteorological inputs are useful as an efficient tool for monitoring irrigation demand in agricultural areas. The purpose of this paper is to present the methodology of how evapotranspiration can be determined for purposes of efficient water management using satellite remote sensing to retrieve input parameters which characterize surface properties such as albedo, and estimate evapotranspiration for the specific crops. This research project integrates the following tools for developing a complete system for monitoring and determining irrigation demand on a systematic basis in Cyprus;

- satellite remote sensing
- GIS

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- ET_c algorithms
- micro-sensor technology

The data produced from this study will be used in decision making procedure regarding irrigation water demand in a very sensitive period where water is considered as a public good on scarcity. The proposed wireless sensor network will provide the monitoring tool for providing measurements of the following parameters: meteorological and climatic data (rainfall, temperature, RH etc and other auxiliary parameters required to be used in the models to determine the ET_c . Reflectance (irradiance values) will be determined directly from the satellite images. GIS will be used to create a database for all the data found in this project so as to be used by the 'Agricultural Department' in Cyprus for taking the required measures for an effective water management used for irrigation in the near future.

2 Review and basics

2.1 Crop evapotranspiration

Evapotranspiration, the mean for manipulating irrigation water, is referred as the combination of two different processes where in the first water is lost from the soil and plant surfaces by evaporation and in the second from the crop by transpiration (Allen et al., 2000). Evapotranspiration constituted a main component of the hydrological cycle and its estimation demanded auxiliary meteorological data (Telis and Koutsogiannis, 2007). Many formulas have been developed by scientists to calculate evapotranspiration. Formulas used to estimate evapotranspiration account all the energy sources a plant had available to it, which included energy from solar radiation (French et al., 2008). In the past decade the estimation of evapotranspiration combining conventional meteorological ground measurements with remotely-sensed data has been widely studied and several methods have been developed for this purpose (Tsouni and Koutsogiannis, 2003). An accurate estimation of actual evapotranspiration is necessary for hydro-resources management. Reference evapotranspiration values, can be calculated by measuring weather conditions and typical reference crops using specialised instruments, the lysimeters. Alfalfa and grass are two commonly used

reference crops of the international literature, due to the fact that they can be maintained at a certain height and stage of growth for long periods during a growing season (Carlson and Buffum, 1989; Caselles and Delegido, 1987).

2.2 Methods for estimating evapotranspiration

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; Meneti, Visser and Morabito, 1989). The spread of modeling techniques using distributed meteorological parameters has largely encouraged the use of input data from satellite remote sensing, with the support of Geographical Information Systems (GIS) for manipulating large data sets. These tools could be used for supporting the decision-making process in the irrigation water management of large districts (Menenti, Visser and Morabito, 1989). It is often used to describe the total water escaping from crop to air. Both evaporation and transpiration processes are driven by energy from solar radiation, air temperature and wind (Boegh and Soegaard, 2004). The actual estimation and calculation of evapotranspiration, are basic and crucial needs for climate studies, weather forecasts, hydrological surveys, ecological monitoring, and water resource management (Hoedjes et al, 2008). With the water resources shortage being a worldwide issue, management of the available water resources is one of the greatest challenges of the 21st century. Especially the agricultural sector is one of the major consumers of water, accounting for more than 70% of the world's fresh diverted water use from rivers and groundwater. Thus the use of irrigation water plays a significant part in increasing land productivity (Ahmad, Turrall and Nazeer, 2008).

2.3 Remote Sensing for estimating evapotranspiration

During the last two decades remote sensing has played an increasing role in the field of hydrology and especially the water management (Bastiaanssen et al., 2005; Bastiaanssen et al., 1998), not just as remotely sensed data but sometimes also as auxiliary data integrated with ground truth data for better results. It is considered that the resolution in time and space of

remotely sensed data is vital in water management (Schultz and Engman; 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 remote sensed data lessens costs for acquiring data especially when the area is expanded (Thiruvengadachari and Sakthivadivel, 1997). Abast et al. (2001) have shown that 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. Environmental physics based on electromagnetic radiation and micro-hydrology has evolved in the development of quantitative algorithms to convert remotely sensed spectral radiances into useful information such as evapotranspiration, root zone soil moisture, and biomass growth. Estimation of crop water parameters using remote sensing techniques is an expanding research field and development trends have been progressing since 1970s (Jackson, Reginato and Idso, 1977; Seguin et al., 1983). The required crop parameters can be derived either directly from canopy reflectance or can be estimated by means of empirical relationships with vegetation indices such as SAVI (Soil Adjusted Vegetation Index) as shown by other studies (Ambast et al., 2001) or WDI (Weighted Difference Vegetation Index) (Clevers, 1988). Today, several researchers recommend a breadth of mathematical equations and modelling (Bastiaanssen et al, 2005; D'Urso and Menenti, 1995; Menenti et al., 1989).

3 Area of interest

The study area was located in the area of Mandria village, in the vicinity of Paphos International Airport (Figure 1). The selected area is a traditionally agricultural area with a diversity of annual and perennial

cultivations and is irrigated by Asprokremnos Dam, one of the biggest dams of Cyprus. The area is at sea level and is characterized by mild climate which provides the opportunity for early production of leafy and annual crops. As in the Mediterranean region, a typical Mediterranean climate prevails in the area of interest, with hot dry summers from June to September and cool winters from December to March, during which much of the annual rainfall occurs with an average record of 425 mm. Nevertheless irrigation is indispensable for any appreciable agricultural development in the area. Morphologically, the area is a flat terrain of about 30 km². The type of soil that is dominant in the area is the Cambisol (calcic and chromic types). Most of these soils make good agricultural land and are intensively used. The soil of the experimental site is calcareous, characterized by a deep brown color, and having a rather heavy to very heavy structure. The main method of irrigation in the area, due to its morphology and the cultivations is sprinklers.

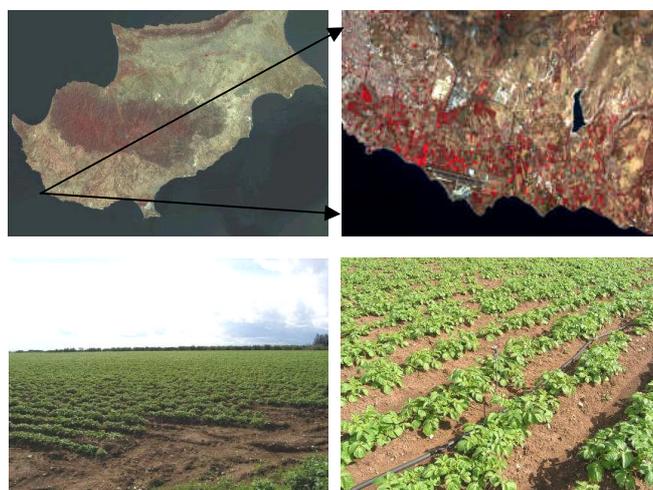


Figure 1 Area of interest in Mandria, Pafos, Cyprus
(Landsat 7 image)

4 Resources

For estimating evapotranspiration, auxiliary meteorological data were used. Air temperature, atmospheric pressure, wind velocity and other data were collected from an automatic weather station, located nearby our case study, at the Paphos International Airport. The necessary meteorological data will be the base for validating the data collected from the wireless sensors

network which is applied in the field of interest. Auxiliary meteorological data and ground measurements are used as inputs to the applied ET_c algorithm of this research.

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

The GER1500 field spectro-radiometer (Figure 2) was also used in this research project (<http://www.spectravista.com>). Intended purpose was to acquire the spectral signature of crops in each phenological stage and to test how accurate the atmospheric correction procedure was.

The Wireless Sensor Network (WSN) consisted of twenty wireless nodes placed in this case study. The WSN (Figure 3) 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 Remote Sensing Laboratory). The micro-sensors

were deployed using ad-hoc multi-hop communication protocol and transmit their data to a gateway which was responsible to collect, save and forward them to a remote database through a GPRS connection. The solar powered gateway was equipped with various meteorology sensors required to assist the indeed research project such as rain, wind, barometric pressure, temperature etc, which gave additional information to the system.

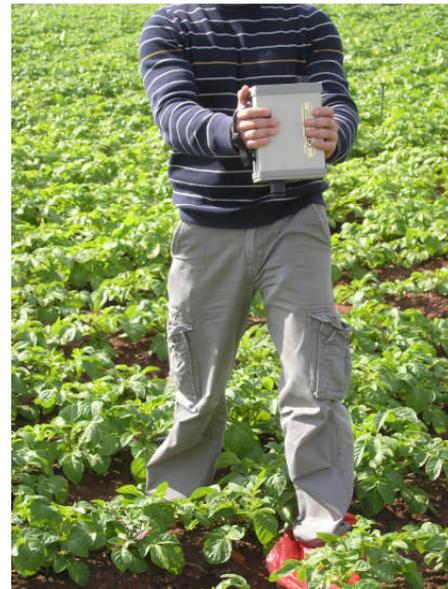


Figure 2 Spectroradiometric measurements using GER1500

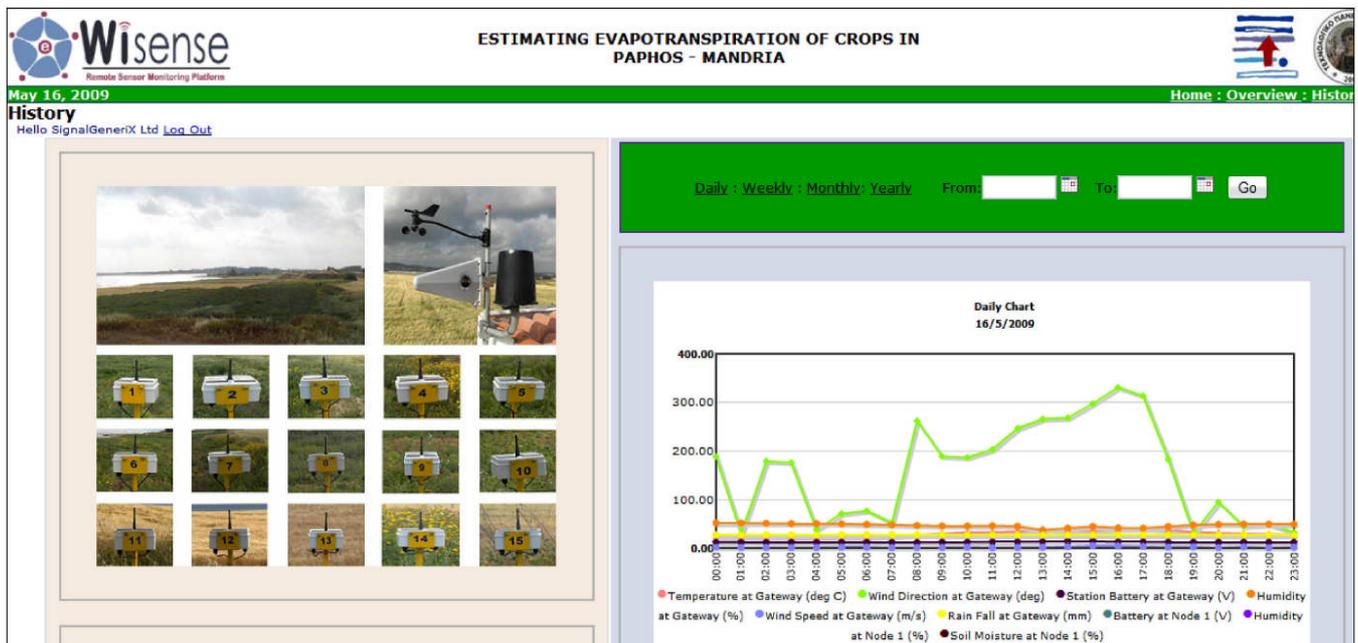


Figure 3 Web site of wireless sensor network developed by Cyprus University of Technology

The gateway also hosted 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. A novel approach for data collection from a wide area using wireless sensor network will be applied. Various environmental sensors such as soil moisture, humidity, temperature, ambient light etc will be deployed in a wide area using ad-hoc wireless sensor nodes. The nodes will be communicating to a central gateway station where all the parameters are stored and then forwarded via GPRS communication link to a remote data base at Cyprus University of Technology. The gateway station will also incorporate meteorological sensors such as barometric pressure, relative humidity, wind; rain sensors etc. The novelty of the specific approach is that by using an ad-hoc wireless sensor network we can very easily move from one data collection area to another and also by having the remote monitoring capability we can achieve an automate high data collection rate without having to visit the deployment area. The ground monitoring system will be based on smart programming of the sensor nodes so as to achieve minimum power consumption. The applied WSN in the area of interest is shown in Figure 4.

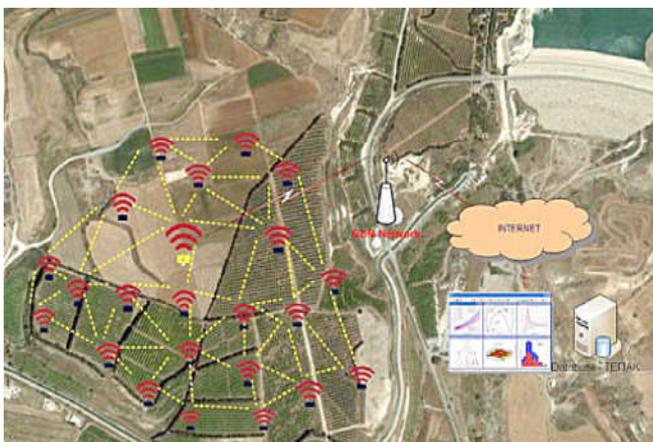


Figure 4 Applied WSN in the area of interest

5 Methodology

The overall methodology is illustrated in Figure 5. The method consists of the estimation of the crop Evapotranspiration (ET_c) using remote sensing techniques, satellite data, wireless sensors for meteorological data and in situ measurements. Estimating ET_c , can provide better management and water allocation, since irrigation scheduling is based on ET_c data for each crop. The method is following the next steps: a) pre-processing of raw satellite data, b) in situ spectro-radiometric measurements for validation of satellite data, c) retrieve meteorological data from the wireless sensor network, and d) employ a model for estimating evapotranspiration for the indifferent crops and finally create ET_c maps.

5.1 Pre-processing

Prior to main analysis and manipulation of satellite data, a process defined as preprocessing is needed in order to bring the data or image to a more accurate and usable condition. Preprocessing is an operation which takes place for all raw satellite data and its purpose is to correct distorted or degraded image data for more accurate and more faithful representation of the real ground scene, by removing any undesirable image characteristics produced during image acquisition process (Mather, 1999). Preprocessing is essential and comprises a series of sequential operations such as atmospheric corrections, image rectification and registration and masking (Hadjimitsis, Papadavid and Kounoudes, 2008).

Preprocessing included geometric and radiometric corrections which were vital for the further use of the satellite images and were necessary for increasing the accuracy of the results (Richards, 1986). In order to bring the raw data to a usable condition, both geometric and radiometric corrections are needed. The correction of these errors has to be defined before the main analysis or processing of the images since the nature of the eliminated errors determines the use of the preprocessed data (Mather, 1999).

All satellite images used for this study have undergone radiometric and geometric corrections. Regarding radiometric corrections, the images were

transposed from Digital Numbers (DN) into Radiance and then to Reflectance applying the necessary equations (Mather, 1999) and using the ERDAS imagine software.

Radiometric corrections refer, besides to satellite sensor system errors, to reflectance of the atmosphere, aerosol

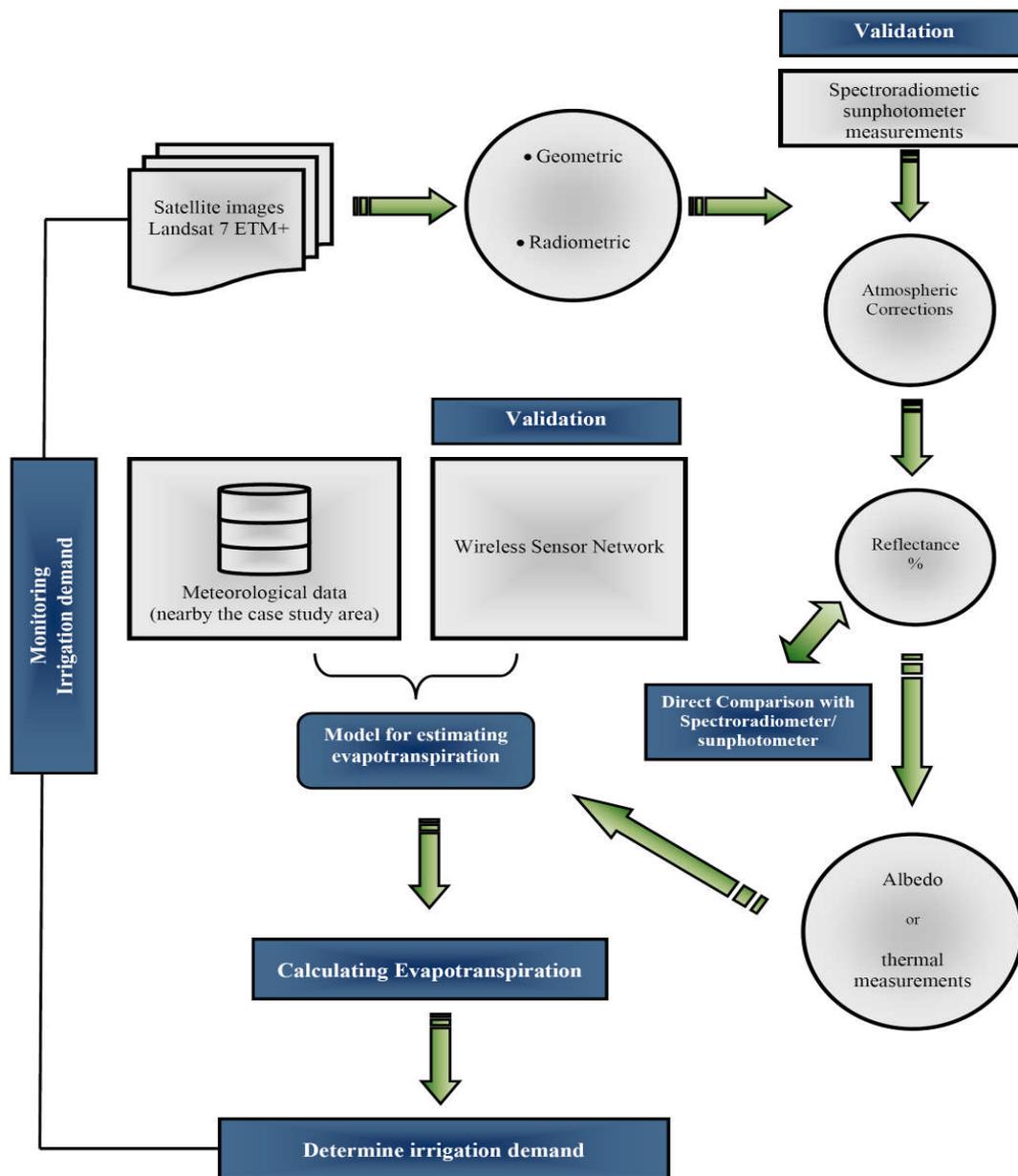


Figure 5 Overall methodology of the project

scattering and absorption, as well as their combined action (Kim and Elman, 1990). Hence, radiometric errors can be categorized into two groups, the atmospheric effects errors and the errors dealing with the construction of the satellite system. Hence, atmospheric corrections were applied to the satellite images in order to remove atmospheric effects. The Darkest Pixel algorithm (Hadjimitsis, Papadavid and Kounoudes, 2008) was employed and applied to all images of Landsat 5 and 7. Radiometric corrections of remotely sensed

data aim to remove effects sourcing from the sensor's building and effects from the atmosphere. The consideration of these effects is very important (Mather, 1999). Geometric corrections were made to the images following the indicated way. The most common method to register imagery to earth coordinates is to find the earth coordinates of known areas on the image, then warp the entire image by an interpolation so these points have the true location (UTM coordinates). These locations clearly identified both on the imagery and the map, have

precise ground positions, called Ground Control Points.

5.2 Vegetation Indices formation from spectroradiometric measurements

Vegetation indices are mostly empirical equations describing vegetation parameters during the lifecycle of the crops (Elvidge and Chen, 1995). Nearly all of the commonly used vegetation indices are only concerned with red/near-infrared spectrum and can be divided to perpendicular (WDVI, SAVI) and ratio based indices (NDVI). The former are generally more influenced by atmospheric effects (Qi, Kerr and Chehbouni, 1994) and more sensitive to atmospheric correction algorithms; thus a sound atmospheric correction algorithm should always be used to increase accuracy on data.

Vegetation indices were calculated using the spectrum range acquired from the spectroradiometric measurements. NDVI, SAVI and WDVI are the spectral vegetation indices that were selected in order to be correlated to LAI and crop height. Such indices are found to be widely used in various evapotranspiration algorithms and models. It has to be mentioned that WDVI is more sensible to atmospheric affects Qi, Kerr and Chehbouni, 1994) than SAVI and NDVI, but this effect was eliminated by using field spectroscopy (Huete and Warrick, 1990). No atmospheric corrections need to be applied on the spectrum data since atmosphere is not interfering in spectroradiometric measurements. This fact also means that the accuracy of the data is high (Curran and Williamson, 1985), while extra atmospheric correction work is avoided. Vegetation Indices will be used for describing statistically, the crop canopy factors, namely crop height and Leaf Area Index (LAI).

5.3 Algorithm employment

As mentioned, many algorithms dealing with ET_c have been developed. In the last decade, research was directed to energy balance algorithms. In this study, an energy balance based algorithm was employed in order to estimate ET_c of the crops in the area of interest: the FAO Penman-Monteith adapted to satellite data. The algorithm is adapted to the conditions of the area of interest, which means empirical equations for crop canopy factors (Papadavid et al, 2009) are used in this study.

One step FAO method adapted to satellite data was

used to estimate ET_c . Difference in the ET_c values calculated from satellite image data and field spectroradiometric data was obtained. The specific equation which is used to estimate ET_c under assumptions, relies on the direct application of the Penman-Monteith equation with canopy parameters estimated from satellite imagery. For estimating evapotranspiration, meteorological and satellite data have been used (Eq. (1)). Air temperature, atmospheric pressure, wind speed and other data were collected from a weather station, located at the Paphos International Airport, very close to the study area.

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

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; p_a air density; $(e_s - e_a)$ vapour pressure deficit; λ , latent heat of vaporisation of water; 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 for Cyprus annual crops.

5.4 Meteorological data “feeding”

A novel approach for data collection from a wide area using wireless sensor network will be applied. Various environmental sensors such as soil moisture, humidity, temperature, ambient light etc will be deployed in a wide area using ad-hoc wireless sensor nodes. The notes will be communicating to a central gateway station where all the parameters are stored and then forwarded via GPRS communication link to a remote data base at Cyprus University of Technology. The gateway station will also incorporate meteorological sensors such as barometric pressure, relative humidity, wind, rain sensors etc. The novelty of the specific approach is that by using an ad-hoc wireless sensor network we can very easily move from one data collection area to another and also by having the remote monitoring capability we can

achieve an automate high data collection rate without having to visit the deployment area. The ground monitoring system will be based on smart programming of the sensor nodes so as to achieve minimum power consumption. Solar powered gateway station and nodes will be considered.

5.5 ET_c maps and values and inter-comparison

All satellite images, used in this study, were transposed into crop evapotranspiration maps. Using ERDAS imagine software and by applying the ET_c algorithms the images were altered in order to display the value of ET_c in the area of interest. The ET_c values of the plots of beans in the area were extracted and have been compared to the reference method's values.

5.6 Statistical analysis

A statistical analysis to test the results of the proposed integrated method and the reference method was employed. The T-test analysis was applied for the two paired samples while the correlation of the two pairs was graphically shown.

6 Results

In order to estimate ET_c , the one step FAO Penman-Monteith adapted to satellite data method was applied. The specific equation which is widely used to estimate ET_c , under assumptions, relies on the direct application of the Penman-Monteith equation with canopy parameters estimated from satellite imagery. For estimating evapotranspiration meteorological and satellite data have been used. Air temperature, atmospheric pressure, wind speed and other data were collected from a through the wireless sensor network which is employed in the fields of the study area. Satellite data, such as LAI and albedo maps, have been derived from satellite imagery using simplified methods. The method also needs empirical equations for describing the crop canopy factors, namely albedo, crop height and LAI. The specific equation is found from Papadavid et al. (2009) with the assistance of field spectroscopy.

FAO adapted to satellite data has been applied to derive ET_c maps and extract the values of ET_c for the crops in the area of interest. Figure 6 interposes the ET_c maps, sourcing from the specific method, in GIS. The

ET_c maps show in a pixel basis the value of ET_c for the specific plots used in this study.

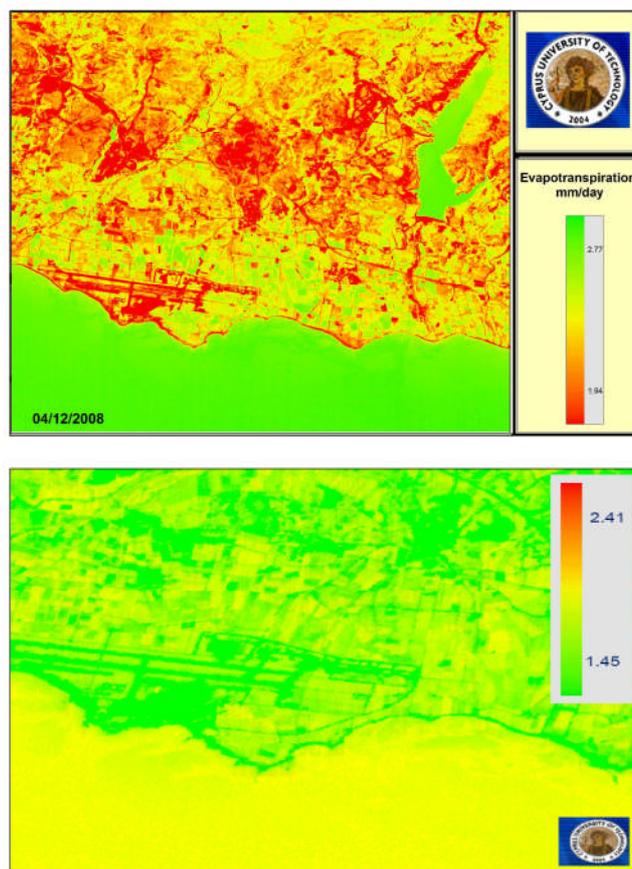


Figure 6 Example of ET_c maps from FAO adapted to satellite data for spring potatoes and peas' plots in the area of interest (16-04-2008 Landsat 7 image)

The values of specific crops are recorded in Table 1 for the dates of acquired images as shown.

Table 1 Results of FAO 56 application for estimating ET_c

No	Date of satellite image	Satellite	Area of Interest	ET_c mean	ET_c by Epan
1	17/12/2007	ASTER	MANDRIA	2.33	2.6
2	24/12/2007	ASTER	MANDRIA	2.34	2.6
3	26/2/2008	ASTER	MANDRIA	2.25	2.20
4	28/7/2008	LANDSAT 7 ETM+	MANDRIA	2.78	2.8
5	13/8/2008	LANDSAT 7 ETM+	MANDRIA	2.84	3.2
6	29/8/2008	LANDSAT 7 ETM+	MANDRIA	3.03	3.2
7	4/12/2008	ASTER	MANDRIA	2.65	2.6
8	4/2/2009	LANDSAT 5	MANDRIA	2.53	2.2
9	21/2/2009	LANDSAT 7 ETM+	MANDRIA	2.62	2.2
10	7/7/2009	LANDSAT 5	MANDRIA	3.32	2.8
11	23/7/2009	LANDSAT 5	MANDRIA	3.5	2.8
12	22/12/2009	LANDSAT 7 ETM+	MANDRIA	2.12	2.6

The results referred to three years. The satellite images referred to 2007, 2008 and 2009 for specific plots

cultivated every year with the same annual crops (peas and ground nuts). The results' values that are recorded in Table 1 are the average value of the total pixels included in the plots (at least 10 pixels each plot).

The two methods' results, FAO adapted to satellite data and the direct Epan method (reference method), are compared graphically and tested statistically to find out if there is a significant difference between them. The results of the methods appear in the last two columns of Table 1, while Figure 7 shows the linear trendline between them. The determination coefficient is low ($R^2=0.49$) indicating that the results could have a significant difference. Then the T-test was employed in order to check the above argument. The value of the observed t was 0.04 while the statistical t , from the statistical tables was 2.20. Since the observed value of t was smaller than the statistical t ($t_{obs} < t_{sta}$), the difference or deviation between the paired samples is not significant. This fact enables policy makers to use the above proposed methodology to estimate and monitor evapotranspiration over the island of Cyprus.

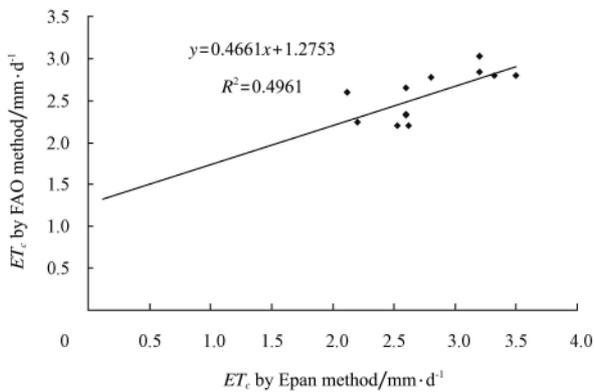


Figure 7 Corellatio of results sourcing from Epan (x-axis) and FAO sat. (y-axis)

7 Conclusions and future work

According to results, spectro-radiometric measurements are of vital importance when estimating ET_c . The use of such tools in research regarding irrigation demand help in validating the research results

and have increased accuracy. The knowledge of spectral signature of the survey object under investigation is of vital importance. Remote Sensing and classification techniques depend on spectral signatures of objectives. Of course the dynamic nature of the crops is complicating the procedure. Contrary to stable standard targets, crops are continually changing morphologically resulting in different spectral signature in each phenological stage. It is obvious that in each stage of their life cycle the reflectance is different since color is changing. The results of this project have shown that even day by day reflectance is changing.

The next step is to compare the results (in band reflectance) to the reflectance of more satellite images which are under pre-processing at the laboratory of Remote Sensing of the Cyprus University of Technology and evaluate the impact of atmospheric correction. The results can be used to monitor life cycle of spring potatoes using satellite imagery (Landsat ETM+, TM data) and to assist the monitoring of irrigation demand using satellite remote sensing and irrigation models. Future work consists of further validation of the results, not only using FAO adapted to satellite data method for other cultivations but other acceptable methods and models for estimating ET .

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