Supplementary information

Multimodel assessments of human and climate impacts on mean annual streamflow in China

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Table S1. Main characteristics of human impacts in the GHMs used in this study.

Model	Water use	Dam and Reservoirs	Source of irrigation water withdrawal
DBH	modeled irrigation	Use GRanD dataset, the number of dams and reservoirs varies according to the construction year for the VARSOC runs.	river, reservoirs
H08	modeled irrigation prescribed domestic and industrial water use	Use GRanD dataset, the number of dams and reservoirs varies according to the construction year for the VARSOC runs.	river, reservoirs, groundwater
LPJmL	modeled irrigation prescribed domestic, industrial and livestock	Use GRanD dataset, the number of dams and reservoirs varies according to the construction year for the VARSOC runs. Evaporation from reservoir surface is calculated.	river, reservoirs
MATSIRO	modeled irrigation prescribed domestic and industrial water use	Use GRanD dataset, the number of dams and reservoirs varies according to the construction year for the VARSOC runs.	river, reservoirs, groundwater
PCR-GLOBWB	modeled irrigation, domestic, industrial and livestock water use	Use GRanD dataset, the number of dams and reservoirs varies according to the construction year for the VARSOC runs. Evaporation from reservoir surface is calculated.	river, reservoirs, groundwater
WaterGAP2	modeled irrigation, domestic, industrial and livestock water use	Use GRanD dataset, the number of dams and reservoirs varies according to the construction year for the VARSOC runs.	river, reservoirs, lakes, groundwater

Table S2. The proportions of river segments of China categorized by MAF changes. “<-10” in the header means the river segment showing MAF changes in [-20%, -10%), and so on.

	<-30	**<-20**	**<-10**	**<-5**	**<0**	**<5**	**<10**	**<20**	**<30**	**>30**
ΔQ_c	2.56	5.24	16.32	13.47	16.42	15.76	10.55	6.84	3.55	9.29
ΔQ_h	2.28	1.00	3.83	9.04	54.27	26.80	1.29	0.85	0.13	0.50
ΔQ_a	3.13	7.13	17.11	13.40	16.29	15.69	9.86	5.87	3.83	7.69

Table S3. Ensemble members of streamflow changes (ΔQ_a, % of MAF) between 1971-1990 and 1991-2010.

Forcing	**Model**	**CN**	**SH**	**LR**	**NW**	**HA**	**YR**	**HU**	**YZ**	**SE**	**SW**	**PR**
PGMFD v.2	H08	-1.21	-6.64	-0.85	19.89	-4.34	-2.29	1.71	-1.56	-4.67	2.35	1.96
	DBH	1.30	-4.29	-6.88	6.98	-13.29	-5.81	2.92	2.13	-1.48	5.77	3.10
	LPJmL	0.54	-3.06	-1.51	5.69	-9.79	-8.85	0.28	0.78	-3.22	2.68	3.81
	PCR-GLOBWB	-1.04	-7.51	-5.99	6.00	-7.80	-2.32	-5.50	-0.95	-2.95	3.13	0.79
	WaterGAP2	0.39	-3.16	-2.48	4.21	-11.09	-3.76	1.84	0.34	-4.30	3.85	1.81
	MATSIRO	-2.43	-10.04	-3.90	31.15	-6.60	-6.37	-0.51	-2.67	-4.94	1.77	-1.44
GSWP3	H08	-0.42	-5.26	-8.20	6.79	-14.20	-12.15	9.84	0.22	5.10	-0.23	3.57
	DBH	-0.66	-4.80	-12.31	16.98	-23.13	-10.53	3.09	0.47	0.99	2.30	-0.17
	LPJmL	-0.87	-2.67	-8.30	12.96	-13.56	-16.26	4.17	-0.21	2.52	-0.19	2.59
	PCR-GLOBWB	-2.14	-6.90	-8.17	11.08	-12.07	-7.35	-0.84	-1.43	1.37	0.60	-1.12
	WaterGAP2	-1.00	-3.34	-9.60	15.45	-21.38	-18.03	4.49	-0.46	1.49	0.28	0.31
	MATSIRO	1.09	0.73	-11.25	22.81	-33.18	-24.49	6.21	1.72	2.79	-1.13	2.37
WFDEI	H08	-6.74	-7.50	-6.16	4.51	-18.85	-14.18	3.31	-6.50	-4.76	-4.34	-6.75
	DBH	-6.38	-8.75	-11.96	-3.84	-26.26	-18.47	-4.47	-5.05	-3.46	-2.85	-6.48
	LPJmL	-4.12	-4.16	-7.66	8.27	-14.78	-16.88	0.61	-3.29	-4.59	-3.73	-4.84
	PCR-GLOBWB	2.82	-1.94	-1.93	31.61	-7.33	-0.83	-0.05	3.35	1.28	4.87	2.65
	WaterGAP2	-4.69	-4.77	-8.08	9.55	-22.00	-23.05	0.62	-3.88	-5.04	-3.87	-5.27
	MATSIRO	10.43	43.02	9.82	178.78	-0.42	27.95	11.69	11.24	2.80	5.33	4.04
All ensembles	Median	-0.93	-4.53	-7.27	10.32	-13.43	-9.69	1.78	-0.34	-2.22	1.19	1.30
	25^{th}	-2.36	-6.83	-8.28	6.20	-20.75	-16.72	0.03	-2.40	-4.52	-0.90	-1.36
	75^{th}	0.51	-3.09	-2.84	19.16	-8.30	-4.27	3.95	0.70	1.46	3.01	2.64

Table S4. Ensemble members of streamflow changes induced by climate change (ΔQ_c, % of MAF) between 1971-1990 and 1991-2010.

Forcing	**Model**	**CN**	**SH**	**LR**	**NW**	**HA**	**YR**	**HU**	**YZ**	**SE**	**SW**	**PR**
PGMFD v.2	H08	-0.82	-6.55	-2.25	7.20	-7.06	-0.54	2.47	-0.99	-5.03	0.35	2.30
	DBH	2.31	-2.15	-2.55	11.29	-0.32	0.93	7.26	2.47	-0.96	3.76	3.05
	LPJmL	1.70	-1.99	0.33	4.41	-3.76	0.20	4.88	1.94	-2.87	0.12	4.43
	PCR-GLOBWB	0.33	-5.87	-3.44	1.09	-2.98	0.21	2.90	0.42	-2.24	1.34	2.23
	WaterGAP2	1.19	-2.73	-0.06	5.34	-3.93	-0.23	7.57	1.12	-3.86	2.04	2.47
	MATSIRO	-3.79	-13.87	-8.12	-5.06	-14.63	-20.25	-8.49	-3.69	-4.73	-2.05	-1.90
GSWP3	H08	0.02	-4.41	-8.83	10.51	-15.67	-10.08	11.16	0.72	4.85	-1.53	3.92
	DBH	0.63	-1.54	-1.94	28.33	-7.97	-5.12	8.66	0.93	1.42	2.02	-0.11
	LPJmL	0.39	-1.19	-4.20	16.21	-8.16	-8.63	9.36	0.75	2.83	-1.54	3.11
	PCR-GLOBWB	-0.72	-5.45	-5.20	10.00	-8.34	-5.57	6.40	-0.16	1.93	-0.05	0.21
	WaterGAP2	-0.08	-2.55	-6.78	27.65	-14.24	-15.34	11.99	0.39	1.94	-0.54	0.86
	MATSIRO	-0.77	-3.21	-16.35	12.44	-53.34	-40.28	5.67	0.19	3.03	-3.49	1.70
WFDEI	H08	-6.12	-7.13	-6.60	5.11	-19.75	-11.21	4.52	-5.75	-5.03	-5.93	-6.47
	DBH	-4.87	-6.37	-6.11	2.70	-13.98	-12.34	1.91	-4.00	-2.90	-4.28	-6.02
	LPJmL	-2.73	-2.91	-4.42	12.00	-10.50	-9.73	6.45	-1.97	-4.10	-4.83	-4.04
	PCR-GLOBWB	4.71	-0.30	1.13	30.71	-2.89	1.44	7.22	4.99	1.97	4.93	4.05
	WaterGAP2	-3.77	-4.03	-5.46	17.37	-15.51	-18.55	8.14	-2.93	-4.44	-5.38	-4.47
	MATSIRO	-1.28	1.25	-6.82	96.98	-13.82	-20.52	4.85	-0.40	-0.52	-3.67	-3.94
All ensembles	Median	-0.29	-3.06	-4.81	17.86	-9.42	-9.35	6.43	0.17	-1.60	0.55	1.28
	25^{th}	-2.24	-5.77	-6.73	11.71	-14.53	-14.85	4.61	-1.89	-4.04	-1.17	-3.43
	75^{th}	0.49	-2.03	-2.32	33.21	-4.71	-0.51	7.99	0.76	1.94	2.82	2.90

Table S5. Ensemble members of streamflow changes induced by DHI change (ΔQ_h, % of MAF) between 1971-1990 and 1991-2010.

Forcing	**Model**	**CN**	**SH**	**LR**	**NW**	**HA**	**YR**	**HU**	**YZ**	**SE**	**SW**	**PR**
PGMFD v.2	H08	-0.42	-0.09	1.39	-2.93	2.72	-1.51	-0.76	-0.44	0.36	-0.06	-0.34
	DBH	-0.98	-2.13	-4.33	-6.68	-12.98	-6.49	-4.35	-0.20	-0.52	-0.08	0.06
	LPJmL	-1.40	-1.07	-1.85	-2.53	-6.03	-8.76	-4.60	-1.11	-0.35	-0.27	-0.62
	PCR-GLOBWB	-1.32	-1.64	-2.55	-0.93	-4.83	-2.24	-8.39	-1.12	-0.71	-0.19	-1.44
	WaterGAP2	-0.86	-0.43	-2.42	-4.40	-7.15	-3.28	-5.73	-0.67	-0.44	-0.05	-0.66
	MATSIRO	1.09	3.83	4.22	-4.91	8.03	14.39	7.98	1.10	-0.21	0.01	0.45
GSWP3	H08	-0.51	-0.85	0.63	-5.07	1.47	-1.88	-1.33	-0.44	0.25	-0.05	-0.35
	DBH	-1.12	-3.26	-10.37	-12.44	-15.16	-5.24	-5.57	-0.31	-0.43	-0.08	-0.06
	LPJmL	-1.31	-1.48	-4.10	-4.66	-5.40	-7.31	-5.19	-0.87	-0.31	-0.25	-0.52
	PCR-GLOBWB	-1.14	-1.45	-2.97	-1.63	-3.72	-1.59	-7.24	-0.95	-0.56	-0.15	-1.33
	WaterGAP2	-0.93	-0.79	-2.82	-12.67	-7.13	-2.33	-7.50	-0.79	-0.45	-0.03	-0.54
	MATSIRO	1.59	3.94	5.10	-6.67	20.16	16.41	0.54	1.57	-0.25	0.17	0.67
WFDEI	H08	-0.65	-0.37	0.44	-4.36	0.89	-2.76	-1.21	-0.58	0.26	-0.05	-0.28
	DBH	-1.45	-2.38	-5.85	-5.73	-12.28	-5.93	-6.38	-0.87	-0.56	-0.05	-0.46
	LPJmL	-1.43	-1.25	-3.24	-6.81	-4.28	-6.81	-5.84	-1.13	-0.49	-0.30	-0.80
	PCR-GLOBWB	-1.32	-1.63	-3.06	-3.35	-4.44	-1.98	-7.27	-1.07	-0.69	-0.16	-1.40
	WaterGAP2	-1.03	-0.73	-2.62	-12.11	-6.48	-4.21	-7.52	-0.86	-0.60	-0.02	-0.79
	MATSIRO	11.57	41.77	16.64	-5.89	13.41	49.06	6.84	11.98	3.32	7.34	7.98
All ensembles	Median	-1.04	-0.96	-2.58	-7.96	-4.63	-2.60	-5.38	-0.74	-0.44	-0.07	-0.49
	25^{th}	-1.40	-1.60	-3.20	-15.58	-6.97	-5.84	-7.03	-0.96	-0.55	-0.19	-0.76
	75^{th}	-0.57	-0.39	0.58	-5.90	1.33	-1.71	-1.24	-0.35	-0.22	-0.05	-0.11

Table S6. Ensemble medians, 25th and 75th percentiles of MAF changes (%) induced by DHI change (ΔQ_h) from 1971-1980 to 1981-1990, 1991-2000, and 2001-2010, respectively. All ΔQ_h values are percentages of the MAF from VARSOC simulations over the 1971-1980 period.

Period / Region	**1981-1990**			**1991-2000**			**2001-2010**		
	ΔQ_h	ΔQ_h_25th	ΔQ_h_75th	ΔQ_h	ΔQ_h_25th	ΔQ_h_75th	ΔQ_h	ΔQ_h_25th	ΔQ_h_75th
CN	-0.37	-0.58	0.05	-0.65	-1.39	0.89	-1.62	-1.94	-0.78
SHJ	-1.78	-2.02	-0.34	-1.46	-2.01	-0.97	-2.15	-2.57	-1.47
LR	-3.43	-4.38	-0.23	-2.30	-3.18	1.92	-5.21	-8.29	-3.67
NW	-6.09	-8.15	-4.18	-8.99	-13.12	-4.58	-13.53	-25.40	-9.97
HA	-2.81	-7.40	-0.98	-4.49	-6.58	2.09	-7.07	-10.65	1.89
YR	-7.49	-13.76	-3.83	-4.10	-6.46	-1.83	-8.95	-10.95	-3.71
HU	-1.97	-3.74	-0.03	-5.53	-7.41	-2.20	-7.01	-10.35	-0.54
YZ	0.05	-0.19	0.64	-0.38	-0.93	1.39	-0.73	-1.18	0.37
SE	-0.32	-0.42	-0.16	-0.37	-0.58	-0.18	-0.85	-1.01	-0.46
SW	-0.03	-0.06	-0.01	-0.07	-0.19	-0.04	-0.08	-0.30	-0.06
PR	-0.31	-0.54	-0.14	-0.75	-1.32	-0.22	-0.42	-0.78	-0.19

Table S7. Relative contributions of DHI from previous studies. ΔQ_a denotes the relative contribution of DHI and is computed as $100\times\Delta Q_h/\Delta Q_a$ in the studies. Period 1 denotes the period without (or with little) human impact, Period 2 denotes the period with human impact. Period 2 is blank when no sub-periods were used in the study.

Major River	**River**	**ΔQ_a (%)**	**Period 1**	**Period 2**	**Station**	**Latitude**	**Longitude**	**Catchment area (km^2)**	**Reference**
Hai River	Qinlong River	-41.5	1957-1979	1980-2000	Taolinkou	40.13	119.05	5060	Bao et al., 2012
	Bai River	-59.9	1954-1979	1980-2004	Zhangjiafen	40.62	116.78	8506	
	Zhang River	-73.9	1951-1972	1973-2004	Guantai	36.33	114.08	17800	
	Chao River	-68.6	1961-1966, 1973-1979	1980-2001		41.00	117.00	6716	Wang et al., 2009
	Bai River	-70.4	1961-1966, 1973-1979	1980-2001		40.55	116.50	9072	
Yellow River	Upper reaches	-37	1956-1989	1990-2000	Tangnaihai	35.50	100.15	121972	Zhao et al., 2009
	Upper reaches	-46	1968-1986	1987-2000	Lanzhou	36.07	103.82	222551	
	Upper reaches	-44	1960-1970	1991-2000	Baimasi	34.72	112.58	13915	Wang et al., 2010
	Wuding River	-84.3	1961-1971	1972-1997	Baijiachuan	37.24	110.42	30261	Li et al., 2007
	Wuding River	-23	1961-2005		Baijiachuan	37.24	110.42	30261	Yuan et al. 2018
Huai River	Upper reaches	-45	1960-2010		Bengbu	32.95	117.27	270000	Ma et al., 2014

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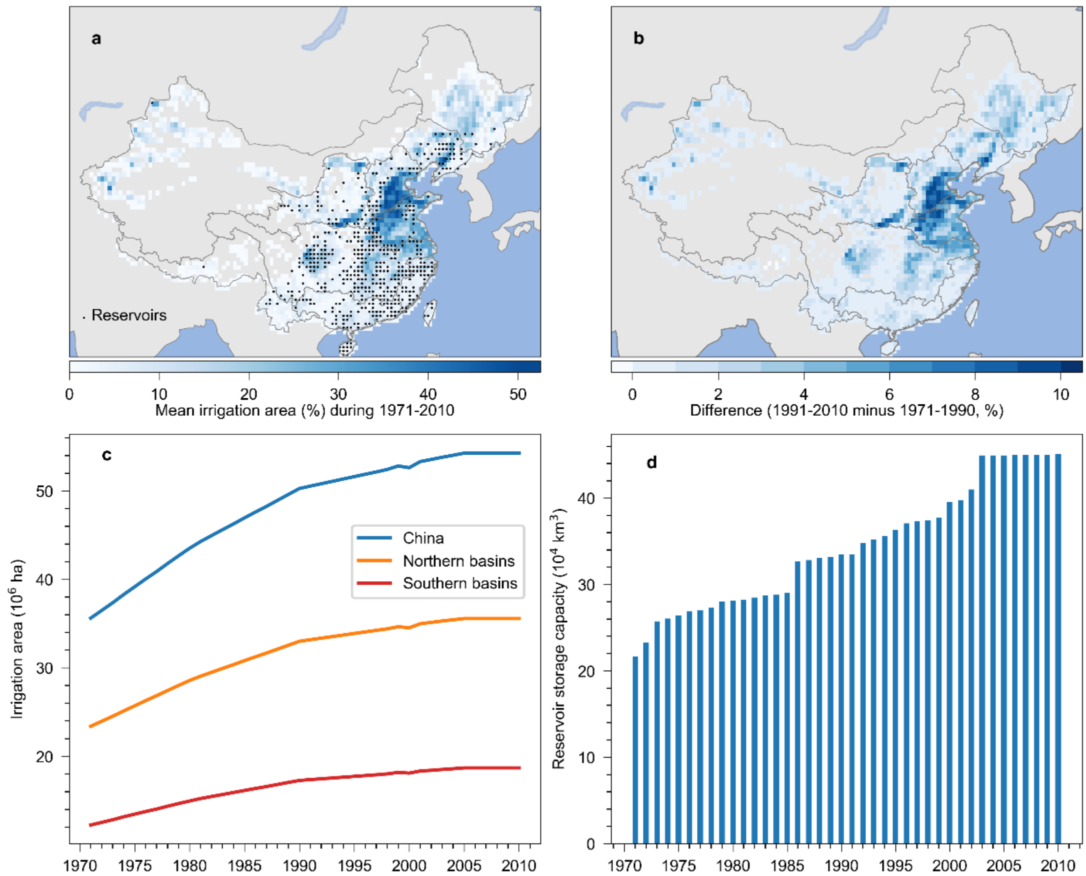

Figure S1. Irrigated areas and reservoirs in China used in the ISIMIP2a VARSOC experiment. (a): mean irrigation area per grid cell (%) over the 1971-2010 period and locations of reservoir; (b): difference in mean irrigation area between the periods of 1971-1990 and 1991 and 2010; (c): annual irrigation area for China, northern basins, and southern basins; (d): annual storage capacity of reservoirs in China. The areas without irrigation are not shown on the map.

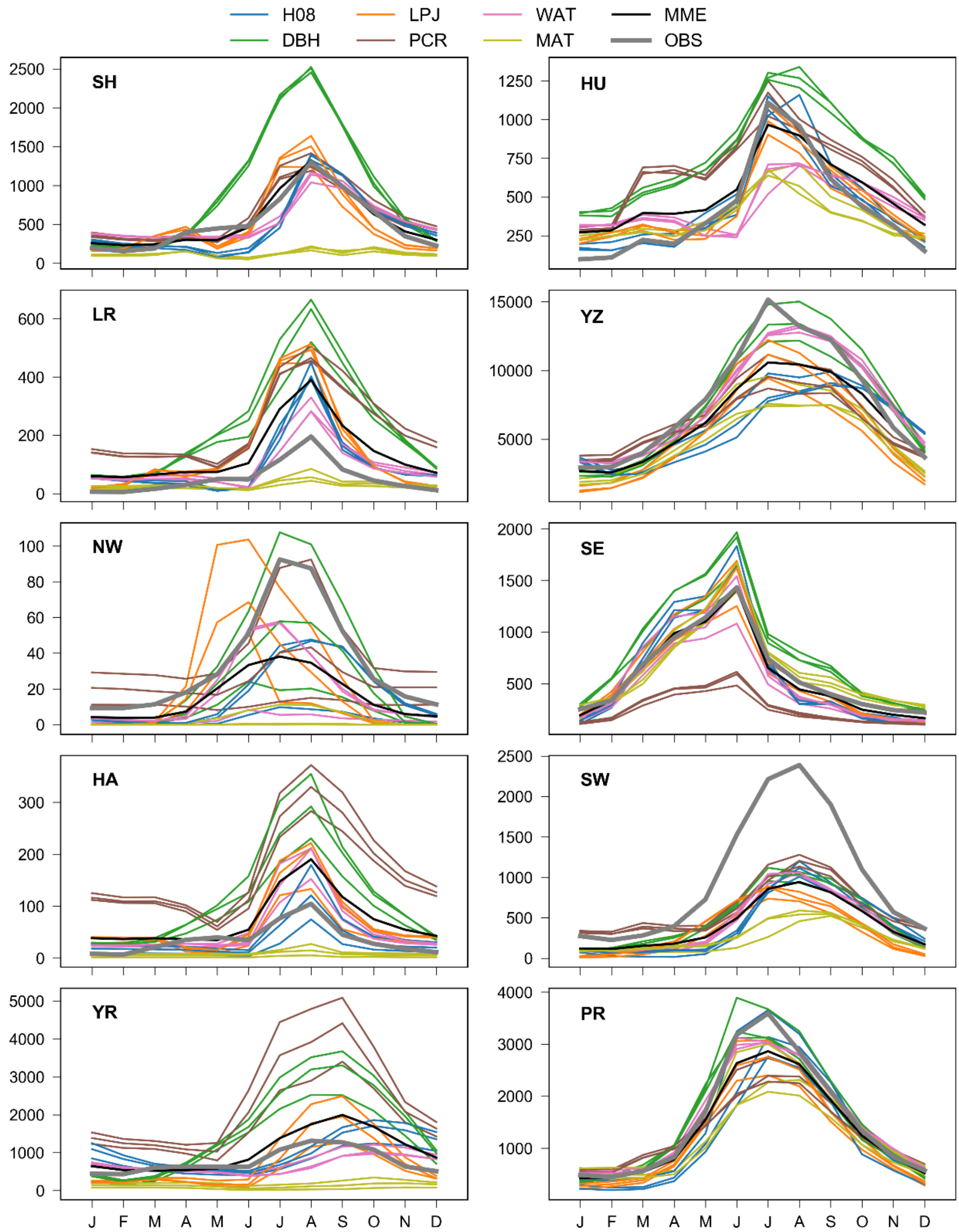

Figure S2. The seasonal cycle of streamflow from observations and GHMs. The seasonal observations are based on monthly streamflow and averaged for the hydrological stations in each basin (Figure 1). The simulations are averaged values over the grid cells identified by the location of stations. H08: H08 model; DBH: DBH model; LPJ: LPJmL model; PCR: PCR-GLOBWB model; WAT: WaterGAP model; MAT: MATSIRO model; MMS: multimodel medians; OBS: observations. Northern basins: Songhua River (SH), Liao River (LR), Northwest Rivers (NW), Hai River (HA), Yellow River (YR), Huai River (HU); Southern basins: Yangtze River (YZ), Southeast Rivers (SE), Southwest Rivers (SW), Pearl River (PR).

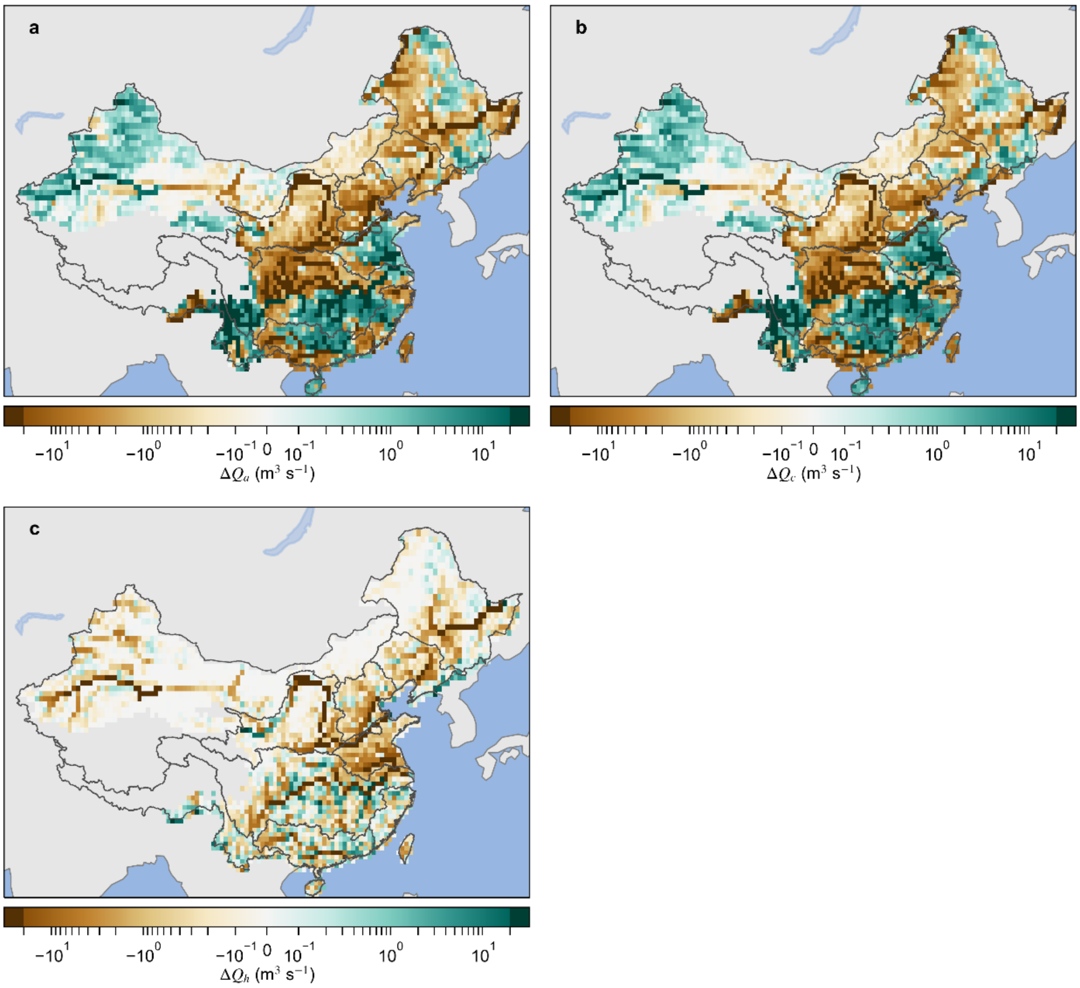

Figure S3. MAF changes (m^3 s^{-1}) over China between the sub-periods 1971-1990 and 1991-2010. (a) Total MAF changes (ΔQ_a), (b) MAF changes induced by climate change (ΔQ_c) and (c) MAF changes induced by DHI change (ΔQ_h).

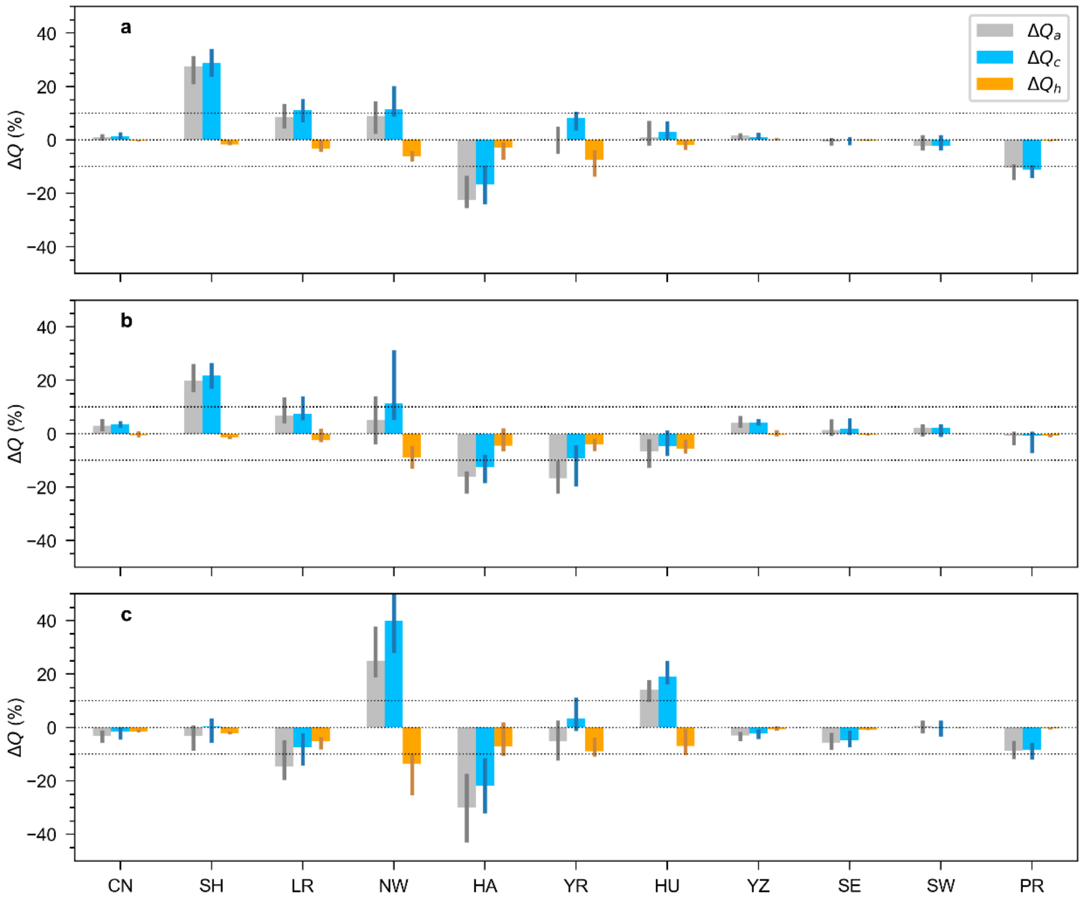

Figure S4. Total MAF change (ΔQ_a), MAF change induced by climate change (ΔQ_c), and MAF change induced by DHI change (ΔQ_h) from the period 1971-1980 to (a) 1981-1990, (b) 1991-2000 and (c) 2001-2010, respectively. The bars show the medians and the error bars show the range of 25th and 75th of MAF changes.