Proactive Producer and Processor Networks for

Troodos Mountains Agriculture

3PRO-TROODOS

Prot. No: INTEGRATED/0609/061

Deliverable type	*Report*
Work package number and name	*WP4: Assessing water resources and irrigation demand under current and future climate conditions*
Date	*April 2023*
Responsible Beneficiary	*HO: The Cyprus Institute*
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Classification of Dissemination	*Public*
Short description	*D4.3: Report with guidelines for sustainable irrigation under current and future climate in the main agricultural areas of the Troodos Mountains*

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Ευρωπαϊκή Ένωση
Ευρωπαϊκό Ταμείο
Περιφερειακής Ανάπτυξης

Κυπριακή Δημοκρατία

Διαρθρωτικά Ταμεία
της Ευρωπαϊκής Ένωσης στην Κύπρο

2016-2020 RESTART RESEARCH
ΠΡΟΓΡΑΜΜΑΤΑ ΕΡΕΥΝΑΣ, ΤΕΧΝΟΛΟΓΙΚΗΣ ΑΝΑΠΤΥΞΗΣ ΚΑΙ ΚΑΙΝΟΤΟΜΙΑΣ

Version	Date	Changes	Partner
v1	22/05/2023	-	HO

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Introduction

The Troodos Mountains are the water tower of Cyprus. Irrigation water use in the mountains reduces the the natural flows in the Troodos watersheds. Climate change will also impact the water resources and irrigation water demand of the region. The objectives of this study are: (i) to calibrate and validate a conceptual hydrologic model to simulate the streamflow of the main Troodos watersheds; (ii) to simulate streamflow under projected climate change conditions ; (iii) to analyse the effect of current and future irrigation water demands on the Troodos Mountain watersheds (iv) to provide recommendations for further research on guidelines for sustainable future water use.

Methods

We used the GR4J model to simulate the streamflow of the Troodos Mountain watersheds. The GR4J is a conceptual, four-parameter, daily rainfall-runoff model. A detailed presentation of the model is given by Perrin et al. (2003). The model showed good performance for streamflow simulations of five Troodos watersheds (Le Coz et al., 2016). The four parameters represent the watershed's soil water or production storage (X1), groundwater exchange acting on streamflow (X2), stream flow storage (X3), and a time parameter for the unit hydrograph (X4). The groundwater exchange coefficient can be positive (inflow to stream) or negative (recharge losses). The parameters are embedded in exponential equations, which are used to represent the hydrologic processes. All input data and model parameters are expressed in mm over the watershed area, except for X4, which is expressed in days. The four model parameters are fitted, using daily precipitation (P), reference evapotranspiration (ETo) as forcing data and daily streamflow for calibration and validation.

We used the GR4J model implementation in R (https://webgr.irstea.fr/en/modeles/journalier-gr4j-2/fonctionnement_gr4j/). We used common hydrologic modeling metrics for optimizing and evaluating the model calibration. These metrics are the standard Nash Sutcliffe Efficiency (NSE), the NSE on square roots of the flow (NSEsqrt), the NSE on logs of the flows (NSElog), the King-Gupta Efficiency (KGE) and the percent Bias (PBIAS). The percent Bias (PBIAS) is 0% if the total observed streamflow equals the modeled streamflow over the modeling period. A positive PBIAS indicates that the model overestimated the observed streamflow and a negative PBIAS indicates that the model underestimated the flow. We used the standard NSE to optimize the model parameter values.

We applied the GR4J model on 32 Troodos watersheds with long-term stream records, using the 15 hydrologic years 1980/81 to 1994/95 for model calibration and the 15 hydrologic years 1995/96 to 2009/10 for evaluation (validation). We extracted the average daily precipitation and daily reference evapotranspiration time series over the area of each watershed from the 1-km gridded climate data sets (see D4.2). The reference evapotranspiration was computed from the daily minimum and maximum temperature with the Hargreaves equation.

Five additional, ungauged watersheds were modelled by transferring the GR4J parameter values from similar watersheds, based on similarities in size and shape of the watershed, geology, proximity and field observations of the stream characteristics. The set of 37 watersheds are presented in Figure 1 and Table 1. Parameters from Peristerona watershed (st18), which has a surface geology made up of 89% diabase and 11% gabbro, were used for the nearby Elia at Vyzakia watershed (st17), which consists also mainly of diabase with a minor area with gabbro. Parameters from Agios Onoufrios watershed (st20) were used for the similar neigbouring Pedieos watershed (st21). Both watersheds are covered for more than 90% by the diabase geologic formation. Parameters from Vasilikos (st29), which is mainly diabase, with 10-15% shares of vulcanic, ultramafic, and gabbro, were used for Maroni (st28), which has a similar geology. The area upstream of Arminou Reservoir (st36), which is mainly diabase, with smaller area covered by ultramafic formations, was modeled with the nearby Xeros watershed (st2), which is 100% diabase. For the Lefka dam watershed (st37) we used parameters of the neighbouring Kargiotis watershed (st14).

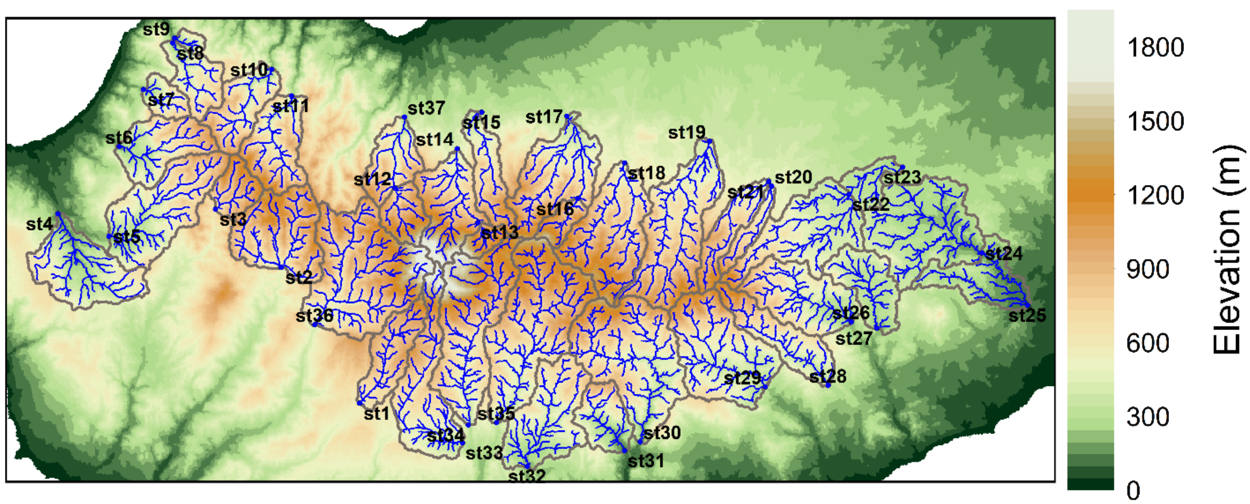

Figure 1. The 37 modeled Troodos Mountains watersheds.

Table 1. The 37 Troodos watersheds with their areas.

Station	Code	Name	Area (km^2)
st1	r1-1-3-95	Chapotami near Kissousa	39
st2	r1-3-5-05	Xeros near Lazarides	72
st3	r1-4-2-15	Agia near Agia Forest Station	24
st4	r2-2-3-95	Chrysochou near Skoulli	79
st5	r2-2-6-60	Stavros Tis Psokas near Skarfos	86
st6	r2-3-4-80	Makounta U/S Argaka Dam	48
st7	r2-3-8-60	Gialia near Pano Gialia	17
st8	r2-4-6-70	Leivadi U/S Pomos Dam	31
st9	r2-4-6-80	Mavros Kremmos U/S Pomos Dam	7
st10	r2-7-2-75	Pyrgos near Fleva	42
st11	r2-8-3-10	Limnitis Saw Mill	52
st12	r3-2-1-85	Marathasa U/S Kalopanagiotis Dam	27
st13	r3-3-2-60	Platania near Kakopetria	14
st14	r3-3-3-95	Kargotis near Evrychou	69
st15	r3-4-2-90	Atsas near Evrychou	36
st16	r3-5-1-50	Lagoudera near Lagoudera Br.	17
st17	r3-5-4-40	Elia near Vyzakia	89
st18	r3-7-1-50	Peristerona near Panagia Bridge	76
st19	r3-7-3-90	Akaki near Malounta	107
st20	r6-1-1-80	Agios Onoufrios near Kampia	15
st21	r6-1-1-85	Pedieos near Kampia	32
st22	r6-5-1-85	Gialias near Kotsiati	79
st23	r6-5-3-15	Gialias near Nisou	98
st24	r8-4-3-40	Tremithos near Agia Anna	99
st25	r8-4-5-30	Tremithos near Klavdia	144
st26	r8-7-2-60	Syriatis near Pano Lefkara	66
st27	r8-7-3-95	Mylos U/S Dipotamos Dam	42
st28	r8-8-2-95	Maroni near Choirokoitia	48
st29	r8-9-5-40	Vasilikos near Lageia	92
st30	r9-2-3-85	Germasogeia near Foinikaria	117
st31	r9-2-4-95	Gialiades (Akrounta) U/S Germasogeia Dam	33
st32	r9-4-3-80	Garyllis U/S Polemidia Dam	71
st33	r9-6-2-90	Kryos near Alasa	73
st34	r9-6-4-90	Kouris R. u/s Kouris Dam	104
st35	r9-6-7-70	Limnatis u/s Kouris Dam	123
st36	d1-2-4-61	Arminou dam	128
st37	d3-2-2-XX	Lefka dam	60

We modelled the 2030-2060 future, under the RCP8.5 scenario, using the bias-corrected data from three EURO-CORDEX Regional Climate Model (RCM) simulations at approximately 12-km resolution, downscaled to 1-km gridded data sets (see D4.2). The three RCMs are: (i) KNMI-RACMO22E, driven by the MPI-M-MPI-ESM-LR global model, referred to as RACMO; (ii) DMI-HIRHAM5, referred to as HIRHAM; and (iii) SMHI-RCA4, referred to as RCA. The last two RCMs were driven by the ICHEC-EC-EARTH global model. Out of 20 evaluated EURO-CORDEX simulations, RACMO was the best performing model over Cyprus, with less than 1 mm bias in average annual precipitation for the 1980-2010 reference period (see D4.1). The bias of the other two RCM simulations was less than 100 mm. These three models were selected to cover the range of projected precipitation changes of the EURO-CORDEX simulations. The decrease in average annual precipitation over Cyprus for 2030-2060, relative to 1980-2010, was less than 1% for RACMO, 8% for RCA and 15% for HIRHAM.

The irrigation water demand of the 2020 agricultural plots of the mountain villages on the Troodos ophiolite formation simulated with the Cyprus blue-green water model (D4.2) was extracted for the watershed areas for the 1980-2010 reference period and the 2030-2060 future.

Results

Hydrologic model calibration and water balance components for 1980-2010

The results of the GR4J calibration and validation for the 32 watersheds are presented in Table 2. Model performance for the calibration was generally very good. The median NSE coefficient was 0.82, whereas the lowest NSE was 0.52, for the downstream Tremithos station (st25). The median NSE values for the squares and the logarithms of the streamflow values, which give more weight to errors for low flows, were 0.60 and 0.65, respectively. There were five negative values for NSEsqrt, but all NSElog values were positive, with a minimum value of 0.43 for st31 (Gialiades). The KGE values also indicated good model performance, with a median value of 0.76. There was only one negative KGE and this worst performing watershed was again for st31 (Gialiades), even though it had an NSE of 0.76. As expected, the validation results were slightly lower, but still very acceptable, with median values of 0.76, 0.47, 0.56 and 0.72 for NSE, NSEsqrt, NSElog and KGE, respectively. The highest production stores (X1) were found for the watersheds that included parts of the fractured ultramafic formations around the top of the Troodos Mountains (Mount Olympos).

Table 2. Calibrated GR4J model parameters (X1: capacity of production store, X2: water exchange coefficient, X3: capacity of routing store, X4: unit hydrograph time base) and evaluation criteria for the calibration (1980/81-1994/95) and validation (1995/96-2009/10) periods for the 32 watersheds.

					Calibration period					Validation period				
Station	X1 (mm)	X2 (mm/day)	X3 (mm)	X4 (days)	NSE	NSEsqrt	NSElog	KGE	PBIAS	NSE	NSEsqrt	NSElog	KGE	PBIAS
st1	986	0.2	46	1.3	0.9	0.6	0.7	0.8	12	0.5	0.1	0.2	0.0	95
st2	297	-4.9	69	1.4	0.8	-0.3	0.7	0.8	-17	0.7	-0.1	0.6	0.7	-14
st3	399	-4.1	84	1.5	0.9	0.8	0.7	0.9	-4	0.9	0.8	0.7	0.8	12
st4	255	-32.9	40	1.4	0.8	-2.1	0.5	0.4	-40	0.2	-0.2	0.5	0.6	4
st5	357	-4.7	55	1.5	0.9	0.9	0.8	0.9	-3	0.8	0.8	0.7	0.9	2
st6	371	-8.6	80	1.6	0.9	0.6	0.7	0.9	-8	0.7	0.5	0.5	0.8	15
st7	1162	0.7	13	1.7	0.9	0.8	0.6	0.9	-3	0.7	0.5	0.4	0.7	19
st8	272	-2.7	64	1.7	0.9	0.7	0.7	0.9	-4	0.5	0.6	0.6	0.6	42
st9	223	-19.0	133	1.4	0.8	0.6	0.7	0.7	-22	0.8	0.7	0.7	0.9	-9
st10	282	-3.2	92	1.5	0.8	0.7	0.7	0.9	-9	0.6	0.7	0.6	0.8	19
st11	285	-2.4	85	1.5	0.9	0.7	0.7	0.9	-9	0.8	0.7	0.7	0.9	10
st12	2205	0.9	62	1.3	0.8	0.6	0.6	0.8	1	0.7	0.5	0.5	0.7	-14
st13	3041	-2.5	103	1.2	0.8	0.8	0.6	0.8	1	0.8	0.8	0.6	0.8	-9
st14	2332	0.8	47	1.2	0.8	0.4	0.6	0.8	7	0.7	0.3	0.6	0.8	-3
st15	853	0.0	51	1.5	0.7	0.2	0.5	0.5	25	0.8	0.4	0.5	0.4	36
st16	235	-15.7	103	1.3	0.7	0.5	0.6	0.7	-20	0.8	0.6	0.7	0.8	-14
st18	201	-4.4	53	1.3	0.8	0.6	0.7	0.7	-19	0.9	0.6	0.6	0.7	-22
st19	209	-5.6	64	1.3	0.8	0.8	0.7	0.8	-13	0.9	0.6	0.7	0.8	-15
st20	188	-6.4	53	1.2	0.7	0.6	0.7	0.6	-28	0.8	0.6	0.7	0.6	-20
st22	461	0.2	13	1.3	0.7	0.4	0.7	0.8	5	0.8	0.3	0.6	0.8	5
st23	433	-0.1	15	1.4	0.7	0.5	0.6	0.6	23	0.8	0.3	0.5	0.4	50
st24	253	-3.1	54	1.2	0.7	0.7	0.7	0.8	1	0.8	0.5	0.6	0.6	35
st25	324	-9.1	37	1.3	0.5	0.6	0.6	0.6	-14	0.7	0.2	0.6	0.7	-20
st26	1432	-0.3	8	1.3	0.7	0.7	0.6	0.8	-11	0.5	0.3	0.5	0.5	-29
st27	414	0.4	19	1.3	0.8	0.6	0.6	0.8	7	0.8	0.3	0.5	0.6	31
st29	328	-6.4	104	1.2	0.9	0.7	0.7	0.8	-14	0.8	0.7	0.7	0.9	0
st30	215	-15.0	163	1.1	0.8	0.6	0.6	0.7	-22	0.6	0.6	0.5	0.8	3
st31	211	-32.0	38	1.3	0.8	-3.1	0.4	-0.5	-62	0.3	-2.1	0.4	-0.3	-60
st32	189	-41.3	122	1.1	0.8	-0.3	0.5	0.4	-35	0.6	0.2	0.5	0.7	-26
st33	1224	-0.1	73	1.3	0.8	0.5	0.6	0.7	16	0.2	0.2	0.4	0.2	-60
st34	2008	0.7	25	1.1	0.8	0.5	0.6	0.8	6	0.2	0.4	0.5	0.1	11
st35	133	-40.3	214	1.2	0.9	0.0	0.6	0.6	-28	0.8	0.1	0.6	0.6	-23

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Table 3 presents the observed average annual precipitation (P), and the modelled evapotranspiration (ET), streamflow (Q) and losses (L) as a fraction of the precipitation for the 30 hydrologic years of the 1980-2010 reference period. The average runoff coefficient (Q/P) of the 37 watersheds is 13%. The lowest runoff coefficients (3%) are found for stations at the lower elevations (st4, st25, st26, st31). The highest runoff coefficients were found to be for 25% for st11 (Limnitis) and 23% for st12 (Marathassa). These two watersheds are relatively undisturbed. There were five watersheds were the modelled evapotranspiration was 90% or higher. Large streamflow losses were modeled for some of the larger watersheds, i.e., 31% for st35 (Limnatis) and 26% for st32 (Garyllis), but also for smaller watersheds, i.e., 25% for st16 (Lagoudera) and st31 (Gialadis). The largest discharge to the stream (9%) was modeled for the small forested Yialia watershed (st7). These streamflow losses and gains can be expected to occur in the complex and fractured Troodos aquifer system, as also indicated by isotope investigations and distributed hydrologic modeling studies (Christofi et al, 2020; Sofokleous et al., 2023). Watershed losses to evapotranspiration are enhanced in almost all watersheds due to streamflow diversions, stone reservoirs, small dams and ponds for irrigation. Even in upstream, forested watersheds we find streamflow diversions with pipes for water supply. Obviously, the balance between groundwater losses and evapotranspiration is not clear cut and we can find different GR4J model parameterizations with acceptable NSE scores that result in a different distribution of these two water balance components. However, the modeling of the streamflow is the most important aspect of these simulations and therefore we accept the single best NSE fit for each watershed.

Table 3. Observed average annual precipitation (P), and modelled evapotranspiration (E), streamflow (Q) and losses (L) as a fraction of the precipitation for the 1980/81-2009/10 reference period for the 37 watersheds.

Station	P (mm)	ET/P	Q/P	L/P
st1	696	0.86	0.16	0.01
st2	688	0.66	0.19	-0.14
st3	701	0.69	0.20	-0.11
st4	543	0.72	0.03	-0.26
st5	603	0.75	0.13	-0.12
st6	578	0.77	0.09	-0.14
st7	513	0.94	0.15	0.09
st8	521	0.75	0.16	-0.09
st9	535	0.70	0.09	-0.21
st10	592	0.71	0.20	-0.09
st11	657	0.67	0.25	-0.08
st12	774	0.83	0.23	0.06
st13	841	0.78	0.15	-0.06
st14	715	0.87	0.19	0.05
st15	528	0.92	0.08	0.00
st16	707	0.60	0.15	-0.25
st17	535	0.71	0.16	-0.13
st18	615	0.66	0.20	-0.14
st19	518	0.73	0.14	-0.13
st20	527	0.70	0.15	-0.15
st21	537	0.69	0.15	-0.16
st22	458	0.90	0.13	0.03
st23	438	0.90	0.09	-0.01
st24	404	0.86	0.08	-0.06
st25	403	0.89	0.03	-0.08
st26	515	0.96	0.03	-0.01
st27	441	0.89	0.15	0.04
st28	540	0.78	0.11	-0.10
st29	557	0.78	0.11	-0.10
st30	593	0.69	0.13	-0.18
st31	511	0.72	0.03	-0.25
st32	532	0.70	0.05	-0.26
st33	660	0.89	0.10	0.00
st34	737	0.88	0.19	0.06
st35	654	0.58	0.11	-0.31
st36	735	0.64	0.21	-0.15
st37	654	0.91	0.14	0.05

Hydrologic model simulations for 2030-2060

The effects of the projected climate changes on the streamflow of the Troodos watersheds are presented in Table 4. The average volumetric decrease in precipitation over the 32 watersheds amounts to 6% for RCA, 15% for HIRHAM and 5% for RACMO for the 2030-2060 period, relative to 1980-2010. We expect that this decrease in precipitation would be amplified in the reduction of streamflow. This is indeed the case for the GR4J modeled simulations forced with the RCA and HIRHAM data, where the reductions in streamflow approximately double those of the precipitation, amounting to an average volumetric decrease in streamflow of 14% (RCA) and 30% (HIRHAM) for 2030-2060, relative to 1980-2010. For the RACMO simulations, the results are unexpected. Here the 5% reduction in rainfall resulted in a 5% increase in streamflow for the 2030-2060 period, relative to 1980-2010.

The rainfall patterns of the three regional climate models results in 39% (RCA), 52% (HIRHAM) and 28% (RACMO) reductions in the average volumetric streamflow of the 32 watersheds. The runoff coefficient over these 32 watersheds decreased from 13% in 1980-2010 to 8% (RCA), 7% (HIRHAM), whereas for RACMO the runoff coefficient increased to 14%.

The main difference between the RCMs is that for the RACMO future simulations a larger share of the rain falls during the cold winter months (Table 5). This is what causes the higher streamflow. Figure 4 shows the boxplots with the precipitation and the modelled streamflow and evapotranspiration for the 32 watersheds. It shows that the future streamflow and evapotranspiration modeled with the RACMO RCM are more similar to the 1980-2010 reference period than the boxplots of the other two RCMs.

There are also small differences in the temperature changes of the models. The highest increase was projected by HIRHAM and the smallest increase was projected by RACMO. The increase in average daily minimum temperature was 1.75°C for RCA, 1.83°C for HIRHAM and 1.66°C for RACMO. The increase in the average daily maximum temperature showed a similar pattern, i.e., 1.83°C for RCA, 1.88°C for HIRHAM, and 1.69°C for RACMO

Table 4. Precipitation (P) and streamflow (Q) in mm over the 32 watershed for 1980-2010 (CYOBS) and the relative change between 1980-2010 and 2030-2060 for the three Regional Climate Model simulations (HIRHAM, RCA, RACMO) and the relative volumetric average changes (Av.).

	P (mm)	$(P_{2030-60} - P_{1980-2010})/P_{1980-2010}$			Q (mm)	$(Q_{2030-60} - Q_{1980-2010})/Q_{1980-2010}$		
Station	CYOBS	RCA	HIRHAM	RACMO	CYOBS	RCA	HIRHAM	RACMO
st1	696	0.00	-0.16	-0.06	111	-0.03	-0.36	-0.07
st2	688	0.01	-0.13	-0.02	132	0.07	-0.18	0.11
st3	701	0.00	-0.14	-0.02	137	-0.04	-0.30	0.04
st4	543	0.03	-0.10	-0.02	13	0.31	-0.13	0.06
st5	603	0.01	-0.11	-0.02	77	0.02	-0.25	0.04
st6	578	0.01	-0.14	-0.01	54	0.02	-0.37	0.07
st7	513	0.02	-0.14	0.00	76	0.02	-0.30	0.02
st8	521	0.02	-0.13	0.00	84	0.06	-0.32	0.07
st9	535	0.02	-0.09	0.01	49	0.51	-0.25	0.06
st10	592	-0.02	-0.16	-0.01	117	-0.11	-0.35	0.07
st11	657	-0.02	-0.16	-0.01	161	-0.08	-0.32	0.07
st12	774	0.00	-0.16	-0.03	181	-0.07	-0.39	-0.10
st13	841	-0.03	-0.16	-0.05	128	-0.15	-0.42	-0.15
st14	715	-0.04	-0.16	-0.04	135	-0.17	-0.40	-0.11
st15	528	-0.06	-0.16	-0.03	43	-0.16	-0.38	0.18
st16	707	-0.07	-0.17	-0.05	106	-0.15	-0.29	0.06
st18	615	-0.08	-0.17	-0.05	124	-0.17	-0.26	0.13
st19	518	-0.11	-0.16	-0.04	72	-0.29	-0.25	0.21
st20	527	-0.12	-0.16	-0.05	77	-0.35	-0.26	0.14
st22	458	-0.14	-0.15	-0.06	58	-0.37	-0.20	0.26
st23	438	-0.14	-0.15	-0.06	40	-0.42	-0.19	0.37
st24	404	-0.13	-0.13	-0.07	32	-0.38	-0.11	0.38
st25	403	-0.13	-0.13	-0.07	10	-0.45	-0.05	0.56
st26	515	-0.13	-0.15	-0.06	17	-0.50	-0.36	0.10
st27	441	-0.13	-0.14	-0.06	65	-0.38	-0.21	0.18
st29	557	-0.12	-0.19	-0.08	63	-0.32	-0.34	0.06
st30	593	-0.08	-0.19	-0.08	77	-0.22	-0.33	0.00
st31	511	-0.07	-0.18	-0.08	15	-0.20	-0.32	-0.04
st32	532	-0.05	-0.17	-0.07	25	-0.11	-0.30	0.02
st33	660	-0.01	-0.16	-0.06	67	-0.06	-0.38	-0.09
st34	737	-0.03	-0.17	-0.06	137	-0.11	-0.38	-0.13
st35	654	-0.04	-0.17	-0.06	69	-0.07	-0.25	0.05
Av.		**-0.06**	**-0.15**	**-0.05**		**-0.14**	**-0.30**	**0.05**

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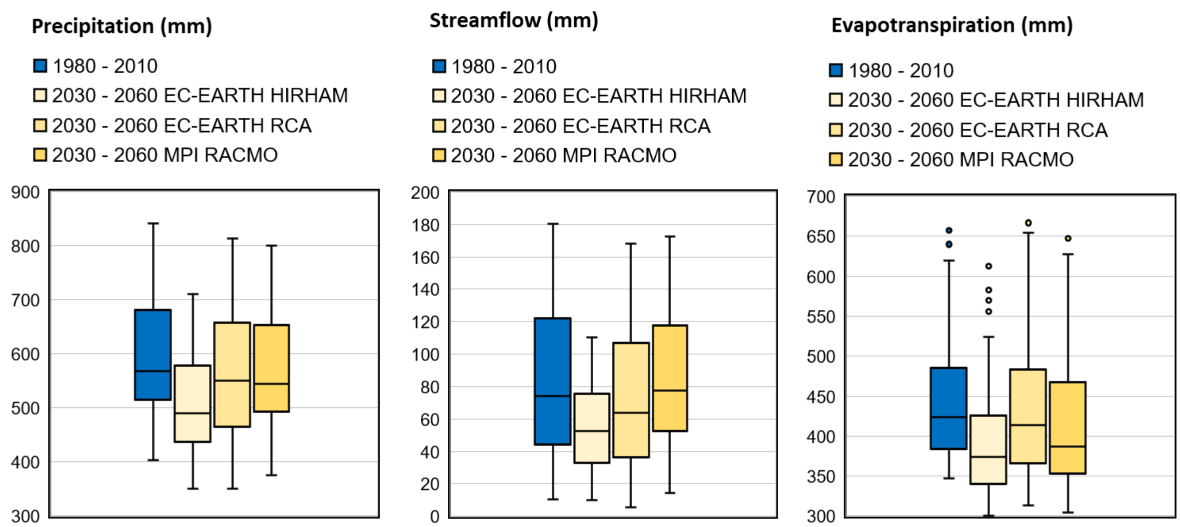

Figure 2. Boxplots of the spread of the precipitation, modelled streamflow and evapotranspiration values of the 32 watersheds, representing the median, 1st and 3rd quartiles, the largest values inside 1.5 times the interquartile range below the first and above the third quartile (whiskers), and any outliers outside this range (dots).

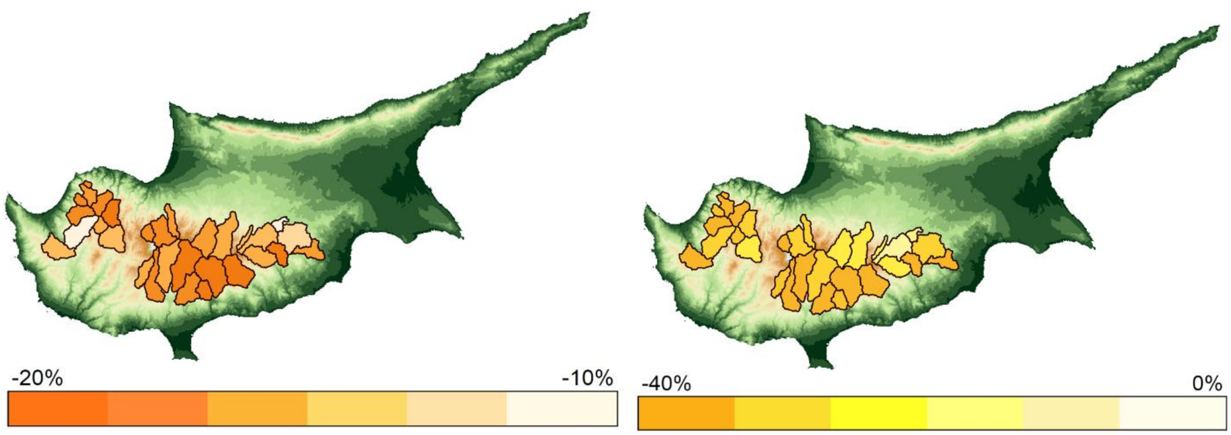

Figure 3. Changes in precipitation (left) and modeled streamflow (right) of the 32 Troodos watersheds for 2030-2060, relative to 1980-2010, for the HIRHAM RCM.

Table 5. Distribution of precipitation (fraction of total annual precipitation) over the wet months (November to February) and dry months (March to October) for the 1980-2010 observed data and the bias-corrected RCM data for 1980-2010 and 2030-2060, for the 55 12-km RCM grid cells over Cyprus.

Period	Data	Nov-Feb	Mar-Oct
1980-2010	CYOBS	0.71	0.29
	RCA	0.68	0.32
	HIRHAM	0.72	0.28
	RACMO	0.73	0.27
2030-2060	RCA	0.68	0.32
	HIRHAM	0.71	0.29
	RACMO	0.77	0.23

Irrigation water demands of the Troodos watersheds

The irrigation water demand of all crop plots of the 70 Troodos mountain villages for the 1980-2010 reference period is presented in the map in Figure 4. The agricultural plots were located in 19 of the 37 Troodos watersheds. Table 6 presents the average annual irrigation water demand over the Troodos watersheds for the 1980-2010 reference period, for the agricultural crop plots. Without irrigation water use, total streamflow of these watersheds could have been 10% higher. The irrigation water use is, however, only a small fraction of the evapotranspiration of these watersheds.

The largest irrigated agricultural area was found in the upstream area of Limnatis watershed (st35), which covers the agricultural mountain villages of Kyperounda, Chandria, Agridia, Dymes, Potamitissa, Pelendri, Agros, Kato Milos and Agios Ioannis. The total irrigated area covered 446 ha, which is 3.6% of the 123.3-km^2 Limnatis watershed area upstream of the streamflow station near Kouris dam. Average irrigation water demand for the 1980-2010 reference period for Limnatis was 3.5 Mm^3, whereas streamflow was 8.5 Mm^2 and the evapotranspiration was 47.0 Mm^3. These numbers showed that the irrigation water resources could add add 41% to the streamflow of the watershed. Other relatively large irrigation water uses were found for the watersheds of Vasilikos (st29), Polemidia (st32), Akaki (st19) and Kouris (st34) and Lefka dam (st37). Without irrigation, streamflow in these watersheds could have been, respectively, 18%, 16%, 14%, 13% and 11% higher.

The streamflow, evapotranspiration and irrigation water demand for these 19 watersheds modeled with the climate data of the three RCMs in 2030-2060 are presented in Table 7. Here we should consider that GR4J already models an increase in the evapotranspiration demand of the watershed through the forcing data. Thus, the modelled future streamflow is affected by this increased demand. Therefore, the irrigation water demand modeled by the blue-green water model (D4.2) presents an upper limit of the water resource use for irrigation in these watersheds for these future simulations. If there was no irrigation water use, the total streamflow of the 19 watersheds could increase by a maximum of 12% (RCA), 16% (HIRHAM) and 11% (RACMO). The largest irrigation water use, relative to the streamflow, occurs in the same watersheds as for the 1980-2010 reference period. For Limnatis (st35), the irrigation water resources could add up to 60% of the streamflow for the HIRHAM RCM, and 47% for RCA and RACMO. For the RACMO future simulations, we find an increase in streamflow in some of the watersheds for 2030-2060, relative to the 1980-2010, while irrigation demands remain nearly the same. Thus, in Akaki (st19), irrigation water resources would add 12% to the streamflow in 2030-2060, while it was 14% during 1980-2010.

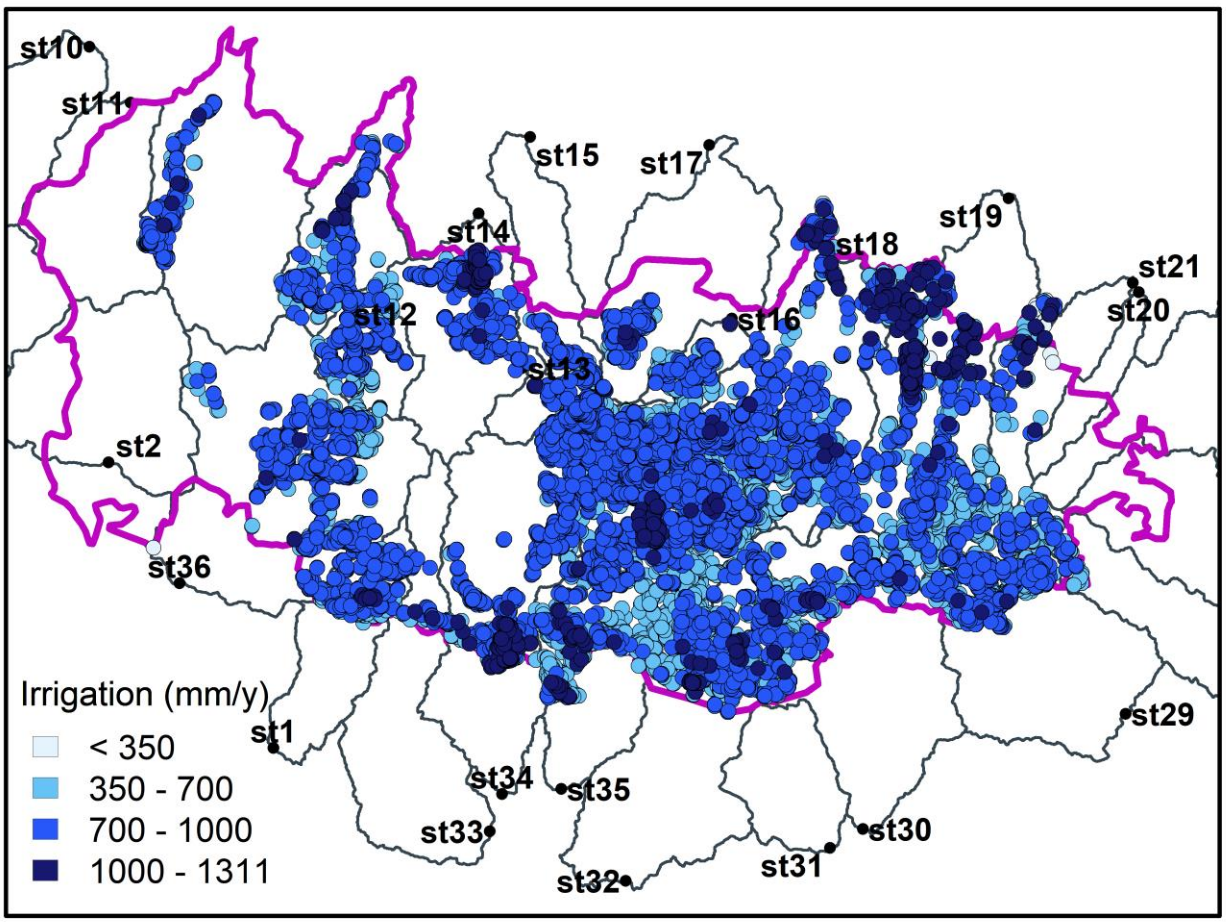

Figure 4. Average annual irrigation water demand (mm) for the 1980-2010 reference period, for all crop plots within the area of the 70 mountain communities on the Troodos ophiolite, as bound by the purple line, and the numbered Troodos watersheds in black.

Table 6. Watershed and irrigated area for the 2020 crop plots in the Troodos mountain villages, modelled streamflow (Q), evapotranspiration (ET) and irrigation water demand (IR) over the the 19 watersheds for the 1980-2010 reference period.

Station	Area (km2) watershed	Area (km2) irrigated	Q (Mm3) CYOBS	ET (Mm3) CYOBS	IR (Mm3) CYOBS
st1	39.1	0.393	4.35	23.26	0.30
st12	27.29	0.297	4.93	17.46	0.22
st13	13.73	0.054	1.75	9.02	0.04
st14	68.82	0.821	9.28	42.63	0.75
st15	35.62	0.090	1.52	17.30	0.07
st16	17.07	0.152	1.82	7.26	0.11
st17	89.18	0.296	7.86	33.73	0.21
st18	75.9	0.590	9.43	30.58	0.43
st19	107.36	1.445	7.70	40.70	1.11
st21	32.44	0.109	2.61	12.09	0.08
st28	48.39	0.116	3.90	18.04	0.08
st29	92.14	1.576	5.82	40.26	1.03
st30	117.03	1.023	9.06	47.76	0.74
st32	70.87	0.396	1.75	26.31	0.28
st33	73.13	0.022	4.93	43.17	0.02
st34	103.85	2.312	14.19	67.01	1.84
st35	123.28	4.458	8.48	46.96	3.47
st36	128.06	1.160	19.70	60.57	0.86
st37	59.85	0.762	5.41	35.67	0.60
Total			**124.48**	**619.80**	**12.25**

Table 7. Watershed and irrigated area for the 2020 crop plots in the Troodos mountain villages, modelled streamflow (Q), evapotranspiration (ET) and irrigation water demand (IR) over the the 19 watersheds for the 1980-2010 reference period.

Station	Q (Mm3) RCA	ET (Mm3) RCA	IR (Mm3) RCA	Q (Mm3) HIRHAM	ET (Mm3) HIRHAM	IR (Mm3) HIRHAM	Q (Mm3) RACMO	ET (Mm3) RACMO	IR (Mm3) RACMO
st1	4.23	23.52	0.32	2.80	20.48	0.34	4.02	21.92	0.36
st12	4.59	17.85	0.23	3.01	15.91	0.25	4.42	17.12	0.29
st13	1.49	9.15	0.04	1.02	8.41	0.05	1.48	8.88	0.06
st14	7.74	42.49	0.79	5.57	38.28	0.81	8.25	41.51	0.81
st15	1.28	16.49	0.07	0.94	14.94	0.08	1.80	16.58	0.08
st16	1.54	7.16	0.11	1.29	6.42	0.12	1.93	6.45	0.13
st17	6.49	32.44	0.23	5.81	29.20	0.24	8.84	29.51	0.25
st18	7.79	29.41	0.46	6.97	26.47	0.48	10.61	26.75	0.51
st19	5.43	38.36	1.17	5.76	35.30	1.21	9.30	35.94	1.15
st21	1.70	11.49	0.08	1.94	10.56	0.08	2.97	10.63	0.08
st28	2.64	16.83	0.08	2.58	15.38	0.09	4.14	16.06	0.10
st29	3.94	37.57	1.10	3.85	34.33	1.14	6.19	35.84	1.29
st30	7.08	46.13	0.78	6.10	41.17	0.82	9.06	42.53	0.87
st32	1.56	26.16	0.30	1.22	23.10	0.31	1.78	23.94	0.28
st33	4.65	43.37	0.02	3.05	37.65	0.02	4.49	40.63	0.02
st34	12.59	66.43	1.95	8.85	59.15	2.03	12.41	63.79	2.21
st35	7.88	46.10	3.68	6.40	40.22	3.84	8.92	40.76	4.16
st36	21.09	60.60	0.91	16.15	54.41	0.96	21.90	56.56	1.14
st37	4.51	35.55	0.64	3.24	32.03	0.66	4.81	34.74	0.74
Total	**108.23**	**607.10**	**12.98**	**86.56**	**543.40**	**13.50**	**127.31**	**570.16**	**14.56**

Conclusion

Irrigation water demand in the mountain villages of the Troodos present a small fraction of the evapotranspiration of the Troodos watersheds. There are six Troodos watersheds were the irrigation water resources could add more than 10% to the streamflow, for the 1980-2010 reference period. The three bias-corrected and downscaled RCM simulations showed a general decrease in streamflow and an increase in irrigation water demand for the 2030-2060 future period. In the worst case, irrigation water demand would use up to 60% of the streamflow for one of the Troodos watersheds (Limnatis).

The irrigation monitoring research with farmers has shown that around 10% reduction in irrigation could be achieved with sensor-based irrigation scheduling (D6.3). However, the research also showed that some farmers already supply deficit irrigation. The application of regulated deficit irrigation i.e., during selected

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crop stages with the aim to prioritize crop quality above quantity, as tested for the medicinal and aromatic plants (D6.5), could also be a good option for reducing irrigation water use. However, such regulated deficit irrigation research requires substantial resources.

Further research is ongoing to analyse all water demands for these watersheds to obtain a better understanding of possible reductions in irrigation to the benefit of ecological flows. Consideration will also be given to the suitability of the areas for selected crops. The water resources that flow towards the dams in the downstream areas are generally used for irrigation in the coastal areas and the inland Mesaoria plain, where temperatures and irrigation water demands are higher, and no deciduous fruit and nut trees and vines can be grown. Thus, it will be essential to improve and maintain irrigated agriculture in the Troodos Mountains.

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