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SIMULATION OF UNGAUGED BASINS IN CLIMATE CHANGE CONDITIONS

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INTRODUCTION

Climate models outputs and indicators demonstrate that in specific geographic areas, e.g. the Mediterranean basin, the projected temperature increase will be coupled with perturbations of the hydrological cycle, i.e rainfall decreases, with direct impact on surface water resources availability, and increases in extreme flood events.

Hence, knowledge on hydrosystems' behaviour at basin scale is a critical prerequisite for climate change adaptation actions.

Climate change and hydrological modeling:
The most common approach in estimating future flow regimes under climate change conditions at basin scales is the forcing of validated hydrology models with climate variables derived either by statistical or dynamic downscale of Global Climate Modes (GCMs) outputs.

However, this kind of assessment is very challenging, in terms of simulation accuracy of the utilized hydrology mode, in ungauged or scarce data basins.

AIM OF RESEARCH

Currently, the advancements of ICTs have fostered the development of scientific research initiatives that produce hydrometeorological datasets for large-scale geographical areas, e.g.

- Gridded rainfall datasets of high spatial resolution covering the globe and
- historic river discharges through global hydrological simulations.

The present work aims at investigating the impact of climate change on the regime of an ungauged river basin through the use of publicly available large-scale datasets and geographic information systems.

- GIS tools and methods are applied to extract topographic and hydrological characteristics used for the parametrization of the utilized hydrology model, namely HEC-HMS.
- The variables of 3 Regional Climate Change Models (RCMs) under the RCP4.5 are used as forcing to the validated hydrology model.
- Assessment of future river discharges for 5 future periods and for 2 different reference periods.

MATERIALS AND METHODS

Case study area

The study basin, namely the Marmara river basin, covers an area of 234.36 km2 and is located at the northern part of Greece, 42.0 km southwest of the city of Kavala, Figure 1. It belongs to the Water District of Eastern Macedonia (EL11) and is an important subbasin of the Strymonas River Basin. The river basin is drained by the perennial homonymous river and outlets on the North Aegean Sea.

Geologically, the crystalline rocks of the Rodopi mass are dominant in the basin. They consist of granites, gneisses and marble inserts; thus, the basin is largely structured by impervious rocky background, apart from marble appearances.

However, the newer geological soil deposits of the riverbed area are permeable with coarse gravel with cobbles to overlay the downstream parts of the river. The presence of coarse channel deposits is expected to cause significant flow losses in the channel.

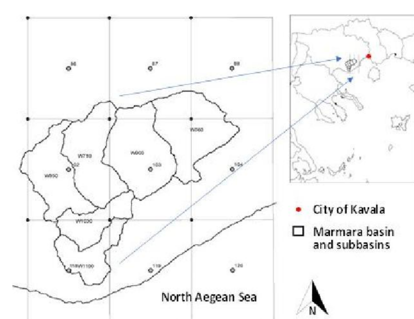


Fig. 1 Marmara's basin and ERA5 grid

Although many historical floods have been recorded in the basin, with significant economic impact on infrastructure and agricultural production, very few time-scattered flow measurements are available.

MATERIALS AND METHODS

Models and tools for data analysis and simulation

- The hydrological model HEC-HMS (Hydrologic Engineering Center – Hydrologic Modeling System), was used to simulate the basin runoff. The applicability of the model for simulating river discharges under current and CC conditions is peer reviewed in the literature (Ouédraogo et al., 2018; Meenu et al., 2013).
- For the case study basin, the utilized loss, transform and baseflow methods for each subbasin is presented in Table 1. The routing method and the channel losses were assessed by the Muskingum-Cunge and Constant losses methods respectively (USACE, 2008).

Table 1. Applied methods in HEC-HMS model for the simulation of the Marmara river basin.

HEC-HMS Process		Applied method
A	Loss	Soil Conservation Service (SCS) Curve Number (CN)
B	Transform	SCS Unit Hydrograph
C	Baseflow	No method

Description and equations		
A	$P_e = \frac{(P-I_a)^2}{(P-I_a)+S}$	(1)
	$I_s = 0.2S$	(2)
	$S = \frac{25400CN}{CN} - 254$	(3)
B	$U_p = C\frac{A}{T_p}$	(4)
	$T_p = \frac{\Delta t}{2} + t_{lag}$	(5)
	$t_{lag} = 0.6t_c$	(6)

where P_e the accumulated excess rainfall (mm), P the rainfall depth (mm), I_a the initial abstraction (initial loss) (mm), S the possible maximum retention after runoff begins, CN the curve number, U_p the unit hydrograph (UH) peak discharge, T_p the time to UH peak, A the watershed area,

C a conversion constant equal to 2.08, Δt the excess precipitation duration, t_{lag} the basin lag time which is defined as the time difference between the center of mass of rainfall excess and the peak of the UH.

MATERIALS AND METHODS

Modes and tools for data analysis and simulation

- GIS tools and the HEC-GeoHMS toolbox used for the estimation of the subbasins' geometric and hydrological characteristics, which are used as input parameters to the model processes depicted in Table 1.
- To do so, an ASTER-GDEM v2 digital elevation model (DEM) of horizontal and vertical resolution of 20 m and of 3.0 m respectively was used for the basin's terrain processing.

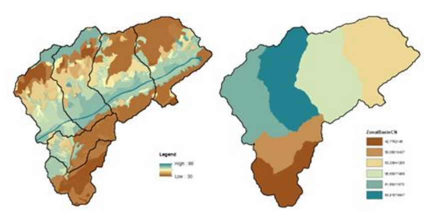


Fig. 2 Exported CN grid and Zonal statistics in sub-basins

- Standard GIS tools facilitated the union of a) geological map with b) soil types and c) land use, for creating the Curve Number (CN) grid map.
- Moreover, GIS zonal statistics tool was applied to address the mean CN number and impervious percentages to the sub-basins.
- The distribution of the rainfall to the subbasins and the calculation of the rainfall impact weights to each subbasin was also performed with GIS.

MATERIALS AND METHODS

swarm

Historic river discharges and rainfalls, and climate change variables

The lack of meteorological and runoff observations at the basin, necessary for the hydrologic model calibration and validation, has overcome with the use of pan European products.

- ERA5 reanalysis rainfall data (Hersbach et al., 2020)
- River discharges produced by the European version of the Hydrological Predictions for the Environment (E-HYPE) semi-distributed physically based catchment model (Donnelly et al., 2016) were retrieved for an historic period of 11 years, i.e. from 1984 to 1994.

For the assessment of climate change on the Marmaras River discharges, precipitation derivatives of 3 Regional Climate Models (RCMs) (Euro-CORDEX) (Jacob et al. 2014), under the RCP4.5 representative concentration pathway were exploited :

1. IPSL-CM5A-MR (hereinafter denoted as CM5A),
2. KNMI-RACMO22E-EC-EARTH (hereinafter denoted as EC-EARTH), and
3. SMHI-RCA4-HadGEM2-ES (hereinafter referred as HadGEM2)

RESULTS AND DISCUSSION

swarm

Hydrologic model calibration and validation

- Eight initial configurations of the HEC-HMS model were created with the corresponding basin simulations to be triggered by the ERA5 reanalysis precipitation data.
- The sensitivity analysis of the model performance demonstrated the decisive effect of the channels' flow loss parameterization.
- The E-HYPE model river discharges for the case study basin were considered as the observation discharges.
- Correlation between the eight configuration outputs and the E-HYPE river discharges for the period from 1984 to 1990 (calibration period) demonstrated the best configuration.
- The best configuration was adopted for the validation (validation period 1991-1994) of the hydrologic model.

RESULTS AND DISCUSSION

Hydrologic model calibration and validation

Model calibration: Overall good correlation between the HEC-HMS simulated discharges and observed ones (Pearson correlation coefficient (PCC) = 0.773, Nash–Sutcliffe efficiency coefficient (NSE) = 0.602, and Root Mean Square Error (RMSE) = 1.672), **Figure 3a**.

Model validation: Similar performance results, PCC = 0.537, NSE = 0.568 and RMSE = 1.472, **Figure 3b**.

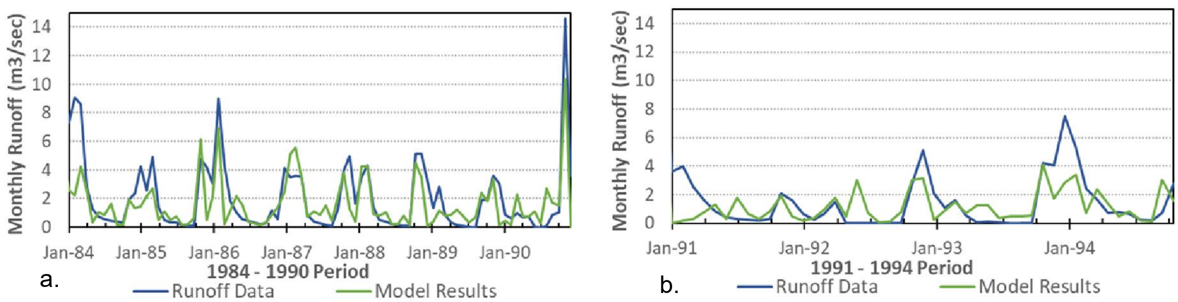


Fig. 3 Hydrological model a) calibration for the period 1984-1990 b) validation for the period 1990-1994

RESULTS AND DISCUSSION

Results under climate change conditions

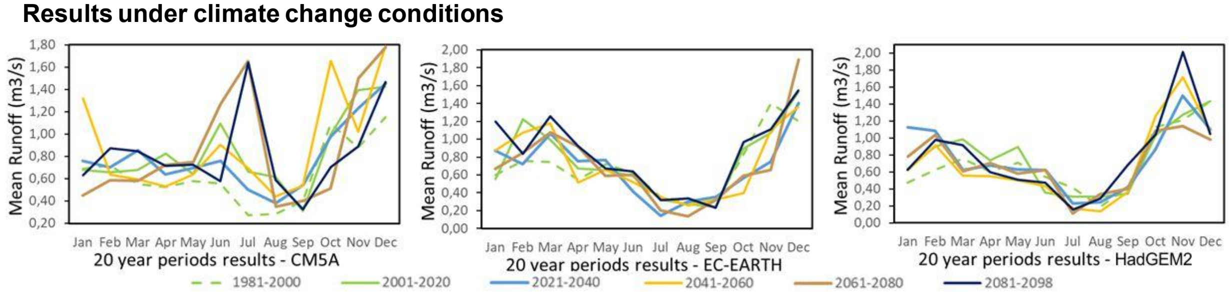


Fig. 4 Hydrological model outputs over 20-year periods under climate change at intermonthly level

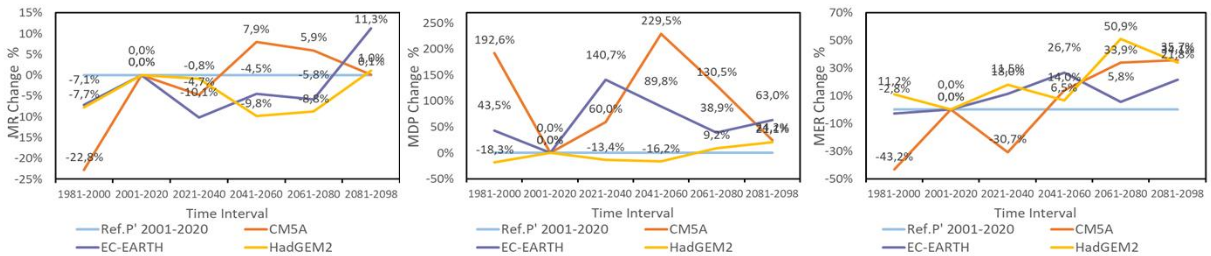
- CM5A model: an increase of the average runoff varying from 23.4% to 39.8% is projected for all the future subperiods in comparison to the relevant reference period.
- EC-EARTH model: a negligible decrease of 3.2% of the river's runoff is foreseen only for the period 2021-2040.
- HadGEM2 model: a decrease of 7.4% of the average runoff during the period 2021-2040, while small discharge decreases varying from 1.1% to 2.3% are foreseen for the periods 2041-2060 and 2061-2080 when compared to the reference period.

RESULTS AND DISCUSSION

Results under climate change conditions

Outputs for the alternative reference period (Ref.P') 2001-2020:

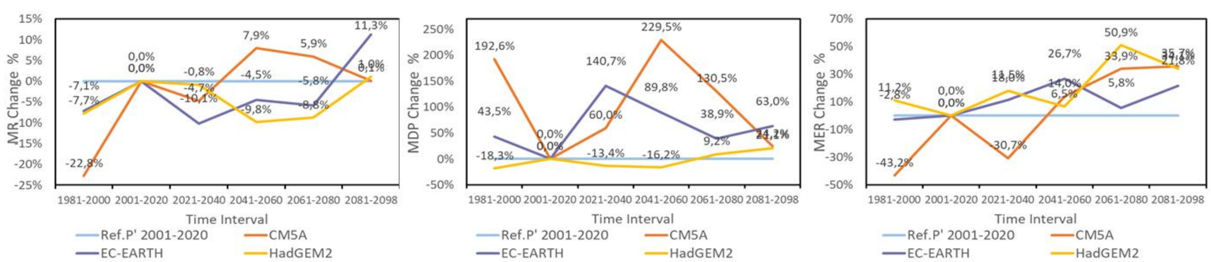
Figure 5: mean runoff (MR) (left hand figure), longest forecast period with absence of runoff (MDP), i.e. periods with no discharges, (middle figure), and mean runoff during the periods of elevated discharges (MER) (right hand figure) as simulated for each of the 20 year periods in comparison to the period 2001-2020 (Ref.P').



According to MR, reduced runoff (compared to the relevant RefP') varying from 4.5% to 9.8% is foreseen for the EC-EARTH and HadGEM2 models throughout the period 2021-2080, while increased runoff from + 5.9% to + 7.9% is forecasted for the CM5A model for the same time period.

RESULTS AND DISCUSSION

Results under climate change conditions



According to the MDP analysis, the maximum duration of dryness increases up to 229% in the CM5A and EC-EARTH models, while the HadGEM2 model demonstrates decreases from 13.4% to 16.2%. in the period 2021-2060.

Based on the MER analysis, it is predicted an increase of the maximum average runoff from +11.5% to +18.0% in the period 2021-2040 and an increase up to +50.9% during the period 2041-2080 for the models EC-EARTH and HadGEM2. The CM5A model shows a reduction of the maximum runoff up to 30.7% during the period 2021-2040 and an increase up to +35.7% from 2041 till the end of the century.

RESULTS AND DISCUSSION

Results under climate change conditions

% to Ref. Period	2021-2040 Ref.P			2021-2040 Ref.P'			2041-2060 Ref.P			2041-2060 Ref.P'		
Climate Model	CM5A	EC-EARTH	HadGEM2	CM5A	EC-EARTH	HadGEM2	CM5A	EC-EARTH	HadGEM2	CM5A	EC-EARTH	HadGEM2
Average runoff	23,4	-3,2	7,4	-4,7	-10,1	-0,8	39,8	2,9	-2,3	7,9	-4,5	-9,8
DJF	13,8	17,0	30,7	5,6	-9,3	11,5	46,1	29,1	3,4	35,6	0,1	-11,7
MAM	32,5	28,7	-6,7	2,2	11,5	-26,2	6,8	17,0	-22,7	-17,7	1,4	-38,8
JJA	44,6	-23,1	-1,9	-18,4	-15,3	15,7	70,7	-7,3	-29,0	-3,7	2,0	-16,3
SON	12,0	-41,3	1,0	-7,5	-33,3	2,5	35,7	-32,9	27,3	12,0	-23,7	29,2
Dryness events	14,3	0,0	-33,3	-11,1	0,0	-11,1	-28,6	22,2	25,0	-44,4	22,2	66,7
Dryness period	-45,3	67,7	6,0	60,0	140,7	-13,4	12,6	32,3	2,6	229,5	89,8	-16,2
Continuous flow	44,4	-21,4	41,7	0,0	-8,3	-29,2	66,7	14,3	-50,0	15,4	33,3	-75,0
Con. Flow period	0,0	27,3	-9,1	44,4	16,7	-41,2	-15,4	27,3	18,2	22,2	16,7	-23,5
High-flow runoff	22,0	14,7	6,1	-30,7	11,5	18,0	100,8	30,4	-4,2	14,0	26,7	6,5

Table 2. Predicted changes of average runoff, seasonal runoff (DJF, MAM, JJA, SON), dryness events (60 consecutive days threshold), maximum dryness period, continuous flow (7 consecutive days threshold), continuous flow periods, and the average runoff of the 20 higher flow events, in comparison to the reference periods 1981-2000 (Ref.P) and 2001-2020 (Ref.P').

CONCLUSIONS

- The sensitivity analysis during the calibration process of the hydrology model at the case study ungauged basin, demonstrated the importance of optimum estimation of channel losses, a parameter that cannot be accurately assessed by the SCS Curve Number method that is applied for estimating the losses in the subbasins.
- In terms of climate change and future runoff, the outputs showed that there is not a clear discharges' trend and the outputs depend on the RCM that is used for triggering the hydrologic simulation.
- At seasonal scale, all simulation outputs agree on decreased runoffs during late summer and early autumn, while varying runoff increases are presented during the winter.
- For most of the future 20-year periods, it can be concluded an increased number of anhydrous days (lack of discharge) together with an increased duration of these incidents. Additionally, for almost all periods and climate models, the maximum runoff is quite bigger than the one observed in the past.
- The findings of the research foster the need for sustainable water resources management also at ungauged basins in the framework of climate change adaptation plans and policies.