

Crop water requirements under present and future climate conditions

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Abstract

The present research work investigates the effects of climate change on crop water requirements in relation to soil water balance of the Pinios delta (Thessaly-Greece) in the frame of the 11SYN_3_1913/AGROCLIMA research project. In this deltaic plain, the dominant activities are related to irrigated agriculture, whose sustainability is depended upon the available surface water resources and the quality of coastal aquifers. Presently, the main cultivations of the area are kiwi and olive tree plantations, maize, alfalfa, sunflowers and cotton. Pinios deltaic plain is part of the NATURA network and is expected to be very sensitive to climate variations and its sustainability will depend on how fresh water supplies meet crop water needs. Therefore, crop water requirements are evaluated utilizing rainfall data, evapotranspiration estimates and soil water balance equations. For the evaluation of evapotranspiration rates the modified FAO 56 Penman-Monteith formula is applied, based on daily meteorological data (temperature, humidity, wind speed, solar radiation), from the recently installed weather station at Palaeopyrgos village. Furthermore, future simulations of crop water requirements are estimated

utilizing the essential crop and climatic data sets derived by the simulations of the RAMCO-2 (KNMI) regional climate model from the ENSEMBLES project, concerning the near future 2021-2050 and the far future 2071-2100 with respect to the reference period 1961-1990 are presented and analyzed. The results of the present study are expected to contribute to sustainable development strategies and mitigate the consequences of climate change.

Keywords: crop water requirements, soil water balance equation, Penman-Monteith formula, climate change, Regional Climate Models-RCMs, ENSEMBLES project, Pinios Delta

1. INTRODUCTION

The coastal zones and especially delta areas are of great environmental and social importance and prone to physical processes and human intervention. Climate change is expected to affect such environments and its multiple effects (Mackay, 2007) should be considered in order to alleviate the risk of environmental degradation.

Pinios river delta plain (Figure 1) has been selected as study area (Poulos *et al*, 2013; Kotsopoulos *et al*, 2014) in the frame of the research project AGROCLIMA of the Operational Programme: “Education and lifelong learning, 2007-2013” of the Hellenic Ministry of Education and Religious Affairs, Culture and Sports that is co-funded by the European Union and the Greek Government. This area is located on the south western coast of Thermaikos Gulf and extends between the Kato Olympus Mountain to the N and NW and Ossa Mountain to the S and SSW.

Pinios river watershed covers the Thessaly plain that is the largest agricultural area in Greece. Under the present water management regime, the available surface and ground water provides only 40-70% of the crop water requirements over much of Thessaly plain and the extensive droughts that occur during critical periods of the growing season are expected to have equally adverse effects Pinios river delta area.

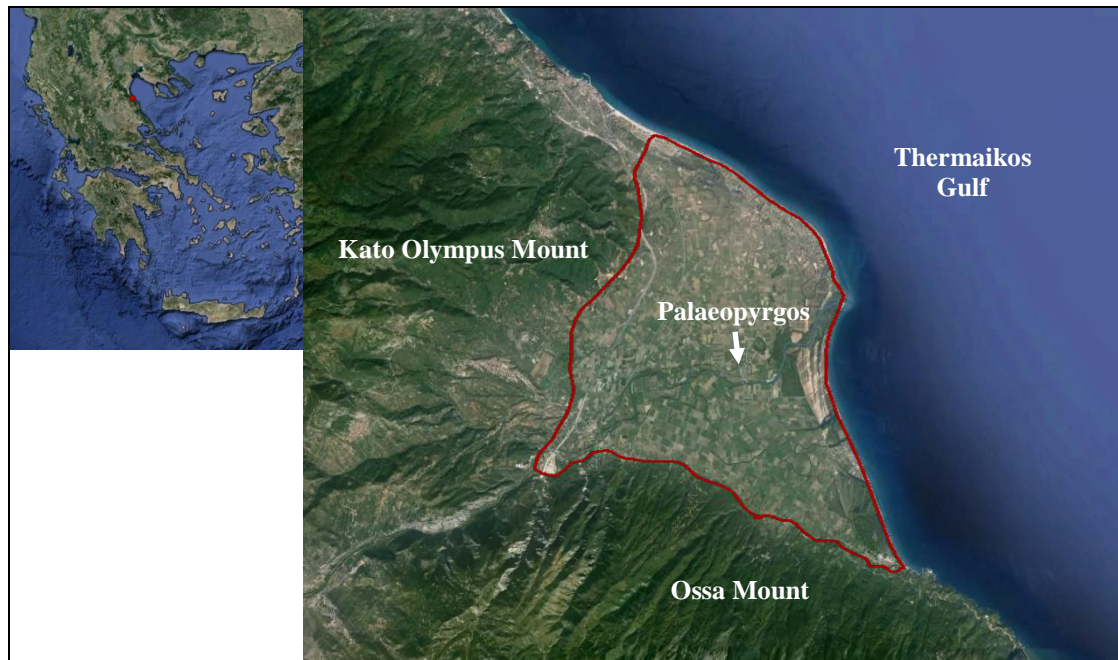


Figure 1. Location map of the project area - Pinios river delta

The present research aims at estimating the effects of climate change on evaporation and evapotranspiration losses in relation to soil water balance of the Pinios delta (Thessaly-Greece). This deltaic plain is mostly cultivated supporting economically the local communities, with its sustainability depended upon the available water resources. Presently, the dominated crops are kiwi and olive tree plantations, alfalfa, maize, sunflowers and cotton while a considerable part of the area is covered by fresh water bodies and natural vegetation. Pinios deltaic plain is under “special protection” according to the Directive 79/409/EEC, NATURA 2000 (GR1420002) and is expected to be very sensitive to climate variations. Its sustainability will depend on, among other facts, how fresh surface and ground water supplies meet crop water needs.

2. MATERIALS AND METHODS

Evaporation and evapotranspiration are principal components for planning, design, operation and management of irrigation and water resources systems. Their evaluation is mostly based on experimental formulae that utilise meteorological data sets. Until recently, there were not any meteorological stations into the main part of the study area. Therefore, it was essential and one

such station has been installed (January 2013) at the central part of Pinios river delta at Palaepyrgos village (39°55'2.6''N, 22°40'50.4''E, Figure 1) to record air temperature, relative humidity, rainfall, barometric pressure, wind speed and direction and solar radiation.

The evaluation of crop water requirements (crop evapotranspiration, ET_c) and free water surface evaporation, E , is based on the reference evapotranspiration, ET_o and the crop coefficient approach, K_c (Doorenbos and Pruitt, 1977; Jensen *et al*, 1990; Allen *et al*, 1998; Kotsopoulos *et al*, 2003; Kotsopoulos, 2006; Alexiou, 2000; Kotsopoulos *et al*, 2009). Nowadays, the most reliable method for such calculations is considered the modified Penman-Monteith equation, as described in FAO-56 (Allen *et al*, 1998; Kotsopoulos *et al*, 2003; Kotsopoulos, 2006). This method overcomes the shortcomings of the previous FAO-24-Penman method (Doorenbos and Pruitt, 1977) and provides ET_c estimates more consistent worldwide (Allen *et al*, 1998; Kotsopoulos *et al*, 2003). The method is applied in two stages. Initially the evapotranspiration of the reference crop is calculated and then crop evapotranspiration is estimated using the corresponding crop coefficient as shown in the following relation:

$$ET_c = K_c \cdot ET_o \quad (2.1)$$

where ET_c the crop evapotranspiration (mm/d), K_c the crop coefficient which is dependant upon the crop development stage (Doorenbos and Pruitt, 1977; Jensen *et al*, 1990; Allen *et al*, 1998; Kotsopoulos, 2006), and ET_o the evapotranspiration of the reference crop (mm/d).

The formulation of the reference evapotranspiration, ET_o , based on the revised FAO-56 Penman-Monteith equation (Allen *et al*, 1998; Kotsopoulos *et al*, 2003; Kotsopoulos, 2006; Alexiou, 2000; Kotsopoulos *et al*, 2009), is expressed as follows:

$$ET_o = \frac{0.408 \cdot \Delta \cdot (R_n - G) + \gamma \cdot \frac{900}{T + 273} \cdot u_2 \cdot (e_s - e_a)}{\Delta + \gamma \cdot (1 + 0.34 \cdot u_2)} \quad (2.2)$$

where ET_o reference evapotranspiration (mm/d), R_n net radiation at the crop surface ($\text{MJ m}^{-2}\text{d}^{-1}$), G soil heat flux density ($\text{MJ m}^{-2}\text{d}^{-1}$) which for daily intervals may be ignored, thus $G \approx 0$, T

mean daily temperature at 2m height ($^{\circ}\text{C}$), u_2 wind speed at 2m height (ms^{-1}), e_s saturation vapour pressure (kPa), e_a actual vapour pressure (kPa), $e_s - e_a$ saturation vapour pressure deficit (kPa), Δ slope saturation vapour pressure curve at temperature T ($\text{kPa } ^{\circ}\text{C}^{-1}$) and γ psychrometric constant ($\text{kPa } ^{\circ}\text{C}^{-1}$).

Apart from the data mentioned above, for the calculation of crop evapotranspiration are required:

- a) the values of the crop coefficients during the various growth stages which are taken from FAO-56 (Allen *et al*, 1998); these values have been found suitable for the local climatic conditions (Kotsopoulos *et al*, 2003; Kotsopoulos, 2006),
- b) The duration of the growth stages. The later are modified in order to incorporate into calculations the local conditions (Kotsopoulos, 2006).

For the evaluation of crop water requirements, WR_c , the amount of effective rainfall, P_e , is required and simple or more complex procedures are available for its estimation (Stamm, 1967; Doorenbos and Pruitt, 1977; Tsakiris, 2006). These P_e values estimated on a monthly basis are utilized to evaluate crop water requirements, WR_c , via the equation:

$$WR_c = ET_c - P_e \quad (2.3)$$

where WR_c crop water requirements (mm/month), ET_c the crop evapotranspiration (mm/month) and P_e effective rainfall (mm/month).

3. RESULTS AND DISCUSSION

The results refer to evapotranspiration [Eq. (2.1) and (2.2)] and crop water requirement estimates [Eq. (2.3)]. For the application of the FAO 56 method the calculation of various parameters related to extraterrestrial radiation, maximum sunshine duration, saturation vapour pressure etc. is required and selected equations (Kotsopoulos and Babajimopoulos, 1997; Kotsopoulos, 2006) have been used.

The daily climatic data from the meteorological station at Palaeopyrgos for the period January 2013 to July 2014 are utilised to calculate daily reference evapotranspiration rates, ET_o [Eq. (2.2)]. The average values of these data and their periodic mean (Yevjevich, 1982) are presented in Figure 2. This figure exhibits the range and periodicity of ET_o . Average ET_o ranges from 0.56mm/day during winter (December) to 4.91mm/day during summer (July). Similar results have been taken from the meteorological data at Stomio (Kotsopoulos *et al*, 2014).

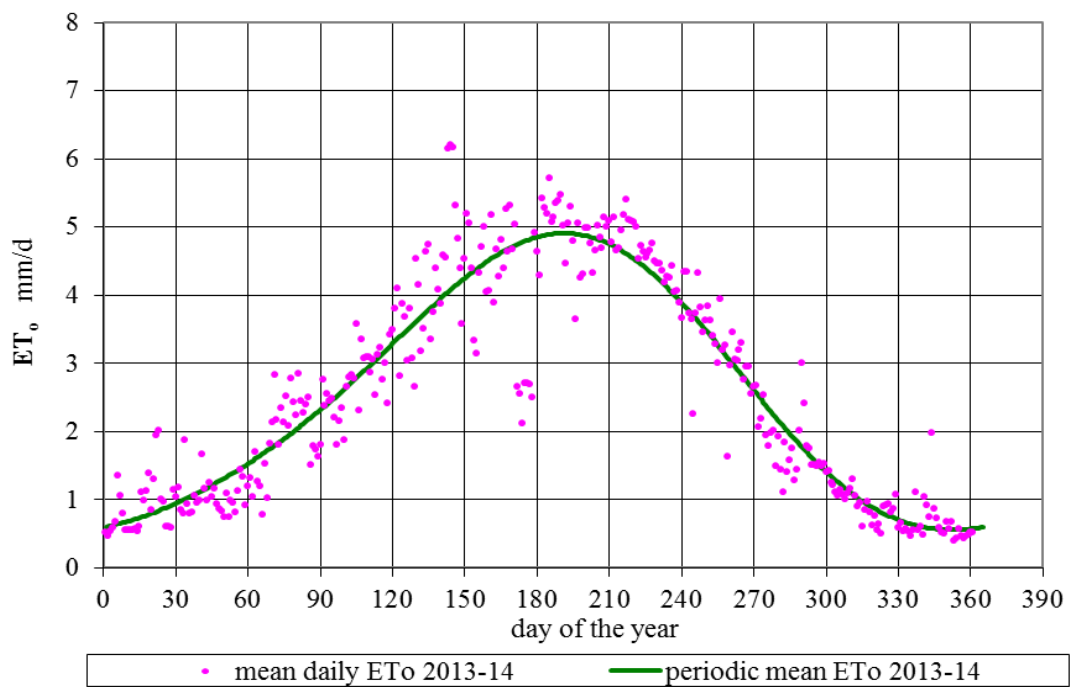


Figure 2. Average daily estimated ET_o and periodic mean for the period 2013-14 at Palaeopyrgos Larissa

Additional datasets are required for ET_o calculation and analysis in order to investigate the impact of the climate change on Pinios river delta. These data sets concern daily average values of air temperature, relative humidity, wind speed and total solar radiation, which are gridded values (spatial resolution $0.22^\circ \times 0.22^\circ$; approximately 25km x 25km) derived by the simulations of the RAMCO-2 (KNMI, Royal Netherlands Meteorological Institute, the Netherlands) regional climate model (Meijgaard *et al*, 2008) for the near future 2031-2050 and the far future 2071-2100 with respect to the reference period 1961-1990, under A1B scenario, which describes a future world of very rapid economic growth. The changes in the land use will

not be enormous while the world population continues increasing rapidly up to year 2050 when it reaches about 9 billions and afterwards decreasing progressively. A1B is distinguished by balance across all energy sources (fossil or non-fossil energy sources), which will have an impact of increase of CO₂ emissions within the 21st century, reaching the concentration of 720 ppm until the year of 2100 (IPCC, 2007).

The present version of RACMO, version 2, consists of the physics package of the global circulation model of the ECMWF (European Centre for Medium-Range Weather Forecasts) embedded in the dynamical kernel of the numerical weather prediction model HIRLAM (High Resolution Limited Area Model). Recently RACMO has been identified as the best European regional climate model participating in the ENSEMBLES project. The model's simulations used as initial and boundary conditions the output data of the ECHAM5 General Circulation Model (GCM).

The simulated daily data sets over three thirty-year periods (1961-90, 2021-50 and 2071-2100) produce three thirty-year daily ET_o rates. These rates exhibit an increasing trend. The average annual ET_o varies (beginning-end) from 2.91 to 2.93 mm/day during the period 1961-90, from 3.02 to 3.22 mm/day during the period 2021-50 and from 3.30 to 3.47 mm/day during the period 2071-2100.

In Figure 3 the periodic average daily ET_o rates during the periods 2013-14, 2047-50 and 2097-2100 are presented. Figure 3 shows clearly the increase of ET_o rates in the near and far future.

The results presented in Figure 3 are utilized to evaluate total crop evapotranspiration during the growing period of six main crops of the study area namely kiwi and olive tree plantations, alfalfa, maize, sunflowers and cotton. The simulation results incorporate crop coefficients, K_c [Eq. (2.1), (2.2)] (Allen *et al.*, 1998; Kotsopoulos, 2006) and are presented in Table 1. This table shows how total crop evapotranspiration rates, ET_c , vary from period to period. They currently vary from ~450 mm/year (sunflower) to ~770 mm/year (kiwi). The most water consuming crop is kiwi and is followed by alfalfa while sunflower is consuming the least. Total ET_c is expected to increase on average from 536 to 931 mm/year during the period 2047-50 and from 577 to 980

mm/year during the period 2097-100. Table 1 presents also the percentage differences of total crop evapotranspiration for the near (2021-50) and far future (2071-2100) in relation to the reference period 2013-14. These differences may reach 22% and 29% for the two periods respectively.

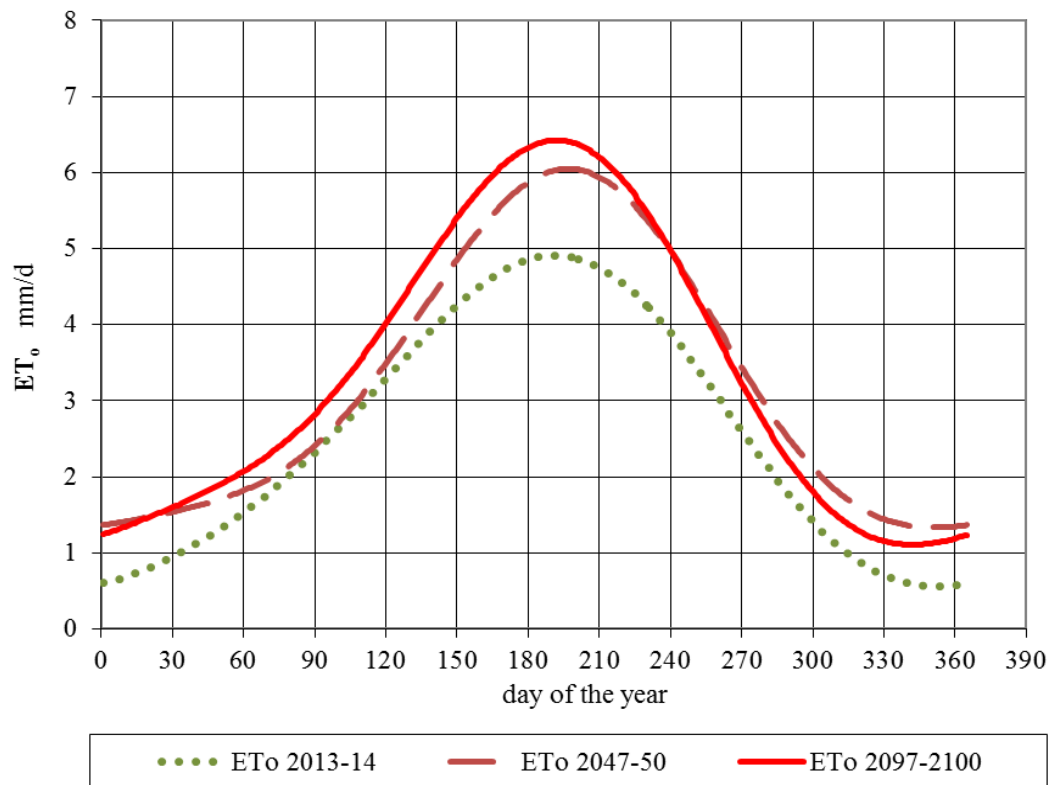


Figure 3. Estimated daily periodic ET_0 for the periods 2013-14, 2047-50 and 2097-00 at Palaioopyrgos Larissa

Of great importance for irrigation water scheduling is the evaluation of seasonal crop evapotranspiration and the seasonal crop water requirements. These seasonal values refer to summer months (June, July and August). The most water consuming crops during the summer period is maize and is kiwi and the least consuming ones are olive and sunflower. Currently, the average seasonal ET_c , as shown in Table 2, may be for maize as high as ~470 mm that is over 50% higher than that of olive (295 mm). Table 2 presents the increase in seasonal ET_c values in the near and far future. These differences may reach 23% and 30% for the two periods respectively.

Table 1. Average total crop evapotranspiration, ET_c , in mm/year for kiwi, olive, alfalfa, maize, sunflower and cotton during the periods 2011-13, 2047-50 and 2097-2100

period	Average total crop evapotranspiration, ET_c , (mm/year)					
	ET_{kiwi}	ET_{olive}	$ET_{alfalfa}$	ET_{maize}	$ET_{sunflower}$	ET_{cotton}
2013-14	769	590	682	565	448	543
2047-50	931 21,1% *	719 21,9% *	815 19,5% *	684 21,1% *	536 19,6% *	664 22,3% *
2097-2100	980 27,4% **	753 27,6% **	870 27,6% **	729 29,0% **	577 28,8% **	699 28,7% **

* Percentage difference of total ET_c during the period 2047-50 to that during 2013-14

** Percentage difference of total ET_c during the period 2097-2100 to that during 2013-14

Table 2. Average seasonal (summer month) crop evapotranspiration, ET_c , in mm/season for kiwi, olive, alfalfa, maize, sunflower and cotton during the periods 2011-13, 2047-50 and 2097-2100

period	Average seasonal (summer) crop evapotranspiration, ET_c , (mm/season)					
	ET_{kiwi}	ET_{olive}	$ET_{alfalfa}$	ET_{maize}	$ET_{sunflower}$	ET_{cotton}
2013-14	444	295	401	467	304	412
2047-50	544 22,5% *	362 22,7% *	491 22,4% *	573 22,7% *	368 21,1% *	506 22,8% *
2097-2100	575 29,5% **	382 29,5% **	520 29,7% **	606 29,8% **	395 29,9% **	535 29,9% **

* Percentage difference of seasonal ET_c during the period 2047-50 to that during 2013-14

** Percentage difference of seasonal ET_c during the period 2097-2100 to that during 2013-14

Greater percentage differences are expected for seasonal crop water requirements, WR_c , due to the significant expected decrease in rainfall and hence effective rainfall P_e in the near (2021-2050) and far future (2071-2100). These differences are presented in Table 3 and may be as high as 42% and 53% for the two periods respectively.

Table 3. Average seasonal (summer month) crop water requirements, WR_c , in mm/season for kiwi, olive, alfalfa, maize, sunflower and cotton during the periods 2011-13, 2047-50 and 2097-2100

period	Average seasonal (summer month) crop water requirements, WR_c , in mm/season					
	WR_{kiwi}	WR_{olive}	$WR_{alfalfa}$	WR_{maize}	$WR_{sunflower}$	WR_{cotton}
2013-14	399	250	356	422	259	367
2047-50	536 34,6% *	354 42,0% *	483 35,9% *	565 34,1% *	360 39,4% *	498 36,0% *
2097-2100	575 44,3% **	382 53,1% **	520 46,3% **	606 43,8% **	395 52,8% **	535 46,0% **

* Percentage difference of seasonal WR_c during the period 2047-50 to that during 2013-14

** Percentage difference of seasonal WR_c during the period 2097-2100 to that during 2013-14

4. CONCLUSIONS

From the estimated total crop evapotranspiration, seasonal crop evapotranspiration and seasonal crop water requirements at the Pinios delta area it may be concluded that:

- The average total crop evapotranspiration is related to crop species and is currently ranging from ~450 mm/year (sunflower) to ~770 mm/year (kiwi).
- Presently, the average seasonal (summer period) crop evapotranspiration and crop water requirements are also related to crop species and vary from 295-467 mm and from 250-422 mm for olive (the least) and maize (the most consuming crop).
- Concerning the climate change scenarios, the total crop evapotranspiration, the seasonal crop evapotranspiration and the seasonal crop water requirements are expected to increase in the near (2021-2050) and far future (2071-2100):
 - ✓ In relation to total crop evapotranspiration, from ~20% (alfalfa and sunflower) to ~29% (maize, sunflower, cotton) at the end of these periods respectively.
 - ✓ In relation to seasonal crop evapotranspiration, from ~21% (sunflower) to ~30% at the end of these periods respectively.
 - ✓ In relation to seasonal crop water requirements, from ~34% (maize) to ~53% (olive, sunflower) also at the end of these periods respectively.

- Currently as well as in the near and far future, the most water consuming crops, in relation to total crop evapotranspiration and seasonal crop water requirements, are kiwi and maize.

The results of the present study exhibit the current and future trends on the parameters total crop evapotranspiration, seasonal crop evapotranspiration and seasonal crop water requirements that affect agricultural activities such as irrigation water delivery. These results would contribute to sustainable development strategies and, if taken into account, may mitigate the consequences of climate change.

Acknowledgements

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