EVAPORATION, EVAPOTRANSPIRATION AND CROP WATER REQUIREMENTS UNDER PRESENT AND FUTURE CLIMATE CONDITIONS AT PINIOS DELTA PLAIN

KOTSOPOULOS S.I.[1], **NASTOS P.**[2], **LAZOGIANNIS K.**[1,2,4], **POULOS S.E.**[2], **GHIONIS G.**[2], **ALEXIOU I.**[1], **PANAGOPOULOS A.**[3], **FARSIROTOU E.**[1] **and ALAMANIS N.**[1]

[1] Department of Civil Engineering T.E., Technologic Education Institute (TEI) of Thessaly, 41110 Larissa, Greece, [2] Department of Geography and Climatology, Faculty of Geology and Geoenvironment, University of Athens, Panepistimioupoli, Zografou, Athens, Greece, [3] Institute of Land Reclamation, ELGO-DIMITRA S.A., Industrial area, 57400 Sindos, Thessaloniki, Greece, [4] Department of Marine Sciences, University of the Aegean, University Hill, 81100 Mytilene, Lesvos, Greece
E-mail: kotsopoulos@teilar.gr,

ABSTRACT

Evaporation and evapotranspiration and crop water requirements estimates are essential for design, operation and management of irrigation projects and are prerequisites for optimal water resources management especially of agricultural areas prone to water deficits. Such estimates are related to the prevailing climate conditions and are expected to vary in future due to climate change.

The present study investigates the effects of climate change on evaporation, evapotranspiration and crop water requirements in relation to soil water balance of the Pinios delta plain. This deltaic plain is mostly agricultural, with its sustainability dependent upon the available water resources, which are very prone to water shortages and the salinization of coastal aquifers. Presently, the dominant crops of the area are kiwi and olive tree plantations, maize, alfalfa, cotton and sunflowers, while a considerable part is covered by fresh water bodies and natural vegetation. Pinios river deltaic plain is part of the NATURA network and is expected to be very sensitive to climate variations. Its sustainability will depend, among other factors, on how fresh water supplies meet crop water needs. Therefore, evaporation and evapotranspiration losses are estimated and the modified FAO 56 Penman-Monteith formula is utilised, based on daily meteorological measurements - temperature, humidity, wind speed, global solar radiation. Crop water requirements, in addition to the aforementioned climatic variables, incorporate daily precipitation data. All these data sets are recordings from the recently installed weather station at Stomio village.

Furthermore, future simulations of evaporation, evapotranspiration and crop water requirements based on the outcomes 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. These results would contribute to the development of sustainable development strategies of the study area and mitigate the consequences of climatic change.

Keywords: climate change, evaporation, crop evapotranspiration, Penman-Monteith formula, Regional Climate Models-RCMs, ENSEMBLES project, Pinios Delta

1. Introduction

In the frame of the research project THALES-DAPHNE (MIS: 375908) the Pinios river delta plain (Poulos *et al.,* 2013) has been selected as study area. This area is located on the western coast of south 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, the largest agricultural area in Greece. Presently, the available surface and ground water resources of the area may suffice only for 40-70% of the crop water requirements and the extensive droughts that occur during critical periods of the growing season are expected to have equally adverse effects on Pinios river delta area. The present research aims at estimating the effects of climate change on evaporation and evapotranspiration losses of Pinios river deltaic plain. This plain is mostly cultivated and its sustainability depends upon the available water resources. 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. Since there were not any meteorological stations into the main part of the study area, it was essential and one such station has been installed (June 2011) at the SE part of Pinios delta at Stomio village (39^{o}52.2' N, 22^{o}43.8' E) to record air temperature, relative humidity, rainfall, barometric pressure, wind speed and direction and solar radiation.

The evaluation of 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 & Pruitt, 1977; Allen *et al.,* 1998; Alexiou *et al.* 2000; Kotsopoulos *et al.* 2003; Kotsopoulos, 2006). Nowadays, the most reliable method for such calculations is considered the modified Penman-Monteith equation, as described in FAO-56 (Allen *et al* 1998). The method is applied in two stages. Initially the evapotranspiration of the reference crop, ET_o, is calculated via the formula:

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

where ET_o reference evapotranspiration (mm/d), R_n net radiation at the crop surface (MJ m^{-2} d^{-1}), G soil heat flux density (MJ m^{-2} d^{-1}) which for daily intervals may be ignored, thus $G \approx 0$, T mean daily temperature at 2m height (^{o}C), u_2 wind speed at 2m height (m s^{-1}), e_s saturation vapour pressure (kPa), e_a actual vapour pressure (kPa), Δ slope saturation vapour pressure curve at temperature T (kPa ^{o}C^{-1}) and γ psychrometric constant (kPa ^{o}C^{-1}).
Then the crop evapotranspiration or the free water surface evaporation is estimated using the corresponding crop coefficient as shown in the following relation:

$$ET_c = K_c \cdot ET_o \quad \text{or} \quad E = K_c \cdot ET_o \qquad (2)$$

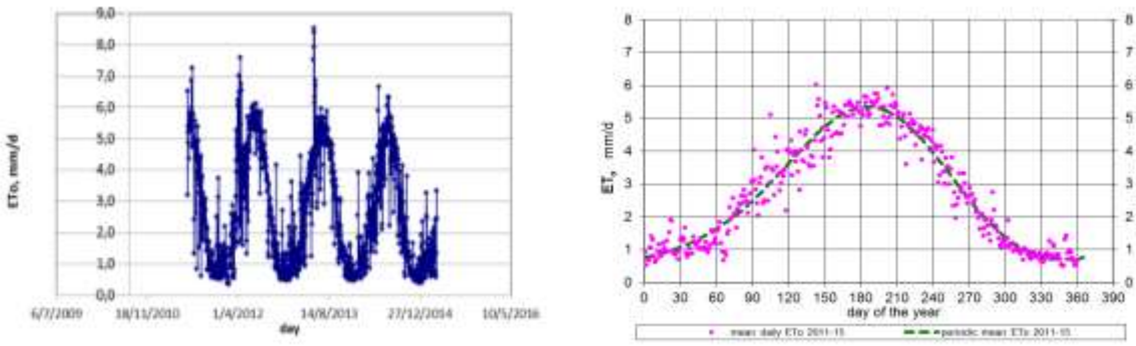
where ET_c the daily evapotranspiration or free water surface evaporation, E, (mm/d), K_c the crop (surface) coefficient which is dependant upon the crop development stage, and ET_o the evapotranspiration of the reference crop (mm/d).
Finally, for the evaluation of crop water requirements, WR_c, the amount of effective rainfall, P_e, is required (Doorenbos and Pruitt, 1977; Tsakiris, 2006). These P_e values estimated on a monthly basis are utilized to evaluate WR_c, ia the equation:

$$WR_c = ET_c - P_e \qquad (3)$$

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 evaporation and evapotranspiration estimates based on the Eq. (1), and (2). The daily climatic data from the meteorological station at Stomio for the period June 2011 to March 2015 are utilised to calculate daily reference evapotranspiration rates, ET_o that are presented in Figure 1a. From these data, their average values and periodic mean are estimated (Yevjevich, 1982) are presented in Figure 1b. Average ET_o ranges from ~0.71mm/day during winter (December) to ~5.35mm/day during summer (July). These average values are slightly lower than those for the period June 2011 to October 2013 (Kotsopoulos, 2014).



(a) (b)

Figure 1. Daily estimated ET_o from June 2011 to March 2015 (a) and average daily estimated ET_o and periodic mean (b) for the period 2011-15 at Stomio Larissa

Additional datasets required for ET_o calculation and analysis in order to investigate the impact of the climate change on Pinios river delta concern daily average values of air temperature, relative humidity, wind speed and total solar radiation, which are gridded values (spatial resolution 0.22° x 0.22°; 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 2021-2050 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. A1B is distinguished by balance across all energy sources (fossil or non-fossil energy sources), which will have an impact on increase of CO_2 emissions within the 21st century, reaching the concentration of 720 ppm until the year of 2100 (IPCC, 2007). 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 rates vary (beginning-end) from 2.91-2.93mm/day during the period 1961-90, from 3.02-3.22mm/day during the period 2021-50 and from 3.30-3.47mm/day during the period 2071-2100.

The analysis of ET_o rates at the end of the near and far future (periods 2047-50 and 2097-2100) give similar periodic results to that presented in Figure 1b but increasing in magnitude. These results are utilized to evaluate evaporation and crop evapotranspiration of six main crops of the study area (kiwi and olive tree plantations, alfalfa, maize, cotton and sunflowers). The simulation results incorporate crop coefficients, K_c and are presented in Table 1. This table shows how annual evaporation, *E,* and crop evapotranspiration, ET_c, vary from period to period. Average annual evaporation, *E* is currently reaching 1055mm/year and is expecting to increase ~18% and ~22.5% by the middle (47-50) and the end (97-00) of the present century respectively. Similarly, annual crop evapotranspiration, ET_c, currently varies from ~480 mm/year (sunflower) to ~820 mm/year (kiwi). The most water consuming crop is kiwi and is followed by alfalfa while sunflower is consuming the least. Seasonal 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.

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 kiwi and the least consuming ones are olive and sunflower. Currently, the average seasonal ET_c, as shown in Table 1b, may be for maize as high as 502mm that is over 50% higher than that of olive (317mm). Table 1b presents the increase in seasonal ET_c values in the near and far future. These differences may reach 14.5% and 21% for the two periods respectively. Concerning seasonal crop water requirements

Table 1. Average annual and seasonal evaporation, *E*, and crop evapotranspiration, ET_c, in mm/year (or season) for kiwi, olive, alfalfa, maize, cotton and sunflower during the periods 2011-15, 2047-50 and 2097-2100

period		Annual (a) and seasonal (b) evaporation, E and crop evapotranspiration, ET_c, (mm/year)													
		E_{water}		ET_{kiwi}		ET_{olive}		$ET_{alfalfa}$		ET_{maize}		ET_{cotton}		$ET_{sunflower}$	
2011-15	a	**1055**		**819**		**628**		**731**		**610**		**580**		**487**	
	b	**477**		**477**		**317**		**430**		**502**		**442**		**332**	
2047-50	a	**1243**	**17.8%***	**931**	**13.7%***	**719**	**14.5%***	**815**	**11.5%***	**684**	**12.1%***	**664**	**14.5%***	**536**	**10.1%***
	b	**544**	**14.0%***	**544**	**14.0%***	**362**	**14.2%***	**491**	**14.2%***	**573**	**14.1%***	**506**	**14.5%***	**368**	**10.8%***
2097-00	a	**1292**	**22.5%****	**980**	**19.7%****	**753**	**19.9%****	**870**	**19.0%****	**729**	**19.5%****	**699**	**20.5%****	**577**	**18.5%****
	b	**575**	**20.5%****	**575**	**20.5%****	**382**	**20.5%****	**520**	**20.9%****	**606**	**20.7%****	**535**	**21.0%****	**395**	**19.0%****

* Percentage difference of annual or seasonal *E* or ET_c during the period 2047-50 to that during 2011-15
** Percentage difference of annual or seasonal *E* or ET_c during the period 2097-00 to that during 2011-15

4. Conclusions

From the estimated annual and seasonal evaporation and crop evapotranspiration, and seasonal crop water requirements at the Pinios delta study area, it is concluded that:

- The current annual evaporation exceeds on average 1050mm/year while crop evapotranspiration is related to crop species and is ranging from ~490 mm/year (sunflower) to ~820 mm/year (kiwi).
- Concerning the climate change scenarios, annual evaporation is expected to increase about ~18% and ~22.5% by the middle and the end of the present century respectively.
- The annual crop evapotranspiration is expected to increase in the near (2021-2050) and far future (2071-2100) from ~10% (sunflower) to ~14% (kiwi) at the end of these periods respectively.
- The current seasonal (summer month) evaporation is on average ~480mm/season while crop evapotranspiration varies from ~330 (sunflower) to ~500mm/season (maize).
- In the near and far future, due to climate change, seasonal evaporation and crop evapotranspiration are expected to increase from about ~11-14.5% and 19-21% by the middle and the end of the present century respectively.
- Greater percentage differences are expected in seasonal crop water requirements in the near and far future due to the fact that rainfalls during the summer months are practically insignificant at the end of the century.

The results of the present study exhibit the current and future trends on parameters (evaporation, evapotranspiration) effecting 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

This work is supported by the project THALES-DAPHNE (MIS: 375908) of the Operational Programme: “Education and lifelong learning, 2007-2013” of the Hellenic Ministry of Education and Religious Affairs, Culture and Sports co-funded by the European Union and the Greek Government.

REFERENCES

1. Alexiou I., S. Kotsopoulos, G. Zerva and P. Vyrlas (2000). Comparative evaluation of crop potential evapotranspiration using the equations of Penman and Penman-Monteith, Proc. 2nd Nat. Conf., Association of Agricultural Engineers, Volos Greece, pp 133-140.

2. Allen R. G., L.S. Pereira, D. Raes and M. Smith (1998). Crop evapotranspiration: Guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper No **56**, FAO, Rome.
3. Doorenbos J. and W.O. Pruitt, (1977). Crop water requirements, FAO Irrigation and Drainage Paper No **24**, FAO, Rome.
4. IPCC, (2007). Climate Change (2007): The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Eds. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.
5. Kotsopoulos S., Kalfountzos D., Alexiou I., Zerva G., Karamaligas C. and Vyrlas P., (2003). Actual evapotranspiration and soil moisture studies in irrigated cotton fields, European Water (e-bulletin of EWRA), Issue **3/4**, pp. 22-28.
6. Kotsopoulos S., Nastos P., Ghionis G., Lazogiannis K., Poulos S, Alexiou I., Panagopoulos A, Farsirotou E. and Alamanis N. (2014). Evaporation and evapotranspiration estimates under present and future climate conditions. Proc. 12th International Conference on Protection and Restoration of the Environment, Skiathos, Greece, June 29 – July 3, 2014.
7. Kotsopoulos, S., (2006). Hydrology, ION Publ., Athens (in Greek).
8. Meijgaard, E. van, Ulft, L.H. van, Berg, W.J. van de, Bosveld, F.C., Hurk, B.J.J.M. van den, Lenderink, G., Siebesma, A.P., (2008). The KNMI regional atmospheric climate model RACMO version 2.1., KNMI technical report, **TR – 302**, KNMI, De Bilt.
9. Poulos S.E, Alexopoulos I., Dassenakis M., Kotsopoulos S., Lazogiannis K., Matiatos I., Paraskevopoulou V., Sifnioti D.E., Ghionis G., Alexiou I. and Panagopoulos A., (2013). An investigation of the impact of the climate change on river deltas. Case Study: the delta of R. Pinios (Thessaly, Greece) – Concept and preliminary results on surface water environmental state. Proceedings of the 13th International Conference on Environmental Science and Technology, Athens, Greece, 5-7 September 2013, Ref. no CEST2013-0372.
10. Tsakiris G., (2006). Hydraulic Works, Design and Management, Volume II, Land Reclamation Works, Symmetry Publ., Athens (in Greek).
11. Yevjevich V., (1982). Stochastic Processes in Hydrology, Water Resources Publications, Colorado, USA.