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An Integrated Understanding of Changes in the Water Budget and Climate of Various US Sectors Over the 21st Century

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ABSTRACT

This study integrates the improved understanding of the effects of future climate change on various sectors across the United States that include 2104 river basins, 14 megaregions, 74 national forests and grasslands, and 5 croplands. The findings highlight that farmers who are living in the Houston region and have sorghum or cotton lands are likely the most vulnerable group to future climate change in the United States. The integrated concepts in this letter can help all decision-makers to combine and coordinate diverse adaptation and mitigation strategies into a whole to attenuate the negative impacts of climate change such as water shortage, aridification, and wildfire disasters.

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Introduction

An integrated and comprehensive understanding of the effects of climate change on important sectors of the United States such as megaregions, river basins, croplands, and forests is a vital need for sustainable development [1,2]. Climate change can lead to shifts in water availability and hence affect the agricultural, economic, social, ecosystemic, and environmental activities in the future and subsequently increase natural hazards such as drought and wildfire [3-6]. A comprehensive preparedness and adaption plan is needed to be implemented to integrate actions of urban planners, farmers, and water, land, and forest managers and address the considerations in water resource planning and management.

An integrated understanding of changes in both long-term anomalies such as aridification and desertification and short-term anomalies such as multi-year and interannual water shortage events and wildfire activities on various sectors of United States in a changing environment is requisite to the appropriate management and planning of future water and natural resources, and improved implementation of regional adaptation and mitigation strategies [1,5,7,8].

Thus, the main goal of this letter is to integrate the key findings of our recent studies on impacts of climate change on the freshwater availability and climate conditions of different sectors of the United States including 2104 U.S. river basins at 8-digit hydrologic unit code (HUC8), 14 megaregions, 74 national forests and grasslands, and 5 croplands and their consequences on natural hazards such as aridification in cropland, short-term and long-term water shortage events in urban areas and wildfire activities in forests. We reviewed only the results and findings of our recent studies so that the future climate and hydrological projections were consistent among all studies and the only variables were the investigated sectors.

To this end, hydroclimatic variables were projected over the 21st century using the Variable Infiltration Capacity (VIC) hydrological model driven by the downscaled Multivariate Adaptive Constructed Analogs (MACA) datasets at the grid size of ~4 km (1/24 degree) [9]. Then, hydroclimatic shifts in response to climate change were evaluated by movements in the Budyko space [10]. The following six steps were addressed to provide an improved and integrated understanding of the effects of climate change on the United States at both regional and national scales (Figure 1).

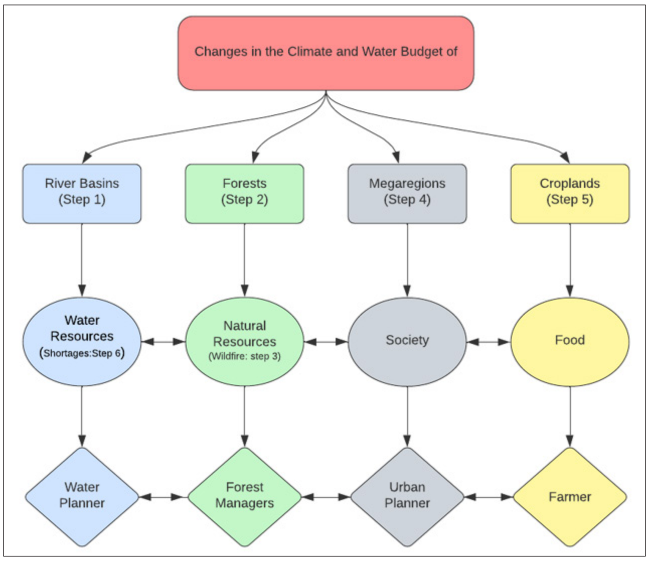

Figure 1: A schematic of the integrated preparedness plan

First, we assessed the effects of climate change on the relationship between climate and water budgets of 2104 HUC8 U.S. river basins over the 21st Century to determine regions with prolonged dry or wetting periods (first step) [11]. Assessing shifts in regional hydroclimatic conditions of river basins across the CONUS can be a different way of approaching future water resource management [12]. We found that future hydroclimatic behaviors of U.S. river basins are highly associated with their regional landform, climate, and ecosystems. In general, the South and Southwest U.S. are the hotspots regions of shifts in long-term water availability and climate conditions with higher chances of aridification or desertification by the end of the century [11].

Second, we focused on the characterization of future hydroclimatic changes in the U.S. national forests and national grasslands (step 2) [13] that provide a wide range of hydrological, ecological, social, economic, recreational, and aesthetic services [14-20]. We found that NFs and NGs are more likely to experience larger changes in hydroclimatic variables compared to the average of the United States. The hydroclimatic conditions of the Southwestern Forest Service region are likely to have the highest sensitivity to future climate changes. The Southwestern Forest Service region is projected to have the highest sensitivity to future climate changes. The Pacific Northwest, Intermountain, and Northern regions may have a less arid climate with lower freshwater availability [13]. Long-term shifts in hydroclimatology of NFs and NGs may change the structure and composition of forests and grasslands [14-20].

Third, we also assessed the effects of shifts in hydroclimatology of U.S. national forests on future wildfire activities by applying the fine K nearest neighbor (KNN) machine learning method (step 3) [21]. The finding reveals that future climate change can add to the occurrence of wildfires in western United States national forests, particularly in Rocky Mountain, Pacific Southwest, and Southwestern United States Forest Service regions [21].

Fourth, we focused on the characterization of shifts in hydroclimatic conditions of fourteen U.S. megaregions including Seattle, San Francisco, Los Angeles, San Diego, Denver, Phoenix, Chicago, Miami, Washington D.C., Philadelphia, New York, Boston, Houston, and Atlanta (step 4) as the clustered metropolitan regions where climate change may amplify negative impacts on energy sources, water supply, air quality, habitat preservation, ecosystem, and natural resources [22-24]. We found that Houston may experience more arid climatic conditions with higher evaporative loss of freshwater resources in the future [22]. The improved understanding of future shifts in long-term hydroclimatology of U.S. megaregions may help urban planners to attenuate the potential consequences of climate change on cities and strengthen economic prosperity [25-27].

Fifth, the primary impacts of future changes in hydroclimatology of five major crops including cotton, corn, soybean, sorghum, and wheat are investigated as other important sectors of the United States (step 5) [28]. Agriculture is by far one of the largest water users in many regions of the United States. Long-term hydroclimatic changes may lead to long-term shifts in water budget and climate conditions of U.S. croplands and hence a decrease in food production [29-31]. We concluded that while the direction and magnitude of hydroclimatic changes are highly variable across the climate projections, hydroclimatic changes on average have a higher impact on sorghum and cotton, respectively [28].

Sixth, by the improved understanding of the effects of climate change on the hydroclimatology of U.S. river basins, national forests, national grasslands, megaregions, and croplands, we assessed changes in future water shortage properties across the United States from 1986-2015 to 2070-2099 periods (step 6) [32]. Climate change combined with population growth can cause water shortage conditions at various scales from short-time (interannual) to long-time (decadal drought) events [33]. Both sub-annual and annual events may lead to significant consequences and disrupt water supply and agricultural systems [34–38]. The Water Evaluation and Planning (WEAP) model was used to project the water supply allocated to each HUC4 river basin [32]. The A1B scenario from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment set of global socioeconomic scenarios was chosen to project future changes in population and income levels using the AIM global emissions model [31,39]. The results indicate that while the frequency of prolonged water shortage events is likely to increase in the Southwest, South, and the middle Great Plain region, the frequency of interannual water shortage events in the West Coast region is more likely to rise in the future in response to climate change and population growth. The prolonged water shortage conditions in drier basins and interannual water shortage events in wetter basins are likely to be the main concerns in the future and should gain more attention in future water resource planning and management [32].

Table 1: The hotspot regions of climate change for different sectors

Sector	Hotspot region	References
River Basins	South and Southwest basins	[11,32].
Forests	Southwestern Forest Service region	[13,21].
Megaregions	Houston megaregion	[22].
Croplands	Sorghum and Cotton	[28].

Overall, the integrated findings of all six aforementioned studies indicate that the South and Southwest U.S. are likely to experience aridification under long-term changes in climate and freshwater availability. This situation may also lead to lower crop yields, increasing wildfire activities, and more frequent, intense, and longer water shortage events. The findings highlight that long-term changes in hydroclimatic conditions of river basins can lead to the initiation of prolonged events, particularly in more arid regions where natural, water, and economic resources even during normal years may be inadequate to meet local needs. Table 1 shows the most sensitive region of each sector to climate change termed hotspot regions. Table 1 indicates that the farmers who lives in Houston areas and have sorghum and cotton croplands can be the most vulnerable people to climate change in the future. This issue can affect not only these farmers, but also all the United States food productions.

Conversely, the West U.S. is likely to experience wetter hydroclimatic conditions. Although this condition can lead to higher freshwater availability, this region is likely to experience increasing forest fires and more frequent water shortage events within the year. The findings highlight that while the long-term hydro climatology of a river basin can tend to wetter conditions, interannual events may develop very rapidly if extreme weather anomalies rise over the basin. Besides, interannual water shortage events are likely to occur during the growing seasons that may exacerbate the negative impacts of interannual events on agriculture and crop yield.

The six developed steps in this letter can help decision-makers to assess the efficiency of various adaptation and mitigation strategies at a regional and national scale to attenuate the negative consequences of water shortage conditions. The conclusion can be used as an input into a comprehensive plan to determine the most appropriate preparedness actions that can be implemented for water shortage, aridification, and wildfire related disasters.

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