

WATER MANAGEMENT USING GEOINFORMATICS AND REMOTE SENSING TECHNIQUES: THE CASE STUDY OF MANDRIA, SW CYPRUS

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ABSTRACT

Estimating crop evapotranspiration (ET_c) is a crucial parameter for monitoring water balance. Further to empirical equations or sophisticated equipments –such as lysimeters– often used for calculating daily ET_c, remote sensing data have been also applied successfully in many parts of the world. The latest has expanded the capabilities of local authorities, since satellite imagery provides a systematically and overall coverage of a vast agricultural area. The final results can be then provided in near –real time to the end users using GIS technology and friendly interfaces.

This paper presents the results of daily ET_c over specific crops in Mandria village, SW Cyprus, using remote sensing data compared to FAO 56 method. Moreover the authors have built the necessary framework where the end users such as the farmers can be benefit from such techniques and innovations. This framework combines both satellite imagery and ground spectroradiometric measurements for verification of the results. Furthermore GIS technology is used in order to archive and analyze the vast amount of data. Water management software can be used from the local authorities for an overall water balance management eg. irrigation demand. The end users may be alert for any over or below ET_c measurements in their field.

1 INTRODUCTION

During the last two decades, remote sensing has played an increasing role in the field of hydrology and especially water management (Bastiaanssen et al., 2003; 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 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 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 et al., 1977; Hiler et al., 1971; 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., 2006) or WDV (Weighted Difference Vegetation Index) (Clevers, 1988). Currently, several researchers recommend a breadth of mathematical equations and modelling (Bastiaanssen et al., 2003; D'Urso et al., 1995; Menenti et al., 1989). The commonly accepted equation for estimating evapotranspiration can be used for defining the crop coefficients as a function of (Bastiaanssen, 2005):

- climate data (temperature, T ; relative humidity, $RH\%$; solar radiation, R_s ; and wind speed, U)
- crop parameters such as the surface albedo, a , the leaf area index (LAI)
- crop height (related to the surface aerodynamic roughness, z_0)

However, some other researchers have shown that crop coefficients are greatly influenced by canopy development and vegetation coverage. Based on the fact that these parameters directly affect the reflectance of cropped areas, it has been demonstrated that is possible to establish a correlation between multi-spectral measurements of canopy reflectance and the corresponding evapotranspiration values (Roerink et al., 1997). Therefore, remotely sensed reflectance values can be used in combination with other detailed information about land uses for mapping crop coefficients in irrigated areas.

2 AREA OF INTEREST

The study area is 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. 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 of 425mm. Nevertheless, irrigation is indispensable for any appreciable agricultural development in the area.

Landsat 5 and Landsat 7 pass over the area with temporal resolution of 15 days. The time of overpass is 11 o'clock am local time for Landsat 5 and 9:30 am local time for Landsat 7. As indicated by Alexandridis (2003), the resolution of the Landsat 5 and Landsat 7 pixel is fine, especially when the work is related to hydrological purposes. Morphologically, the area is a flat terrain of about 30 km²). The soil of the experimental site is calcareous, characterized by a deep brown color, having a rather heavy to very heavy structure. The main method of irrigation in the area, due to its morphology and the cultivations, is with the use of sprinklers.



Figure 1. Area of interest in Mandria, Pafos, Cyprus

3 RESOURCES AND METHODOLOGY

A two year (2009-10) field campaign was undertaken using a field spectroradiometer (*GER 1500*) for acquiring the reflected spectrum of each crop while simultaneously LAI measurements were taken using the *SunScan* canopy analyzer. Crop height measurements were also taken using a simple ruler. A time series of satellite images of Landsat 5 TM and Landsat 7 ETM+ were used in this study in order to create ETC maps while ERDAS Imagine v.10 software was used to process the satellite images. Meteorological parameters such as Relative Humidity, temperature and atmospheric pressure, in addition to wind velocity at the time and date of satellite overpass have been obtained from an automatic weather station that was placed at the area of interest from the authors.



Figure 2. In situ spectroradiometric measurements of Potatoes

Methodology

There is an attempt to statistically describe the crop canopy factors, namely crop height and LAI, through the vegetation indices. Crop canopy factors are vital elements in the procedure of estimating ET_c. These indices will be produced from the spectroradiometric measurements using a handheld field spectroradiometer (GER 1500) and after this data is filtered through the Relative Spectral Response (RSR) filters. At the same time LAI and CH direct measurements are taken in situ. Hence time series of LAI, CH and VI have been created and can be used to model LAI and CH to VI. After applying the needed statistical methods and evaluate them, the best model for each crop, based on the determination factor (r^2), was used in specific ET_c algorithms in a procedure to adapt and modify the algorithms in the geo-morphological and meteorological conditions of the island of Cyprus. Crop Water requirements were inferred applying the algorithms and it was tested to check if the specific modifications have assisted the algorithms to improve their precision when estimating ET_c. More specifically the whole methodology is illustrated below in the following stages:

- Choosing the Area of interest. Based on the fact that Remote Sensing Techniques will be applied but also on the crops that were chosen for the study the area that was selected is a flat area with mild climate, at sea level and with fertile soil.
- Spectroradiometric measurements: a two year field campaign was undertaken in order to collect spectral signatures of each crop included in the study. For each crop the average spectral signature in each phenological stage was created based on the two cultivating periods (2009-2010). The purpose is to have the reflectance of each crop during their phenological stages after the data was filtered through the Relative Spectral Response filters.
- Leaf Area Index (LAI) and Crop Height (CH) measurements were also taken simultaneously to spectroradiometric measurements and following the same phenological cycle of each crop for the corresponding cultivating periods. The purpose is to create time series of these two parameters to correlate them to VI.
- VI creation. Time series of VI (SAVI, NDVI and WdVI) have been created based on the reflectance of each crop, in each phenological stage.
- Modeling VI to LAI and CH. Different models were tested in order to identify the best possible model which better describes LAI and CH through VI. The models used in the study are mathematically expressed through equations 1,2,3,4:

Linear: $LAI = a(VI) + b$ (1)

Exponential: $LAI = ae^{b(VI)}$ (2)

Logarithmic: $LAI = a \ln(VI) + b$ (3)

Polynomial: $LAI = a(VI)^2 + b(VI) + c$ (4)

and they will be used for all four crops (potatoes, beans, peas, ground nuts). In this modeling procedure, an attempt for modeling LAI and crop height (Y of the model) to one of the three vegetation indices (NDVI, SAVI, WDI) (X of the model) found earlier, is being done. Coefficients a, b and c are found from the statistical analysis and the strongest model depending on the determination factor (R^2) will be used in the algorithms for estimating ET_c.

- Preprocessing of satellite images. Geometric rectification, radiometric correction and atmospheric corrections of satellite data is necessary before main processing of the data.
- Mapping LAI, CH and albedo. The three crop canopy parameters were mapped using the ERDAS Imagine. The satellite images were transformed into maps in order firstly to test in practice the models and secondly to be inserted as inputs in ET_c algorithms.
- Models verification. After inferring the best model describing LAI or CH using VI, an evaluation of this procedure is taking place. A priori knowledge of satellite over passing over the area of interest has assisted the procedure of taking LAI and CH measurements in different plots and different cultivating period. These average measurements were compared to the predicted measurements arising from the models application found in the previous step.
- Application of ET_c algorithms. SEBAL methodology was followed in order to estimate the ET_c of each crop and finally create an irrigation schedule for the producers of the area. The SEBAL method derives the evaporative fraction from satellite data. Actual evapotranspiration can be easily obtained from the product of the evaporative fraction and the net radiation. The SEBAL remote sensing technique is not restricted to irrigated areas, but can be applied to a broad range of vegetation types. Data requirements are low and restricted to satellite information although some additional ground observations can be used to improve the reliability (Kite and Droogers, 2000).
- Economic assessment of irrigation costs in order to find out how the new results can affect the profit margin of the producers in the area of interest.

4 RESULTS AND DISCUSSION

A common and widely used approach has been the development of relationships between ground-measured LAI and vegetation indices (Chen & Cihlar, 1996; Fassnacht et al., 1997). Consequently, a large number of relationships have been established, and a wide range of determination factor ($0.05 < r^2 < 0.88$) between vegetation indices and LAI were found (Brown et al., 2000).

Time series of LAI, crop height measured directly in the field and all three vegetation indices, which were produced earlier from the spectroradiometric data which was acquired from the ground truth data campaign, were created and elaborated using the statistical software SPSS in order to test the level of correlation between LAI-VI and CH-VI. Using the SPSS, coefficients for all four models were found and new models were created defining LAI and CH through the vegetation indices. This procedure was performed for all five crops under investigation, while the best model in each case was

chosen based on the determination factor. Table 1 shows the results of the statistical correlations between LAI/CH and VI. The models appear on the table are the ones with the highest determination factor (r^2).

Table 1. Correlation's results of LAI/CH and VI for each crop

Crop	LAI-VI	Vegetation	r^2	CH-VI	Vegetation	r^2
	Model	Index		Model	Index	
Potatoes	$y = 0,23\exp(4,20x)$	WDVI	0,86	$y = 1,33x^2 - 0,74x + 0,32$	SAVI	0,77
Beans	$y = 5,05x - 0,79$	WDVI	0,89	$y = 35,11\ln(x) + 44,71$	WDVI	0,83
Peas	$y = 0,06\ln(x) + 0,88$	NDVI	0,73	$y = 42,67x - 12,86$	SAVI	0,85
Groundnuts	$y = 8,84x - 2,53$	WDVI	0,79	$y = 92,8x - 12,64$	NDVI	0,66

As mentioned, many algorithms dealing with ET_c have been developed. The last decade, research has been directed to energy balance algorithms. In this study, an energy balance based algorithm has been employed in order to estimate ET_c of the crops in the area of interest: the Surface Energy Balance Algorithm for Land. Both algorithms are adapted to the conditions of the area of interest by using the empirical equations found earlier. SEBAL computes a complete radiation and energy balance along with the resistances for momentum, heat and water vapour transport for each pixel (Bastiaanssen *et al.*, 1998; Bastiaanssen, 2005). The key input data for SEBAL consists of spectral radiance in the visible, near-infrared and thermal infrared part of the spectrum. So, the model can be applied using satellite sensors having a thermal band. Landsat 5 and 7 images were used in this study. In addition to satellite images, the SEBAL model requires weather parameters (wind speed, humidity, solar radiation, air temperature). These meteorological parameters were used as inputs for the algorithm and they were provided from the national meteorological station next to the area of interest. Evaporation was calculated from the instantaneous evaporative fraction λ , and the daily averaged net radiation, R_{n24} . The evaporative fraction λ was computed from the instantaneous surface energy balance at satellite overpass on a pixel-by-pixel basis through the equation 5:

$$\lambda E = R_n - (G_0 + H) \quad (5)$$

where: λE is the latent heat flux ($W m^{-2}$), R_n is the net radiation ($W m^{-2}$), G_0 is the soil heat flux ($W m^{-2}$) and H is the sensible heat flux ($W m^{-2}$). Using SEBAL, ET_c maps were created where users can retrieve the estimated value of the specific parameter directly. Figure 3 is an example of ET_c map of the area of interest.

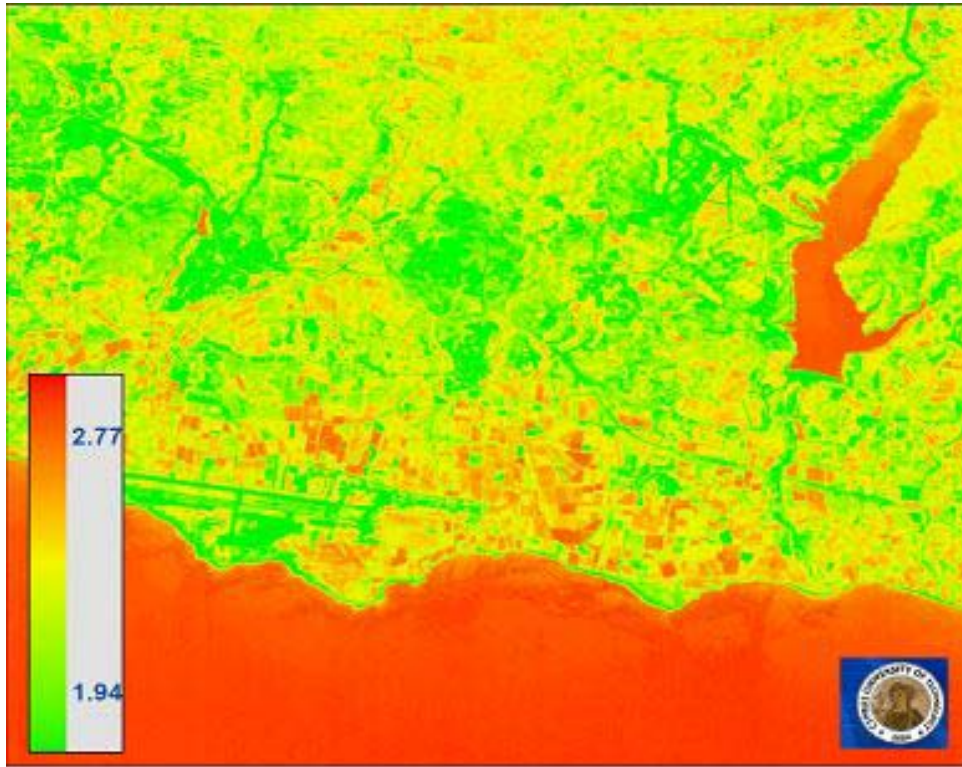


Figure 3. ETc map of the area of interest (Landsat 5 TM image of 7 July 2009).

The results given by the SEBAL methodology are in mm/day and can easily transformed to tones/month/ha. Table 2 shows an irrigation schedule based on the results of the project.

Table 2. Project's Crop water requirements per month

Crops	J	F	M	A	M	J	J	A	S	O	N	D	Total
Potatoes							450	850	1200	1550	1300		5330
Groundnuts							620	1450	1650	300			4020
Beans							450	850	1200	990			3490
Peas			200	800	480								1480

The results of the project were also used to compare the existing regime of irrigation with the proposed, in terms of economic values. *Ceteris paribus*, irrigation cost that is practically applied in the area of interest, is compared to the irrigation cost that is sourcing employing the results of the project for each crop cultivation. The purpose is to test if remote sensing has the potential to improve the variable costs of the producers. Irrigation costs based on the Norm Input Data for Cyprus (Markou and Papadavid, 2007) is illustrated in Table 3.

Table 3. Revenues, costs and profits per hectare for each crop (Markou and Papadavid 2007)

COSTS/REVENUES	Potatoes	Beans	Groundnuts	Peas
Yield (t/ha)	50	2,7	4	15
Price: (€/t)	276	2.511	1.767	874
Subsidies (€/ha)	99	99	99	99
A. GROSS REVENUE	€ 13.899	6.879	7.167	13.209
Variable cost				
Fertilizers	462	150	295	162
Plant protection	552	69	20	480
Weed control	101	47	120	42
Irrigation	1552	837	986	357
Machinery inputs	675	344	535	377
Hired labour	1800	1132	1566	4206
Other expenses	2550	460	530	550
Crop insurance	414	180	180	850
Interest on operating capital	123	112	120	165
B. TOTAL VARIABLE COSTS	€ 8230	3331	4352	7190
Fixed costs				
Rent of land	331	331	170	331
Family labour	2.041	1132	1566	2609
Interest on fixed capital	291	241	232	270
Depreciation and establishment cost	813	621	600	629
C. TOTAL FIXED COSTS	€ 3476	2325	2568	3840
D. TOTAL COSTS (B+C)	€ 11705	5656	6920	11030
E. GROSS MARGIN (A-B)	€ 5670	3548	2815	6019
F. NET PROFIT (A-D)	€ 2194	1223	247	2179

Keeping the same methodology but substituting the data regarding irrigation, meaning using the data from the project, table 4 shows the new economic results regarding the four cultivations. It is obvious that table 4 is providing better economic profits than the corresponding of table 3. The cost of irrigation in the total variable costs was reaching 0.19% for potatoes, 25% for beans, 23% for groundnuts and 0,05% for Peas. Using the results of the project the costs were reduced to 0,12%, 0,19%, 0,17 %and 0,04% respectively. Regarding the total costs, there was a proportional reduction too. The proportion of irrigation cost to the total was 0.13%, 0,15%, 0,14% and 0,03% and they became 0,08%, 0,11%, 0,10% and 0,02% respectively.

Table 4. Revenues, costs and profits per hectare for each crop except irrigation cost, *ceteris paribus*

COSTS/REVENUES	Potatoes	Beans	Groundnuts	Peas
Yield (t/ha)	50	2,7	4	15
Price: (€/t)	276	2.511	1.767	874
Subsidies (€/ha)	99	99	99	99
A. GROSS REVENUE	€ 13.899	6.879	7.167	13.209
Variable cost				
Fertilizers	462	150	295	162
Plant protection	552	69	20	480
Weed control	101	47	120	42
Irrigation	906	593	683	251
Machinery inputs	675	344	535	377
Hired labour	1800	1132	1566	4206
Other expenses	2550	460	530	550
Crop insurance	414	180	180	850
Interest on operating capital	123	112	120	165
B. TOTAL VARIABLE COSTS	€ 7584	3087	4049	7084
Fixed costs				
Rent of land	331	331	170	331
Family labour	2.041	1132	1566	2609
Interest on fixed capital	291	241	232	270
Depreciation and establishment cost	813	621	600	629
C. TOTAL FIXED COSTS	€ 3476	2325	2568	3840
D. TOTAL COSTS (B+C)	€ 11059	5412	6617	10924
E. GROSS MARGIN (A-B)	€ 6316	3792	3118	6125
F. NET PROFIT (A-D)	€ 2840	1467	550	2285

Using the new irrigation data producers can avoid extra cost on irrigation and maximize their profit. More specifically, there can be an increase of 1,29% for potatoes, 1,20% for beans, 2,23 for groundnuts and 1,05 for Peas.

5 CONCLUSIONS

Remote sensing for hydrological purposes is a very powerful tool and has to be utilised by the irrigation precisionists. The application of these techniques in Cyprus has provided new opportunities in micro-economic level (the producers) to improve the margin of economic profit but can also indirectly increase the volume of stored water reserves, by reducing the irrigation water volume. The results of the project has shown that remote sensing can provide very accurate results on ET_c, depending on the algorithm used, which can be used to improve irrigation management. Project's results can assist in the worldwide effort to avoid wasting water for any purpose and especially irrigation water which is over than 70% of the total consuming water.

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7 REFERENCES

- Ambast SK, Ashok K, Keshari, Gosain AK. 2006. Satellite remote sensing to support management of irrigation systems: concepts and approaches. *Irrigation and Drainage systems* 51:p 25-39,
- Alexandridis T. 2003. Effect of scale on hydrological and vegetation parameters estimation using remote sensing techniques and GIS, PhD study, Aristotle University of Thessaloniki, Greece
- Bastiaanssen, W.G.M., and Ali, S., 2003 A new crop yield forecasting model based on satellite measurements applied across the Indus Basin, Pakistan. *Agriculture, Ecosystems and Environment*, 94:321-340.
- Bastiaanssen WGM, Brito, Bos MG, Souza KA, Cavalcanti E.B and Bakker MM., 1998 Low cost satellite data for monthly irrigation performance monitoring : *Irrigation and Drainage systems* 15 : p 53-79.
- Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes and A.A.M. Holtslag, 1998. A remote sensing surface energy balance algorithm for land (SEBAL), part 1: formulation, *Journal of Hydrology*. 212-213: 198-212.
- Bastiaanssen, W. G. M., E. J. M. Noordman, H. Pelgrum, G. David, B. P. Thoreson, and R. G. Allen. 2005. SEBAL model with remotely sensed data to improve water resources management under actual field conditions. *ASCE J. Irrig. Drain. Eng.* 131(1): 85-93
- Brown, L., Jin, M. C., Lablanc, S. G., & Cihlar, J. (2000). A shortwave infrared modification to the simple ratio for LAI retrieval in boreal forests: An image and model analysis. *Remote Sens. Environ.*, 71, 16– 25.
- Chen, J., & Cihlar, J. (1996). Retrieving leaf area index of boreal conifer forests using Landsat Thematic Mapper. *Remote Sens. Environ.*, 55, 153– 162.
- Clevers, J. G. P. W. 1988. "The derivation of a simplified reflectance model for the estimation of leaf area index, *Remote Sensing of Environment*", vol 35., pp. 53-70.
- D'Urso G., Menenti M., 1995. Mapping crop coefficients in irrigated areas from Landsat TM images; Proceed. European Symposium on Satellite Remote Sensing II, Europto, Paris, Sept.'95; SPIE, Intern. Soc. Optical Engineering; 2585: 41-47.
- Fassnacht, K. S., Gower, S. T., MacKenzie, M. D., Nordheim, E. V., & Lillesand, T. M. (1997). Estimating the leaf area index of north central Wisconsin forest using Landsat Thematic Mapper. *Remote Sens. Environ.*, 61, 229–245
- Hiler, E.A., and Clark, R.N., 1971. Stress day index to characterize effect of water stress on crop yields, *Transactions of the American Society of Agricultural Engineering* (ASEA) 14:757-761
- Kite, G. W. and P. Droogers. 2000. Comparing Evapotranspiration Estimates from Satellites, *Hydrological Models and Field Data. Journal of Hydrology* 229: 3-18.
- Markou M. and Papadavid G. (2007). Norm input output data for the main crop and livestock enterprises of Cyprus. *Agricultural Economics Report* 46, ISSN 0379-0827, p.196-199
- Meneti M., Visser TNM, Morabito Jaovandi A., 1989. Appraisal of irrigation performance with satellite data and georeferenced information. *Irrigation theory and practice*, London, :785-801 (1989)
- Roerink, G.J., W.G.M. Bastiaanssen, J. Chambouleyron and M. Menenti., 1997. Relating crop

- water consumption to irrigation water supply by remote sensing. *Water Resources Management* 11: 445-465
- Schultz G. and Engman E., 2001. Present use and future perspective of remote sensing in hydrology and water management
- Seguin, B., and Itier, B., 1983. Using midday surface temperature to estimate daily evaporation from satellite thermal IR data, *Int. J. Remote Sens.*, 4:371-383
- Tasumi m., Trezza R., Allen R., Wright J., 2003. Validation tests on the SEBAL Model for evapotranspiration via satellite: ICID Workshop on Remote sensing of ET
- Thiruvengadachari S and Sakthivadivel K., 1997. Satellite remote sensing for assessment of irrigation system performance. Research Report 9, IWMI Colombo, Sri Lanka