

## An implementation of a water balance model in the Evrotas basin

P.G. Marinou<sup>1</sup>, E.G. Feloni<sup>1\*</sup>, O. Tzoraki<sup>2</sup> and E.A. Baltas<sup>1</sup>

<sup>1</sup> Department of Water Resources and Environmental Engineering, School of Civil Engineering, National Technical University of Athens, 5 Iroon Polytechniou, 157 73, Zografou, Attiki, Greece

<sup>2</sup> Marine Sciences Department, School of Environment, University of the Aegean, Greece

\* e-mail: feloni@chi.civil.ntua.gr

**Abstract:** This research paper focuses on the implementation of the “abcd” water mass balance model in Evrotas River Basin for the runoff simulation. The study area, which is located in Greece and more specifically at SE. Peloponnese, is the Evrotas river basin, covering a total area of 1739 km<sup>2</sup> with its main watercourse of 90 km length. The model is performed in four subbasins of Evrotas; Oinountas (the outlet of which is in Kladass station), Rasina I (up to the Koumousta Station), Rasina II (up to the station located at the Rasina Airport) and Vivari (up to Sellasia station). The first three subbasins were studied on a daily step for an entire water year (2009-2010), while the later one on a monthly basis for a five-year period (2006-2009). The model’s calibration was accomplished by the calculation of the Nash-Sutcliffe coefficient (N-S); for the estimated and the measured discharges. The performance of the “abcd” model was good for monthly flows simulation (N-S=0.82 for Vivari subbasin) and adequately in the daily interval application (N-S>0.62). Additionally, a sensitivity analysis in the parameters of the model is provided, establishing the different results per subbasin.

**Key words:** water balance, “abcd” model, Evrotas, sensitivity analysis

### 1. INTRODUCTION

Hydrologic modeling has become an indispensable tool for the assessment, management, and use of water resources. For hydrologists, such models are especially useful in the evaluation of assumptions and theories about the dominant hydrologic processes in a basin (Al-Lafta et al., 2013). Watershed models are powerful tools for simulating the effect of watershed processes and management on soil and water resources. However, no comprehensive guidance is available to facilitate model evaluation in terms of the accuracy of simulated data compared to measured flow and constituent values.

The “abcd” model was originally introduced by Thomas (1981) and Thomas et al. (1983) and it is a simple, nonlinear watershed model which accepts precipitation and potential evapotranspiration as input, producing streamflow as output. Internally, the model also represents soil moisture storage, groundwater storage, direct runoff, groundwater outflow to the stream channel and potential evapotranspiration. The “abcd” model has been used in a large number of hydrologic applications, especially in America (indicatively: Martinez et al., 2010; Al-Lafta et al., 2013).

This work therefore aims to study the hydrologic regime of four different watersheds, namely Oinountas (Kladass station), Rasina I (Koumousta station), Rasina II (Airport station) and Vivari by the use of the “abcd” hydrologic model. These subbasins are located in a complicated hydrogeologically and geomorphologically basin, the Evrotas River Basin (Tzoraki et al., 2011 and 2013). At the same time, this work intends to illustrate the different characteristics per subbasin through a sensitivity analysis in the model’s parameters. In this work, the model was initially implemented using monthly time series for Vivari basin for a period of four hydrologic years. However, the suitability for the daily water balance simulation was examined, and, for this reason, the “abcd” model was also performed for the daily timeseries in three subbasins and for a whole hydrologic year. These subbasins are Oinountas (Kladass), Rasina I (Koumousta) and Rasina II (Airport).

## 2. STUDY AREA AND DATA USED

### 2.1 Description of the region

Evrotas River, as many rivers in the Mediterranean region, is a temporary river with intermittent flow in the main stream and many tributaries. Evrotas basin (Figure 1) is located in the south-eastern Peloponnese (Greece) in the Prefectures of Laconia and Arcadia, covering an area of 2410 km<sup>2</sup>, with a main stream length of 90 km (up to Vrontamas karst). The population of the region has reached 66000 inhabitants and the largest town is Sparta with 18000 inhabitants. The basin has a Mediterranean climate with mild or cold winters and prolonged hot and dry summers, with a mean annual temperature of 18.5°C at the town of Sparta. Monthly mean temperatures in the meteorological station of Sparta are typically 10.3°C in winter and 27.6°C in summer. The basin is bounded by the Taygetos (2407 m) and Parnonas (1940 m) mountains from which numerous intermittent streams discharge into the river network. The main tributaries are the Oinountas, Magoulitsa, Gerakaris, Kakaris, Rasina, Mariorema, Xerias (Querner et al., 2016). By using GIS technics, it was found that the 40% of the basin area is above 600 m elevation, the 45% between 150 and 600 m, and the 15% <150 m.

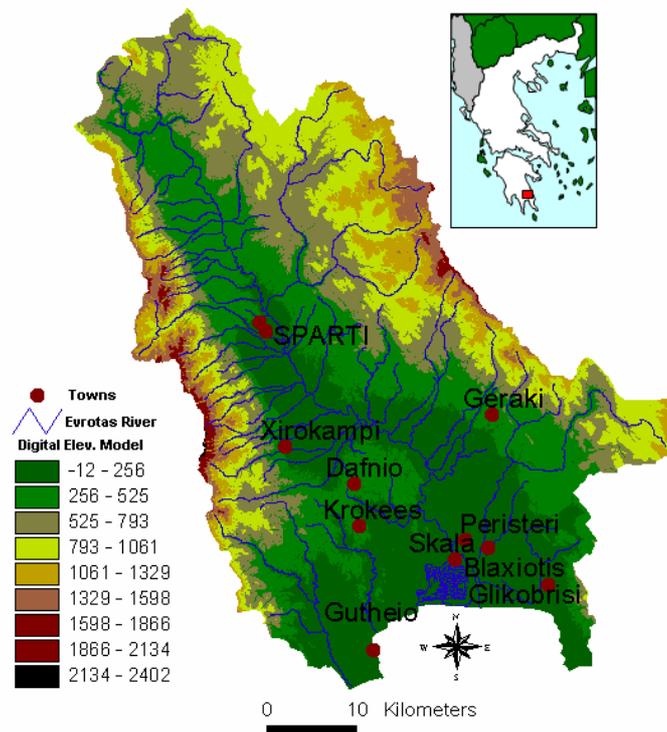


Figure 1. Location of the Evrotas river basin

Concerning the land cover type, approximately the 59% of the surface is forest, bareland or grassland, the 40% is covered by agricultural uses and only the 1% is urban. More specifically and according to CORINE (2012), the land cover classes are scrub and herbaceous vegetation associations (60.8%), forests (16.0%), heterogeneous agricultural areas (15.0%), permanent crops (6.5%), open spaces with little or no vegetation (1.1%), urban fabric (0.3%), arable land (0.1%) and the rest (0.2%) are industrial, commercial and transport units, mine, dump and construction sites and artificial, non-agricultural vegetated areas. The geological structure of the area mainly consists of limestone (49%) and schist (29%). The valley is filled with fluvial sediments of different ages and alluvial deposits are covering the river floodplain area. Taygetos and Parnonas mountains are mainly karstic, but with areas of impermeable formations. A unit of low-transmissivity alluvial fans, restricted adjacent to the east edge of the Taygetos mountains, comprise significant water storage.

Taygetos karst has high transmissivity ( $1.16 \times 10^{-8} - 1.16 \times 10^{-9} \text{ m}^2 \text{ d}^{-1}$ ) and recharges the alluvial fans and associated aquifer north-west of the town of Sparta. The unsaturated zone in this region is between 20–30 m depth, with hydraulic conductivity varying between  $8.1 \times 10^{-12} - 9.2 \times 10^{-10} \text{ md}^{-1}$  (Antonakos and Lambrakis, 2000). The Sparta aquifer is penetrated by numerous wells used to provide water for irrigation. Long sections of the river have intermittent flow, influenced by the local geology, low rainfall, abstraction and high evaporation. The river discharge has declined markedly in recent decades. In a total river network of 5143 km length, the 3.5% has permanent flow, the 4.5% is intermittent and the 92% of the stream network has rain-generated flow which is episodic and appears only during a rain event. The largest change is in the period between 1980 and present and is the result of irrigating olives. A comparison between the current situation and the natural one in 1900 leads to the conclusion that currently 79% of the stream network is in a poor hydrological and ecological condition due to human influence (Querner et al., 2016). The main causes of desiccated river bed are the steep topography of the terrain, the karst geology and groundwater abstraction for irrigation (Gamvroudis et al., 2015).

## 2.2 Data

The “abcd” water balance model was implemented in four subbasins and at various temporal scales, given the existing data limitations and the large area of the watershed. In this study, data used for processing generated from the meteorological and hydrological stations which are located in the region (Figure 2a). There are six stage recording stations on the Evrotas and its tributaries. Two of these, at Vrontamas and Vivari, are on the main river; two are on the Oinountas and two on the Rasina tributary. Vrontamas station is the oldest one, providing flow data since 1973 on a monthly basis, while the Kladas and the Rasina hydrometric stations provide daily runoff data since 2008 and 2009, respectively.

Daily precipitation has been measured since 1970 at six stations: Ellos (4 m elevation), Riviotissa (163.5 m), Vrontamas (280 m), Perivolia (490 m), Sellasia (590 m) and Vasaras (646 m) (Thiessen polygons in Figure 2b).

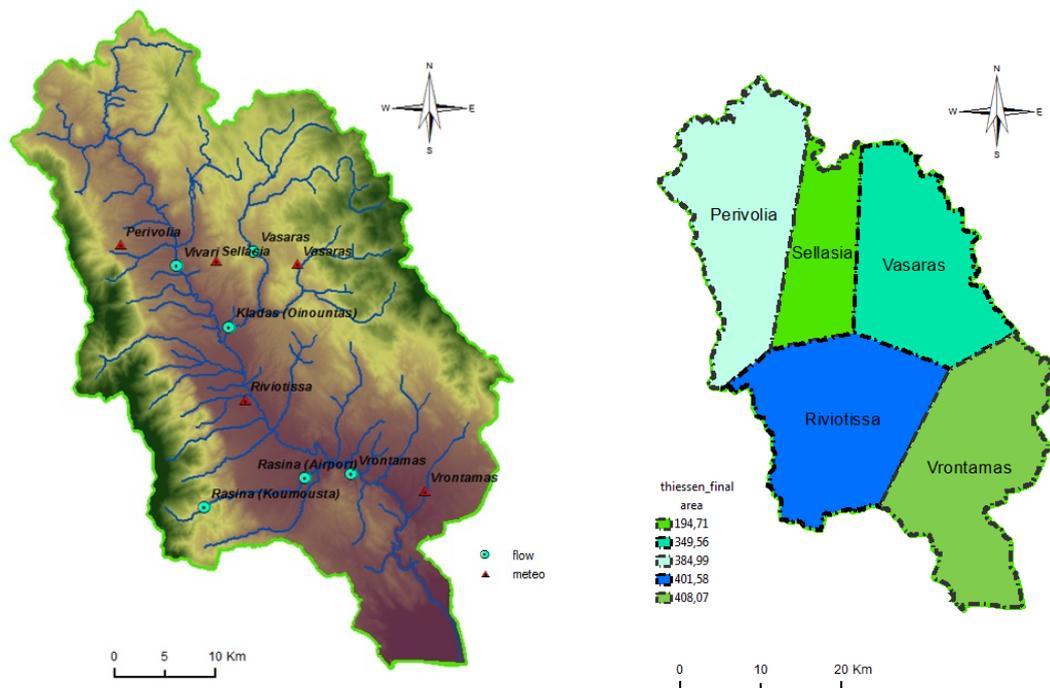


Figure 2. (a) Meteorological (red triangles) and stage recording (blue circles) stations in Evrotas river basin, (b) Thiessen polygons of the 5 rain gauge stations in Evrotas river basin.

According to these stations measurements for the hydrologic years 1969-2011, mean annual precipitation in the region varies between 565 mm (Vrontamas) and 1341 mm (Perivolia). Two temperature stations located within the basin were used to drive the hydrologic model using daily data. These stations are Riviotissa and Sellasia which have been in operation since 1966. Temperature time series in a daily time step of Sellasia station were used for the two subbasins of Oinountas (Kladas) and Vivari, while the temperature data of Riviotissa were used for the other two subbasins of Rasina. The data of wind speed and relative humidity received by the meteorological station of Sparta for the period of 1974 - 2004, provided by the Hellenic National Meteorological Service. As the station of Sparta did not provide sunshine data, for model processing purposes the only available time series of relative sunshine (in hr) was at the station of Kalamata (HNMS), which was finally used. In a Geographic Information System (GIS), thematic maps of the hydrological network, geology, type of soil, and slopes were created and analysed in order to estimate the specific characteristics of the whole basin.

### 3. METHODOLOGY

For modeling purposes, the main physiographic characteristics were estimated for each sub-basin, including drainage area, mean elevation and also spatially discretization of the basin, using the ArcGIS 10 interface.

In this paper, the application of the “abcd” water balance model is studied, by implemented it on both a daily and a monthly basis. For the estimation of mean areal rainfall, the Thiessen method was applied (Figure 2b). The individual weights are multiplied by the station observation and the values are summed to obtain the areal average precipitation. Evapotranspiration is a process depending on solar radiation, air temperature, relative humidity and wind speed. In this study, daily and monthly evapotranspiration time series was estimated using the FAO Penman-Monteith method (FAO-PM). This method is recommended, as the standard  $ET_0$  method, with which the evapotranspiration of a hypothetical reference vegetated field is unambiguously determined (Allen et al., 1998). The method has been reported to be able to provide consistent  $ET_0$  values in many regions and climates (Allen et al., 2005; Allen et al., 2006) and it has long been accepted worldwide, as a good  $ET_0$  estimator when compared with others methods, especially for daily computations (e.g. Chiew et al., 1995; Jacobs and Satti, 2001; Temesgen et al., 2005). Concerning the available hydrological data, which were used for the hydrologic modeling, those in a daily time step refer to the water year 2009 - 2010 for Oinountas (Kladas), Rasina I (Koumousta), Rasina II (Airport) subbasin, while those in a monthly time step (for Vivari subbasin) are provided for the period 2006-2009. The four subbasins are presented in Figure 4.

The “abcd” model is schematically comprised of two storage compartments: soil moisture and groundwater (Figure 3). The soil moisture storage (S) receives water from precipitation (P) and loses water through potential evapotranspiration (ET), surface runoff (DR) and groundwater recharge (GR). The groundwater compartment gains water from recharge and loses water as discharges. The total streamflow is the sum of surface runoff from the soil moisture and groundwater discharge.

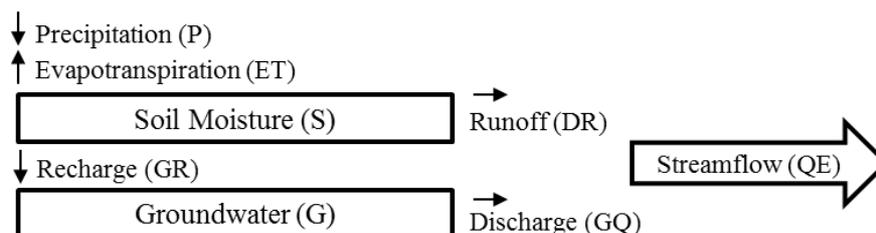


Figure 3. Streamflow simulation by Thomas (1981) - “abcd” model

There are four parameters governing the model behavior:

- a: controls the amount of runoff and recharge that occurs when the soil is not saturated.
- b: controls the saturation level of the soil.
- c: defines the ratio of groundwater recharge to surface runoff.
- d: controls the rate of groundwater discharge.

The calibration of the model parameters was based on the maximization of the Nash-Sutcliffe coefficient value (Nash and Sutcliffe, 1970) via the Excel Solver.

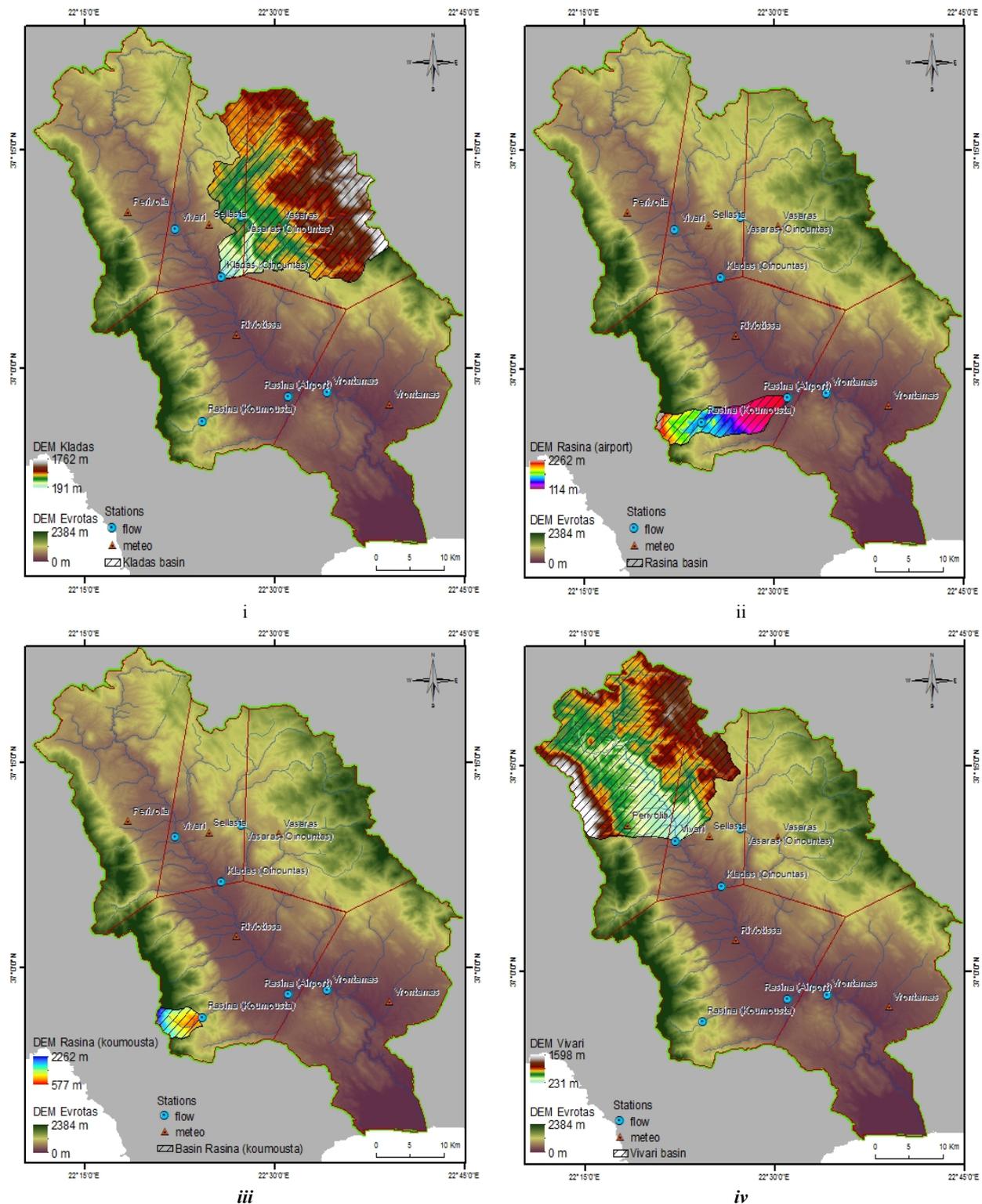


Figure 4. (i) Oinontas (Kladas) subbasin, (ii) Rasina II (Airport) subbasin, (iii) Rasina I (Koumousta) subbasin, (iv) Vivari subbasin

Additionally, in order to demonstrate the different characteristics per subbasin, a one-factor-at-a-time (OAT/OFAT) sensitivity analysis was carried out in the model parameters specifically and separately for each subbasin. In order to quantify what effect produces a change in the model parameters to the efficiency coefficient (EC), the sensitivity was estimated by altering the optimal values of one parameter in equal percentages (Figure 6) and calculating the change in one output (e.g., mean discharge).

#### 4. RESULTS

Results reveal that in both daily and monthly application of the “abcd” model, the values of N-S efficiency coefficient are satisfactory. More specifically, Nash index is greater than 0.6 in all cases; with its best values (>0.8) in Kladas and Vivari subbasins, providing a reliable model, proper for all subbasins (see EC values in Table 1).

Table 1. Values of basic parameters for each subbasin after calibration of the model

Parameter	Oinountas (Kladas)	Rasina I (Koumousta)	Rasina II (Airport)	Vivari
a	0.9995	0.9662	0.8852	0.9906
b	732.30	995.99	503.92	1500.00
c	0.41	0.95	0.90	0.77
d	0.00	0.00	0.00	0.00
S <sub>0</sub>	312.88	210.03	180.35	100.00
G <sub>0</sub>	50.00	80.00	80.00	40.00
EC (N-S)	0.85	0.71	0.62	0.83

Figure 5 presents the observed versus simulated discharges for (a) Kladas, (b) Rasina I (Koumousta), (c) Rasina II (Airport) and (d) Vivari stage recording stations, for the step of calibration. The fit between the simulated and the observed discharge denotes adequate agreement, as indicated by the values of the EC.

Regarding to the sensitivity analysis, the simulation output that has been controlled over the sensitivity analysis was the change of the average discharges, by changing one-at-a-time model parameter (Figure 6). The results of sensitivity analysis are concentrated as follows:

- The amount of runoff and recharge that occurs when the soil is not saturated (parameter a) and the saturation level of the soil are the most crucial parameters for Kladas basin, while the contribution to the river of the groundwater storage (parameter c) is found to be lower (0.40) than the rest subbasins.
- For the Rasina basins (I-Koumousta, II-Airport), the most important parameter affecting the model is the fraction of streamflow coming from groundwater (parameter c), while change in the potential evapotranspiration and soil water storage does not entail significant change.
- The Vivari basin seems to be more "sensitive" for an up to 30% increase or decrease of the value of the parameter a, while with further percentage reduction in parameters the most critical parameter is c. The potential evapotranspiration and storage of soil moisture (parameter b) seems to be a minor factor at that location.
- The initial value of G(0) [not shown] and S(0) seems not to affect any model.

#### 5. SUMMARY AND CONCLUSIONS

The “abcd” water balance model implementation in four subbasins of Evrotas River and in monthly and daily temporal scale showed a satisfactory agreement with field observations. The discharge simulation can be characterized as adequate, taking into account the use of a simplistic model.

- Sensitivity analysis in the parameters a, b, c, d, S(0), G(0) reveals that, in all cases, either parameter ‘a’ or ‘c’ is the most crucial.

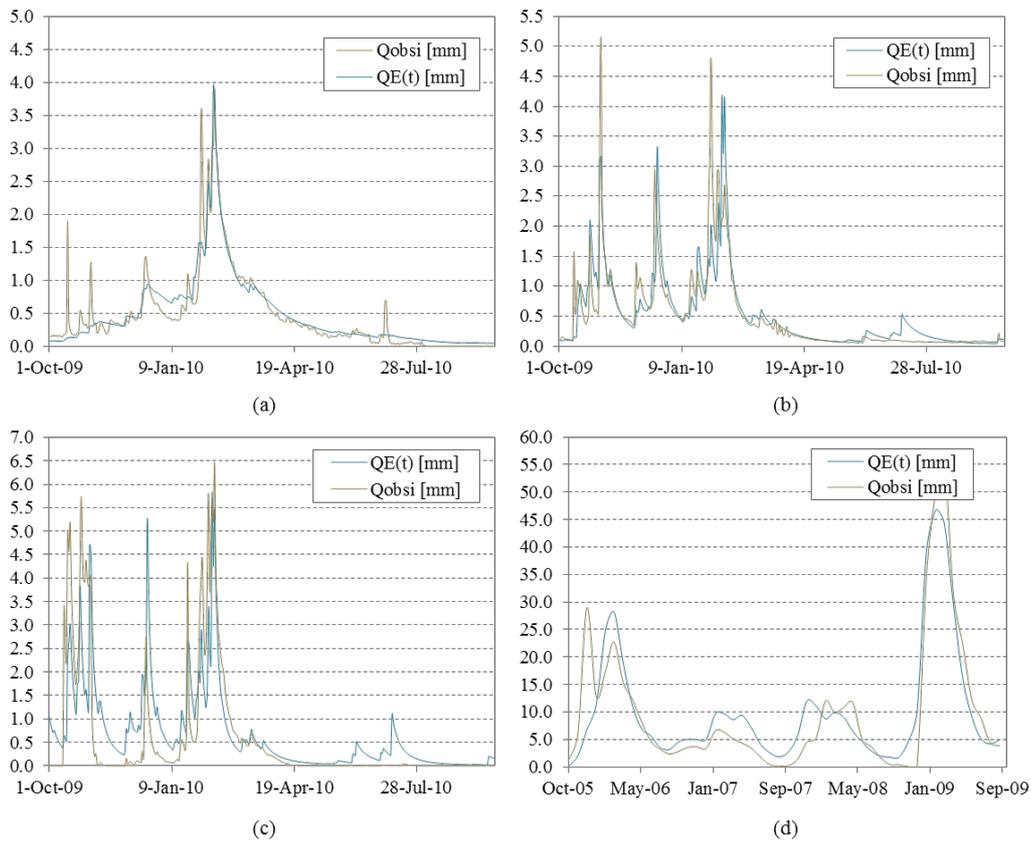


Figure 5. Simulated and observed discharge for (a) Kladas (daily runoff data), (b) Rasina I (Koumousta) (daily runoff data), (c) Rasina II (Airport) (daily data) and (d) Vivari stations (monthly runoff data)

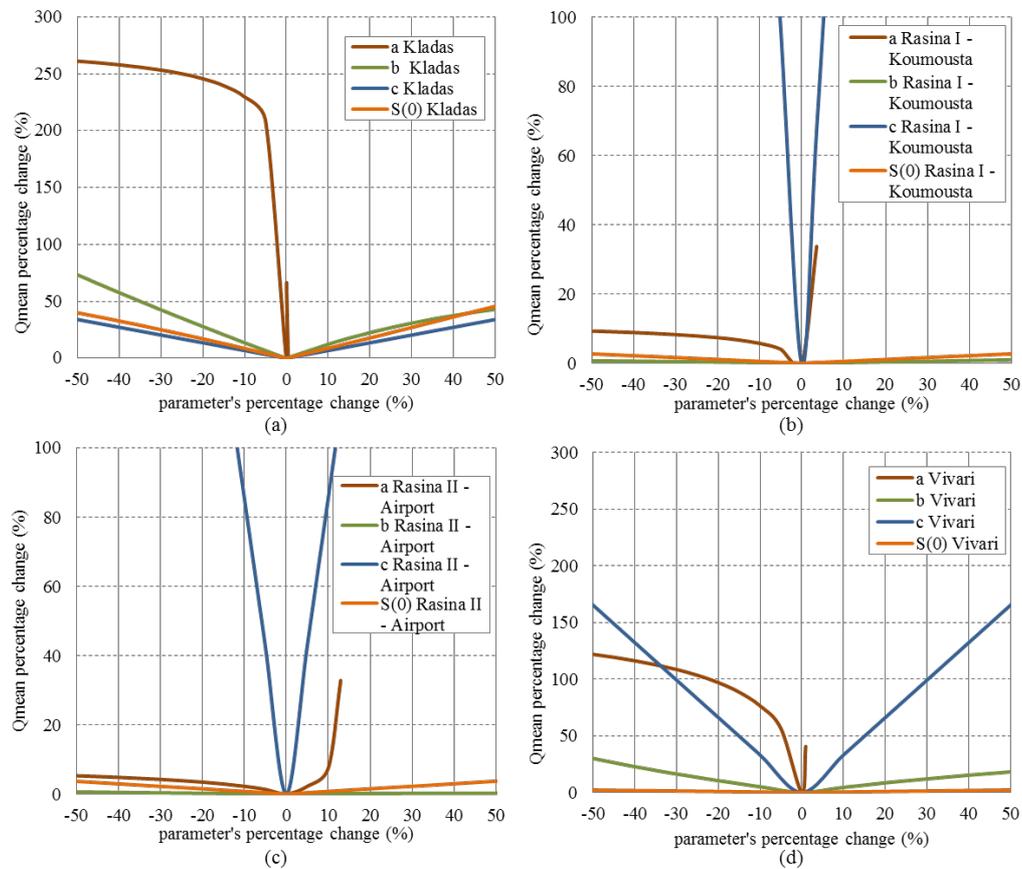


Figure 6. OAT Sensitivity analysis results for the subbasins of (a) Kladas, (b) Rasina I (Koumousta), (c) Rasina II (Airport) and (d) Vivari

- As expected, Rasina I and Rasina II seem to follow similar patterns, however, in Rasina I, which is a mountainous basin, parameter ‘a’ is comparatively more important.
- Concerning future research, additional daily flow data should be taken into account, an aspect that may give a more reliable simulation output, as in the current research the model applied to just one hydrological year. Moreover, extra performance indicators can be introduced for the evaluation of the “abcd” model's suitability in both temporal scales for the examined area.

## REFERENCES

- Al-Lafta, H.S., Al-Tawash, B.S. and Al-Baldawi, B.A., 2013. Applying the “abcd” Monthly Water Balance Model for Some Regions in the United States. *Advances in Physics Theories and Applications*, 25: 36-47.
- Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56*. FAO, Rome, 300(9): D05109.
- Allen, R.G., Clemmens, A.J., Burt, C.M., Solomon, K. and O'Halloran, T., 2005. Prediction accuracy for projectwide evapotranspiration using crop coefficients and reference evapotranspiration. *Journal of Irrigation and Drainage Engineering*, 131(1): 24-36.
- Allen, R.G., Pruitt, W.O., Wright, J.L., Howell, T.A., Ventura, F., Snyder, R., Itenfisu, D., Steduto, P., Berengena, J., Yrisarry, J.B. and Smith, M., 2006. A recommendation on standardized surface resistance for hourly calculation of reference ET by the FAO56 Penman-Monteith method. *Agricultural Water Management*, 81(1): 1-22.
- Antonakos, A. and Lambrakis, N., 2000. Hydrodynamic characteristics and nitrate propagation in Sparta aquifer. *Water Research*, 34(16): 3977-3986.
- Chiew, F.H.S., Kamaladasa, N.N., Malano, H.M. and McMahon, T.A., 1995. Penman-Monteith, FAO-24 reference crop evapotranspiration and class-A pan data in Australia. *Agricultural Water Management*, 28(1): 9-21.
- Gamvroudis, C., Nikolaidis, N.P., Tzoraki, O., Papadoulakis, V. and Karalemas, N., 2015. Water and sediment transport modeling of a large temporary river basin in Greece. *Science of the Total Environment*, 508: 354-365.
- Jacobs, J.M., Satti, S.R. and Fitzgerald, J.M., 2001. Evaluation of reference evapotranspiration methodologies and AFSIRS crop water use simulation model. Publ. SJ2001-SP8. Available online at <http://www.sjrwmd.com/programs/outreach/pubs/techpubs/sj2001-sp8.pdf> (Verified 20 October, 2003).
- Martinez, G.F. and Gupta, H.V., 2010. Toward improved identification of hydrological models: A diagnostic evaluation of the “abcd” monthly water balance model for the conterminous United States. *Water Resources Research*, 46(8).
- Nash, J.E. and Sutcliffe, J.V., 1970. River flow forecasting through conceptual models part I - A discussion of principles. *Journal of Hydrology*, 10(3): 282-290.
- Temesgen, B., Eching, S., Davidoff, B. and Frame, K., 2005. Comparison of some reference evapotranspiration equations for California. *Journal of Irrigation and Drainage Engineering*, 131(1): 73-84.
- Thomas, H.A., 1981. Improved methods for national water assessment. Report WR15249270, US Water Resource Council, Washington, DC.
- Thomas, H.A., Marin, C.M., Brown, M.J. and Fiering, M.B., 1983. Methodology for water resource assessment, report to US Geological Survey. Rep. NTIS84-124163.
- Tzoraki, O., Papadoulakis, V., Christodoulou, A., Vozinaki, E., Karalemas, N., Gamvroudis, C. and Nikolaidis, N.P., 2011. Hydrologic modelling of a complex hydrogeologic basin: Evrotas River Basin. In: *Advances in the Research of Aquatic Environment* (pp. 179-186). Springer Berlin Heidelberg.
- Tzoraki, O., Nikolaidis, N.P., Keldjsen, T., Cooper, D., Gamvroudis, C., Gallart, F., Froebrich, J., Querner, E., 2013. Flood Generation and Classification of a semi-arid Intermittent Flow Watershed: Evrotas river. *Int. J. River Basin Management*, 11(1): 77-92
- Querner, E.P., Froebrich, J., Gallart, F., Prat, N., Cazemier, M., Tzoraki, O., 2016. Simulating stream flow variability in temporary streams using a coupled groundwater – surface water model. *Hydrological Sciences Journal*, 1(1): 146-161