Mapping irrigated areas and water consumption in Crete

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1. Introduction

Water scarcity is a major global problem and more threatening in the near future. Overexploitation of groundwater, from direct and indirect activities, mainly because of intensive agricultural activity, with a combination of climatic changes, has a great impact in the hydrological/hydrogeological conditions of the Mediterranean region. Climate projections in the Mediterranean region in combination with an expected continuation of intensive activity generate concern over the sustainability of groundwater resources (Varouchakis, 2015). More specific, since the early 80's, intensive irrigation in Crete, Greece, has increased productivity at the cost of an alarming drawdown of the water table (Varouchakis, 2015).

Evapotranspiration process due to irrigation could be characterized as an indirect parameter that contributes to the overexploitation of groundwater. However, one of the most important and worth mentioned direct activity that leads to the lowering of the groundwater table is the intense irrigation for agricultural use.

The purpose of this study is to get more information and a better understanding on the water consumption of the irrigation system of Crete and relate this to available water resources such as rainfall and groundwater.

More specific the given actual evapotranspiration data (ETensv1.0), at a resolution of 250×250 m and a monthly time step, will be validated with a water balance. The discharge (Q) will be subtracted by the precipitation data (CHIRPS) giving an estimation of the bulk evapotranspiration values for one specific catchment, the Messara catchment. Before starting the validation, the given precipitation data (CHIRPS) will be compared with the precipitation data obtained by stations, for the island of Crete, and corrections will be made if needed. Another comparison will be achieved between the calculated crop coefficient, being defined as ET_{act} / ET_0 where ET_0 is the FAO56 reference evapotranspiration, and the ET_{max}/ET_0. Last, actual evapotranspiration is the sum of evapotranspiration due to irrigation (blue water) and due to rainfall (green water) (Kwast et al., 2012). IHE has developed Budyko tools to compute ET from green and blue water resources. This will yield at the same time to the identification and mapping of irrigated areas following a GIS-based approach.

2. Study area

2.2 Crete

Crete is the biggest island of Greece and the fifth biggest island in the Mediterranean region. The northern part of the island is wet by the Cretan sea whereas the southern part by the Libyan sea. It constitutes the southern part of the European Union and it is surrounded by smaller uninhabited islands. The area of the island is 8.335km^2. It is 269 km long, 12 to 57 km wide and its coastline is equal to 1.306 km (Water Resources Management Plan, 2015).

The climate of Crete varies strongly between summer and winter season. During summer the temperatures are very high and the atmosphere is very dry whereas during the winter the humidity levels are high and the temperature is low (Varouchakis, 2015).

Since Crete is an island it receives water only from precipitation (rain, hail and snow). However its location and its geophysical environment do not favor the concentration of large volumes of water (Water Resources Management Plan, 2015).

The island receives $7{,}5 \cdot 10^9$ m^3 precipitation per year from which approximately $5 \cdot 10^9$ m^3 are evaporated due to high temperatures throughout the year. The rest of the water is infiltrated enriching the groundwater resources (Water Resources Management Plan, 2015). Because of extensive agricultural activities there is an overexploitation of the groundwater resources (Varouchakis, 2015).

The sum of the agricultural areas of the water district of Crete is around 2.554 km^2. In 2000, 10.790,93 km^2 were irrigated in total. The sum of the irrigated water needed for the island is up to 439×10^6 m^3/year, a percentage of 85,3% of the total water need of the water district. Due to wineries and a great number of olive mills there is a big demand in water. In the table below the values of the water needs are indicated (Water Resources Management Plan, 2015).

Table 1. Estimation of the yearly water needs (2001) (Water Resources Management Plan, 2015)

Water supply	Livestock	Irrigation	Olive trees	Industry	Sum
m^3/year					
65.388.000	6.173.000	439.618.000	930.000	3.176.000	515.237.000
12,68%	1,20%	35,32%	0,18%	0,62%	

The average yearly supply (theoretically) of surface and groundwater is $2860 \cdot 10^6$ m^3 whereas the demand is $515 \cdot 10^6$ m^3. However, the geology and geomorphology of the water district and the climatic conditions turn this strong surplus in a much smaller one (Water Resources Management Plan, 2015).

The spatial heterogeneity of availability but mainly the capability of using the water is another factor exacerbating the problem of meeting the demand. The Western part of Crete has an average annual yield of water supply of 11,9% higher than the Easter part. However, from hydro geological point of view the water resources are more profitable. In the other hand, problems with water availability occur locally also in the Western part (Water Resources Management Plan, 2015).

Table 2. Irrigation demand for every Regional Prefectures (Water Resources Management Plan, 2015)

Regional Prefectures	Area (km^2)	Irrigation needs ($10^6 m^3$/year)
Chania	112,097	65,8
Rethimno	56,091	34,1
Heraklion	220,542	134,2
Lasithi	137,367	85,9
Sum	526,097	320

The yearly demand of irrigated water is estimated to be $439{,}6 \cdot 10^6 m^3$/year to cover the needs of 1.079,093 km^2 of irrigated land (Water Resources Management Plan, 2015).

In the water district of Crete, the demand for irrigated water for agricultural use, as it is mentioned in table above, is $320 \cdot 10^6$ m^3 per year, where $27 \cdot 10^6$ m3 come from surface water and 290 hm3 form groundwater (drilling, natural sources) (Water Resources Management Plan, 2015).

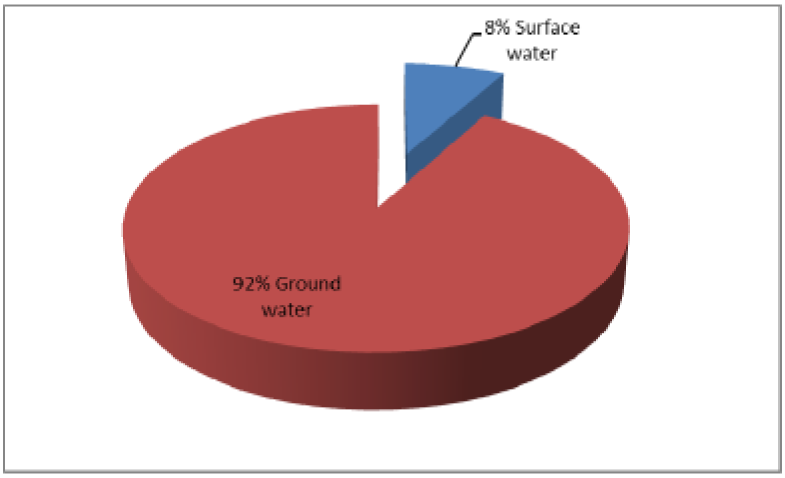


Figure 1. Source of water supply (Water Resources Management Plan, 2015)

An important irrigation development for the last 50 years, promising to change the current situation, in the water district of Crete was the construction of two dams, one in the region of Rethimno (Potamwn dam) and one in the region of Heraklion (Faneromenis dam) (Water Resources Management Plan, 2015).

2.3 Messara catchment

The area of the Messara catchment is 398 km^2 and it is located in the south Heraklion Prefecture (Fig. 2). The Messara catchment is consisted of two basins, the Mires Basin on the west and the Vayionia Basin on the east. The biggest part of the catchment is cultivated, so intense irrigation is taking place in the area lowering dramatically the groundwater table (Varouchakis, 2015).

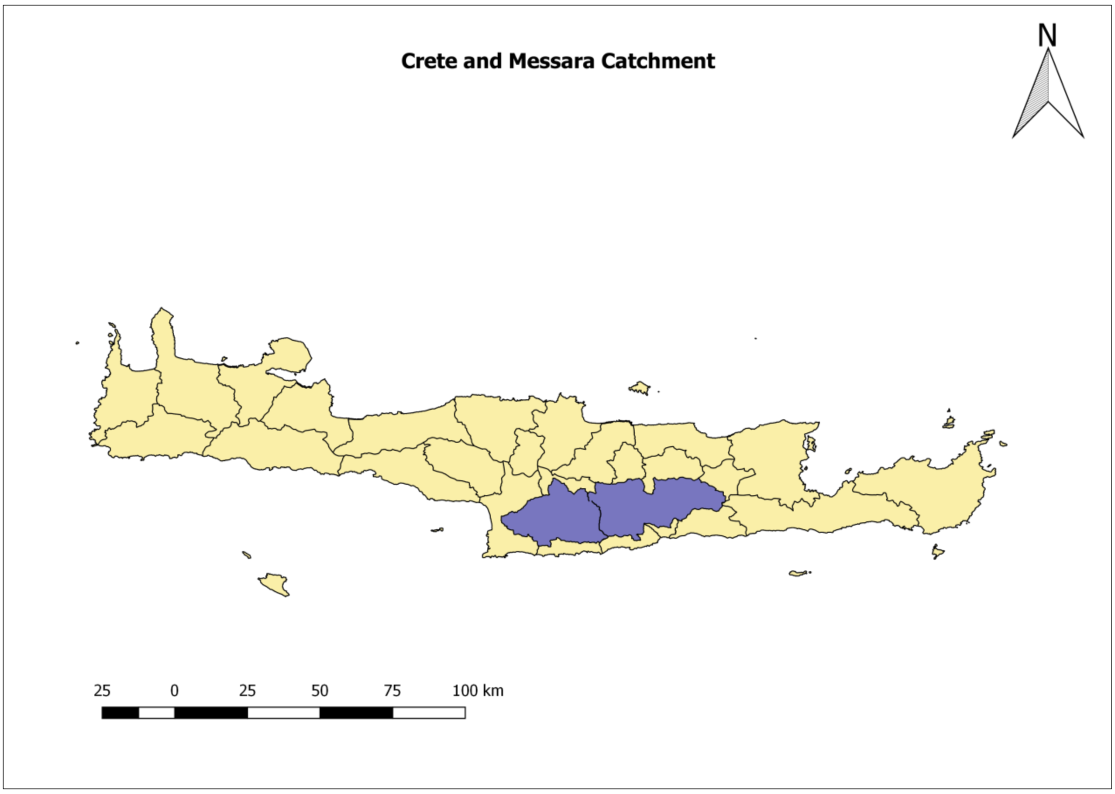


Figure 2. Crete watersheds and Messara catchment

3. Methods and results

3.1 Precipitation validation

In order to start the validation for the evapotranspiration data, first the precipitation data needed to be validated. The validation of the precipitation data was done for the whole island of Crete. It was achieved by comparing the CHIRPS and the precipitation data that were obtained from rain gauges in the island. The CHIRPS data were given in mm/month and the precipitation data form the rain gauges in mm/year. The comparison was conducted only for two hydrological years and more specific for the year 2003-2004 and 2004-2005, because the data from the rain gauges were given only until 2005 and for the CHIRPS from 2003 to 2014. A hydrological year is defined as the period starting from the September of one year and ending on August of the next one, so by adding the data for this period the CHIRPS in mm/year were obtained. In Figure 3 the locations of the rain gauges are presented.

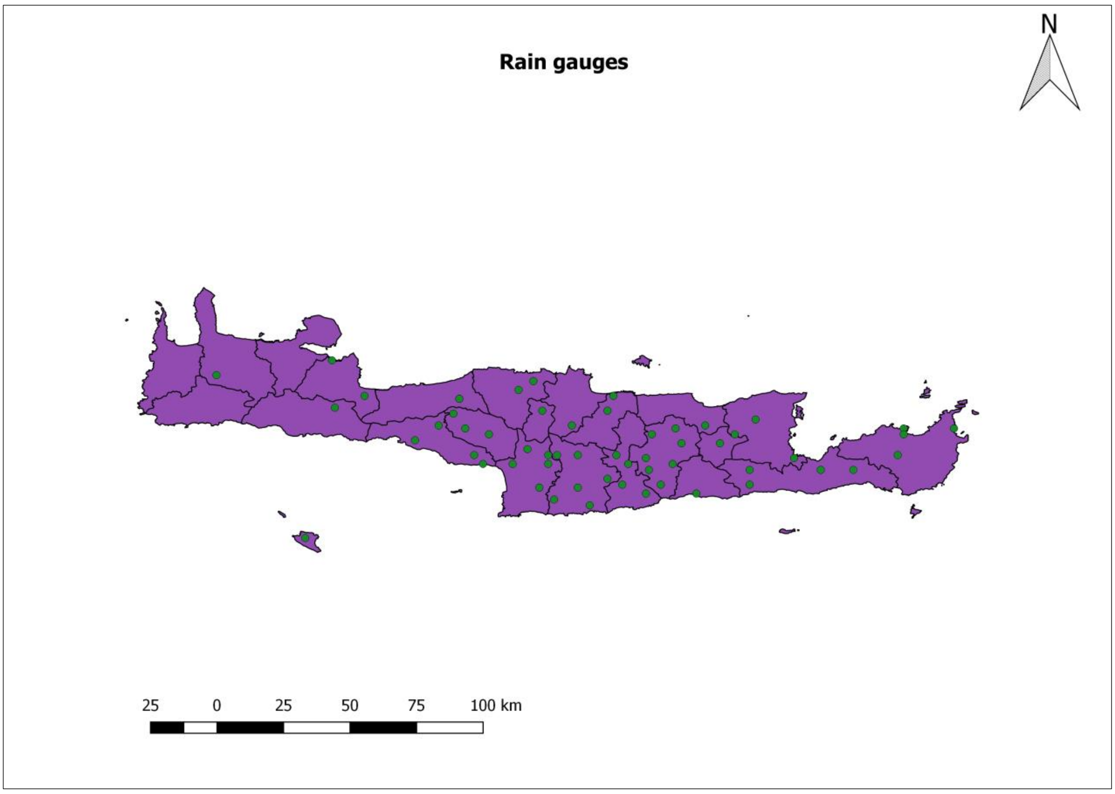
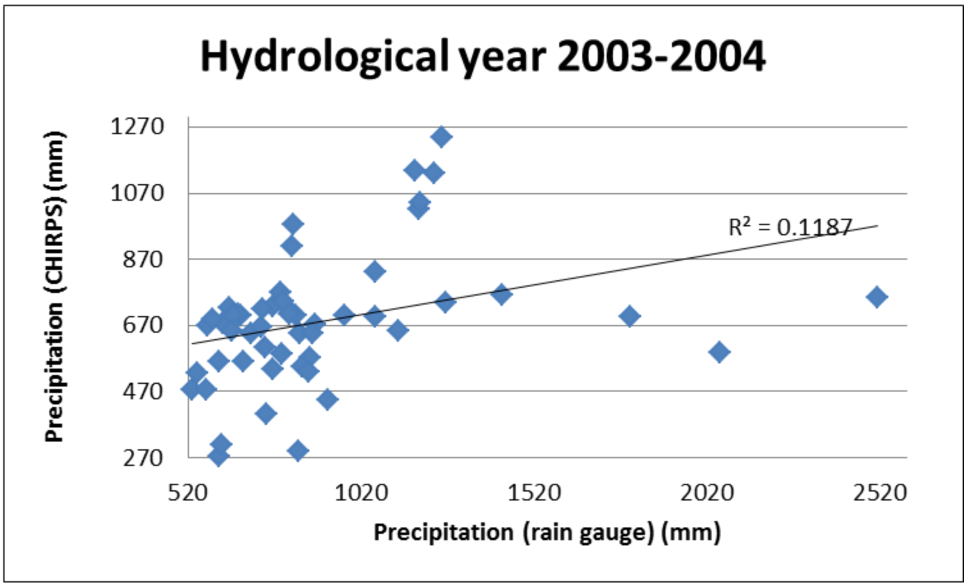
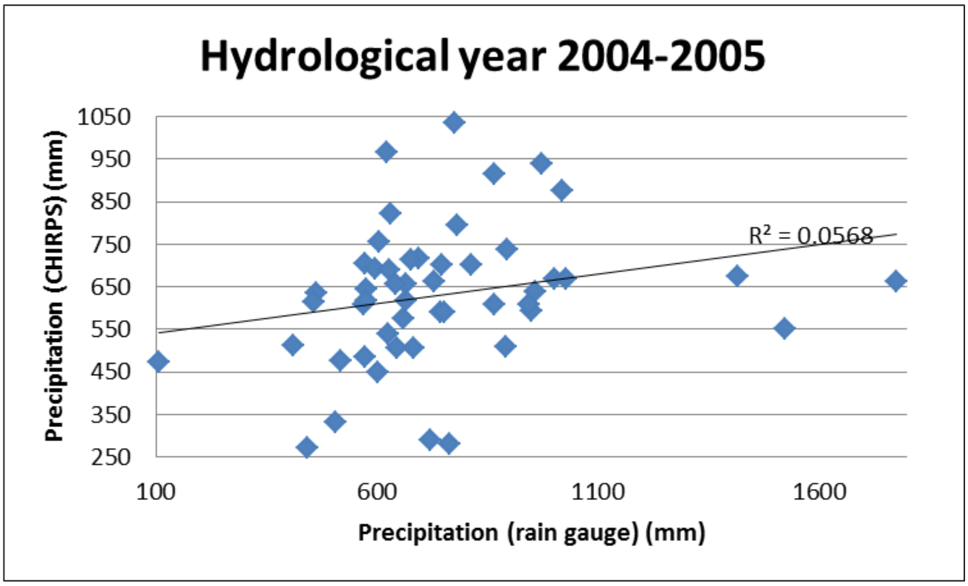


Figure 3. Rain gauges in the island of Crete

Graph 1 and 2 show the correlation between the CHIRPS and the precipitation data from the rain gauges. It should be mentioned that in some rain gauges for those specific years there were missing values, so in order to make the graphs more accurate those stations and also the CHIRPS values for those specific locations were excluded from the graphs.

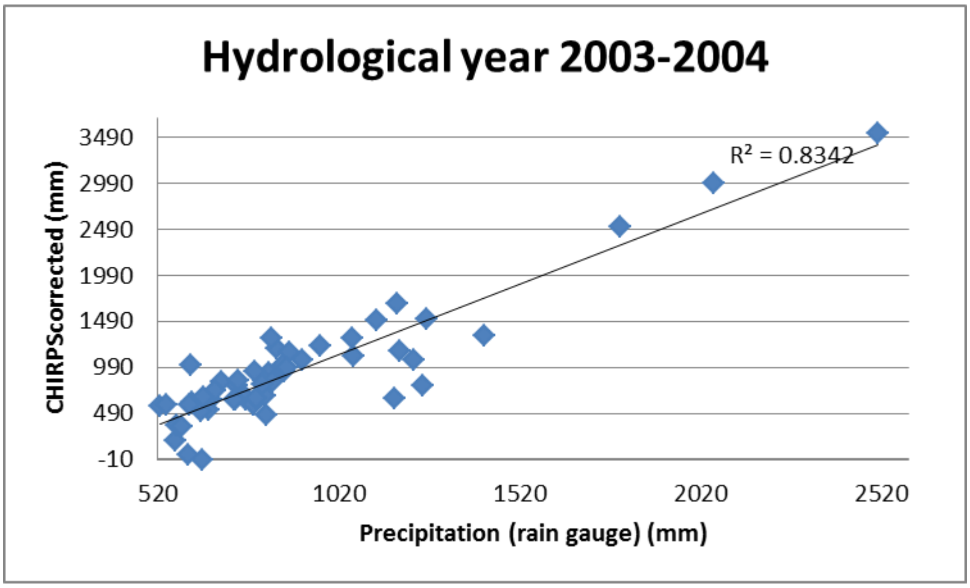


Graph 1. Comparison between CHIRPS and rain gauges

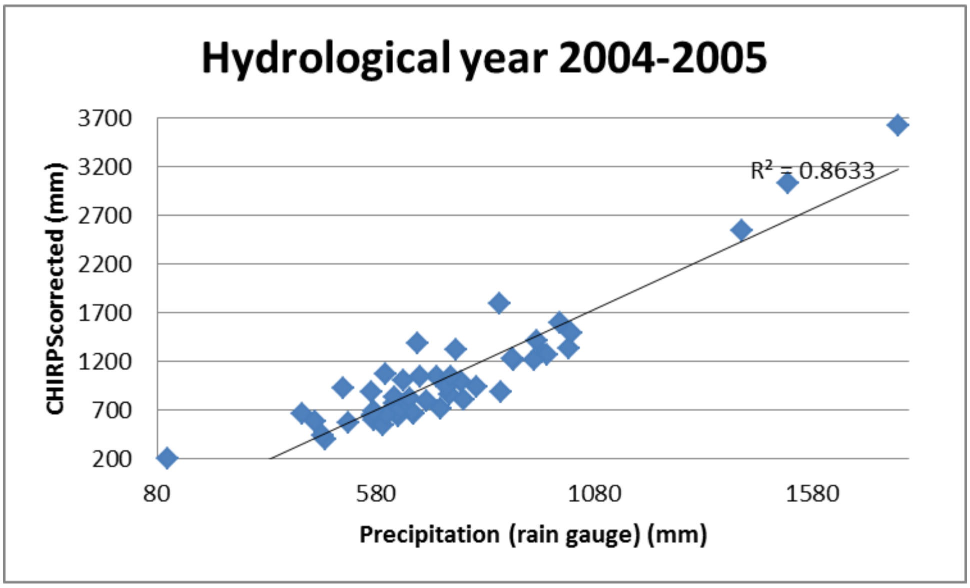


Graph 2. Comparison between CHIRPS and rain gauges

It is obvious that the two forms of data do not have a good correlation. That means that a correction needed to done. The correction was achieved by the creation of a new map, for both hydrological years, called ΔP. More specific, *ΔP= precipitation data from rain gauges-original precipitation data (CHIRPS)*. The following step was the creation of a new 'corrected' map which is the combination of the original precipitation data (CHIRPS) and the created ΔP maps. Specifically, $CHIRPS_{corrected}=CHIRPS_{original}+\Delta P$. Last a new comparison between the $CHIRPS_{corrected}$ data and the ones from the rain gauges was completed (Graph 4).



Graph 3. Comparison between $CHIRPS_{corrected}$ and rain gauges



Graph 4. Comparison between $CHIRPS_{corrected}$ and rain gauges

Following the steps that were described above the new precipitation data ($CHIRPS_{corrected}$) are much more improved and closer to the data obtained from the rain gauges. The $CHIRPS_{corrected}$ are the data that will be for the validation of the actual evapotranspiration.

3.2 Actual evapotranspiration validation

The validation of the actual evapotranspiration and the following ones as well were limited to the Messara catchment. The general equation that was used to validate the evapotranspiration data was the following one:

$$ET_{act} = P - Q \quad (1)$$

Where,

ET_{act} is the actual evapotranspiration [mm/month]

P is the $CHIRPS_{corrected}$ data [mm/year]

Q is the stream data [m^3/year]

The stream data were provided only in six stations in the catchment as they are presented in Figure 4. They were measured only until the hydrological year of 1996-1997. In order to obtain the data for the following years, the factor 0,21 was used, lowering the value of the previous year and this was done stepwise until the year of 2014 (Water Resources Management Plan, 2015).

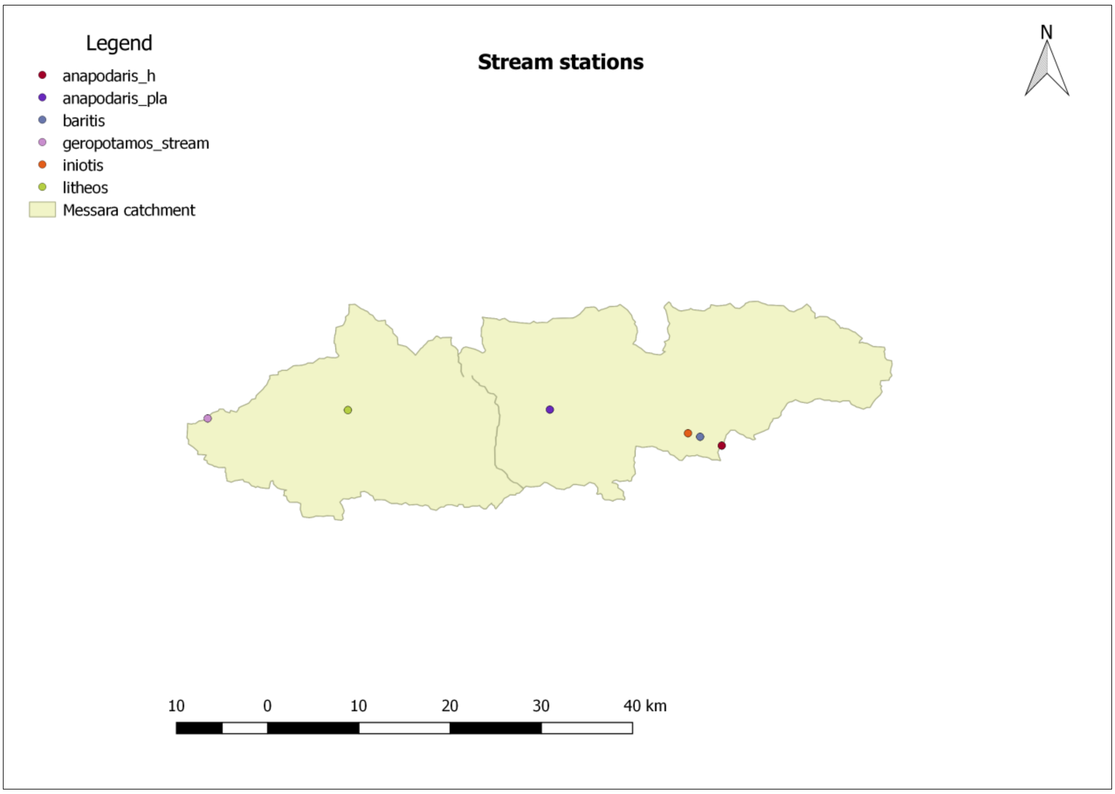


Figure 4. Location of each stream station in the catchment

The first step of the validation was the creation of the hydrological years of 2003-2004 and 2004-2005 for the actual evapotranspiration data by adding the raster files from the September of one year until the August of the next one. The second step was the creation of the watersheds for every station (Figure 5). Then, the area of each watershed was calculated in m^2. This was required because the stream data were given in m^3/year, whereas the evapotranspiration data and the precipitation data in mm/year, so the evapotranspiration and the precipitation data were fist converted in m/year and then multiplied by the area of the watersheds to be obtained in m^3/year.

Thereafter, the evapotranspiration was calculated and plotted against the actual evapotranspiration (Graph 5). It has to be mentioned that two out of the six stations were excluded from the graphical representation because in the calculation of the evapotranspiration the result that was given was negative.

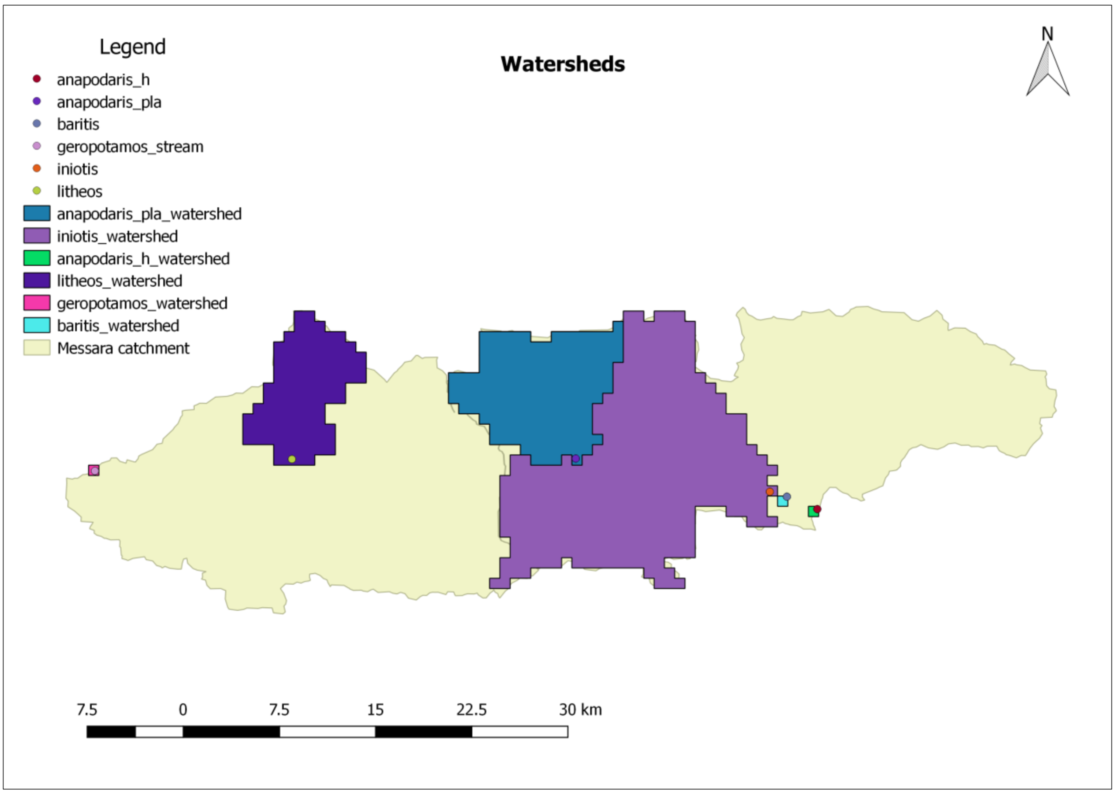
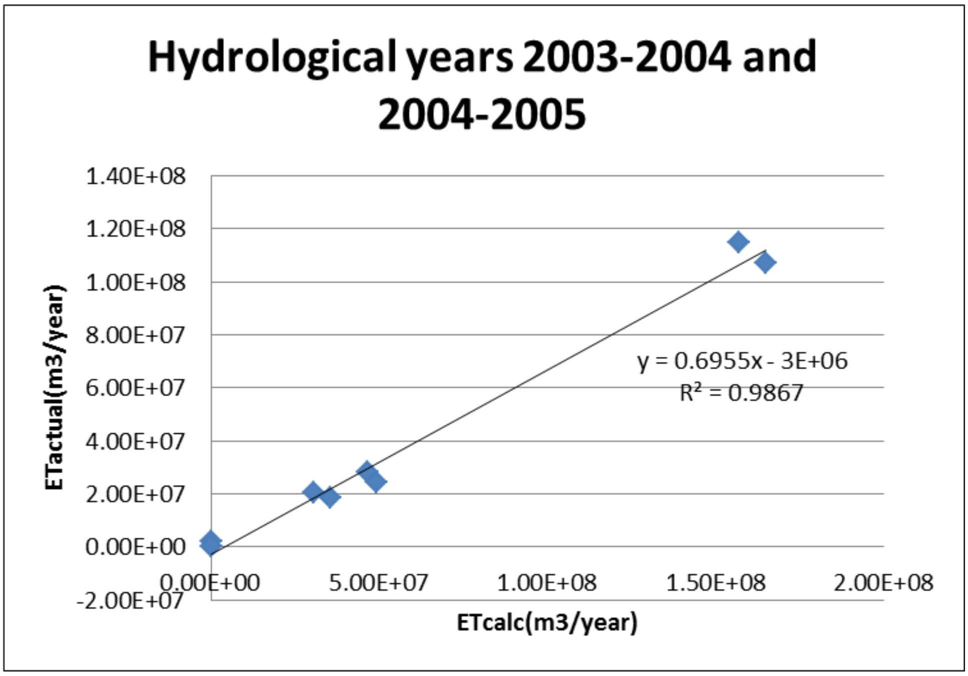


Figure 5. Watershed of each stream station



Graph 5. Comparison between actual and calculated evapotranspiration

As it is seen in the above graph there is a very good correlation between the actual evapotranspiration, which is the ensemple of seven evapotranspiration products, and the calculated evapotranspiration.

3.3 Crop coefficient comparison

This comparison was achieved through the calculation of the crop coefficient being defined as ET_{act}/ET_0, where ET_0 is the FAO56 reference evapotranspiration. Then, those calculated values were compared to the values of the crop coefficients, which are defined as ET_{max}/ET_0, that were obtained from the literature review (Table 3), but first the land use of the area had to be defined.

The data that were provided for the land use were consisted of 21 categories (CORINE, 2012). Those categories were grouped in four main classes (Figure 6). For instance, vineyards, olive groves and other types of cultivation were grouped as “cultivated areas”. Natural pastures, shrubs, etc. were grouped as “non-cultivated areas with sparse vegetation”. Built areas were characterized as others and the last category was the forest areas.

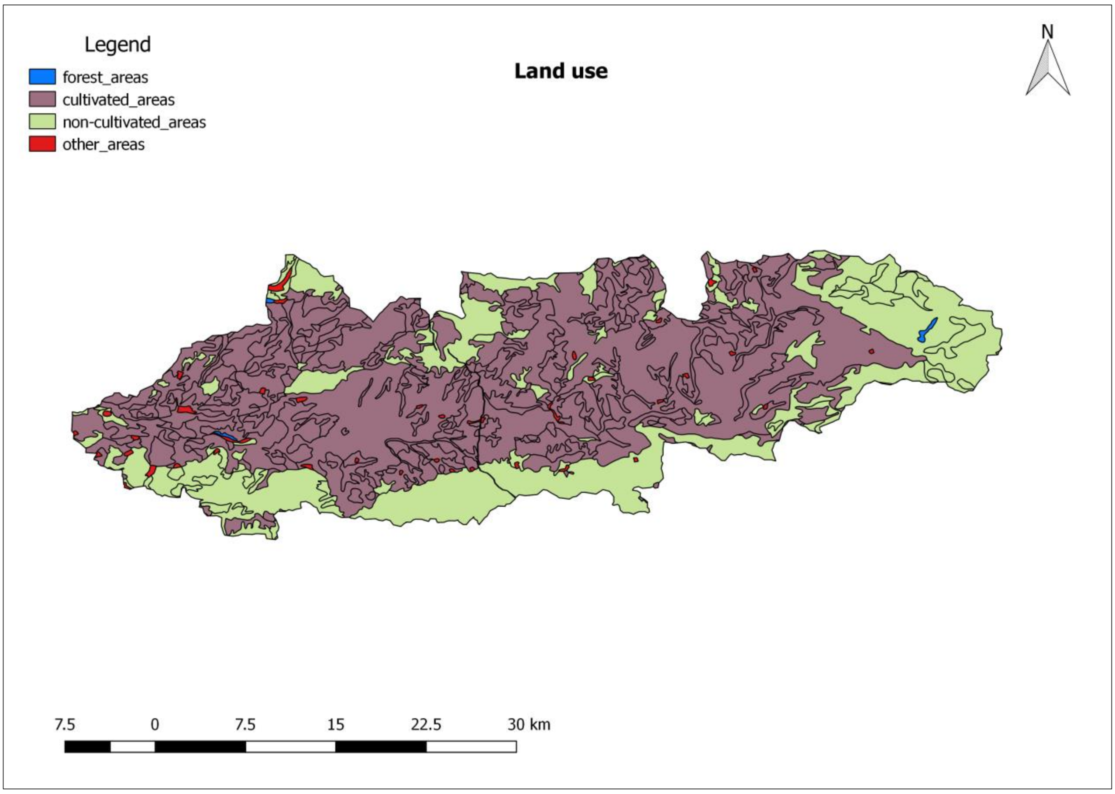


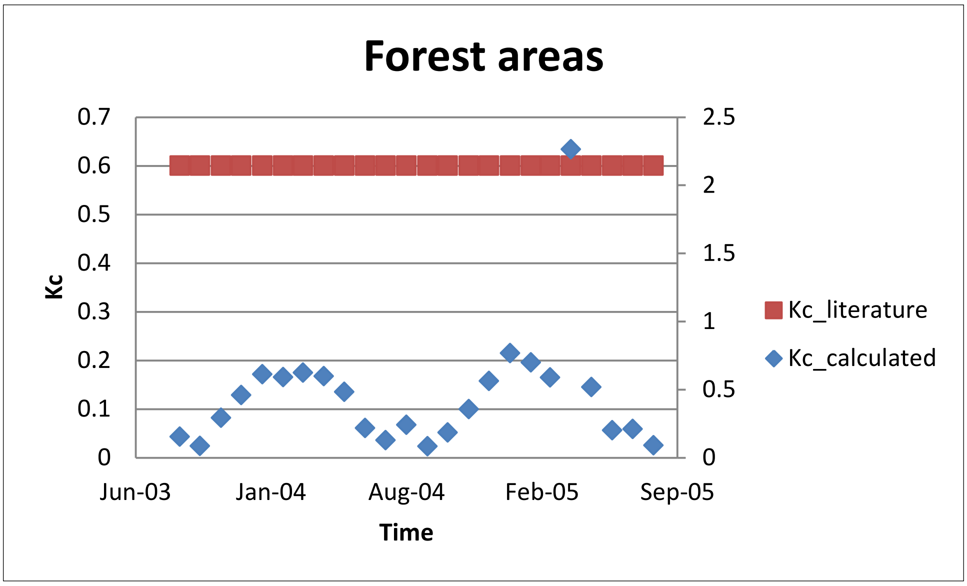
Figure 6. Land use map of the catchment

In Table 3 the average values of the crop coefficients that were used for the comparison are presented.

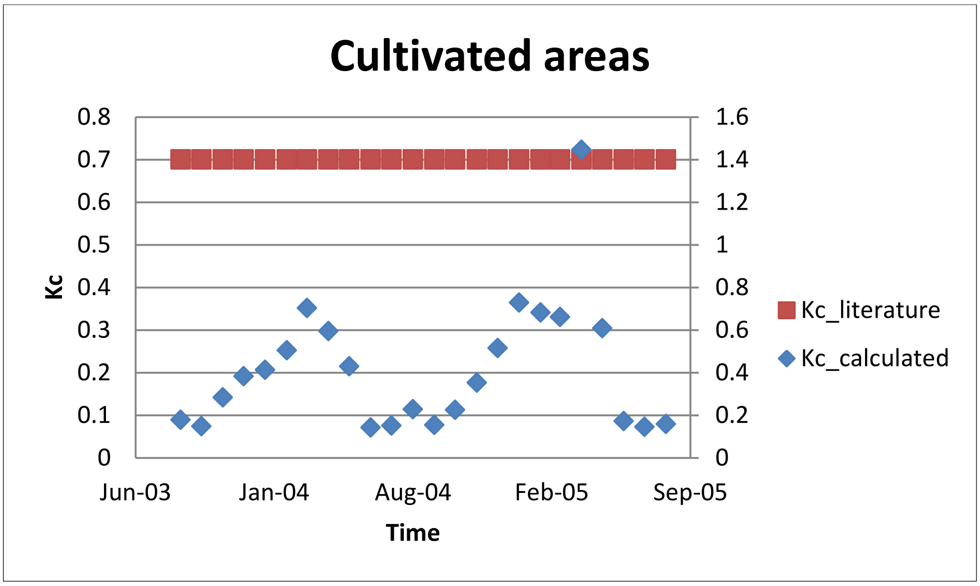
Table 3. Crop coefficients for each land use (Allen et al., 1998; Tsanis et al., 1996;)

Land use	Crop coefficient (K_c)
Forest areas	0,6
Cultivated areas	0,7
Non-cultivated areas with sparse vegetation	0,3
Other areas	0

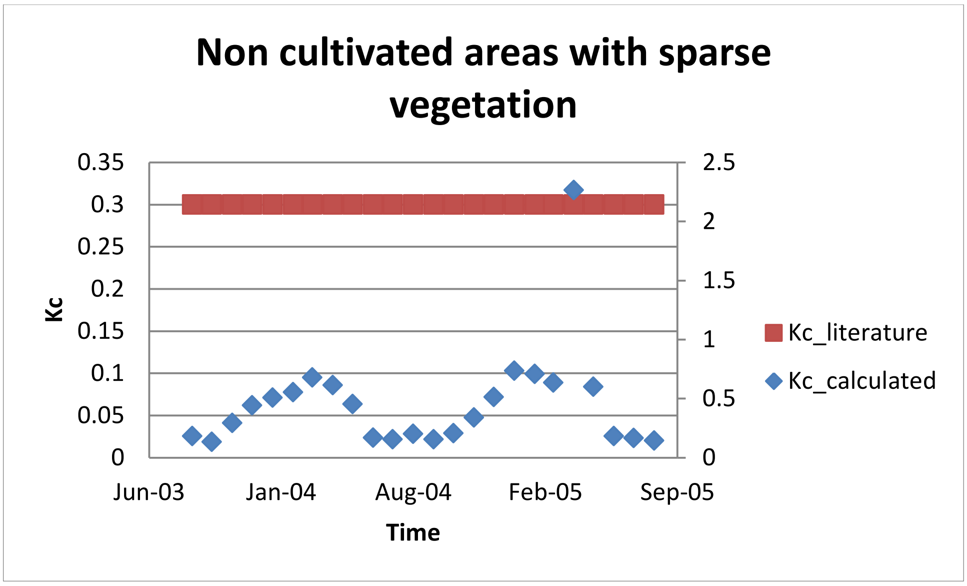
The graphs below present the relation between ET_{act}/ET_0 and ET_{max}/ET_0.



Graph 6. Crop coefficients for forest areas



Graph 7. Crop coefficients for cultivated areas



Graph 8. Crop coefficients for non-cultivated areas with sparse vegetation

There is quite a big difference between the ET_{act}/ET_0 and ET_{max}/ET_0. The main reason for this difference is the existence of water stress within the areas. Another possible reason might be the grouping of the smaller categories in bigger ones for narrowing the number of the investigated land use. A more detailed analysis might have given better results.

Because the above results were not satisfying a frequency distribution of all the pixels will be presented for the months of May and August for 2003, 2004 and 2005 individually to get a better estimation of the situation.

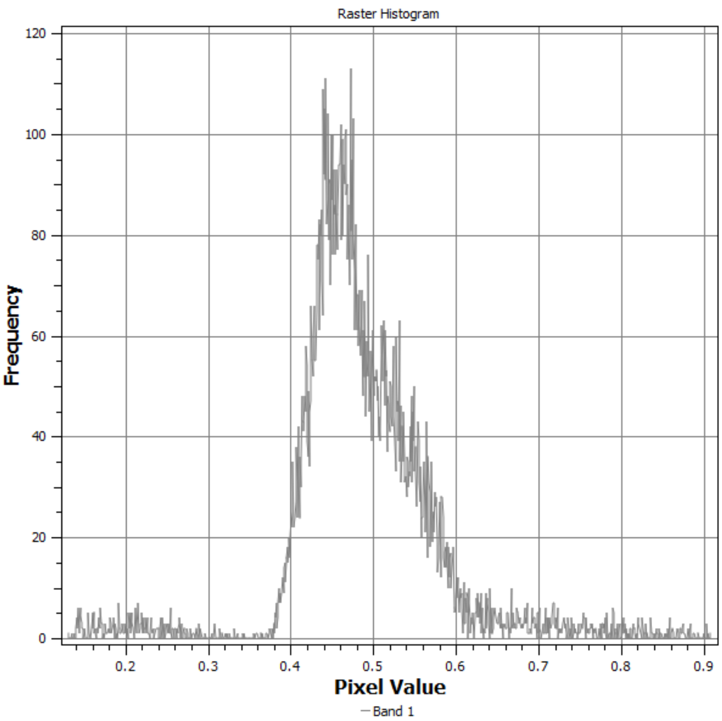


Figure 7. Frequency distribution of all the pixels for the calculated crop coefficient for May 2003

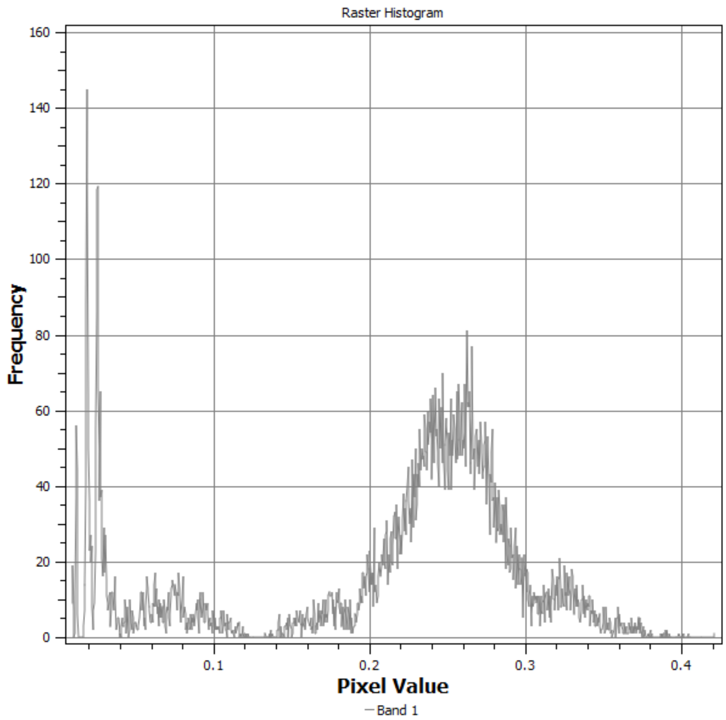


Figure 8. Frequency distribution of all the pixels for the calculated crop coefficient for August 2003

From Figure 7 and Figure 8 we get a more representative idea of how the values of calculated crop coefficients vary throughout each month but more specific which value is the more frequent. For May 2003 the most frequent value of the crop coefficient is approximately 0,45, whereas for the same year but for August is around 0,25. In Graphs 6, 7 and 8 the average values of each month were used, making the validation not so illustrative.

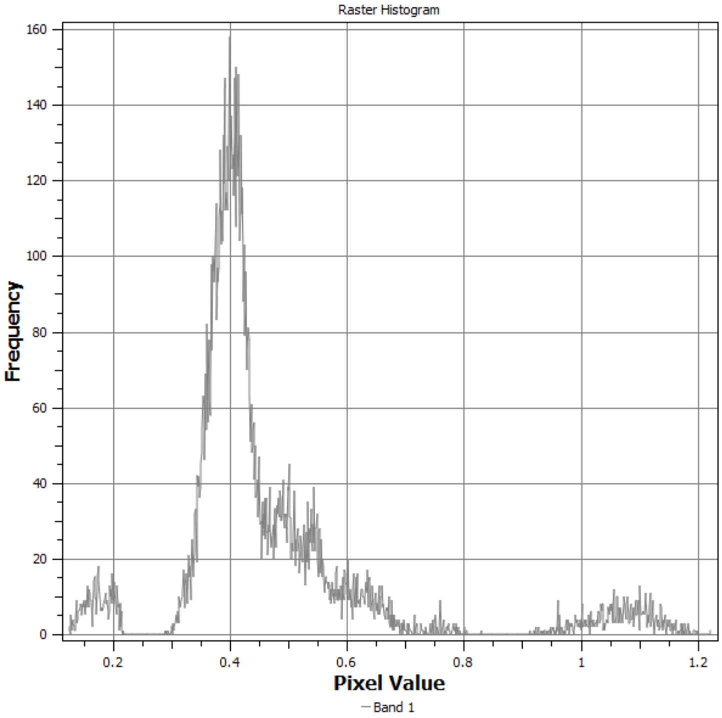


Figure 9. Frequency distribution of all the pixels for the calculated crop coefficient for May 2004

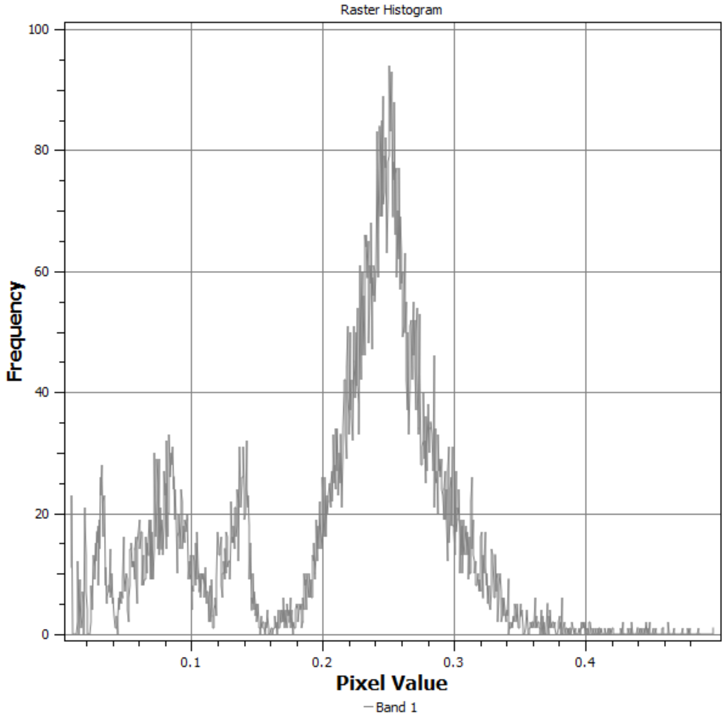


Figure 10. Frequency distribution of all the pixels for the calculated crop coefficient for August 2004

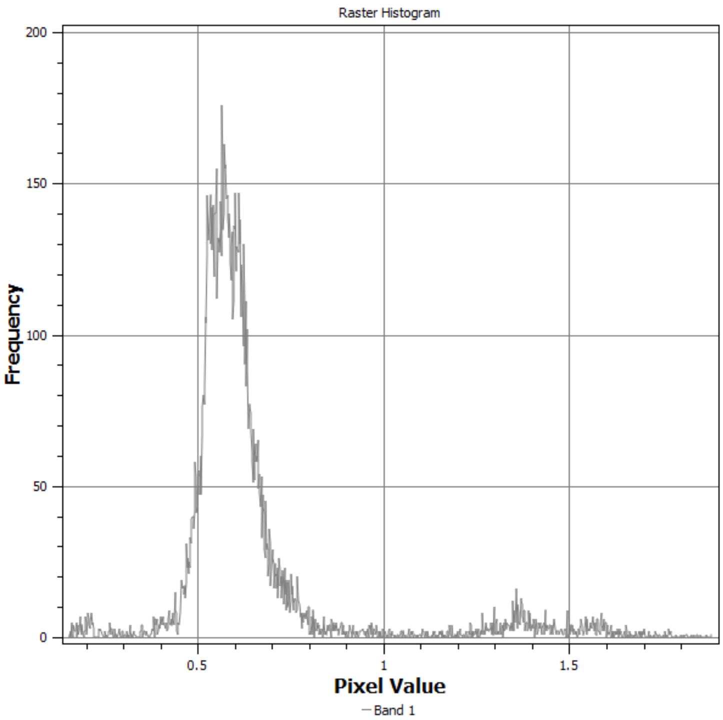


Figure 11. Frequency distribution of all the pixels for the calculated crop coefficient for May 2005

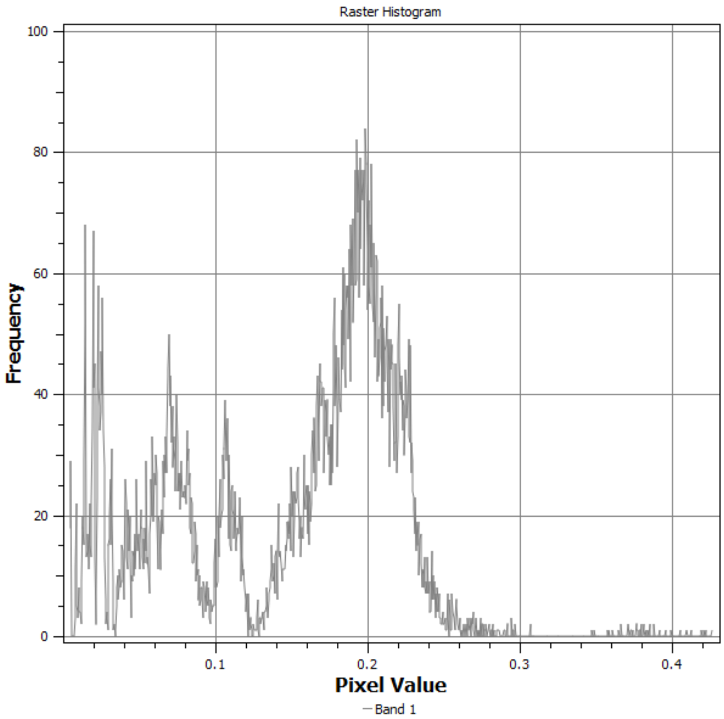


Figure 12. Frequency distribution of all the pixels for the calculated crop coefficient for May 2005

For May 2004 the most frequent value of the crop coefficient is 0,25and for August is around 0,25. For the last year of 2005, on May the value that appears often is approximately 0,55 and on August 0,2.

The values for August of each year appeared to be lower than the ones on May. The most probable reason is because a big amount of the cultivated areas is already harvested before August.

3.4 Calculation of ET_{blue} and ET_{green}

The actual evapotranspiration is separated in the evapotranspiration due to irrigation (blue water) and due to rainfall (green water). The Budyko curve was used to make this separation (Bastiaanssen, 2017).

$$\varphi_t = \frac{\overline{ET\theta}_t}{\bar{P}_t} \quad (2)$$

Where,

φ is the Dryness index [-]

$\overline{ET\theta}$ is the averaged reference Evapotranspiration [mm/month]

$\bar{P}$ is the averaged Precipitation [mm/month]

t is the date [-]

$$\beta = \alpha\sqrt{\varphi_t tanh\frac{1}{\varphi_t}(1 - exp^{-\varphi_t})} \quad (3)$$

Where,

β is the Budyko Index [-]

α is the scaling factor [-]

$$ET_{G,t} = \min(\beta \cdot P_t, ET_{A,t}) \quad (4)$$

Where,

ET_G is the green Evapotranspiration [mm/month]

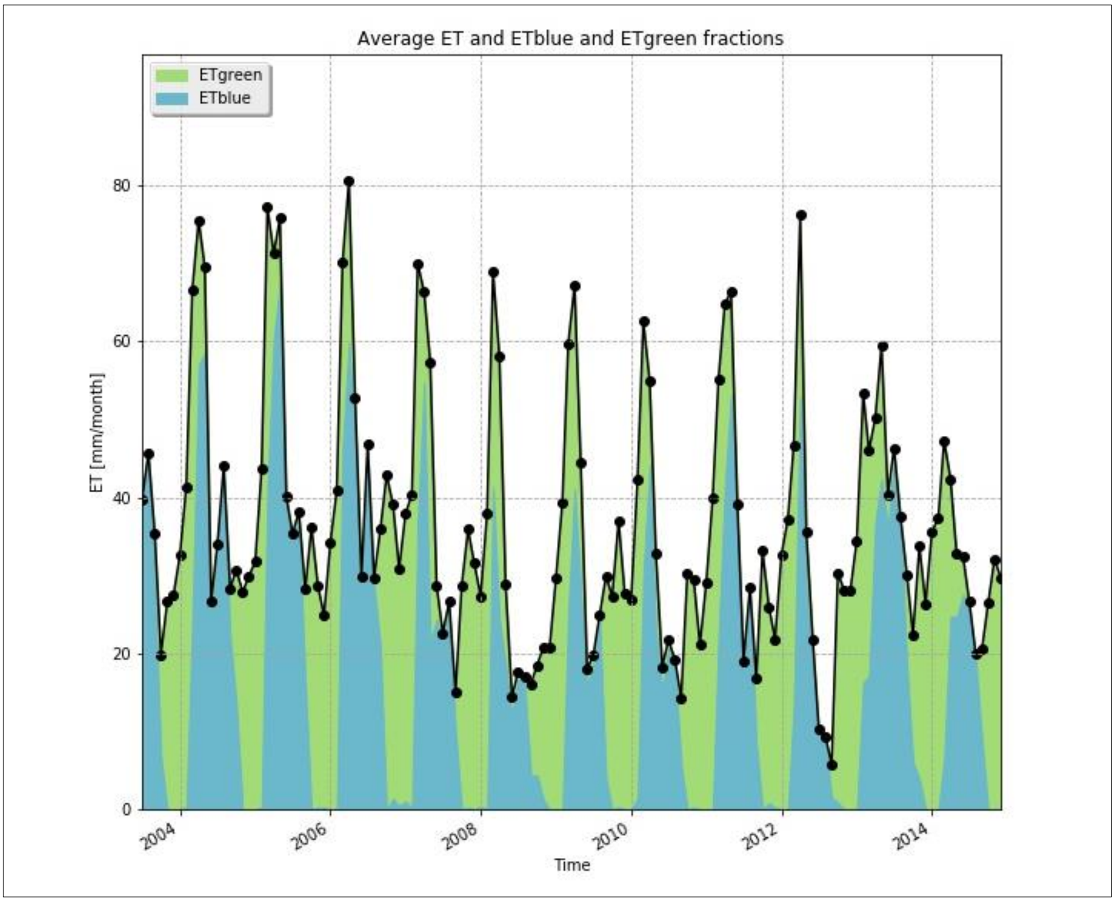
ET_A is the actual Evapotranspiration [mm/month]

$$ET_{B,t} = ET_{A,t} - ET_{G,t} \quad (5)$$

Where,

ET_B is the blue Evapotranspiration [mm/month]

The calculations were made on a monthly basis for each cell, by a script developed by Bert Coever. For every month a plot was made indicating the values of the Dryness index (φ) and the Budyko Index (β). Also a graph indicating the fractions of ET_{blue} and ET_{green} against time was produced (Graph 9). The Budyko curves indicate the separation between the incremental evapotranspiration and the evapotranspiration due to natural processes (Kwast et al., 2016).



Graph 9. Quantification of the fractions of ET_{blue} and ET_{green}

3.5 Water consumption

In order to map the irrigated areas and account the amount of water that is being consumed for irrigation reasons MODIS images were being used. There are certain criteria that had to be met for a pixel to be considered as irrigated for a specific month. Those criteria had to be met for 3 months and more specific for 2 months ago, 1 month ago and the current month. The citeria are the following ones (Kwast, 2016):

- $NDVI_{max}$ > 0.6
- $NDVI_{min}$ > 0.4
- Monthly values of (P-ET_{act}) < 0
- $\sum$(P-ET_{act}) < -200mm

After creating individually those maps for each month, the map with the cultivated areas was also used to produce new, monthly maps, by adding all the above. Those maps were then multiplied by the monthly maps of ET_{blue}(mm/month) that were obtained from the previous step. This calculation resulted in the maps indicating the irrigated areas.

In Figure 13 is presented one map as an example indicating the irrigated areas in white, whereas the black areas are not irrigated.

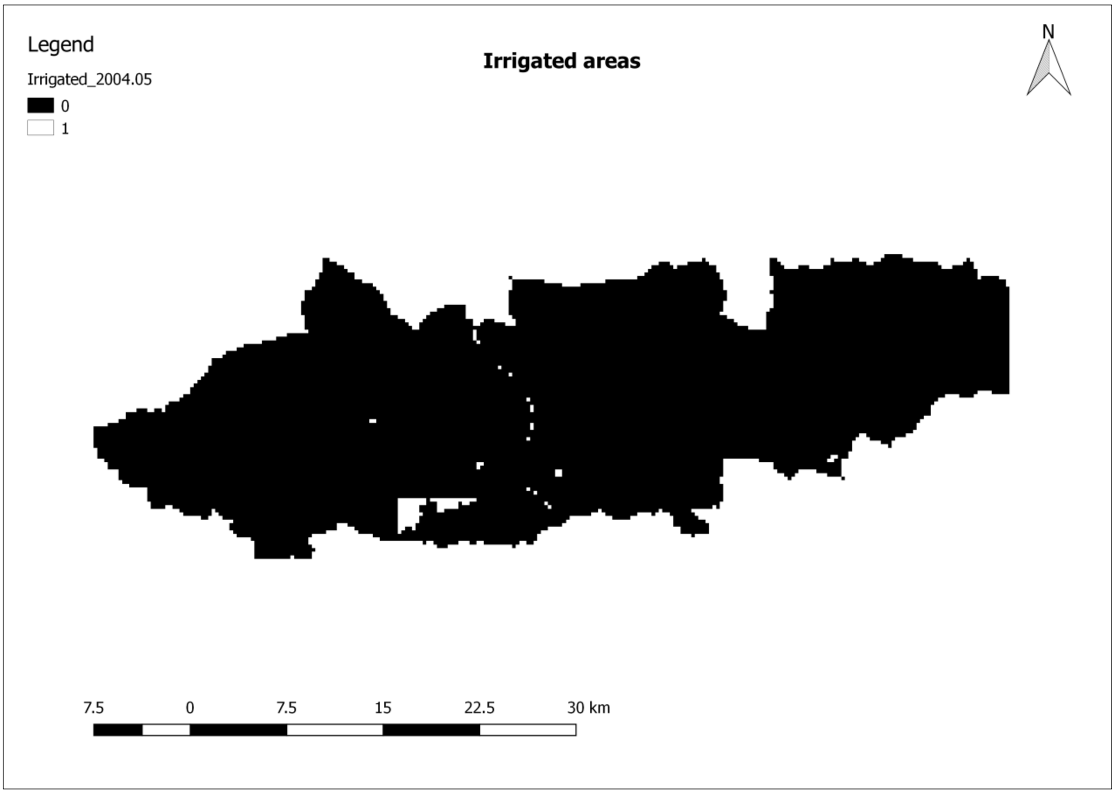
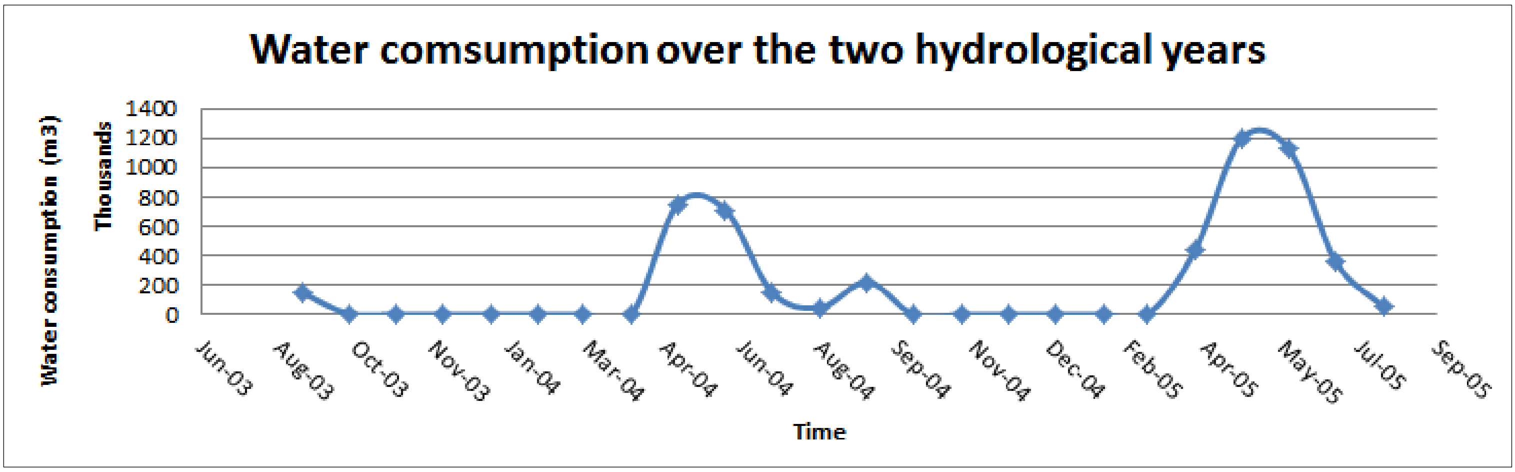


Figure 13. Irrigated areas for the May of 2004

The last step was the calculation of the water consumption. This was achieved by converting the irrigated maps from mm/month to m/month and multiplying them with the area of each pixel, which was 250 × 250m. The outcome of these calculations was to obtain the water that in consumed in m^3/month. The results from the described procedure are presented in Graph 10.



Graph 10. Water consumption in the Messara catchment for the hydrological years of 2003-2004 and 2004-2005

In Graph 10 the variations of the water consumption throughout the under examination years are presented. It is obvious that more water is used for irrigation during the summer seasons and especially on May. It would be expected that the amount of the water that is being irrigated would be higher, but this is not happening. A possible explanation would be that for its calculation the values of the ET_{blue} were used. Those values may not be very representative for the area because the biggest part of the cultivated areas are being greenhouses and not open surface cultivations. The only cultivations that are open surface are olive trees and vineyards, which are being irrigated by drip irrigation, so the water goes immediately to the root and it is not distributed spatially in the surrounded area, meaning that not much water is required.

In Table 4 the irrigated areas (km^2) and the water consumption ($10^3 m^3$) for every month of the two hydrological years are presented, giving us a better understating of how much or the area is being irrigated and the exact amounts of water that are being extracted.

Table 4. Irrigated areas and water consumption for the hydrological years of 2003-2004 and 2004-2005

Time	**Irrigated areas (km^2)**	**Water consumption (10^3 m^3)**
Sep-03	2,5	149,701
Oct-03	0,125	7,859
Nov-03	0	0
Dec-03	0	0
Jan-04	0	0
Feb-04	0	0
Mar-04	0	0
Apr-04	0	0
May-04	6,125	750,344
Jun-04	11,625	710,148
Jul-04	2	154,465
Aug-04	0,75	48,982
Sep-04	3,9375	221,024
Oct-04	0	0
Nov-04	0	0
Dec-04	0	0
Jan-05	0	0
Feb-05	0	0
Mar-05	0	0
Apr-05	3,875	435,657
May-05	12,375	1195,244
Jun-05	14,5	1123,279
Jul-05	4,875	363,065
Aug-05	0,9375	52,613
Sum	**63,625**	**5212,381**

4. Conclusions

The aim of this paper was to map the irrigated areas and account the water consumption in the area of Crete and more specific in the Messara catchment. This catchment was chosen because there is a continuous drawdown in the groundwater table. The remote sensing data that were used as inputs were the precipitation (CHIRPS), the actual evapotranspiration (ETensv1.0.), the reference evapotranspiration (ET_{ref}) and the normalized difference vegetation index (NDVI).

The precipitation data (CHIRPS) were examined and compared to the precipitation data given from rain gauges. From this comparison it resulted that the CHIRPS overestimate the precipitation measurements for the island of Crete. For this reason appropriate corrections needed to be done using a combination of the CHIRPS and the data from the rain gauges, resulting in satisfying results.

As a validation of the method, the calculated evapotranspiration, ET_{calc}, which is on an annual basis equal to the P-Q, was compared to the actual evapotranspiration ET_{act}. This comparison showed that there is a linear relation between them, meaning that the ET_{act} data are very trustworthy and that their resolution in very detailed and accurate.

Proceeding to the crop coefficient comparison the research has shown that the creation of bigger groups of land use, rather than taking into account the type of every single crop that is present in the area does not provide us with good results. The comparison that was done showed big differences between the calculated and the obtained from the literature values. For this reason the frequency distribution plots were presented in order to see how the values are distributed throughout the month and not get a unilateral idea from the average values.

The last part of the research which was actually the main goal of the project was to map the irrigated areas and account the water consumption. The visualization of the irrigated areas was very accurate according to the open surface cultivation that exists in the area. The results for the water consumption were also very satisfying and as they were expected, the higher amount of water that is used for irrigation reasons was mainly for the months of May, June and July.

5. References

Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. *FAO, Rome*, *300*(9), D05109.

Bastiaanssen, W., Coerver, B. (2017), Water Accounting Plus-Formulas, Split ET into ET_{blue} and ET_{green}.

CORINE Land cover 2012 raster data, European Environment agency, http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012.

J van der Kwast, W Bastiaanssen, T Uyttendaele, T Hessels, 2016. Estimating Water Consumption with a 30m Grid for Irrigated Land in Colombia During 2012, The IRRigation Water Consumption tool (IrriWC). UNESCO-IHE.

Tsanis, I. K., Londra, P. A., & Angelakis, A. N. (1996, September). Assessment of water needs for irrigation in Greece. In *II International Symposium on Irrigation of Horticultural Crops 449* (pp. 41-48).

Varouchakis, E. A. (2015). Integrated water resources analysis at basin scale: a case study in Greece. *Journal of Irrigation and Drainage Engineering*, *142*(3), 05015012.

Water resources management plan (in Greek), 2015, Special secretariat for Water, Ministry of Environment and Energy.