

BASIN-SCALE WATER RESOURCES ASSESSMENT IN A SICILIAN BASIN UNDER CLIMATE CHANGE SCENARIOS USING THE CONCEPTUAL MODEL TOPDM

*Lorena LIUZZO¹, Elisa ARNONE¹, Leonardo V. NOTO¹, Francesco VIOLA¹ &
Goffredo LA LOGGIA¹*

(1) Dipartimento di Ingegneria Civile, Ambientale e Aerospaziale, Università degli Studi di Palermo, Italia, email: lorenaliuzzo@yahoo.it, arnone@idra.unipa.it, valerio@idra.unipa.it, viola@idra.unipa.it, glal@idra.unipa.it.

ABSTRACT

Climate change resulting due to the greenhouse effect is expected to have great implications for hydrological cycle and for existing surface and groundwater resources systems. The effects of climate variability and climate change have to be fully considered in current water management and planning, since water availability, quality and streamflow are very sensitive to changes in temperature and precipitation regimes. International literature proposes several models, attempting to assess accurately the available water resources under stationary and changing climatic conditions at different spatial and temporal scales.

In order to assess the potential impacts of climate change on surface and groundwater resources water availability in a Southern area of Italy, a conceptual hydrologic model, the TOPDM, was applied at daily scale to simulate the hydrological processes in the Belice river basin, located in Sicily. The analysis of the climatic forcing trend provided the parameters needed in order to generate synthetic climate forcing series through the use of stochastic approaches.

The hydrological model has been used to estimate the basin water balance components and the surface and groundwater availability in a no trend scenario, representing the current climate conditions, and in three different groups of scenarios, in which a decrease of precipitation, an increase of temperature, and a combination of these effect were reproduced. The application of TOPDM to the test basins provided some important conclusions about the implications of climate change in the Southern part of Italy. Results show that runoff and evapotranspiration reflect variations in precipitation and in temperature; in particular the negative trend in precipitation determines a decrease in surface and groundwater resources, and this effect is intensified in the scenarios that include a temperature trend as well. Therefore the climate change, occurring as precipitation amount reduction and temperature rise, could exacerbate the water resources stresses in the area of study, in which water scarcity is already an important issue for water resource management.

1 INTRODUCTION

The repeated and intense climate anomalies observed during the last decades led the scientific community to admit the existence of a modification of the observed climate. Particularly, the effects of global warming are now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global mean sea level. Trends and variations in global stratospheric temperatures represent the most evident effect of the changes occurring in the Earth's climate system.

According to Arnell (1999), climate change resulting from the enhanced greenhouse effect will influence hydrological cycle and existing surface and groundwater resources systems in great part of the world. The hydrological cycle will be intensified, with more evaporation and more precipitation, but the extra precipitation will be unequally distributed around the globe. Some parts of the world may be interested by significant reductions in precipitation, or major alterations in the timing of wet and dry seasons.

The implications of climate change on water resources may be the most dramatic and certainly they affect the global water supply. Understanding and investigating these implications is important for future water resources management, since water availability and quality are sensitive to changes in temperature and precipitation regimes.

Hydrologic models are important tools to investigate the relationships between water resources and climate change. The international literature over the past decade provides a large number of studies, describing the application of hydrologic models to the assessment of the potential effects of climate change on surface and groundwater resources. Examples of these works include Nemec and Schaake (1982), Gleick (1987), Bultot et al. (1988), Lettenmaier and Gan (1990), Nash and Gleick (1991), Cohen (1991) and (Liuzzo et al., 2010).

In most of the studies provided in literature, researchers typically make use of time series of observed precipitation and temperature, modified with information from climate model simulations, in hydrological models to gain some indication of how streamflow and hydrological cycle might change in different climate scenarios. For instance, Arnell (1999) carried out an assessment of the implications of climate change for global hydrological regimes and water resources. In a study by Milly et al. (2005), the results of 12 climate models exhibiting qualitative and statistically significant skill in simulating observed regional patterns of 20th century multi-decadal changes in streamflow, were described.

In order to assess the potential impacts of climate change on surface and groundwater resources water availability in a Southern area of Italy, the lumped conceptual model TOPDM (TOpography based Probability Distributed Model) (Liuzzo et al., 2007; Noto et al., 2011) has been used to simulate the hydrological processes.

The model has been applied to the Belice river basin (Sicily) for current climate conditions as well as under the hypothesis of climate variations, as represented by scenarios consistent with a climate trend analysis previously carried out. The synthetic climate forcing series has been generated through the use of stochastic weather-generating approaches and used as input for the TOPDM model. The effects of climate change on water resource availability have been assessed analyzing the variations of surface and groundwater resources, due to the climate trends detected.

2 STUDY BASIN AND DATA

The analysis has been carried out for a sub-basin of Belice catchment, located in the Southern Sicily. The climate of this part of Sicily is classified as semi-arid, according to the *Global Humidity Index* classification (Thornthwaite, 1948). Figure 1 shows the location of the basins. Belice has an area of $\sim 950 \text{ km}^2$, while Casa Balate sub-basin has an area of $\sim 350 \text{ km}^2$, characterized by croplands (wheat) and orchards, pastures and small urban areas. The mean annual discharge for Casa Balate is $\sim 2.2 \text{ m}^3/\text{s}$ (mean annual surface runoff of $\sim 200 \text{ mm}$), while the mean annual precipitation over the area is $\sim 700 \text{ mm}$ distributed primarily in winter and autumn.

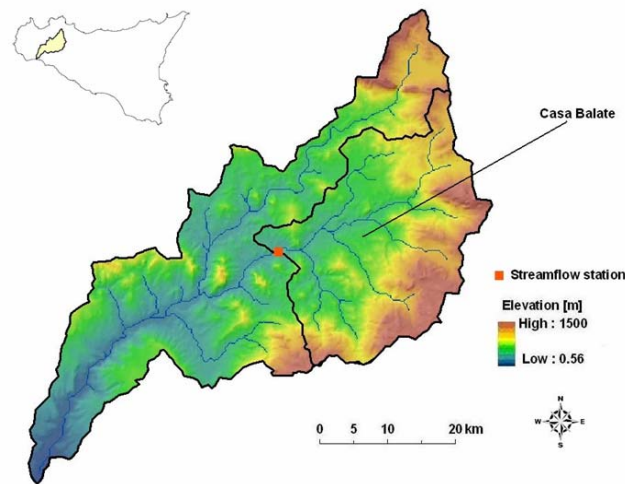


Figure 1. Location of the study basin, topographic distribution and river network. Analysis has been carried out for the sub-basin of Belice catchment, Casa Balate.

Daily precipitation, streamflow and temperature are available for the period 1950-1990, provided by the *Osservatorio delle Acque - Agenzia Regionale per i Rifiuti e le Acque* (OA-ARRA) of Sicily. Historical observations have been used as input of the hydrological model, in order to carry out the calibration of the TOPDM, and also to assess water resource availability under the current climate conditions, i.e. in absence of any trend in hydrometeorological variables.

Starting from above mentioned hydro-climatic data, a trend analysis on precipitation and temperature was carried out to provide a reliable basis for generation of climate scenarios (Cannarozzo et al., 2006; Liuzzo et al., 2010).

3 GENERATION OF CLIMATE SCENARIOS

The generation of rainfall and other climate data needs a range of models depending on the time and spatial scales involved. In regional climate studies, hydrometeorological variables for climate scenarios are generated through statistical techniques. Among the statistical models, stochastic weather generators represent the most used tools, able to produce synthetic daily time series of a suite of climate variables, such as precipitation,

temperature and solar radiation, with certain statistical properties (Richardson 1981; Richardson and Wright 1984; Racsco et al. 1991).

The basic idea for the construction of a scenario consists, on the one hand, in observed time series of meteorological parameters and, on the other hand, in information about the future development of climate, in term of climate parameters.

The first step in the analysis is thus the estimation of the observed weather data statistics (i.e. mean and variance); the following step is the detection of trend in the hydrometeorological data. Once a significant trend is detected, it needs to be quantified, in order to make consistent modifications of the weather data parameters. Parameters can be modified imposing a percentage increase or decrease at the time scale considered (annual, seasonal, monthly or daily). Starting from the modified parameters, new series of hydrometeorological data can be simulated, using a stochastic weather generator.

In this study, the results of trend analysis described in Cannarozzo et al., 2006 and Liuzzo et al., 2010 (Table 1) have been used in the generation of physically consistent climate scenarios, to generate synthetic series of precipitation and evapotranspiration. As regards to precipitation, the used trend series are consistent with trend analysis results of the IPCC report (2007), according to which the area of study could be characterized by a 20% annual decrease in precipitation.

In order to generate the synthetic series of the potential evapotranspiration, trend analysis results on temperature data have been used. The daily potential evapotranspiration, has been estimated through the Hargreaves formula (Hargreaves & Samani, 1982).

Table 1. Mean monthly precipitation decreases (P) and temperature increases (T) imposed in the generation of climate scenarios (results from Cannarozzo et al., 2006 and Liuzzo et al., 2010).

Black dot indicated trend existence; sign + indicated positive trend; sign – indicated negative trend; white dot indicates absence of significant trend.

Month	P		T	
January	-0.6	●/-	0.026	●/+
February	-	○	0.022	●/+
March	-0.3	●/-	0.023	●/+
April	-	○	0.013	●/+
May	-	○	0.035	●/+
June	-	○	0.029	●/+
July	-	○	0.037	●/+
August	-	○	0.030	●/+
September	-	○	0.012	●/+
October	-	○	0.031	●/+
November	-0.3	●/-	0.014	●/+
December	-0.55	●/-	0.024	●/+

3.1 Precipitation generating procedure

The generation of precipitation synthetic series has been carried out following the procedure described by Rodriguez-Iturbe and Porporato (2004). Since both the amount of rainfall can be considered to be stochastic, the occurrence of rainfall is idealized as a series of point events of continuous time, arising according to a Poisson process of rate λ and each carrying a random amount of rainfall extracted from a given distribution.

The pulse of rainfall correspond to daily precipitation assumed to be concentrated at an instant in time. With these assumptions, the distribution of the times τ between precipitation events is exponential with mean $1/\lambda$ (Cox and Miller, 1965):

$$f_T(\tau) = \lambda e^{-\lambda\tau} \quad \text{for } \tau \geq 0 \quad (1)$$

with the depth of rainfall events is assumed to be an independent random variable h , described by an exponential probability density function:

$$f_H(h) = \frac{1}{\alpha} e^{-\frac{1}{\alpha}h} \quad \text{for } h \geq 0 \quad (2)$$

where α is the mean depth of rainfall events.

Precipitation reduction scenarios have been generated accounting for a decrease of the mean depth of rainfall events α . Parameters α have been modified in order to account for the presence of a decreasing trend in winter months. In this way, a group of three scenarios have been obtained, involving three different climate projections (2020, 2050 and 2100). Each scenario has been denoted with an alphanumeric string in which the first letter denotes the group (in this case the P indicates the decrease precipitation scenarios) and the number the climate projection year.

The mean annual precipitation for each scenario is shown in Figure 2a. Comparing the mean annual precipitation of the no trend scenario with Group P scenarios, the decrease is about 4%, 8% and 20% for the P2020, P2050 and P2100 respectively. The mean monthly precipitation of each scenario of Groups P are shown in Figure 2b, indicating that the January and December are characterized by higher values of decrease.

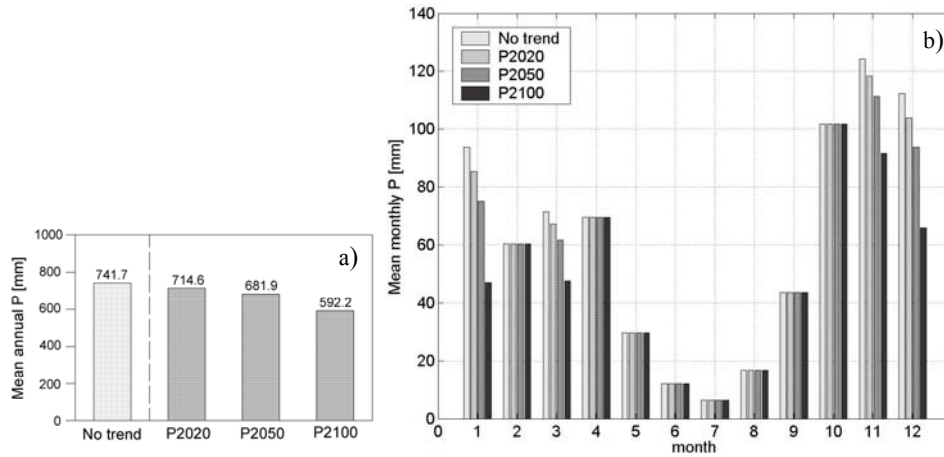


Figure 2. Mean annual precipitation P (mm) (a) and mean monthly precipitation P (mm) (b) in each scenario of Group P.

3.2 Evapotranspiration generating procedure

The generation of synthetic potential evapotranspiration (ET) series has been carried out using a first-order autoregressive model (Pickering et al., 1988), that allowed to generate daily temperature sequences:

$$ET_k = \mu_{ET} + \rho_{1ET}(ET_{k-1} - \mu_{ET}) + \sqrt{1 - \rho_{1ET}^2} \sigma_{ET} v_k \quad (3)$$

where ET_k denotes the potential evapotranspiration on day k , μ_{ET} is the mean potential evapotranspiration for a period (here one month), σ_{ET} is the standard deviation of ET during that period, ρ_{1ET} is the lag-one coefficient of ET during that period, and v_k is the random standard normal variate. Given the parameters μ_{ET} , σ_{ET} and ρ_{1ET} a daily ET sequence can be generated.

Using the increase amounts resulted from the trend analysis a group of three scenarios of potential evapotranspiration increase have been generated, involving the three different climate projections (2020, 2050 and 2100). As made for precipitation scenarios, each evapotranspiration scenario is denoted with alphanumeric string in which the first letters (ET) denotes the group of increasing evapotranspiration and the number the climate projection year.

The mean annual potential evapotranspiration for each scenario is shown in Figure 3a. For Group ET scenarios the mean annual potential evapotranspiration increases by 3%, 9% and 20% for the ET2020, ET2050 and ET2100, respectively. The mean monthly potential evapotranspiration of each scenario are shown in Figure 3b, indicating that the summer months are characterized by higher increases.

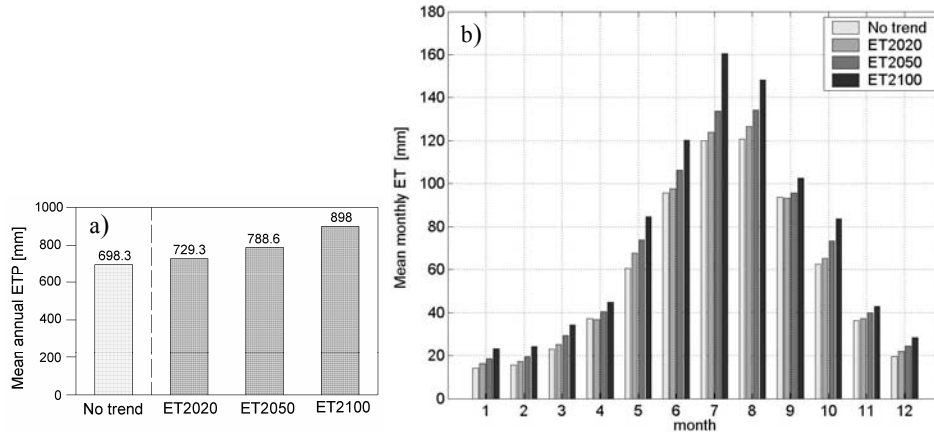


Figure 3. Mean annual potential evapotranspiration ET (mm) (a) and mean monthly potential evapotranspiration ET (mm) (b) in each scenario of Group P.

Finally, a group of three scenarios, indicated as PET, has been generated, considering the combination of the series of decreased precipitation and increased evapotranspiration. Therefore three groups of scenarios have been considered, each involving three climate projections. Table 2 summarizes the scenarios considered in this study.

Table 2. Climate scenarios generated: the sign (-) indicates decrease, sign (+) indicates increase.

Scenario	P	ET
No trend		
P2020	-	
P2050	-	
P2100	-	
ET2020		+
ET2050		+
ET2100		+
PET2020	-	+
PET2050	-	+
PET2100	-	+

4 CONCEPTUAL HYDROLOGICAL MODEL AND NUMERICAL EXPERIMENTS

The effects of climate change on water resource availability have been assessed using the conceptual hydrological model *TOpography based Probability Distributed Model*, TOPDM (Liuzzo et al., 2007; Noto et al., 2011), resulting from the combination and integration of topographic index into a probability distributed model.

In TOPDM the spatial distribution of the topographic index is used to infer the storage capacity probability distribution. The relationship between topographic index and storage capacity allows the transformation of elements with a high value of topographic index (elements placed along the network that have an higher probability of saturation) into elements with a low value of storage capacity, and vice-versa. Through this relationship the model reflects adequately the influence of basin topography in the hydrological process of runoff generation.

TOPDM, based on a simple water balance, in which the components are basin soil moisture storage, precipitation, drainage and evapotranspiration, is able to simulate the generation of Dunnian and Hortonian surface runoff. Vertical drainage to groundwater, represented as a storage with unlimited capacity, is also simulated. This storage does not exchange water with the sub-surface system, and it generates the slow response of the basin. The inclusion of groundwater resources in the model is particularly important since most of the population in the Mediterranean areas relies on groundwater as its primary water resource.

The model simulates hydrological processes at two time scales, daily and hourly; here, since the aim of the study is the assessment of climate change effects on water resources, a daily scale application of the model has been considered appropriate.

Description of all TOPDM simulations is given in the following.

4.1 Experiments setup

TOPDM simulations have been carried out for a no trend scenario, which reflects the current climate conditions, and with climate scenarios generated starting from the trend analysis.

Firstly, an analysis of sensitivity and a Monte Carlo procedure have been used in order to identify the set of model parameters that provides a good fit between observed and simulated discharges. The different set of parameters has been assessed based on efficiency indexes of Nash and Sutcliffe (Nash & Sutcliffe, 1970) with regards to

volume and runoff as well. Once the best set of parameters has been identified, the TOPDM model has been applied to each generated scenario described in section 3 for the basin Belice at Casa Balate.

The hydrologic variables have been simulated for a 10 year period, assumed long enough to detect the effects climate change on the basin water balance. In each simulation, the hydrometeorological forcings have been considered spatially uniform for simplicity, due to the point nature of the stochastic methods used to generate the series, and because of the lumped approach of the hydrological model here used. Moreover, the same initial conditions in term of stored volume in the reservoirs have been considered.

5 RESULTS AND DISCUSSION

Surface runoff and the main components of the water balance have been estimated for the no trend case and for the nine climate change scenarios previously described (Table 2). The estimation of these variables allows assessment of the impact of precipitation trends on water resources.

The annual water balance, calculated as $\Delta S = P - ET_a - R$, provides information on the effects of precipitation (P) changes on the watershed response, including the total storage (S), actual evapotranspiration (ET_a) and runoff (R). Table 3 shows the mean annual values for the water balance components for the no trend case and *Groups P*, *ET* and *PET* scenarios.

As regards the scenarios of *Group P*, results indicate that the decreasing precipitation trend has a strong impact on surface runoff and a comparatively weaker effect on evapotranspiration. In the scenarios of *Group ET*, the increase of potential evapotranspiration produce a slight decrease of runoff. The combined effect of reduction of precipitation and rise of potential evapotranspiration in the scenario *PET* produces a dramatic decrease of runoff.

Table 3. Water balance components for the climate scenarios of *Group P*, *ET* and *PET*.

Scenario	P [mm/yr]	ET_a [mm/yr]	R [mm/yr]	ΔS [mm/yr]
No trend	741.7	495.6	246.2	-0.1
P2020	714.6	494.2	209.2	11.2
P2050	681.9	493.3	188.6	0.0
P2100	592.2	487.1	106.2	-1.1
ET2020	741.7	509.6	231.1	1.0
ET2050	741.7	531.9	208.8	1.0
ET2100	741.7	567.8	172.9	1.0
PET2020	714.6	508	194.9	11.7
PET2050	681.9	506.7	174.3	0.9
PET2100	592.2	517.1	76.1	-1.0

Table 4 shows that a percentage change in precipitation produces a larger percentage change in runoff (PCR) and a slighter percentage change in evapotranspiration ($PCET$). Analysis of the sensitivities of runoff to precipitation (SR) and the sensitivities of evapotranspiration to the precipitation (SET) variations confirms these results. Sensitivities have been estimated as the ratio of the relative increase in ET and R over

the relative increase of precipitation ($SR=PCR/PCP$ and $SET=PCET/PCP$).

For simulations of *Groups P* and *ET* range of variations of decrease of runoff varies from -6.1 to -20.8% for the projections to 2020, from -15.2 to -29.2% for the projections to 2050, and from -29.8 to -69.1% for the projections to 2100. With regard to actual evapotranspiration, the range of variations of are -0.3 to 2.8% (2020), -0.5 to 7.3% (2050), and -1.7 to 14.6% (2100). Scenarios of precipitation decrease are characterized by a decrease of actual evapotranspiration, while the scenario of increased potential evapotranspiration show an increase of actual evapotranspiration. In each climate scenario the ranges of variation of runoff are wider than for actual evapotranspiration. As regard to the *Group PET*, the actual evapotranspiration increases for the scenarios *PET2020* and *PET2100*, because of the increase of the potential evapotranspiration, but in the *PET2100*, the drastic reduction of precipitation causes a decrease of actual evapotranspiration.

Table 4. Changes in precipitation, runoff and evapotranspiration for each scenario in mm/yr and percentage (%) relative to the no trend simulation. SR is the sensitivity of runoff to variation in precipitation and SET is the sensitivity of the evapotranspiration to variation in precipitation.

Scenario	P		R		ET _a		SR	SET
	Δ [mm]	%	Δ [mm]	%	Δ [mm]	%		
P2020	-27.1	-3.7	-37.0	-15.0	-1.4	-0.3	4.1	0.0
P2050	-59.8	-8.1	-57.6	-23.4	-2.3	-0.5	2.9	0.0
P2100	-149.5	-20.2	-140.0	-56.9	-8.5	-1.7	2.8	0.0
ET2020	-	-	-15.1	-6.1	14.0	2.8	-	-
ET2050	-	-	-37.4	-15.2	36.3	7.3	-	-
ET2100	-	-	-73.3	-29.8	72.2	14.6	-	-
PET2020	-27.1	-3.7	-51.3	-20.8	12.4	2.5	5.7	-0.7
PET2050	-59.8	-8.1	-71.9	-29.2	11.1	2.2	3.6	-0.3
PET2100	-149.5	-20.2	-170.1	-69.1	21.5	4.3	3.4	-0.2

The effect of climate change on surface water resources availability has been evaluated through the analysis of the streamflow exceedance curves (Figures 4). The three scenarios groups are characterized by a progressive decrease of the available surface water resources. The area under each exceedance curve represents the volume available in 10 years. This volume clearly decrease from the no trend to the P2100, ET2100 and PET2100 scenarios. By comparing the curves, the scenarios of Group PET shows the highest decrease of surface water resource availability, while scenarios of Group ET are characterized by a slighter decrease.

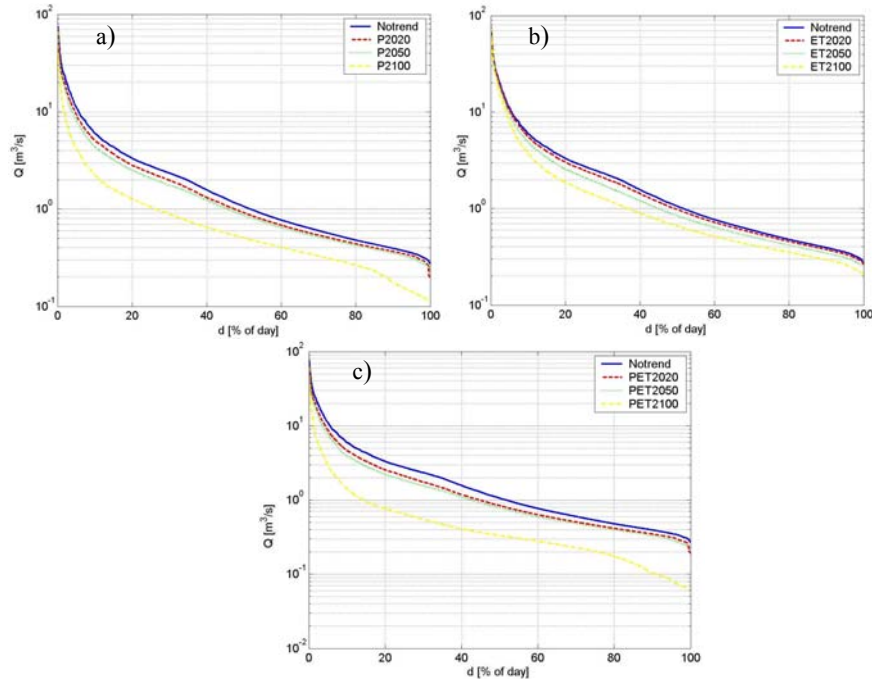


Figure 4. Streamflow exceedance curves for the scenarios of Group P (a), ET (b) and PET (b).

Water volumes percentage variation of each scenario are shown in Figure 5. These results indicate that in future, under the hypothesized climate change, the water resources availability in the basin could be affected by a progressive reduction.

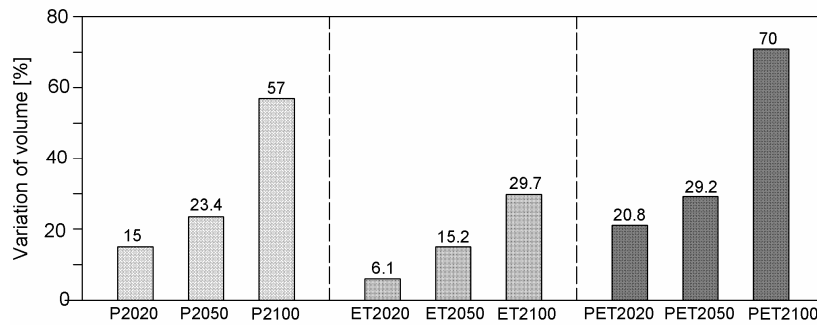


Figure 5. Surface runoff volume percentage variation in each scenario compared to the no trend case.

Similar analysis have been carried out with regard to the groundwater resources, in term of groundwater volume W . The mean groundwater volumes for each scenario, and the relative variations compared to the no trend case are summarized in Figure 6.

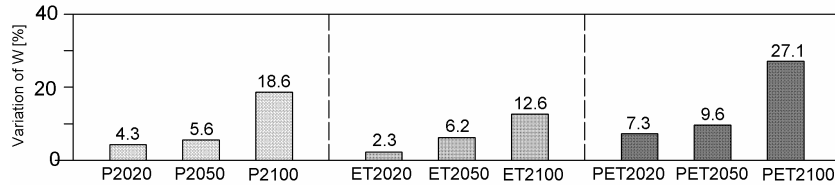


Figure 6. Groundwater volume variation (%) in each scenario compared to the no trend case.

By comparing Figure 5 and Figure 6 it can be concluded that reduction of groundwater due to the trends is less marked than the reduction of surface water resources. This aspect can be observed in Table 5 as well, which shows the ratio of the variation of surface water resources to the variation of groundwater resources (SWR/GWR) calculated in each scenario. Results show that the reduction of surface water resources is 3–4 times greater than the reduction of groundwater resources in the scenarios of *Group P*. The ratio is about 2 in the scenarios of *Group ET*, while it ranges from 2 to 3 in the scenarios of *Group PET*.

Table 5. Surface and groundwater resources variation (%) and their ratio in each scenario.

Scenario	SRV [%]	GRV [%]	SRV/GRV [-]
P2020	15	4.3	3.5
P2050	23	5.6	4.1
P2100	56	18.6	3.1
ET2020	6.1	2.3	2.6
ET2050	15.2	6.2	2.5
ET2100	29.7	12.6	2.4
PET2020	20.8	7.3	2.8
PET2050	29.2	9.6	3.0
PET2100	69.1	27.1	2.5

6 CONCLUSIONS

The potential impacts of climate change on surface and groundwater resources water availability in a Southern area of Italy, have been assessed, using the *TOpography based Probability Distributed Model* (TOPDM) to simulate the hydrological processes in a sub-basin of Belice, Casa Balate, located in Sicily.

Numerical simulations have been carried considering a no trend case and some climate change scenarios, based on a trend analysis of precipitation and potential evapotranspiration for area of study. The trend analysis, highlighted a decrease of precipitation and an increase of potential evapotranspiration for the study area. The model has been applied for current climate conditions as well as under the hypothesis of climate variations, as represented by scenarios consistent with the climate trend analysis. Three different group of scenarios have been generated, in which a decrease of precipitation, an increase of temperature, and a combination of these effect were reproduced.

The effect of climate change on water resource availability has been assessed by analyzing the variations of surface water resources, due to the detected climate trends. Results showed that runoff and evapotranspiration reflect variations in precipitation and

in temperature, in particular the negative trend in precipitation determines a decrease in surface and groundwater resources, and this effect is intensified in the scenarios that include the potential evapotranspiration positive trend as well.

The analysis of exceedance curves for each climate scenario showed that the trend of precipitation and potential evapotranspiration implies a progressive decrease of the available surface water resources. Therefore, the climate change could exacerbate the water resources stresses in the area of study, in which water scarcity is already an important issue for water resource planning and management.

As regards to climate scenarios generation, it is important to remark that a climate scenario is not intended to explicitly represent real future climate, since it represents just one of all possible climate realizations; then an high degree of uncertainty is associated to the climate scenario used in the study.

In climate change scenarios generations, the assumption of a climate system in “equilibrium” here adopted is frequently used (i.e. with stationary mean values of all climatic parameters), while the climate system is strongly non linear and unpredictable.

In conclusion, the assessment of climate change implications on water resources is highly dependent on the scenarios considered and the models used to simulate the hydrological processes. The reliability of the estimated impacts of climate change on surface and groundwater hydrology is affected by large uncertainties. Nevertheless, these studies provide useful information about the quantification of the potential effects of climate change, in order to develop new strategies to deal with these changes.

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