Comparative assessment of drought effects on the agricultural industry in the Colorado basin region of the United States

By

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Introduction

The 7 states of the Colorado basin are experiencing the worst drought in the region in more than 1200 years. This is a region well regarded for agricultural production, as such periods of less than normal precipitation during a growing season will have serious consequences on the economy and environment of the region in terms of agricultural production and natural resource management. Agriculture worldwide consumes over 70% of the freshwater resources on the planet, and the US agricultural industry is no different, hence, there will be sectoral competition for water resources in the western US, from residential and municipal to industry and agriculture which takes the largest share of the pie.

The upper Colorado basin consists of Colorado, Utah, Wyoming and New Mexico while the lower basin consists of California, Nevada and Arizona. These states are heavily dependent on water from the Colorado river and surface precipitation, but with the onset of the drought which has persisted since the year 2000, a lot of strain has been placed on existing water resources such that reservoirs on the Colorado river such as Lake Mead and Powell are at critical water threshold levels.

This study ultimately seeks to better understand the extent to which climate change and drought has influenced crop production and cropping in the basin, through the availability of freshwater from stream and river sources. There have been several studies on the present drought and climate change effects in the western US, but most have been focused on the spatial extent of the drought itself, some on different sectors or industries to which drought is affecting, less on the different dynamics this is having on agricultural systems and the decisions being made to survive this drying event. Results from this study will ultimately provide datasets and decision tools for not only the farmers, but agricultural policy makers in how to mitigate the effects of drought and climate change in the industry.

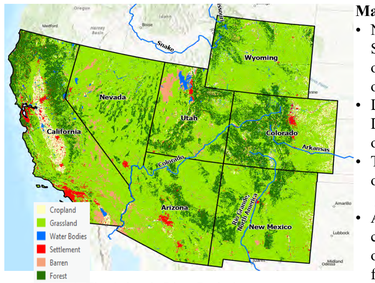


Figure 1: The Colorado River Basin States

Materials and Methods

- NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor data was obtained to investigate the spatiotemporal dynamics of drought in the Colorado basin.
- Land Surface Temperature (LST) and Normalized Difference Vegetation Index (NDVI) datasets were obtained from the terra satellite.
- The LST, NDVI and precipitation data were all obtained from the NASA Giovanni data portal: https://giovanni.gsfc.nasa.gov/giovanni/.
- A comparative analysis of agricultural output was carried out within the time period of the datasets, to observe the effects the ongoing drought had on the farming or cropping decisions within this highly agricultural area.

Data Analysis

- The drought temporal period was from 2000 – 2022,
- June to August reflects the peak periods of water usage for agricultural crops.
- Using the NDVI and LST obtained the following drought indices were computed:

VCI = $((NDVI - NDVI\ min))/((NDVI\ max - NDVI\ min))$ **(Vegetation Condition Index)**

TCI = $((LST\ \max - LST))/((LST\ max - LST\ min))$ **(Temperature Condition Index)**

VHI = $a*VCI+(1-a)*TCI$ **(Vegetation Health Index)**

VCI: This monitors local variations in ecosystem production, the VCI for each image year is utilized using time averaged NDVI maps for the summer months. The minimum and maximum NDVI values for the combined imagery are obtained using cell statistics tool in ArcGIS Pro.

TCI: This is used to define the stress on vegetation. I obtained the TCI foe each image year while ArcGIS Pro is used to obtain the minimum and maximum TCI value for the combined temporal imagery.

VHI: This illustrates the severity of drought based on the vegetation health and the influence of temperature on plant conditions. It makes use of the yearly VCI, and TCI produced and applies a weighting constant of a = 0.5 in its computation.

Results

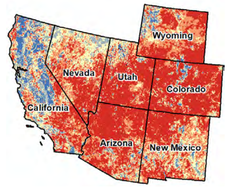


Fig. 2: VCI 2002

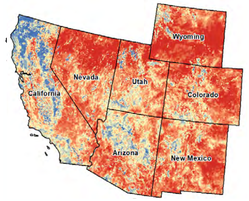


Fig. 3: VCI 2012

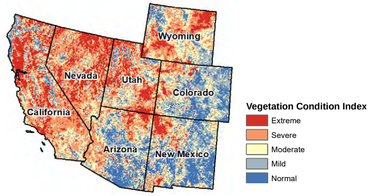


Fig. 4: VCI 2021

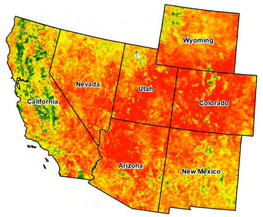


Fig. 5: VHI 2002

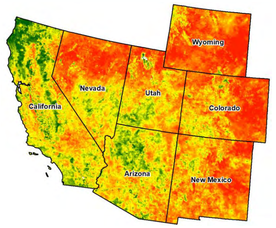


Fig. 6: VHI 2012

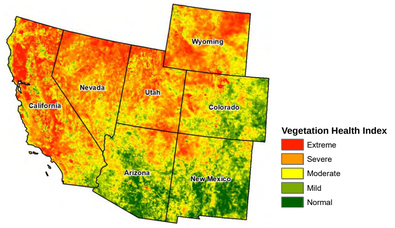
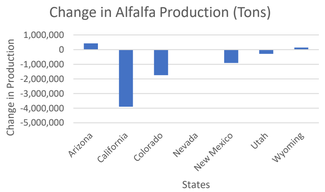
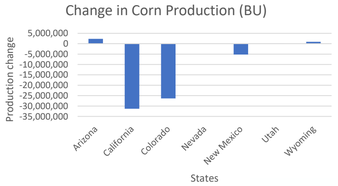


Fig. 7: VHI 2021

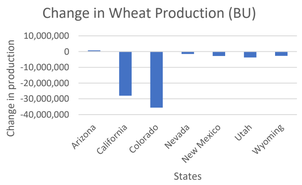
2000-2022 Alfalfa Production		
State	Δ in Harvested Acres	Δ in Production (TONS)
Arizona	55,000	430,000
California	-570,000	-3,900,000
Colorado	-340,000	-1,746,000
Nevada	10,000	-11,000
New Mexico	-165,000	-908,000
Utah	-85,000	-291,000
Wyoming	-80,000	146,000

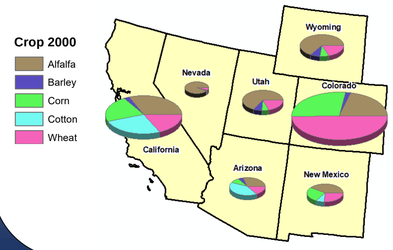


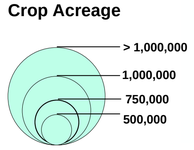
2000-2022 Corn Production		
State	Δ in Planted Acres	Δ in Production (BU)
Arizona	24,000	2,332,000
California	-170,000	-31,310,000
Colorado	0	-26,320,000
Nevada	10,000	0
New Mexico	-50,000	-5,196,000
Utah	6,000	48,000
Wyoming	5,000	912,000

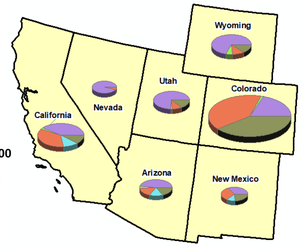


2000-2010 Wheat Production		
State	Δ in Harvested (Acres)	Δ in Production (Bu)
Arizona	-8,000	801,000
California	-382,000	-28,040,000
Colorado	-966,000	-35,620,000
Nevada	-15,000	-1,470,000
New Mexico	-90,000	-2,755,000
Utah	-78,000	-3,682,000
Wyoming	-83,000	-2,697,000









California & Almonds

Year	State	Crop	Value (LB)
2000	California	ALMONDS, UTILIZED, SHELLED - PRODUCTION, MEASURED IN LB	703,000,000
2010	California	ALMONDS, UTILIZED, SHELLED - PRODUCTION, MEASURED IN LB	1,640,000,000
2021	California	ALMONDS, UTILIZED, SHELLED - PRODUCTION, MEASURED IN LB	2,915,000,000

Results

- Figure 2,3,4,5,6 & 7are drought severity maps generated from the VCI and VHI indices. For VCI the legend indicated severity from normal to extreme with blue indicating normal and red extreme, while the VHI has a legend of green for normal and red for extreme.
- The years 2002, 2012 and 2021 show significant portions of the region under extreme drought conditions.
- Despite the prolonged drought the years 2005, 2015 and 2019 are considered as mild or wet years within the period.
- The years 2000, 2001, 2003, 2004, 2006-2011, 2013, 2014, 2016-2020 and 2022 displayed moderate to severe drought conditions, most noticeably year 2018 which just fell short of extreme drought conditions.
- The maps show different levels of drought severity between the states of the region, year on year.
- Temperature Condition Index (TCI) and Land Surface Temperature (LST) maps are utilized to obtain the vegetation Health Index (VHI) as such they are not displayed in this presentation
- Crop production data was obtained from the USDA quick data repository and compared to drought conditions on a yearly basis, which reveals farming crop decision changes as drought conditions take effect within the period.
- Six (6) water intensive crops are utilized in this assessment, they are Alfalfa, Barley, Wheat, Corn, Cotton and Almonds
- The results show a large decline in cropping output for the six (6) crops especially in states like California, Colorado and New Mexico whose water needs are high for some low value – high water use crops such as Alfalfa, Barley and Cotton.
- Results for Arizona and to some level Wyoming show a difference compared to other states as there is growth in production despite the drought figures. Wyoming has additional glacial sources of water which might contribute to this growth, while the growth in Arizona may require some more study.
- Most noticeable is the growth in Almond production, a crop with a high-water footprint within this period in California which is the only Almond producing state in the region.

Conclusion

This paper is focused on the Colorado basins, composed of California, Wyoming, New Mexico, Nevada, Colorado, Arizona and Utah states. For this study, the use of remote sensing to derive temperature and vegetation parameters was employed using NDVI and LST data obtained from the MODIS. These datasets were used to derive several drought indices such as Vegetation Health Index (VHI), Vegetation Condition Index (VCI) and Temperature Condition Index (TCI). The results show 2002, 2012 and 2021 being the driest years with increased moisture and temperature stress with a consequential impact on crop output. Such studies can help to understand the impact to agricultural concerns and food security, with a view to preparing solutions towards future drought effects.

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