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Supplemental material of manuscript entitled: Danger of groundwater contamination widely underestimated because of shortcuts for aquifer recharge

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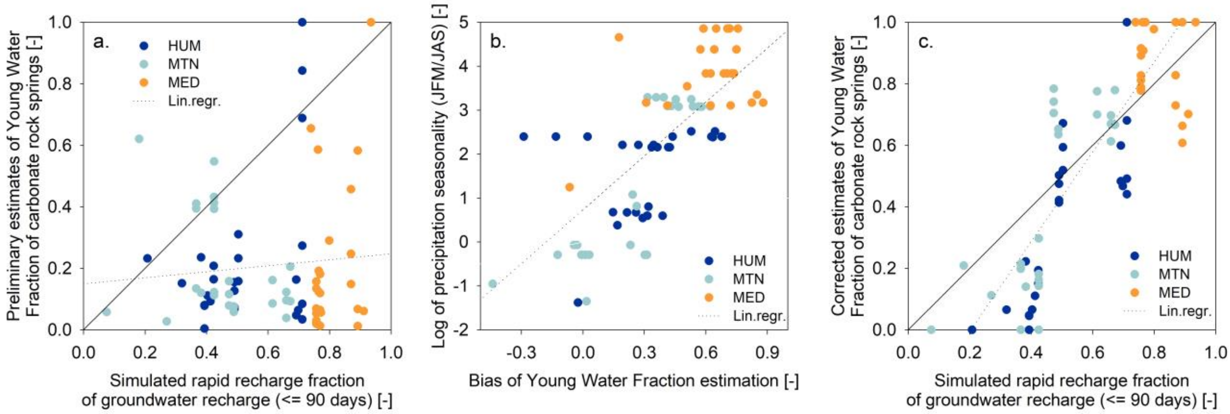

Fig. S 1.

Bias correction of Observed Young Water fractions of carbonate rock springs due to precipitation seasonality. (a) Relation between simulated rapid recharge fractions (90-day threshold) and preliminary estimates of Young Water Fractions of the carbonate rock springs ($r=0.09$, $p=0.46$), (b) relation between the bias of Young Water Fractions estimation defined as the difference between preliminary Young Water Fractions of the springs and the simulated rapid recharge fractions and the logarithm of rainfall seasonality defined as the sum of January, February and March precipitation divided by sum of July, August and September precipitation ($r=0.69$, $p\leq0.001$), and (c) relation between simulated rapid recharge fractions (90-day threshold) and precipitation seasonality corrected estimates of Young Water Fractions of the carbonate rock springs corrected by using the precipitation seasonality ($r=0.83$, $p\leq0.001$).

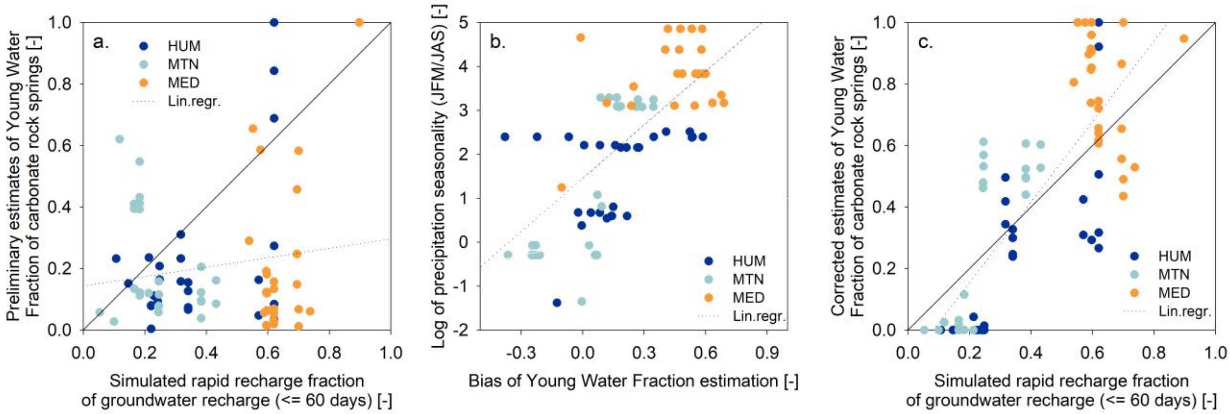

Fig. S 2.

Bias correction of Observed Young Water fractions of carbonate rock springs due to precipitation seasonality. (a) Relation between simulated rapid recharge fractions (60-day threshold) and preliminary estimates of Young Water Fractions of the carbonate rock springs ($r=0.14$, $p=0.21$), (b) relation between the bias of Young Water Fractions estimation defined as the difference between preliminary Young Water Fractions of the springs and the simulated rapid recharge fractions and the logarithm of rainfall seasonality defined as the sum of January, February and March precipitation divided by sum of July, August and September precipitation ($r=0.68$, $p\leq0.001$), and (c) relation between simulated rapid recharge fractions (60-day threshold) and precipitation seasonality corrected estimates of Young Water Fractions of the carbonate rock springs corrected by using the precipitation seasonality ($r=0.79$, $p\leq0.001$).

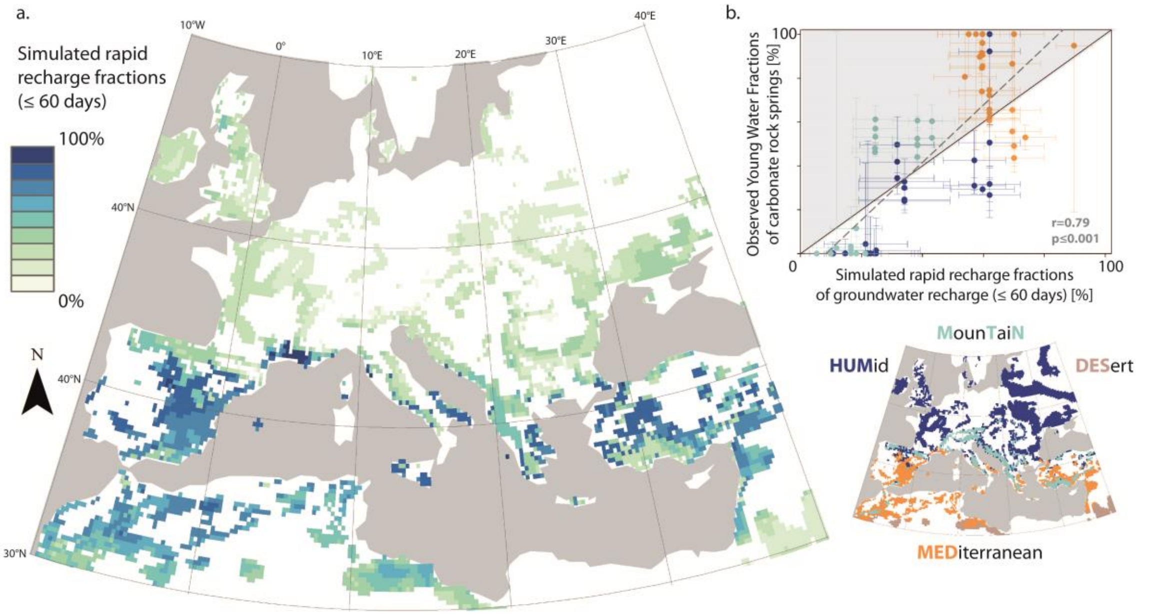

Fig. S 3.

The simulated rapid recharge fractions of groundwater recharge [%] across the study domain show the highest values of rapid recharge fractions in the Mediterranean. A comparison with observed Young Water Fractions of carbonate rock springs indicates realistic model behaviour. (a) Simulated rapid recharge fractions of groundwater recharge (≤ 60 days), (b) simulated rapid recharge fractions of groundwater recharge (≤ 60 days) compared to observed Young Water Fractions of the carbonate rock springs across the simulation domain (see methods); whiskers indicate standard error of simulations and observations.

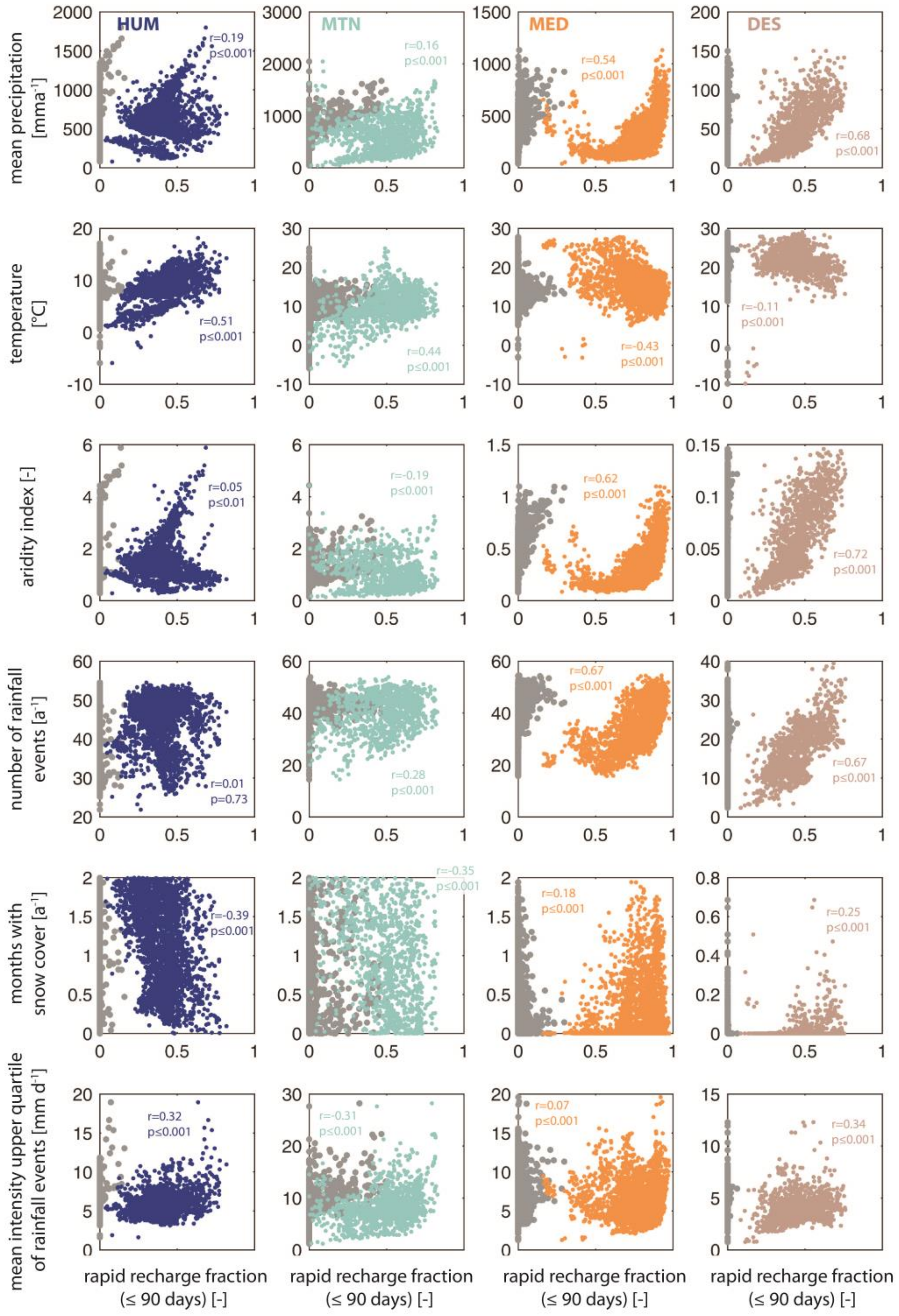

Fig. S 4.

Scatter plots showing how rapid recharge fractions (≤ 90 days) correlate with all climatic descriptors for the humid, mountain, Mediterranean and desert regions. Grey dots indicate the same relations but with rapid recharge fractions derived from the model with concentrated recharge not considered.

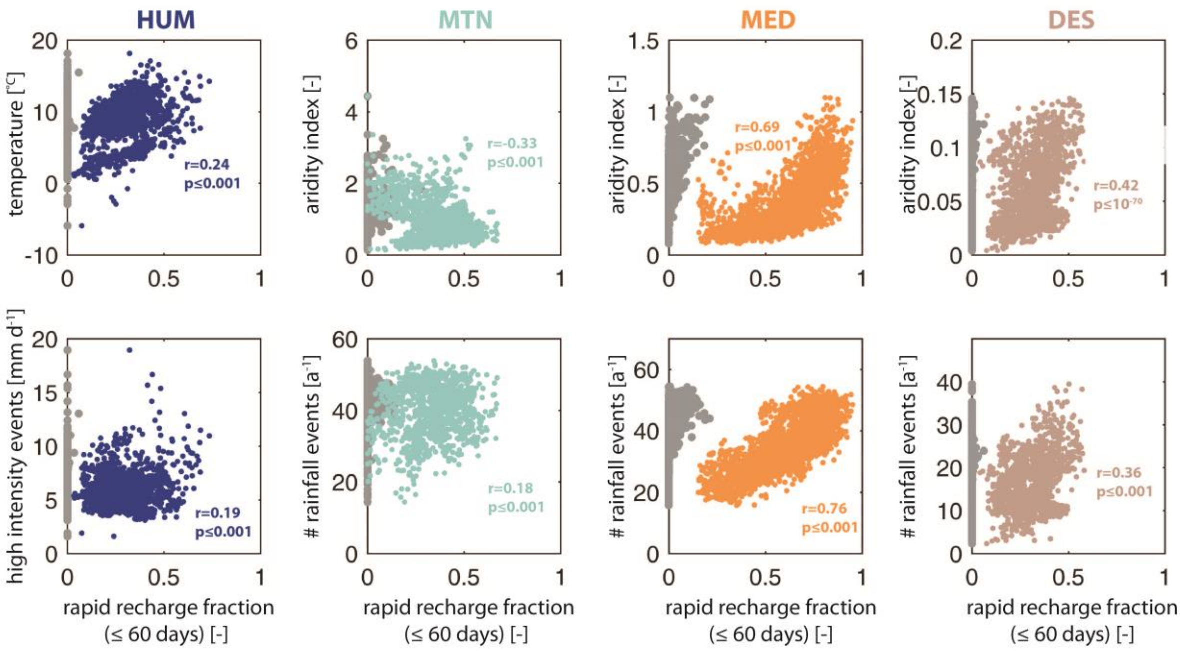

Fig. S 5.

Scatter plots of the strongest and 2nd strongest correlation of rapid recharge fractions (60-day threshold) and climatic descriptors for the humid (HUM), mountain (MTN), Mediterranean (MED), and desert (DES) regions. Aridity index, the average number of rainfall events and mean annual precipitation have the strongest control on rapid recharge fractions at the Mediterranean and the desert regions. Grey dots indicate the same relations but with rapid recharge fractions derived from the model with concentrated recharge not considered.

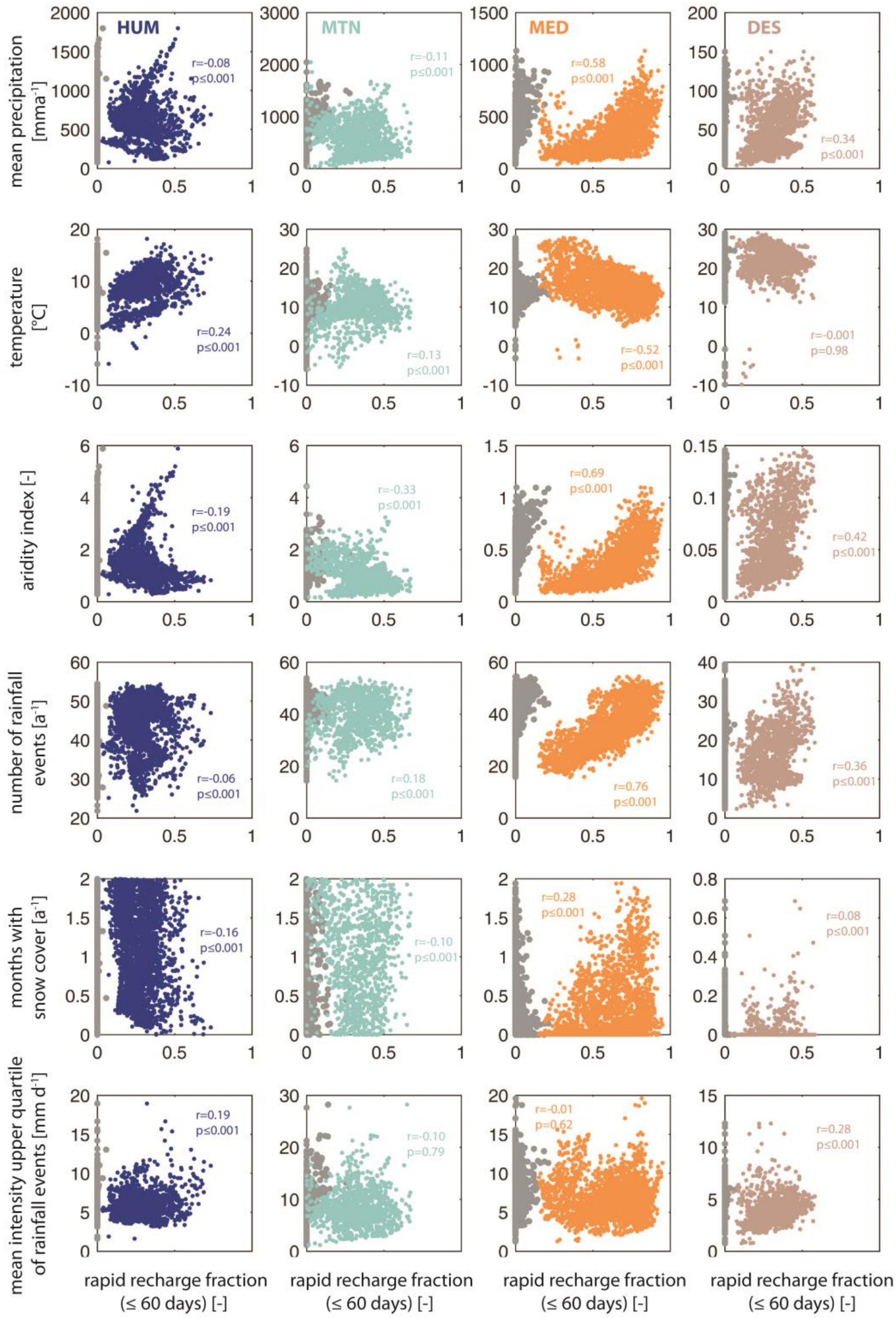

Fig. S 6.

Scatter plots showing how rapid recharge fractions (≤ 90 days) correlate with all climatic descriptors for the humid, mountain, Mediterranean and desert regions. Grey dots indicate the same relations but with rapid recharge fractions derived from the model with concentrated recharge not considered.

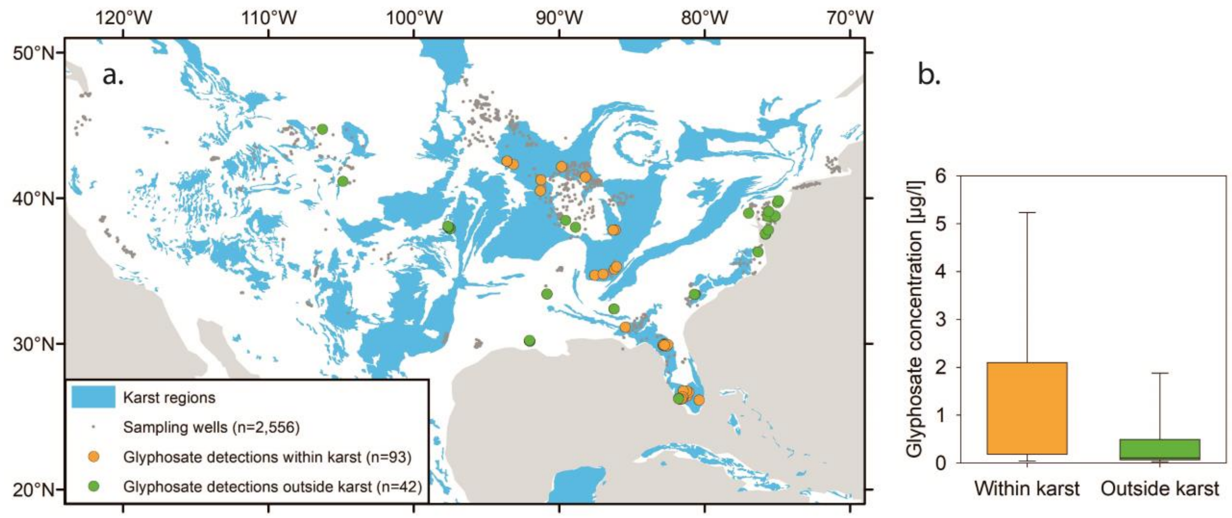

Fig. S 7.

Glyphosate was detected ~5.3 times more often within carbonate rock regions, and with concentrations ~4.1 times higher compared to non-carbonate rocks regions in a study across the contiguous United States[1,2]. (a) Location of sampling wells relative to the location of karst regions over the United States (derived from the World Karst Map[3]), Glyphosate detections within karst areas (93 out of 751) and Glyphosate detections outside karst areas (42 out of 1805), and (b) Concentrations among Glyphosate detections within and outside the karst. Whiskers indicate the 10th and 90th percentile; boxes and intermediate lines the 25th, 50th and 75th percentile.

Supplemental tables

Table S 1.

Correlation r_{YWF3} between simulated rapid recharge (≤ 90 days) and climatic descriptors, and the respective p-values for the four different carbonate rock landscapes. Strongest correlations are marked bold.

Variable Name	Unit	HUM		MTN		MED		DES	
		r_{YWF3}	p-value	r_{YWF3}	p-value	r_{YWF3}	p-value	r_{YWF3}	p-value
Precipitation	mm a^{-1}	0.19	≤0.001	0.16	≤0.001	0.54	≤0.001	**0.68**	**≤0.001**
Temperature	C°	**0.51**	**≤0.001**	**0.44**	**≤0.001**	-0.43	≤0.001	-0.11	≤0.001
Aridity Index	-	0.05	≤0.01	-0.19	≤0.001	**0.62**	**≤0.001**	**0.72**	**≤0.001**
# Rainfall events	-	0.01	0.73	0.28	≤0.001	**0.67**	**≤0.001**	0.67	≤0.001
# Snow cover	months a^{-1}	**-0.39**	**≤0.001**	**-0.35**	**≤0.001**	0.18	≤0.001	0.25	≤0.001
High intensity events	mm d^{-1}	0.32	≤0.001	0.31	≤0.001	0.07	≤0.001	0.34	≤0.001

Table S 2.

Correlation r_{YWF2} between simulated rapid recharge (≤ 60 days) and climatic descriptors, and the respective p-values for the four different carbonate rock landscapes. Strongest correlations are marked bold.

Variable Name	Unit	HUM		MTN		MED		DES	
		r_{YWF2}	p-value	r_{YWF2}	p-value	r_{YWF2}	p-value	r_{YWF2}	p-value
Precipitation	mm a^{-1}	-0.08	≤0.001	-0.11	≤0.001	0.58	≤0.001	0.34	≤0.001
Temperature	C°	**0.24**	**≤0.001**	0.13	≤0.001	-0.52	≤0.001	0.001	0.98
Aridity Index	-	-0.19	≤0.001	**-0.33**	**≤0.001**	**0.69**	**≤0.001**	**0.42**	**≤0.001**
# Rainfall events	a^{-1}	-0.06	≤0.001	**0.18**	**≤0.001**	**0.76**	**≤0.001**	**0.36**	**≤0.001**
# Snow cover	months a^{-1}	-0.16	≤0.001	-0.10	≤0.001	0.28	≤0.001	0.08	≤0.001
High intensity events	mm d^{-1}	**0.19**	**≤0.001**	-0.01	0.79	-0.01	0.62	0.28	≤0.001

Table S 3.

Observed Young Water Fractions of the precipitation seasonality corrected 78 remaining carbonate rock springs as well as simulated rapid recharge fractions of recharge for the 90-day threshold. The identifier includes the country code of each carbonate rock spring followed in the next column by the name of each spring. Coordinates are provided in latitude and longitude (WGS84), both Young Water Fractions and rapid recharge fractions are given in % (SE: standard error).

Identifier	Name	Latitude (WGS84)	Longitude (WGS84)	Corrected Young Water Fraction [%]	SE Young Water Fraction [%]	Rapid Recharge Fraction (90 days) [%]	SE Rapid Recharge Fraction (90 days) [%]
CH-0001	Rappenfluh	47.487	7.666	0.00	0.07	0.32	0.14
ES-0002	Benaojan (Spring S-2)	36.715	-5.245	0.82	0.10	0.66	0.13
ES-0004	Pileta	36.665	-5.280	1.00	0.63	0.89	0.09
ES-0005	Genal	36.640	-5.118	0.74	0.08	0.66	0.13
ES-0006	Verde	36.672	-5.026	0.79	0.06	0.66	0.13
ES-0007	Grande	36.722	-4.938	0.89	0.12	0.67	0.13
ES-0008	Jorox	36.732	-4.891	0.78	0.08	0.67	0.13
ES-0021	Canamero	36.893	-4.998	0.76	0.06	0.91	0.08
FR-0046	St. Andre	43.693	3.601	1.00	0.76	0.93	0.05
FR-0047	Rogues	43.879	3.600	1.00	0.65	0.71	0.07
FR-0048	Hortus	43.829	3.798	1.00	0.84	0.71	0.07
IL-0001	Dan	33.249	35.653	0.93	0.04	0.77	0.11
IL-0002	Banias	33.248	35.695	0.87	0.02	0.77	0.11
FR-0049-L	Fontanilles	43.753	3.623	0.52	0.08	0.71	0.07
FR-0050-L	Cents-Fonts	43.760	3.624	0.71	0.12	0.71	0.07
FR-0051-L	Bueges	43.813	3.591	0.47	0.07	0.71	0.07
FR-0052-L	Lamalou	43.823	3.801	1.00	0.33	0.71	0.07
ES-0001-L	9_Canos	36.681	-5.445	0.79	0.04	0.89	0.09
ES-0002-L	Algarrobal	36.671	-5.446	0.84	0.08	0.89	0.09
ES-0003-L	Arroyomolinos	36.810	-5.373	1.00	0.17	0.87	0.08
ES-0004-L	Benamahoma	36.768	-5.463	1.00	0.10	0.87	0.08
ES-0005-L	Bocaleones	36.768	-5.463	0.96	0.06	0.87	0.08
SL-0001-L	Timavo	45.786	13.587	0.40	0.07	0.50	0.12
SL-0002-L	Sardos	45.793	13.587	0.55	0.13	0.50	0.12
SL-0003-L	Moschenizze_North	45.803	13.582	0.47	0.09	0.50	0.12
GB-0001-L	Blewbury	51.567	-1.239	0.00	0.37	0.38	0.13
GB-0002-L	E_Ginge	51.577	-1.358	0.00	0.09	0.39	0.13

GB-0003-L	Jannaways	51.425	-1.355	0.00	0.16	0.42	0.13
GB-0004-L	Kimber	51.439	-1.164	0.00	0.12	0.41	0.13
GB-0005-L	Letcombe_B	51.565	-1.461	0.00	0.50	0.39	0.13
GB-0006-L	Upton	51.573	-1.253	0.00	0.51	0.39	0.13
GB-0007-L	Weston	51.463	-1.426	0.00	0.11	0.42	0.13
GB-0008-L	Woolstone	51.582	-1.574	0.00	0.17	0.40	0.13
AT-0002-L	Hammerbachquelle	47.210	15.350	0.00	0.05	0.21	0.12
AT-0004-L	Gerstenboedenquelle	47.260	9.770	0.03	0.03	0.27	0.10
JO-0001-L	Tanour Spring	32.408	35.745	1.00	0.19	0.74	0.12
FR-0001-A	Cernon	43.975	3.146	0.43	0.04	0.69	0.08
FR-0002-A	Durzon	43.991	3.262	0.47	0.02	0.70	0.07
FR-0003-A	Esperelle	44.121	3.208	0.04	0.05	0.49	0.13
FR-0004-A	Homede	44.077	3.060	0.04	0.05	0.49	0.13
FR-0005-A	Boundou	44.067	3.048	0.10	0.06	0.49	0.13
FR-0006-A	Lavencou	44.036	3.042	0.12	0.10	0.49	0.13
FR-0007-A	Mouline	43.992	3.094	0.55	0.14	0.69	0.08
IT-0001-A	Molinetto	46.008	12.473	0.00	0.04	0.42	0.11
IT-0002-A	Santissima	46.021	12.475	0.07	0.21	0.42	0.11
IT-0003-A	Gorgazzo	46.040	12.497	0.03	0.25	0.42	0.11
IT-0004-A	Agaroi	46.070	12.511	0.00	0.15	0.37	0.10
IT-0005-A	Budoia	46.076	12.512	0.21	0.20	0.37	0.10
IT-0006-A	Tornidor	46.073	12.511	0.23	0.13	0.37	0.10
IT-0007-A	Polla1 Santissima	46.018	12.476	0.05	0.71	0.42	0.11
IT-0008-A	Polla2 Santissima	46.018	12.476	0.19	0.32	0.42	0.11
IT-0009-A	Cavalli	46.010	12.477	0.00	0.08	0.42	0.11
IL-0001-A	Ein Moda	32.496	35.445	0.97	0.08	0.77	0.11
IL-0002-A	Ein Harod	32.548	35.355	1.00	0.13	0.76	0.10
IL-0003-A	Ein Homa & Ein Migdal	32.500	35.453	1.00	0.12	0.76	0.10
IL-0004-A	Ein Amall	32.505	35.445	0.93	0.07	0.76	0.10
IL-0005-A	Leshem	33.249	35.651	0.99	0.06	0.77	0.11
IL-0006-A	Kezinim	33.247	35.688	0.82	0.02	0.77	0.11
IQ-0001	Sarwchawa	36.280	44.757	0.90	0.02	0.76	0.11
IQ-0002	Shkarta	36.306	44.722	0.87	0.03	0.76	0.11
IQ-0003	Betwata	36.343	44.709	0.86	0.01	0.76	0.11
IQ-0004	Zewa	36.396	44.645	0.91	0.03	0.76	0.11
IQ-0005	Chewqa	36.349	44.578	0.87	0.04	0.76	0.11
IQ-0006	Bla	36.519	44.493	0.95	0.04	0.38	0.12
IQ-0007	Qala Saida	36.340	44.765	0.98	0.04	0.76	0.11
IQ-0008	Gullan	36.388	44.694	1.00	0.05	0.76	0.11
LB-0001	Jeita	33.944	35.642	0.90	0.04	0.47	0.13

LB-0002	Naber al Labbane	33.995	35.828	0.86	0.03	0.47	0.13
LB-0003	Naber al Assal	34.010	35.839	0.87	0.02	0.49	0.14
LB-0004	Kashkoush	33.943	35.639	0.94	0.06	0.47	0.13
LB-0005	Afqa	34.068	35.893	0.85	0.02	0.49	0.14
LB-0006	Rouaiss	34.109	35.909	0.87	0.03	0.49	0.14
PA-0001	Sultan_Elisha	31.870	35.443	1.00	0.53	0.76	0.13
GR-0001	Uni Patras P1	37.868	22.473	0.67	0.04	0.61	0.07
GR-0002	Uni Patras P2	37.869	22.464	0.74	0.07	0.61	0.07
IT-0001	Angheraz spring	46.284	11.922	0.25	0.06	0.07	0.05
IT-0002	Pradidali spring	46.228	11.869	0.53	0.99	0.18	0.09
MA-0001	WT spring	30.681	-9.345	1.00	0.25	0.80	0.12

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ES-0004	Pileta	36.665	-5.280	1.00	0.63	0.70	0.10
ES-0005	Genal	36.640	-5.118	0.56	0.08	0.38	0.08
ES-0006	Verde	36.672	-5.026	0.62	0.06	0.38	0.08
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ES-0004-L	Benamahoma	36.768	-5.463	0.88	0.10	0.70	0.09
ES-0005-L	Bocaleones	36.768	-5.463	0.78	0.06	0.70	0.09
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IT-0004-A	Agaroi	46.070	12.511	0.00	0.15	0.17	0.08
IT-0005-A	Budoia	46.076	12.512	0.04	0.20	0.17	0.08
IT-0006-A	Tornidor	46.073	12.511	0.05	0.13	0.17	0.08
IT-0007-A	Polla1 Santissima	46.018	12.476	0.00	0.71	0.18	0.08
IT-0008-A	Polla2 Santissima	46.018	12.476	0.02	0.32	0.18	0.08
IT-0009-A	Cavalli	46.010	12.477	0.00	0.08	0.18	0.08
IL-0001-A	Ein Moda	32.496	35.445	0.79	0.08	0.59	0.10
IL-0002-A	Ein Harod	32.548	35.355	0.92	0.13	0.60	0.11
IL-0003-A	Ein Homa & Ein Migdal	32.500	35.453	0.86	0.12	0.60	0.11
IL-0004-A	Ein Amall	32.505	35.445	0.75	0.07	0.60	0.11
IL-0005-A	Leshem	33.249	35.651	0.81	0.06	0.60	0.10
IL-0006-A	Kezinim	33.247	35.688	0.64	0.02	0.60	0.10
IQ-0001	Sarwchawa	36.280	44.757	0.72	0.02	0.62	0.10
IQ-0002	Shkarta	36.306	44.722	0.69	0.03	0.62	0.10
IQ-0003	Betwata	36.343	44.709	0.69	0.01	0.62	0.10
IQ-0004	Zewa	36.396	44.645	0.73	0.03	0.62	0.10
IQ-0005	Chewqa	36.349	44.578	0.70	0.04	0.62	0.10
IQ-0006	Bla	36.519	44.493	0.77	0.04	0.21	0.08
IQ-0007	Qala Saida	36.340	44.765	0.80	0.04	0.62	0.10
IQ-0008	Gullan	36.388	44.694	0.82	0.05	0.62	0.10
LB-0001	Jeita	33.944	35.642	0.72	0.04	0.25	0.07

LB-0002	Naber al Labbane	33.995	35.828	0.69	0.03	0.25	0.07
LB-0003	Naber al Assal	34.010	35.839	0.69	0.02	0.24	0.08
LB-0004	Kashkoush	33.943	35.639	0.77	0.06	0.25	0.07
LB-0005	Afqa	34.068	35.893	0.68	0.02	0.24	0.08
LB-0006	Rouaiss	34.109	35.909	0.69	0.03	0.24	0.08
PA-0001	Sultan_Elisha	31.870	35.443	1.00	0.53	0.58	0.11
GR-0001	Uni Patras P1	37.868	22.473	0.49	0.04	0.43	0.08
GR-0002	Uni Patras P2	37.869	22.464	0.57	0.07	0.43	0.08
IT-0001	Angheraz spring	46.284	11.922	0.07	0.06	0.05	0.04
IT-0002	Pradidali spring	46.228	11.869	0.36	0.99	0.12	0.08
MA-0001	WT spring	30.681	-9.345	1.00	0.25	0.54	0.10

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