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GRACE satellite observations reveal the severity of recent water over-consumption in the United States

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Changes in the climate and population growth will critically impact the future supply and demand of water, leading to large uncertainties for sustainable resource management. In the absence of on-the-ground measurements to provide spatially continuous, high-resolution information on water supplies, satellite observations can provide essential insight. Here, we develop a technique using observations from the Gravity Recovery and Climate Experiment (GRACE) satellite to evaluate the sustainability of surface water and groundwater use over the continental United States. We determine the annual total water availability for 2003–2015 using the annual variability in GRACE-derived total water storage for 18 major watersheds. The long-term sustainable water quantity available to humans is calculated by subtracting an annual estimate of the water needed to maintain local ecosystems, and the resulting water volumes are compared to reported consumptive water use to determine a sustainability fraction. We find over-consumption is highest in the southwest US, where increasing stress trends were observed in all five basins and annual consumptive use exceeded 100% availability twice in the Lower Colorado basin during 2003–2015. By providing a coarse-scale evaluation of sustainable water use from satellite and ground observations, the established framework serves as a blueprint for future large-scale water resource monitoring.

The ability to sustainably manage water resources to avoid long-term depletion or environmental harm is of increasing importance due to the numerous alarming observations of diminishing global freshwater resources[1–4]. Approximately 80% of the population worldwide resides in an area with present threats to water security[5]. Over 50% of the world's largest aquifers show declining trends in groundwater storage[6] and 1.7 billion people inhabit areas where groundwater resources are considered stressed[7]. Many of these water shortages and groundwater declines affect transboundary regions—such as the Middle East and India-Pakistan border region—which is particularly worrisome given the already tense political relations in these areas coupled with the lack of institutional transparency and international cooperation[8–10]. Within the United States, of greatest concern is the Southwest, which includes the transboundary Colorado River basin that shares a border with Mexico and contains seven US states. Changes in snowmelt are driving seasonal shifts in extremes[11] and near-decadal groundwater and surface water declines have been reported in this region due to the high intensity of water resource management primarily for irrigation[12–14].

The magnitude and extent of global water scarcity has been examined in a number of previous studies[15–20]. One critical outcome of these studies is the finding that nearly one-quarter of global river basins are observed to be under severe water stress by comparing water demand to availability[16]. In addition, findings indicate projected global blue (renewable surface and groundwater) and green water (precipitation that naturally infiltrates) shortages of 36% and 50%, respectively[17]. Using a different approach, monthly modeled and observed data were used to identify that nearly 40% of the global population inhabits river basins with blue water shortages[18].

Collectively, this research has provided deeper insight into the global sustainability of water management systems, but several key deficiencies exist with the formulation and calculation of these indices. First, the use of

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