Assessing Surface Runoff in Future Climate Conditions in Mountainous Catchments (Case Study: Klinovitikos Torrent, Central Greece)

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Abstract. During the last decades there is a growing concern about climate change and its devastating effects on water availability. The aim of this study was to assess surface runoff changes in the mountainous catchment of the Klinovitikos torrent (Central Greece) under climate change. To this end, precipitation and temperature data were derived from a high-resolution (25×25 km) RegCM3 regional climate model for the baseline period 1974-2000 and future period 2074-2100. Subsequently, Thornthwaite and Mather water balance model was applied to quantify the effects of precipitation and temperature changes on surface runoff. The results showed a decrease in surface runoff until the end of the 21st century, approximately -35.5%, -14.4%, -49.8% and -43.7% for winter, autumn, spring, and summer, respectively. It is also noted that the reduction will be greater in the dry season. To this end, adaption of mountainous catchment management to climate change is crucial to avoid water scarcity.

Keywords: runoff; climate change; RegCM3; mountainous catchment.

1 Introduction

The existence of life depends on the availability of freshwater on earth's surface. During the last decades, the world's rapid population growth, urbanization and industrialization have increased the demand for water worldwide (Beran et al., 2016). Additionally, the increased greenhouse gas emissions lead to negative impacts on the availability of global water resources (Gosling and Arnell, 2016).

The climate regime in Mediterranean regions favors the development of drought phenomena due to the pre-long dry period and the uneven distribution of rainfall (Nastos et al., 2013, Cook et al., 2016, Myronidis et al., 2018). The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2013) emphasizes that the Mediterranean basin is expected to become warmer and dryer until the end of the 21th century, while future warming will possibly be larger than the global mean (Giorgi and Lionello, 2008).

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The aforementioned changes will highly influence catchments hydrologic response. Therefore, water resources management has become a crucial challenge needs to be addressed. To this end, stakeholders should also quantify surface runoff under future climate conditions for infrastructure projects scheduling.

General Climate Models (GCMs) are very helpful in understanding the future evolution of the global climate, but have a spatial resolution (100–300 km) too coarse for assessing regional or local changes (D'Oria et al., 2018) Thus, it is not possible to precisely simulate phenomena related to the effect of topography on a local and regional scale due to local conditions and particularities, such as complex topography, coastlines, lakes and small islands (Mearns et al., 2001, Zanis et al., 2015). In order to overcome these limitations, Regional Climate Models (RCMs) are obtained by dynamically downscaling GCM data (Rummukainen, 2010, Xue et al., 2014).

During the last years, several studies assessed the effect of climate change on streamflow using high resolution RCMs (Kling et al., 2012, Fiseha et al., 2014, Paparrizos and Matzarakis, 2016, Venetsanou et al., 2017, Rončák et al., 2019). Although, similar researches are limited in mountainous catchments of the Mediterranean region (Senent-Aparicio et al., 2017), while no such research has been carried out in Greece. It is worth mentioned that mountainous areas are of great interest, since runoff generates and supplies lowlands with water.

The main object of the current research is to quantify the effect of climate change on surface runoff in a mountainous catchment of Central Greece using the Thornthwaite-Mather water balance model and climate simulation of RegCM3 regional climate model.

2 Material and Methods

2.1 Study Area

The study was conducted in the mountainous catchment of Klinovitikos torrent (Fig.1). It is located in Thessaly Regional Unit (Central Greece) over the mountain range of Pindus and is a tributary of Pinios River. It covers an area of 171.1 km2 and the relief is rather intense. The mean elevation is 1112 m.a.sl (maximum 2204 m.a.s.l and minimum 320 m.a.s.l) whereas mean catchment slope is 48.4% and main stream slope 6.5%. Moreover, the region has great environmental importance as belongs to the European nature conservation network Natura 2000 according to the criteria of Directive 92/43/EEC and specifically includes the Site of Community Importance (SCI) with code GR1440002.

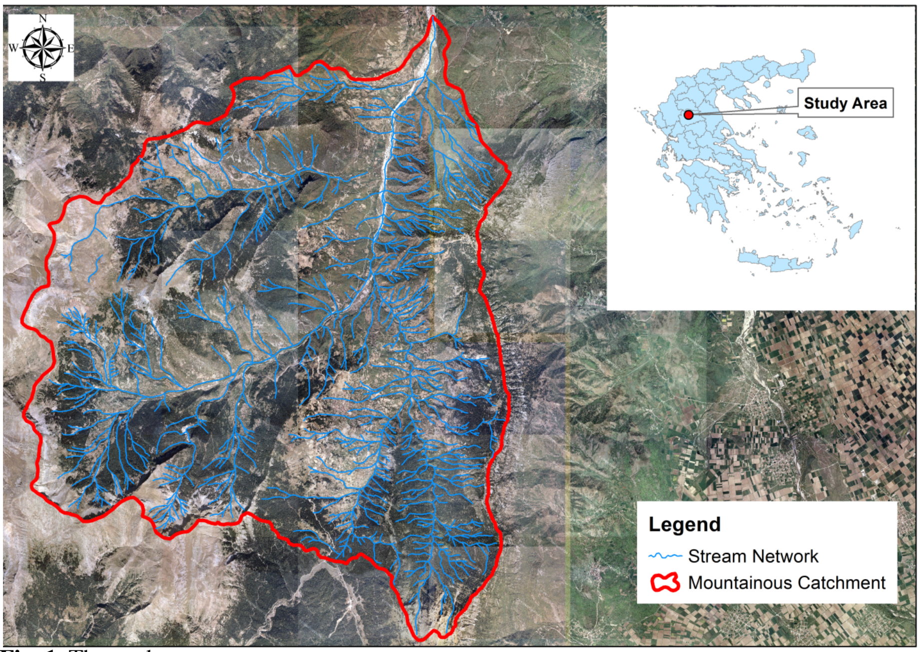

Fig. 1. The study area

In the frame of the EU funding project ENSEMBLE (http://ensembles-eu.metoffice.com/) a set of multi-model RCM simulations to characterize climate change in Europe with high spatial resolution (25×25 Km) were produced. Data from the RCMs used as input in hydrological models, so their ability to represent climate conditions should be examined prior to their use in impact assessment studies (Koutsoyiannis et al., 2007).

To this end, a recent study by Stefanidis (2018) evaluates the ability of seven RCMs of ENSEMBLE project, under A1B SRES emission scenario, to represent temperature and precipitation conditions over the mountainous Central Pindus (study area) for the baseline period 1974-2000. The results concluded that best simulations were made by the International Centre for Theoretical Physics Regional Climate Model (RegCM3) (Jacob et al., 2007). Therefore, in this study, regional climate analysis was performed using daily temperature and precipitation simulated data derived from RegCM3 model for the baseline period (1974-2000) and future period (2074-2100).

2.3 Water balance model

In order to estimate surface runoff, the Thornthwaite and Mather (1957) water balance model was chosen. This model uses as parameter the maximum soil-moisture holding capacity (K) and having as input precipitation and temperature data, given as result the surface runoff and the actual evapotranspiration. The mathematical description of the model given by Equation 1:

$$\Delta S = P - E - Q \quad (1)$$

where ΔS is change in soil moisture, P is the annual rainfall, E is annual actual evapotranspiration, and Q is water surplus (percolation και surface runoff). The corresponding equations of the monthly water balance described below:

- If $P_n > ET_p$

$$S_n = \min(S_{n-1} + P_n - ET_p), \max(K) \quad (2)$$

$$Q_n = \max(S_{n-1} + P_n - ET_p - K), \min(0) \quad (3)$$

- If Pn< ETp

$$S_n = S_{n-1} * \exp(\frac{P_n - ET_P}{K}) \quad (4)$$

$$Q_n = 0 \quad (5)$$

$$ET_a = (S_{n-1} - S_n) + P_n - Q_n = P_n - \Delta S_n - Q_{An} - D_n \quad (6)$$

$$\Delta S = S_n - S_{n-1} \quad (7)$$

$$Q_{An} = a(Q_n + Q_{An-1}) \quad (8)$$

For the month n, P_n is mean monthly rainfall, ET_p is mean monthly potential evapotranspiration, ET_a is mean monthly actual evapotranspiration, S_n: maximum soil retention, Q_n: water surplus, Q_{An}: surface runoff, D_n is infiltration and α: runoff coefficient.

In order to calculate the amount of precipitation that evaporates or transpires back to the atmosphere the generally accepted method proposed by Thornthwaite (1948) were used. The monthly potential evapotranspiration (PET) is estimated from average monthly temperature (T).

$$ET_p = 16(\frac{10tn}{J})^a * Ld \quad (9)$$

$$a = 0.0016J + 0.5 \quad (10)$$

$$J = \sum_{n=1}^{12} (\frac{t_n}{5})^a \quad (11)$$

where, ET_P is the potential evapotranspiration, t_n is mean monthly temperature and Ld is coefficient depending on the latitude (in decimal degrees) of the location of the study area.

Additionally, to take into account the snow accumulation a revised version of the model was used as proposed by Dingman (2002). In this method, mean monthly precipitation (P_m) divided into rainfall (RAIN) and snowfall (SNOW) according the snow melt factor F_m based on mean monthly temperatures (T). The equations calculate these factors were given below:

$$T \leq 0^O C : \mathrm{F}_m = 0 \tag{12}$$

$$0^o C < T < 6^O C : \mathrm{F}_m = 0.167 * \mathrm{T} \tag{13}$$

$$\mathrm{T} \geq 6^O C : \mathrm{F}_m = 1 \tag{14}$$

Therefore:

$$RAIN = F_m * P_m \tag{15}$$

$$SNOW = (1 - F_m) * P_m \tag{16}$$

The monthly melting amount of snow (MELT) was given by equation:

$$MELT = F_m * (\mathrm{SNOW} + \mathrm{PACK}_{m-1}) \tag{17}$$

where $PACK_m$, the snow accumulation for each month m, was estimated from the above equation:

$$PACK_m = (1 - F_m)^2 * \mathrm{P} + (1 - F_m) * \mathrm{PACK}_{m-1} \tag{18}$$

Monthly precipitation considering both rainfalls and snowfall was estimated as described below:

$$Pn = RAIN + MELT \tag{19}$$

Subsequently, the known equations were applied if $P_n > ET_P$ and if $P_n < ET_P$.

Moreover, the potential maximum soil moisture storage after runoff begins (K), related to curve number and was computed by Equestion 20:

$$K = \frac{25400}{CN} - 254 \tag{20}$$

Curve number (CN) is an index that represents the combination of a hydrologic soil group and land use and management class and has a range of 30 to 100. SCS developed a soil classification system that consists of four groups, which are identified by the letters A, B, C, and D according to their infiltration, retention and evaporation capacity. There are tables from USDA Soil Conservation Service that indicate CN for characteristic land cover descriptions and a hydrologic soil group (USDA 1972).

Finally, infiltration process was assessed using empirical coefficients according the literature (Voudouris et al. 2007), as showed in table 1.

Table 1. Infiltration coefficients for each petrographic formation in the study area.

a/a	Petrographic Formation	Infiltration Coefficient (%)
1	Alluvial deposits	20
2	Flysch	7
3	Limestone	52
4	Neogene	18

Based on the values of the above mention table (Table 1) and the equation 21, a mean infiltration coefficient was estimated for the study catchment.

$$w = \frac{w_1 * F_1 + w_2 * F_2 + \ldots w_n * F_n}{F_{Sum}} \quad \textbf{(21)}$$

where $w_1 \ldots w_n$ is the infiltration coefficient for each petrographic formation, $F_1 \ldots F_n$ is the area of each petrographic formation and F_{sum} is the total catchment area.

3 Results

Regarding the data of RegCM3 model for the baseline period (1974-2000) and future period (2074-2100) it was highlighted a decrease (-20%) of annual precipitation (mm) and increase (+3.7 ^{o}C) of mean annual temperature until the end of the 21th century. The decrease of precipitation will be higher in spring, while the increase of the temperature will be higher in summer (Fig 2).

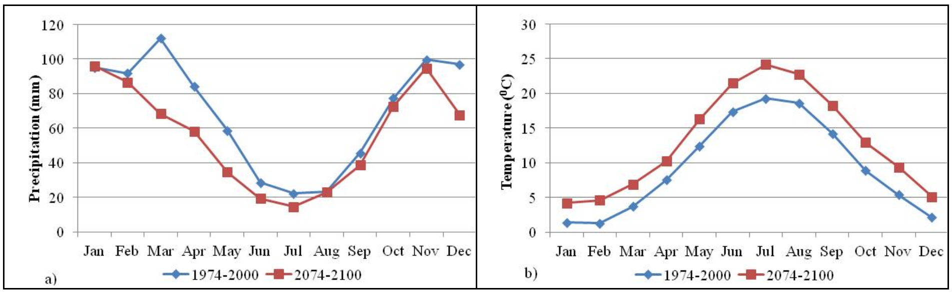

Fig. 2. Comparison of a) precipitation (mm) and b) temperature (°C) regime in the study area as revealed from RegCM3 model.

In order to determine the effect of climate change on surface runoff it was necessary to estimate the input parameters of the water balance model. To this end, geological subsoil, land cover and soil data layers were generated using Geographical Information Systems (GIS) (Fig. 3). Taking into account the above mention parameters mean CN values for Klinovitikos catchment was estimated to 54.2, the potential maximum soil moisture storage (K) equal to 214.29 and mean infiltration rate (w) equal to 0.33.

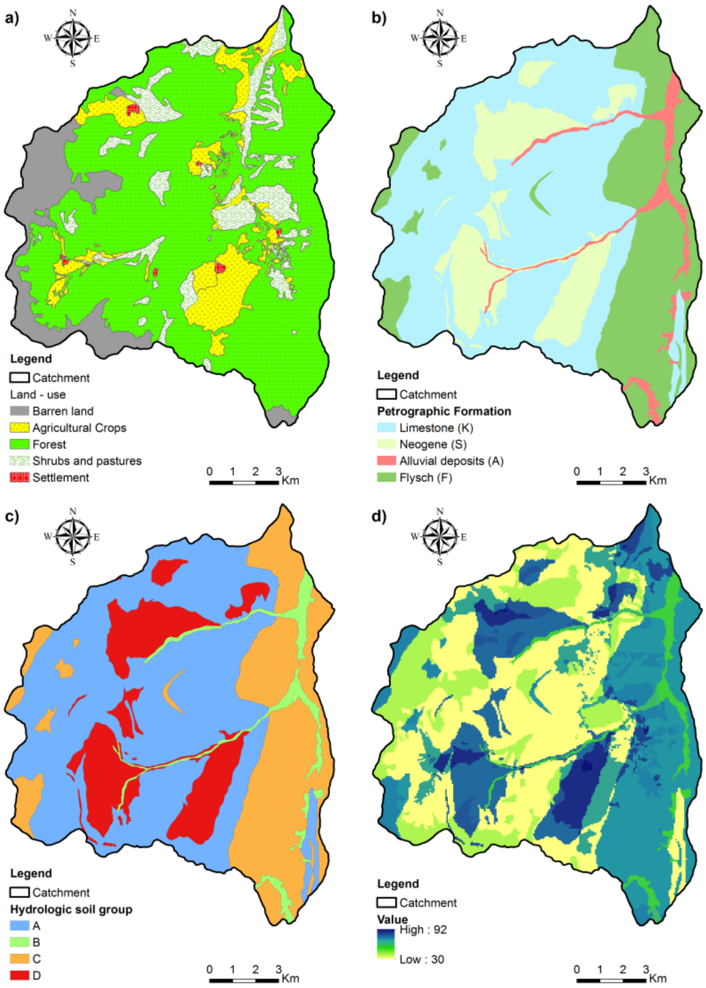

Fig. 3. Spatial distribution of a) land-use, b) petrographic formation, c) hydrologic soil group and d) CN values within Klinovitikos catchment.

Based on the above mention parameters, the water balance model was applied and surface runoff was estimated for both baseline (1974-2000) and the future (2074-2100) period. The results showed that the decrease in rainfalls and increase in temperatures lead to decrease of surface runoff.

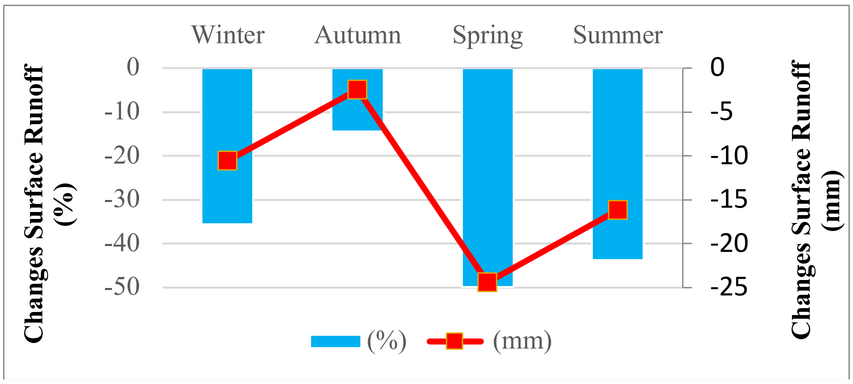

Fig. 4. Seasonal changes of surface runoff in Klinovitikos catchment.

Additionally, the results between the two aforementioned periods were compared so as to quantify the effects on climate change of surface runoff. It was noticed a decrease in surface runoff until the end of the 21st century, approximately -35.5%, -14.4%, -49.8% and -43.7% for winter, autumn, spring, and summer, respectively (Fig. 4).

4 Conclusion

During the last decades there is a growing concern about the effects of climate change on water resources, especially in Mediterranean region where climate expected to be warmer and dryer. In this study, the effect of climate change on surface runoff in a mountainous catchment of Central Greece was assessed using the Thornthwaite and Mather water balance model and climate simulation of RegCM3 regional climate model.

Regarding future climate conditions in the study area, a decrease of precipitation (mm) and increase of temperature is expected until the end of the 21th century. Additionally, the higher decrease of monthly rainfall was recorded in spring, while the higher increase is occurred in summer. Taking into account the reported changes of climatic condition significant decrease of surface runoff changes was estimated especially in spring and summer months.

The need for rational water resources management nowadays is a necessity. Despite the construction of classical water saving dams (reservoir), appropriate adaption measures must be applied in the mountainous forested regions where surface runoff generates. These measures include appropriate silvicultural treatments in order to achieve all-aged forest stands structure which can increase water production and stream regulation using check dams as after their siltation, water infiltrated through the deposits that act as ideal artificial aquifers.

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