Short Communication

Increased adversely-affected population from water shortage below normal conditions in China with anthropogenic warming

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Whilst climate warming is expected to speed up the water cycle, it is not clear how the renewable freshwater availability and societal impact would change globally and regionally. Recent call for reporting naturally occurring drought with anthropogenic water shortage and the need for new scientific knowledge around the warming targets (e.g., 1.5 and 2 °C) prompts us to tackle this challenge [1–4]. Recently, we published a research paper in *Geophysical Research Letters*, a journal of the American Geophysical Union [5]. We presented an assessment of global changes in water availability below normal conditions (WABNC, e.g., 20th percentile water availability) and subsequent population impact in 1.5 and 2 °C warmer worlds using the newly released Half a degree Additional warming, Prognosis, and Projected Impacts (HAPPI) experiments [1]. We found that WABNC is likely to decrease in the tropics and the mid-latitudes under both warming levels. Consequently, more (less) people in Central Europe, East Asia, Southeast Asia and South Asia (Alaska/Northwest Canada and West Africa) would face water shortage below normal conditions (WSBNC). The number of people suffering from WSBNC would be constrained in most of the regions except for Amazon, Southeast Asia and Alaska/Northwest Canada, if global temperatures increase 2 °C instead of 1.5 °C above the preindustrial levels [5].

The previous study has provided international policymakers with information on the societal impacts of water shortage triggered by WABNC at global and continental scales. However, the reference information provided in such a study is still very limited at national level due to the relatively coarse spatial resolutions (from $2.81° \times 2.81°$ to $1.25° \times 0.94°$) of HAPPI climate models used [5], which will constrain its implications in addressing local water management and climate adaptation strategies in specific countries. Although the climate model outputs were uniformly rescaled to a $0.5° \times 0.5°$ grid using bilinear interpolation in order to accommodate their spatial resolution to those of climate data record and the World Population Prospects of United Nation (WPPUN), they actually cannot provide more detailed information at finer scales (e.g., spatial resolution higher than $1.0° \times 1.0°$) without spatial downscaling. In view of above mentioned reason, we design a follow-on study to show how would WABNC change in 1.5 and 2 °C warmer worlds and their potential population impact in China (a highly populated country which is susceptible to climate change) using a high spatial-resolution dataset and a distinct approach.

In this study, we compute the water availability from the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP) fast-track multi-model hydrological simulations at each $0.5° \times 0.5°$ grid cell over China. The ensemble comprises monthly runoff simulations (35 combinations) of 7 global hydrological/land surface models (i.e., H08, HPM-HM, LPJmL, PCR-GLOBWB, WaterGAP, VIC and WBM) forced with bias-corrected forcing from 5 global climate models (GCMs, i.e., HADGEM2-ES, GFDL-ESM2M, IPSL-CM5A-LR, NorESM1-M and MIROC-ESM-CHEM) [6]. The ISIMIP GCM outputs $(0.5° \times 0.5°)$ were bias-corrected (statistically downscaled) through a trend-preserving method to adjust the difference of probability density functions between the original CMIP5 (Coupled Model Inter-comparison Project Phase 5) GCM outputs and EWEMBI (E2OBS, WDFEI and ERAI data merged, $0.5° \times 0.5°$ daily data) data, which have been widely applied to drive global impact models for assessing the inter-sectoral risks under climate change at global and regional scales [6,7].

We present changes in WABNC (Q_{20}^{*}, the 20th percentile water availability, in this study) and population impacts between the baseline (1976–2005, approximately 0.7 °C warmer than the

preindustrial levels) and two future periods (two 30-year time windows centered on the year when global mean air temperature is 1.5 and 2 °C above the preindustrial levels). Timing to reach the two specific warming levels for the ISIMIP climate models used in this study refer to previous work [6]. To analyze both two considered specific warming levels in the same set of simulations, we only use climate projections from Representative Concentration Pathways (RCP) 8.5. We apply the WPPUN-adjusted and gridded population count of the world in 2005 and keep it constant to make it consistent with the baseline period. We define WSBNC per grid cell as the case when water supply (water availability) is less than water demand (population count × water demand threshold, 1,700 m³ person⁻¹ -a⁻¹ in this study following the Falkenmark water stress indicator [8]). We aggregate our projections to national and regional scales following the definition of regions in previous work [9]. We perform significance testing for projected changes in Q_{20}^* and related population impacts between the baseline and future periods across all the GCMs and global hydrological/land surface models using Wilcoxon Sign Test at the 5% significance level.

We found that the Q_{20}^* would decrease in eastern China (e.g., East China, Central China and South China), where the vast majority of China's population lives in, in +1.5 and +2 °C warmer worlds ((d)–(f) in Fig. 1). Conversely, the simulations indicate a significantly increase in the Q_{20}^* in western China (e.g., Tibet, Northwest China, and North China). The spatial pattern of Q_{20}^* changes for the +2 °C

warming level is similar to that of 1.5 °C warming with magnitude of both negative and positive changes intensifies in most areas, which are consistent with previous study [10]. Compared with the 2 °C warmer world, a 1.5 °C warmer world is more likely to alleviate WSBNC nationally and regionally (excluding Tibet and Northwest China). The number of population adversely affected by WSBNC in +1.5 (+20 million, the sign of +/− means that the number of population adversely affected by WSBNC would increase/decrease) and +2 °C (+25 million) warmer worlds would overall increase in China (especially in Southwest China and the middle and lower parts of the Yangtze River basin) ((g)–(i) in Fig. 1). From regional aggregation, we found that more (less) population in Tibet (+0.5 million and + 0.03 million), Northeast China (+0.2 million and +0.8 million), East China (+4.7 million and +5.6 million), Central China (+9.0 million and +10.8 million) and South China (+6.3 million and +58.6 million) (North China, −40.6 million and −0.4 million) would be exposed to the WSBNC in +1.5 and +2 °C warmer worlds. Holding global warming at 1.5 °C instead of 2 °C, adverse influences on population suffering from WSBNC would be constrained in most regions (particularly East China, Central China and South China) but less effective in Tibet and Northwest China. Approximately 4.6 million more people could face WSBNC in China if stabilizing global temperature increase at 2 °C relative to the 1.5 °C warming target.

We calculated WABNC and water shortage using the Q_{20}^* and 1,700 m³ person⁻¹ a⁻¹ water demand thresholds in this study,
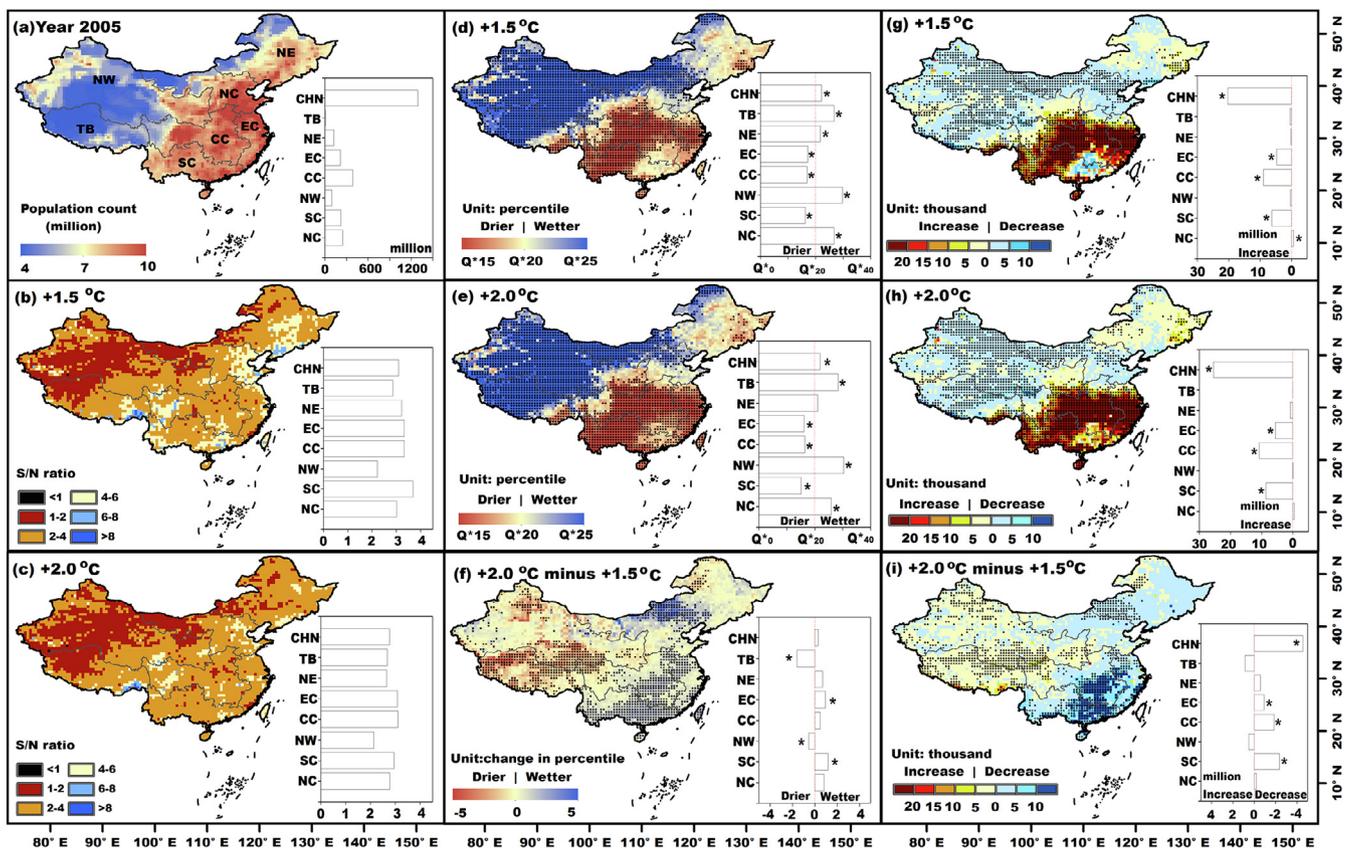
Fig. 1. Multi-model ensemble mean percentile in the historical period for monthly water availability corresponding to the future period Q_{20}^* (the percentile lower than Q_{20}^* indicates that magnitude of the future period Q_{20}^* would decrease, and vice versa) in China for (d) +1.5 °C experiment, (e) +2.0 °C experiment and (f), (d) minus (e). Spatial distribution of people (estimated based on population data that is consistent with the United Nation's World Population Prospects (UNWPP, constant 2005), (a) The population data is unavailable in Taiwan in UNWPP, thus its population count/affected population in (a) and (g)–(f) are not shown) affected by water shortage (water demand threshold: 1,700 m³ person⁻¹ a⁻¹) triggered by freshwater availability below normal conditions: (g) +1.5 °C experiment minus the historical period, (h) +2 °C experiment minus the historical period and (i), (g) minus (h). Signal-to-noise (S/N) ratio of mean percentile in the historical period for monthly water availability corresponding to the future period Q_{20}^* among the ISI-MIP models (5 climate models × 7 global hydrology/land surface models) are shown for (b) +1.5 °C experiment and (c) +2.0 °C experiment. The embedded sub-figures exhibit the corresponding aggregated results for North China (NC), South China (SC), Northwest China (NW), Central China (CC), East China (EC), Northeast China (NE), Tibet (TB) and the entire China (a). Hatching (and asterisk) in (d)–(i) indicates changes that are significant according to a Wilcoxon Sign Test (95% confidence).

because we have confirmed that the geographical pattern of their changes are not sensitive to the selected threshold (e.g., 1,000 m^3 - $person^{-1}$ a^{-1} water demand threshold; the 5th and 10th percentile water availability, Q_5^* and Q_{10}^*) in our previous study [5]. Hydrological models usually have weakness in low-flow simulations due to their inadequate mathematical representation about hydrological systems under low-flow conditions [5]. However, the results of the signal-to-noise (S/N) ratio ((b) and (c) in Fig. 1, the S/N ratio is calculated by comparing the magnitude of the mean of 35 percentile changes (signal) to the standard deviation of those changes (noise) with the ensemble signal considered to be robust if the S/N ratio exceeds one) and Wilcoxon Sign Test confirm that the projected changes in Q_{20}^* are robust across GCMs and global hydrological/land surface models (especially in eastern China). The findings of this study will provide Chinese policymakers with useful and valuable information about the societal impact of WSBNC at national and regional scales.

Conflict of interest

The authors declare that they have no conflict of interest.

Acknowledgments

Author contributions

F. Sun designed the research and led the drafting of this manuscript. W. Liu contributed to the drafting of this manuscript, the development and implementation of methodology and the interpretation of results.

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