Title: The Impact of Drought on Vegetation Water Use in Different Climatic Divisions across Oklahoma

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Students: Kul Khand

Student Status	Number	Disciplines
Undergraduate	0	
M.S.	0	
Ph.D.	1	Biosystems & Agricultural Engineering
Post Doc	0	
Total	1	

Principal Investigators: Saleh Taghvaeian, Assistant Professor, Oklahoma State University; Kul Khand, PhD Student, Oklahoma State University; Prasanna Gowda, Research Leader, USDA-ARS Grazinglands Research Laboratory, El Reno, OK.

Publications:

1) Ajaz, Ali; Saleh Taghvaeian; Kul Khand; Prasanna Gowda; Jerry Moorhead, 2019, Development and evaluation of an agricultural drought index by harnessing soil moisture and weather data. (under review in Agricultural Water Management)

2) Khand, Kul; Salah Taghvaeian; Prasanna Gowda; George Paul, 2019, A modeling framework for deriving daily time series of evapotranspiration maps using a surface energy balance model, Remote Sensing, 11(5), 508.
3) Ajaz, Ali; Saleh Taghvaeian; Kul Khand; Al Sutherland, 2018, Tracking drought using soil moisture information. Oklahoma Cooperative Extension Service, BAE-1541 (Available in: http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-11133/BAE-1541web.pdf).
4) Khand, Kul; Saleh Taghvaeian; Ali Ajaz, 2017, Drought and its impact on agricultural water resources in Oklahoma. Oklahoma Cooperative Extension Service, BAE-1533 (Available in: http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-10705/BAE-1533web.pdf).

Conference Presentations:

1) Ajaz, Ali; Saleh Taghvaeian; Kul Khand; Prasanna Gowda; Jed Moorhead, 2018, Development and evaluation of a new agricultural drought index using Mesonet soil and weather data. 39th Annual Oklahoma Governor's Water Conference & Research Symposium, Midwest City, OK, December 5-6, 2018.
2) Khand, Kul; Saleh Taghvaeian; Prasanna Gowda, 2018, Impacts of drought on evapotranspiration across humid and semi-arid climates of Oklahoma. ASABE International Meeting, Detroit, MI, July 29-August1, 2018.
3) Ajaz, Ali; Saleh Taghvaeian; Kul Khand; Prasanna Gowda; Jed Moorhead, 2018, Development of agricultural drought indices by harnessing soil moisture and weather data. ASABE International Meeting, Detroit, MI, July 29-August1, 2018.
4) Ajaz, Ali; Saleh Taghvaeian; Kul Khand; Prasanna Gowda; Jed Moorhead, 2018, Development of soil moisture based indices for monitoring agricultural drought. 38th Annual Oklahoma Governor's Water Conference & Research Symposium, Norman, OK, October 31-November 1, 2017.

Problem and Research Objectives:

Water use by vegetation is one of the major components of water budget, having a significant impact on water availability at variable scales. The state of Oklahoma lies in a transitional zone between eastern humid and western semi-arid climates. These climatic variations lead to differences in vegetation water use (also termed evapotranspiration) across the state. At the same time, the vegetation water use behavior is impacted by frequent droughts. Therefore, capturing water use variations in relation to climatic conditions and droughts can provide critical information for decision makers to optimize water management plans and conserve the finite water resources of Oklahoma. The main objective of this study was to analyze in-situ and remotely sensed data to study the interrelations between evapotranspiration (ET), droughts and climatic conditions, as well as their impacts on water resources.

Methodology:

The study has been conducted in three phases. At first, an initial study was conducted to synthesize the drought impacts on water resources in western Oklahoma. Three different sites were selected based on water resources: the Oklahoma Panhandle (Ogallala aquifer region), southwest region (Lugert-Altus Irrigation District), and central (the Rush-Springs aquifer) region. Groundwater level data from the USGS monitoring wells and the surface water level data were collected and analyzed to assess the impact of droughts on water resources.

In the second phase, meteorological and soil moisture data from Mesonet stations were used to develop drought indices. Daily meteorological data such as solar radiation, air temperature, wind speed and relative humidity were used to compute daily reference ET (ASCE-EWRI, 2005). These daily reference ET values were integrated with soil moisture data to develop a new drought index - Soil Moisture Evaporation Index (SMEI). Five sites were selected in this study to capture climatic conditions across Oklahoma (Figure 1). SMEI was computed for the period of 2000 to 2017 and compared with previously developed drought indices and the US Drought Monitor.

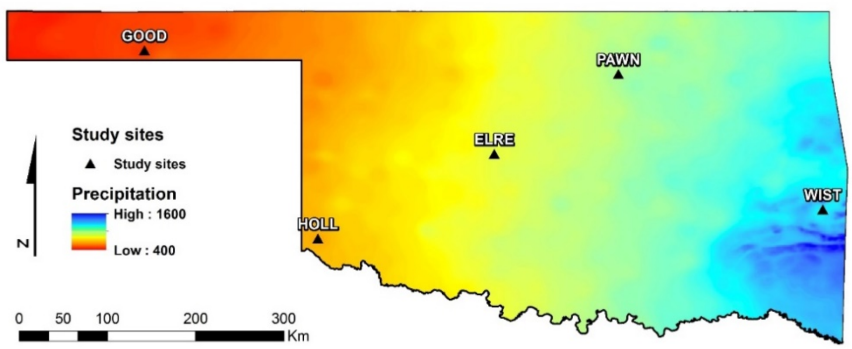

Figure 1. Location of five Mesonet study sites across Oklahoma

In the third phase, a modeling framework was developed to derive time series of daily ET maps by integrating MODIS (Moderate Resolution Imaging Spectroradiometer) imagery, Surface Energy Balance System (SEBS) model (Su, 2002) and Oklahoma Mesonet data. The SEBS model estimates the actual ET as a residual of energy balance at the earth's surface. Readers are referred to Khand et al. (2019) for the detailed description of the ET modeling framework. The actual ET results from all nine climate divisions of Oklahoma for the period of 2001 to 2014 were evaluated. A ratio of actual ET to reference ET (ASCE-EWRI, 2005) was used as in indicator of water scarcity. Results from all three phases were integrated to analyze the impact of drought on water resources and vegetation water use across different climatic conditions.

Principal Findings and Significance:

Drought impacts on water resources: The Ogallala aquifer in the Panhandle regions is a major source of irrigation water and has been diminishing during the past few decades. Based on water level data collected from 42 monitoring wells across the Panhandle, water levels in the Ogallala aquifer declined 19 feet from 2001 to 2017 (Figure 2). About 50 percent of decline (9 ft) occurred in the recent drought between 2011 and 2015. The average decline rate during the drought period was 2.2 feet per year, which is 2.75 times greater than during non-drought years (0.8 feet per year).

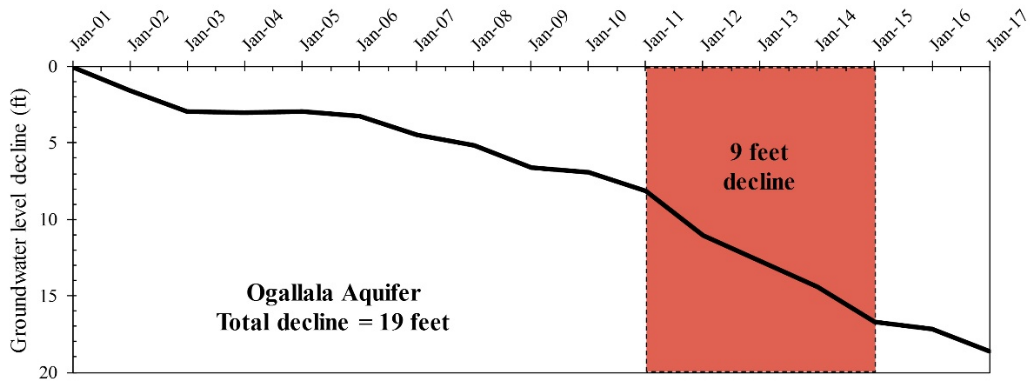

Figure 2. Groundwater level decline in the Ogallala aquifer of Oklahoma Panhandle

Rush Springs is the second most important aquifer within the state and provides irrigation water to several counties in western Oklahoma. This aquifer also experienced groundwater level depletion during droughts. The water level data from 12 monitoring wells showed that the water level in the Rush Springs aquifer dropped 10 feet during 2001 to 2017. About 70 percent of that decline was observed in recent drought between 2011 and 2015 (Figure 3). The average rate of water level decline during drought years was 1.8 feet per year, nine times the average decline rate in non-drought years (0.2 feet per year). Unlike Ogallala, the Rush Springs aquifer showed increases in groundwater level after rainy periods in 2005, 2007 to 2009 and 2015 to 2017.

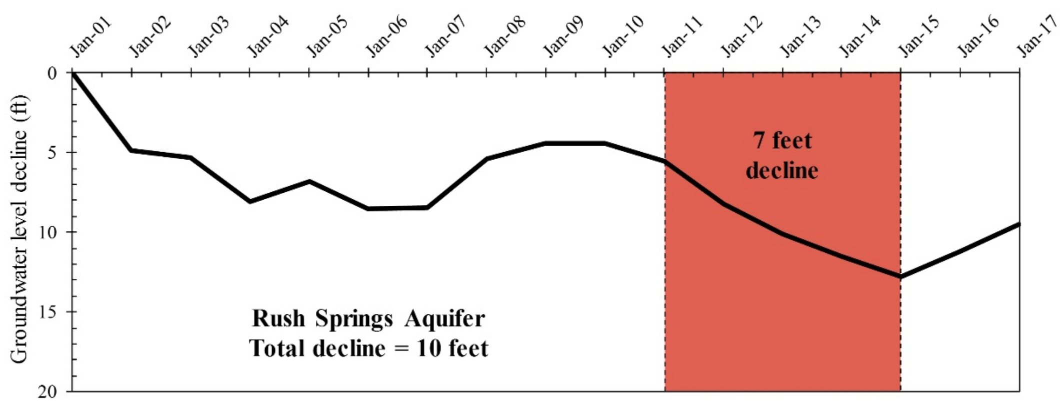

Figure 3. Groundwater level decline in the Rush Springs aquifer

Similar to groundwater resources, surface water resources were impacted by droughts. Lake Altus in southwest Oklahoma is a primary source of irrigation water for the Lugert-Altus Irrigation District (LAID). The lake was significantly impacted by the drought of 2011. Water storage in the lake was declined by about 70 percent in July 2011 compared to July 2010. Due to this decline, irrigation water was restricted to LAID, which ultimately decreased the irrigated area to near zero in 2011. In July 2014, water storage in Lake Altus was about 85 percent less than that in July 2010. After receiving rainfall in early 2015, the water level in July 2015 in Lake Altus overpassed the water level than that in July 2010.

The study documented the vulnerability and resilience of water resources in response to recent drought. The Rush Springs aquifer, which is hydrologically connected to surface water resources showed a quicker response to the rainfall (Figure 3), indicating greater resilience to drought. However, the Ogallala aquifer did not show any response even after rainy periods. The report on these results was published by the Oklahoma Cooperative Extension Service and is available online (http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-10705/BAE-1533web2018.pdf).

Development of drought index: The new drought index, SMEI, integrates soil moisture and reference ET from Mesonet stations to capture the drought magnitudes across the state. The SMEI results from 2000 to 2017 indicated the successful detection of droughts across different climates of Oklahoma (Figure 4). Comparison with existing soil moisture-based and meteorological drought indices showed good correlations.

The performance of the new indices for temporal and spatial tracking of drought was also studied. For temporal analysis, changes in SMEI-1 were compared against fluctuations in Z-index, NSM-1, and USDM for a drought period of 2011 to 2015. The SMEI was able to capture the magnitude and duration components of drought episodes as indicated by the US Drought Monitor and other indices (Figure 4).

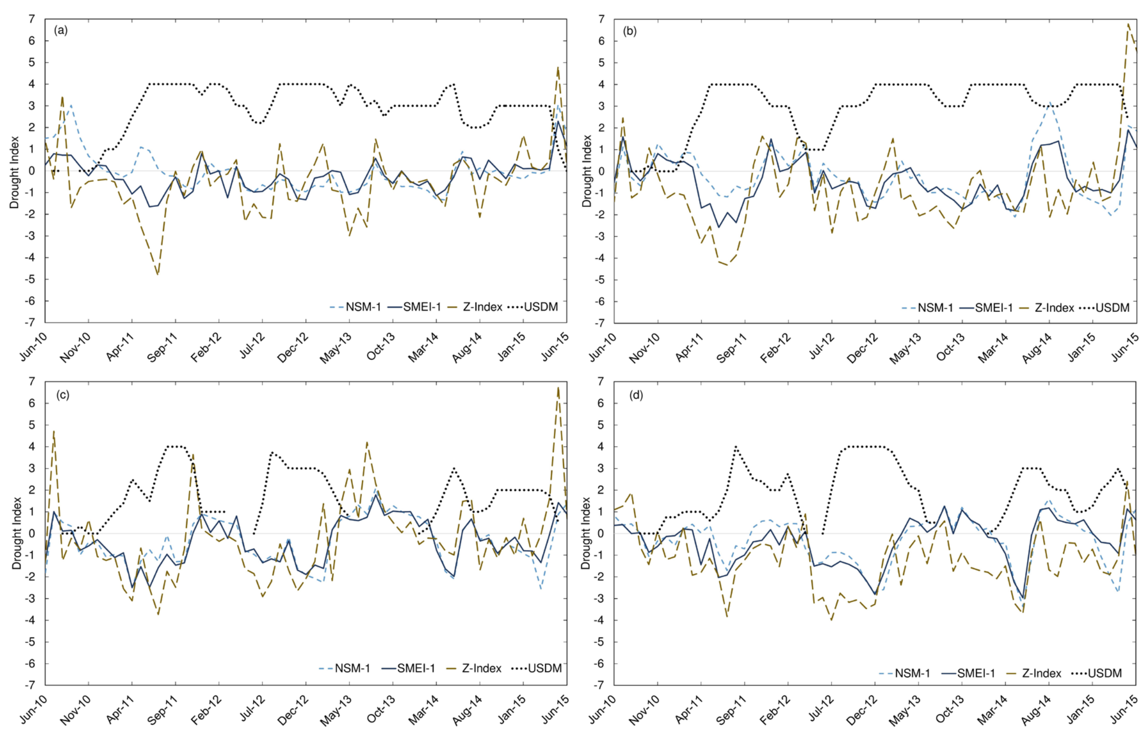

Figure 4. Time series of drought indices at Goodwell (a); Hollis (b); El Reno (c); and Pawnee (d).

The spatial pattern of drought indicated by SMEI was similar to the US drought monitor, indicating successful incorporation of spatial variation of drought across the state. Application of soil moisture and meteorological data from Mesonet stations across the state was useful for tracking drought and for developing indices suitable for the climates of Oklahoma. The soil moisture and reference ET data could be further explored for predicting droughts and making timely decisions to minimize losses from droughts. The manuscript on this study under review on Agricultural Water Management journal.

Drought impacts on vegetation water use: The daily vegetation water use, or evapotranspiration (ET), maps were developed and then summed to estimate annual ET across Oklahoma during the period of 2001-2014 (Figures 5 and 6). The statewide average annual ET varied from 33.1 to 43.3 inch/yr among studied years, with an average of 39.1 inch/yr during the 15-year period. Among the climate divisions (CD), the Southeast (CD9) had the largest average annual ET of 50.1 inch/yr and the Panhandle (CD1) had the smallest average annual ET of 23.1 inch/yr (Table 1). The reference ET (ET_r) had the opposite pattern in comparison to actual ET. The CD9 had the smallest (53.5 inch/yr) and CD1 had the largest average annual ET_r (84.3 inch/yr).

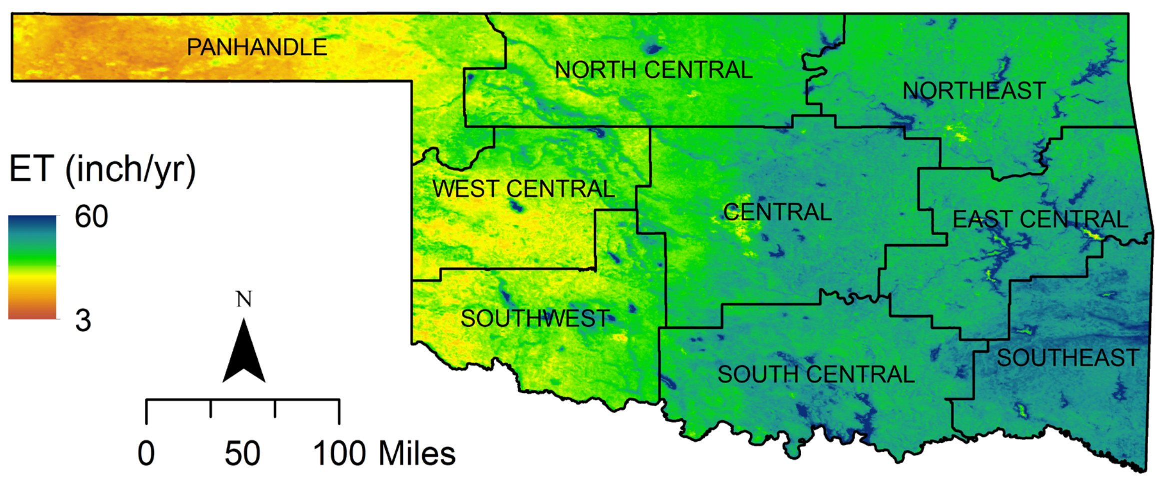

Figure 5. Average annual ET map of Oklahoma from 2011 to 2014

The ratio of SEBS-ET to ET_r, known as crop coefficient (Kc), can provide information on regional water scarcity. For example, Kc was 0.27 at CD1, indicating that only 27% of atmospheric demand was fulfilled in this CD. In contrast, Kc was 0.94 at CD9, suggesting that almost all atmospheric demand was fulfilled at this CD during the study period. Average Kc values for each CD in Oklahoma are presented in Table 1. In addition, the average Kc map of Oklahoma during the study period is shown in Figure 6. The western parts of the state had lower values of Kc compared to the eastern parts, suggesting the western parts were under more water scarcity. Similar Kc maps can be created for monitoring water stress at varying temporal and spatial scales to be used in decision-making processes by state agencies.

Table 1. Average annual actual ET (SEBS-ET), reference ET (ET_r), and crop coefficient (Kc) estimated as a ratio of SEBS-ET to ET_r

Climate Division	SEBS-ET (inch/yr)	ET_r (inch/yr)	Kc ($SEBS\text{-}ET/ET_r$)
CD1 (Panhandle)	23.1	84.3	0.27
CD2 (North Central)	36.1	73.7	0.49
CD3 (Northeast)	43.2	59.9	0.72
CD4 (West Central)	31.1	79.4	0.39
CD5 (Central)	43.1	66.9	0.64
CD6 (East Central)	46.3	58.7	0.79
CD7 (Southwest)	33.3	79.1	0.42
CD8 (South Central)	45.8	66.3	0.69
CD9 (Southeast)	50.1	53.5	0.94
Oklahoma	**39.1**	**69.1**	**0.57**

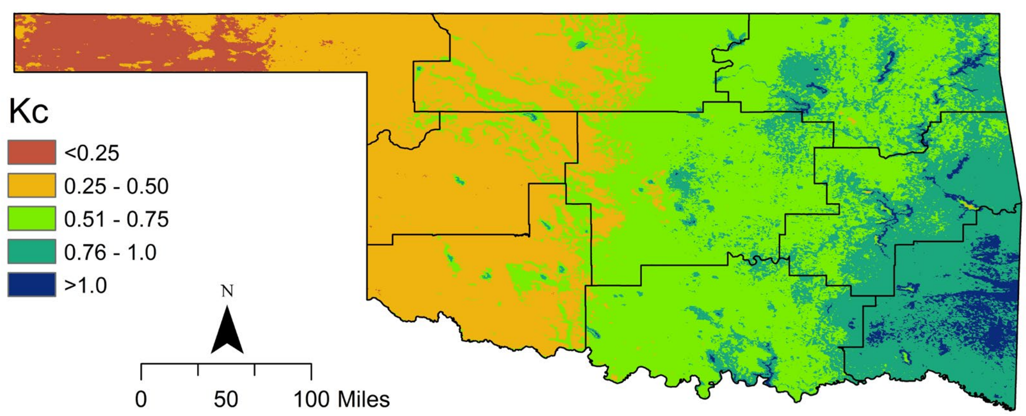

Figure 6. Average annual Kc map of Oklahoma (2001 to 2014).

The inter-annual variations in annual ET cross Oklahoma CDs is shown in Figure 7 and Figure 8. The results indicated the larger impact of drought on ET in western Oklahoma CDs compared to eastern CDs during the recent drought of 2011 to 2014. The maximum reduction in ET occurred in 2011 for the three western CDs of CD1, CD4 and CD7 (Figure 8). The percent deviations from average was −22%, −21% and −33% for the same CDs, respectively. At the same year, three eastern CDs of CD3, CD6 and CD9 were above average, with percent deviations of 9%, 8% and 10%, respectively. During the drought period, annual ET from western three CDs (CD1, CD4, CD7) was always less than their 14-year (2001-2014) average. In contrast, annual ET from three eastern CDs (CD3, CD6, CD9) from 2011 to 2013 was more than their average. Annual ET from eastern three CDs was reduced only in 2014. The western part of the state is primarily grasslands and croplands, and the eastern part is mostly covered by forests.

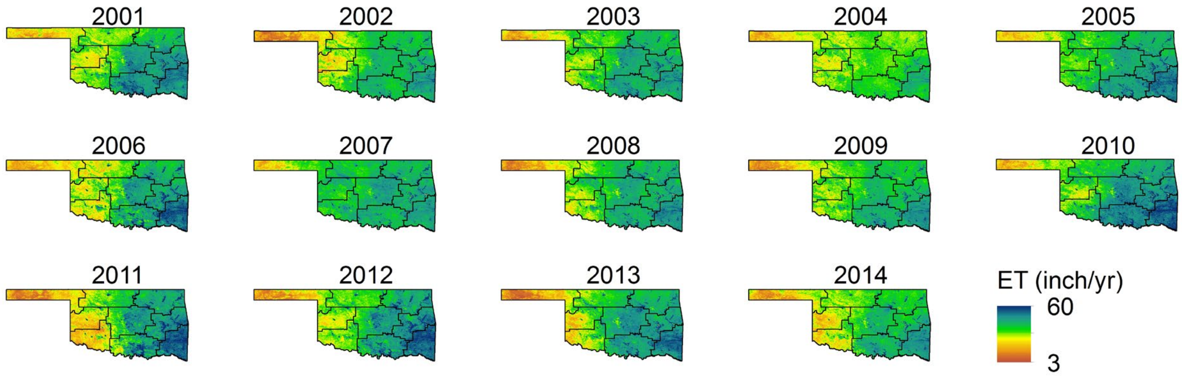

Figure 7. Annual ET maps of Oklahoma from 2001 to 2014.

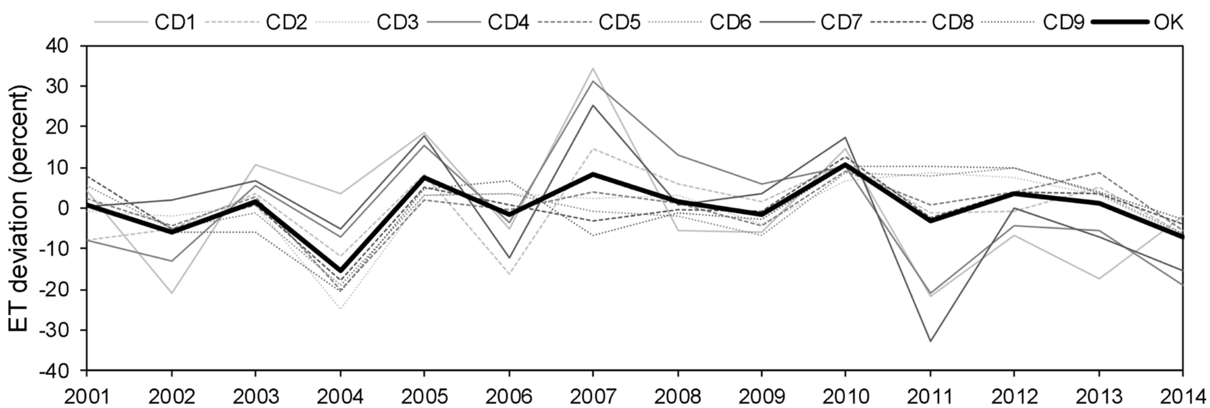

Figure 8. Annual ET deviation across Oklahoma climate divisions from 2001 to 2014.

The study developed and documented the ET modeling framework for deriving time series of daily ET maps of Oklahoma. The results indicated the western parts of Oklahoma is more susceptible to droughts compared to the eastern parts. The analysis was made at CD scale but a further analysis could be made at a county scale or even finer scales. The results from this study will be publicly disseminated through a website from where users can extract the ET information at varying temporal and spatial scales. The report on this study is published in Remote Sensing journal and available online (https://www.mdpi.com/2072-4292/11/5/508)

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