EC2003

Monthly, Seasonal, and Annual Spatial and Temporal Variability of Reference (Potential) Evapotranspiration Across Nebraska

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Spatial and temporal variation in reference (potential) evapotranspiration (ET_{ref}) is critical to monitor the changes in ET_{ref} over time so that accurate agro-water resource management strategies/decisions can be developed to meet current and future crop water demand under changing climatic conditions. This Extension Circular provides annual, seasonal (growing season), and monthly spatial and temporal variation in ET_{ref} for Nebraska. In this publication, ET_{ref} represents alfalfa-reference evapotranspiration.

Evapotranspiration (ET) is one of the most important hydrological components to consider when estimating hydrologic water balance; allocating water resources; establishing efficient irrigation scheduling and environmental assessment; and assessing hydrological impact of changing climate conditions. Evapotranspiration represents the combined loss of soil water from the earth's surface to the atmosphere through evaporation of water from the soil or plant surfaces and transpiration via stomata of the plant. In agricultural systems, these two losses of water represent a major component of the water balance within a field, watershed, or region.

When an evaporative loss exceeds the amount of precipitation, crop production may be adversely affected due to soil water stress. Reference (potential) evapotranspiration is often used to determine crop water requirements. ET_{ref} is defined as a rate of water loss by evaporation and transpiration from healthy (free of water stress and diseases) grass or alfalfa reference surface, with an assumed crop height of 4.72 inches for grass and 19.7 inches for alfalfa, a fixed surface resistance to water transports of 21.87 sec ft^{-1} for grass and 14.06 sec ft^{-1} for alfalfa, and an albedo of 0.23 for both reference crops. In general, ET_{ref} is explained as the ability of environment to extract water from surface, which varies considerably interannually and within the growing season as a function of climatic variables. Detailed description of ET_{ref} and its relationships to crop water requirements was provided in University of Nebraska–Lincoln (UNL) Extension publications:

- *Magnitude and Trends of Reference Evapotranspiration Rates in South Central Nebraska: Daily, Monthly, Growing Season Total, and Annual Total* (EC765)
- *Potential (Reference) and Actual Evapotranspiration Trends Across U.S. High Plains in Relation to Irrigation Development and Climate Change* (EC712)
- *Variability of Reference Evapotranspiration Across Nebraska* (EC733)

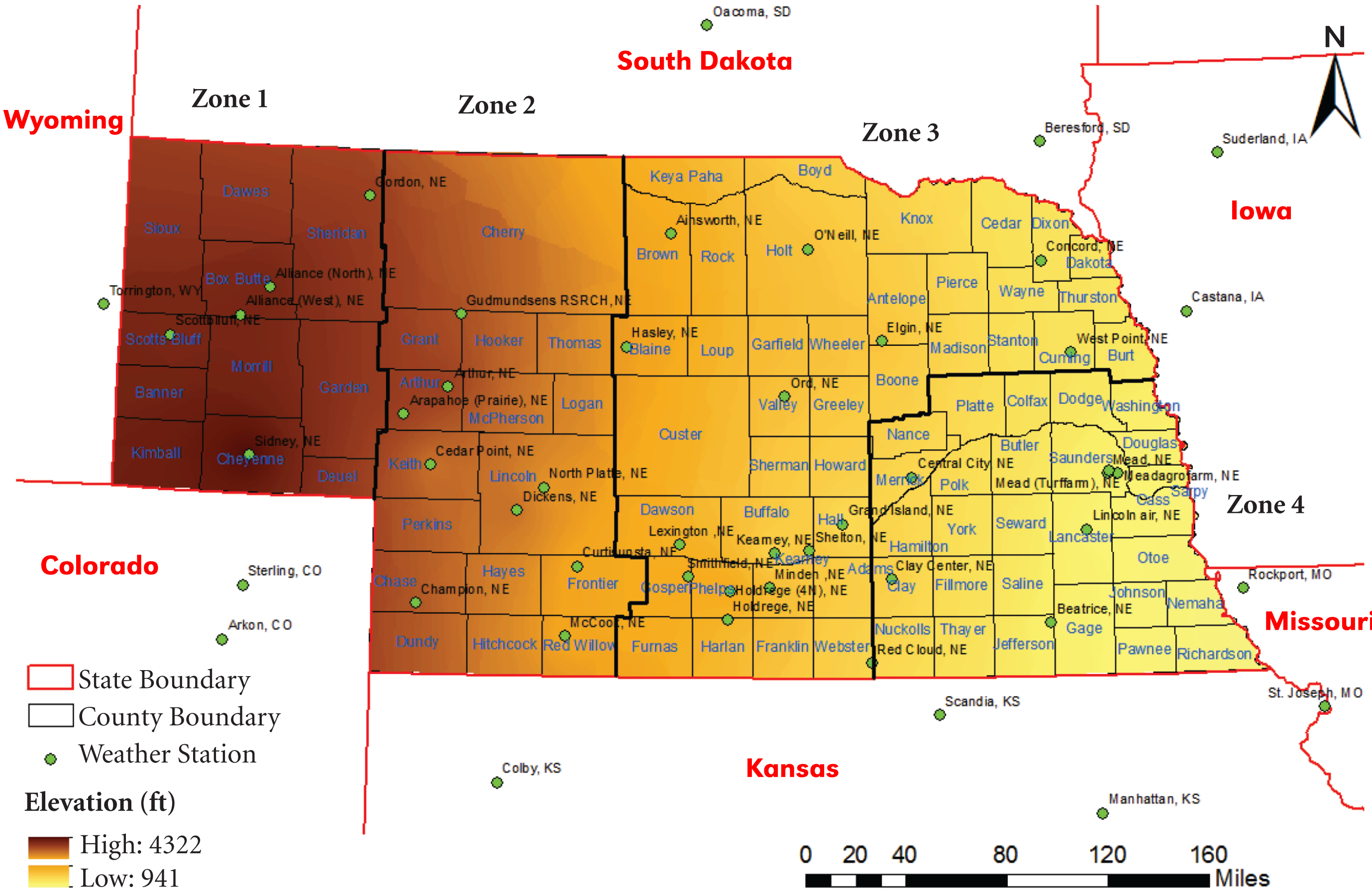


Figure 1. Location of the weather stations used in the analysis and delineation of four zones. The colored scale indicates the elevation above mean sea level.

In Nebraska, freshwater availability and sustainability for agricultural and environmental use has been a concern due to the rapid depletion of surface water and groundwater resources, increasing competition for water by the domestic and industrial sectors, and the impact of climate change on spatial and temporal ET_{ref} patterns. Such conditions demonstrated that it is critical to monitor the changes in ET_{ref} over time so that accurate water resources management decisions can be developed and implemented for specific locations to meet crop water demands under changing climatic conditions. In this publication, long-term (1986-2012) average alfalfa reference ET_{ref} spatial and temporal variations are analyzed and discussed.

For close monitoring, Nebraska is divided into four zones according to differences in soil and topographic and climatic conditions across the state. Zone 1 and Zone 2 represent the Panhandle and Sandhills part of the state, while Zone 3 and 4 represent the central and southeastern portion of the state (*Figure 1*).

The eastern part (Zone 4) of the state is characterized by relatively high precipitation and superior soil rich in organic matter, and is generally very favorable for crop production. The central part of Nebraska is generally characterized by flat topography and moderate precipitation supplemented by irrigation. The western part receives the least precipitation and has soil with lower potential for agronomic productivity, as compared to Zone 3 and Zone 4. Historical climate data from 50 High Plains Regional Climate Center (HPRCC), Automated Weather Data Network (AWDN) weather stations (38 in Nebraska and 12 in neighboring states) were used.

Figure 1 represents the locations of the weather stations used in the analysis as well as delineation of the four zones. At each of the 50 weather stations, daily maximum and minimum air temperature (˚F), relative humidity (percent), wind speed (mph), incoming shortwave radiation (W/m²), and precipitation (inch) were recorded. *Table 1* represent the long-term annual and seasonal average values of weather variables for each Zone. Daily climate data were used to calculate ET_{ref} on a daily basis, and daily values were summed to obtain monthly, seasonal (May 1 to September 30) and annual ET_{ref} values. ArcGIS 10.2 was used to generate the monthly, seasonal, and annual ET_{ref} maps for the exploratory spatial analysis.

Table 1. Long-term (1986-2012) annual and seasonal average values of weather variables for each zone across Nebraska.

	T_{max} (°F)		T_{min} (°F)		T_{avg} (°F)		u (mph)		RH (percent)		R_s (W/m²)	
	A	S	A	S	A	S	A	S	A	S	A	S
Zone 1	62.0	80.2	34.2	50.4	48.1	65.3	20.0	18.6	58.4	55.7	177.1	244.8
Zone 2	63.0	80.9	35.6	53.0	49.3	66.9	18.2	18.6	63.3	63.0	176.5	242.2
Zone 3	61.3	80.1	37.2	55.6	49.2	67.9	19.0	18.6	69.2	68.8	166.8	232.0
Zone 4	61.3	79.3	40.2	59.0	50.7	69.2	16.0	18.6	68.4	69.5	161.9	219.3
Statewide	61.7	80.0	37.4	55.6	49.6	67.8	18.1	18.6	66.7	66.5	168.2	231.4

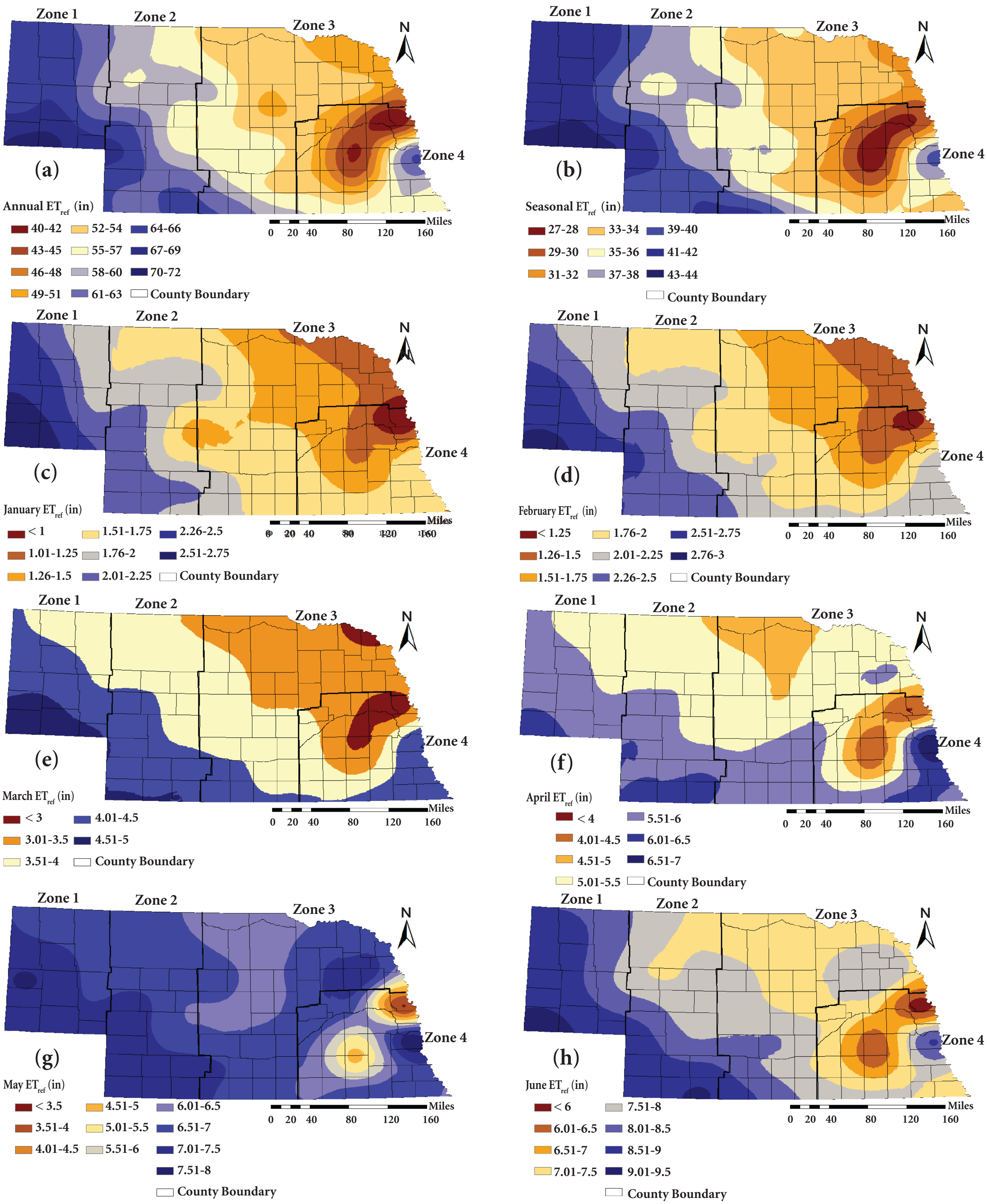
A = Annual; S = Seasonal; T_{max} = Maximum air temperature; T_{min} = Minimum air temperature; T_{avg} = Average air temperature; u = Wind speed; RH = Relative humidity; R_s = Solar radiation.

Spatial Variation of Annual, Seasonal and Monthly Reference Evapotranspiration (ET_{ref})

Spatial distribution along with descriptive statistics [mean, maximum, minimum, and standard deviation (SD)] of long-term average (1986-2012) annual, seasonal (May 1 to September 30), and monthly ET_{ref} for all counties are presented in *Figure 2* and *Table 2*. SD is the measure of the amount of variation from the average values (ET_{ref}) in each period. Higher SD indicates more variation or deviation of data point from average value in a given period, while the low SD indicates that the data points are close to the average value. A gradual decrease in ET_{ref} totals from the western to eastern part of the state was observed (*Figure 2a*). The statewide long-term average annual ET_{ref} value was 56.2 inches with significant differences across the state: average ET_{ref} of 66.2 inches in Zone 1 (SD = 2.30 inches), 62.1 inches in Zone 2 (SD = 3.64 inches), 54.3 inches in Zone 3 (SD = 3.38 inches), and 51.6 inches in Zone 4 (SD = 5.23 inches). On a

Table 2. Long-term average monthly (statewide), seasonal (typical growing season May 1 to September 30) and annual statewide and zonewise alfalfa-reference evapotranspiration, ET_{ref} (inch), of all 93 counties for the observation period of 1986-2012 across Nebraska. (SD = Standard Deviation)

		Reference (Potential) Evapotranspiration (ET_{ref})			
	Month	Mean (inch)	Maximum (inch)	Minimum (inch)	SD (inch)
Monthly	Jan	1.63	2.65	0.80	0.39
	Feb	1.92	2.78	1.22	0.38
	Mar	3.75	4.68	2.83	0.48
	Apr	5.45	6.71	4.08	0.48
	May	6.79	7.76	4.39	0.57
	Jun	7.83	9.22	6.31	0.68
	Jul	8.12	10.53	5.76	1.10
	Aug	6.90	9.17	4.83	1.02
	Sep	5.75	7.25	3.95	0.69
	Oct	4.16	5.12	2.70	0.51
	Nov	2.40	3.27	1.24	0.39
	Dec	1.51	2.43	0.59	0.38
Seasonal	Statewide	35.40	43.35	27.45	3.72
	Zone 1	41.50	43.32	39.70	1.06
	Zone 2	38.95	41.70	35.60	1.91
	Zone 3	34.46	40.42	31.77	1.94
	Zone 4	32.29	37.32	27.43	2.60
Annual	Statewide	56.21	69.76	42.83	6.37
	Zone 1	66.20	69.70	62.91	2.30
	Zone 2	62.14	67.03	55.54	3.64
	Zone 3	54.25	63.87	48.33	3.38
	Zone 4	51.62	61.13	42.80	5.23



Zone 1
Zone 2
Zone 3
Zone 4
N
(a)
Annual ET$_{ref}$ (in)
40-42
43-45
46-48
49-51
52-54
55-57
58-60
61-63
64-66
67-69
70-72
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(b)
Seasonal ET$_{ref}$ (in)
27-28
29-30
31-32
33-34
35-36
37-38
39-40
41-42
43-44
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(c)
January ET$_{ref}$ (in)
< 1
1.01-1.25
1.26-1.5
1.51-1.75
1.76-2
2.01-2.25
2.26-2.5
2.51-2.75
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(d)
February ET$_{ref}$ (in)
< 1.25
1.26-1.5
1.51-1.75
1.76-2
2.01-2.25
2.26-2.5
2.51-2.75
2.76-3
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(e)
March ET$_{ref}$ (in)
< 3
3.01-3.5
3.51-4
4.01-4.5
4.51-5
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(f)
April ET$_{ref}$ (in)
< 4
4.01-4.5
4.51-5
5.01-5.5
5.51-6
6.01-6.5
6.51-7
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(g)
May ET$_{ref}$ (in)
< 3.5
3.51-4
4.01-4.5
4.51-5
5.01-5.5
5.51-6
6.01-6.5
6.51-7
7.01-7.5
7.51-8
County Boundary
Miles
0 20 40 80 120 160
Zone 1
Zone 2
Zone 3
Zone 4
N
(h)
June ET$_{ref}$ (in)
< 6
6.01-6.5
6.51-7
7.01-7.5
7.51-8
8.01-8.5
8.51-9
9.01-9.5
County Boundary
Miles
0 20 40 80 120 160

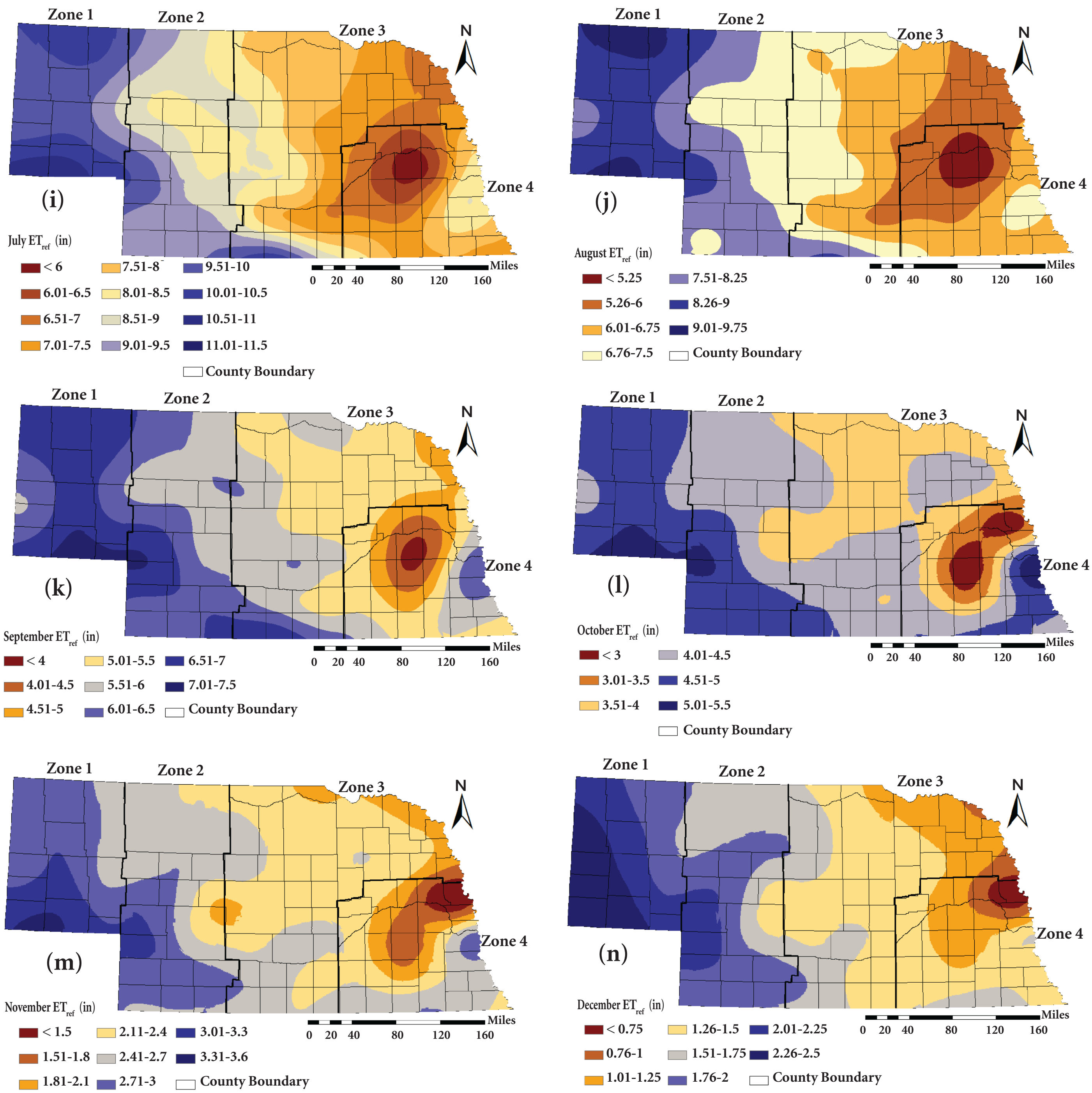


Figure 2. Spatial variation of long-term average (1986-2012) annual (a), seasonal (typical growing season May 1-September 30) (b), January (c), February (d), March (e), April (f), May (g), June (h), July (i), August (j), September (k), October (l), November (m), and December (n) alfalfa-reference (potential) evapotranspiration (ET$_{ref}$, inch) across Nebraska.

statewide scale, the long-term maximum and minimum values of annual ET_{ref} of 69.8 inches and 42.83 inches were observed in Kimball County (Zone 1) and in Seward County (Zone 4), respectively. There was about 39 percent difference in the annual ET_{ref} amounts between the western and eastern parts of the state. The long-term average seasonal values show a similar distribution to annual ET_{ref}, but lower in magnitude (*Figure 2b*). The long-term average seasonal ET_{ref} of 35.4 inches (37 percent of annual ET_{ref}) with maximum of 42.4 inches and minimum of 27.5 inches was observed in Cheyenne and Butler County, respectively. On average, there is about 37 percent difference in seasonal ET_{ref} from the eastern to western part of the state, with an average of 41.5 inches (SD = 1.06 inches), 39 inches (SD = 1.91 inches), 34.5 inches (SD = 1.94 inches), and 32.3 inches (SD = 2.60 inches) in Zone 1, Zone 2, Zone 3, and Zone 4, respectively, which is 36-37 percent of annual ET_{ref} for all Zones.

Table 2 represents the long-term average monthly statewide ET_{ref} statistics across Nebraska. Maximum and minimum monthly ET_{ref} values ranged from 2.4 to 10.5 inches and 0.59 to 6.31 inches, with maximum values being in July and June and minimum values in December. Higher SD values were observed during the growing season (from May to September) and lower in winter months. The maximum SD of 1.1 inches was observed in July and minimum of 0.38 inches was observed in December and February. *Figure 3* represents the long-term average annual and seasonal ET_{ref} values along with SD for each county across Nebraska. During the growing season (May to September) in the southeast (Cass and Otoe Counties) there was a small patch (bull eye) of high ET_{ref} values (*Figures 1* and *2*). A total of seven weather stations located in and around the urban cities (Lincoln and Omaha, Neb., and Rockport, Mo.) were used to calculate the ET_{ref} for that location. Thus, since ET_{ref} values were generally higher for these urban stations than rural areas around the stations, the ET_{ref} values that were interpolated for Cass and Otoe Counties were also high.

Figure 3 also represents the difference in annual and seasonal ET_{ref} across the state. On an average, a difference of 25 inches was observed in the western part (Zone 1) of the state, which reduced to 16.5 inches toward the eastern part of the state (Zone 4). However, for both annual and seasonal ET_{ref} data, higher SD was observed for Zone 4, which gradually decreased towards the western part of the state, indicating a higher degree of spatial pattern in ET_{ref} in eastern Nebraska.

Monthly Distribution of Long-term Average Alfalfa-Reference (Potential) Evapotranspiration (ET_{ref})

Zonal long-term (1986-2012) monthly ET_{ref} values along with zonal SD are presented in *Figure 4*. Each monthly value was calculated by averaging monthly data of 27 years. For example, July ET_{ref} in *Figure 4* is the average ET_{ref} of 27 months of July from 1986 through 2012. The monthly ET_{ref} ranged from 2.18 to 9.97 inches in Zone 1, from 1.84 to 9.03 inches in Zone 2, from 1.36 to 7.79 inches in Zone 3, and from 1.25 to 7.30 inches for Zone 4. In all zones, as well as on a statewide basis, the maximum values were observed in July and minimum values were observed in December. On average, the high and low ET_{ref} values in July and December in Zone 1 is about 27 percent, and 43 percent higher than in Zone 4. However, the lowest difference of 7.5 percent in ET_{ref} was observed in March. Higher ET_{ref} in July corresponds to higher monthly air temperature and solar radiation during July in all zones.

The long-term average statewide monthly maximum air temperature is about 74.6°F, with the maximum observed in Zone 4 (75.9°F), decreasing by 3°F to Zone 1. Long-term average monthly incoming solar radiation (R_s) of 168 W/m^2 was observed statewide with maximum and minimum of 177 W/m^2/day and 162 W/m^2/day in Zone 1 and Zone 4, respectively (*Table 1*). In all zones, the maximum R_s was observed in June and July, and minimum was observed in winter months. For all months, Zone 1 R_s is greater than Zone 4, with a maximum difference of 11.5 percent, which was observed in July. However, in case of wind speed, maximum wind speed was observed in April (9.62 mph) with lowest values being in August (7.12 mph) in all zones. For all months, wind speed in Zone 4 is about 19 percent higher than Zone 1, with a maximum difference of 33 percent which was observed in December, and the minimum of 0.6 percent which was observed in September. On a yearly basis, low relative humidity (RH) was observed in Zone 1 and Zone 2. Relatively high solar radiation and wind speed, and low relative humidity result in high vapor pressure deficit, which is the main driver of high ET_{ref} in Zone 1 as compared with the other zones during the growing season.

The maximum SD of ET_{ref} was observed in Zone 4, with a maximum of 0.03 inch in July and minimum of 0.001 inch in December and January. On average, Zone 4 SD was 44, 36, and 29 percent higher than Zone 1, Zone

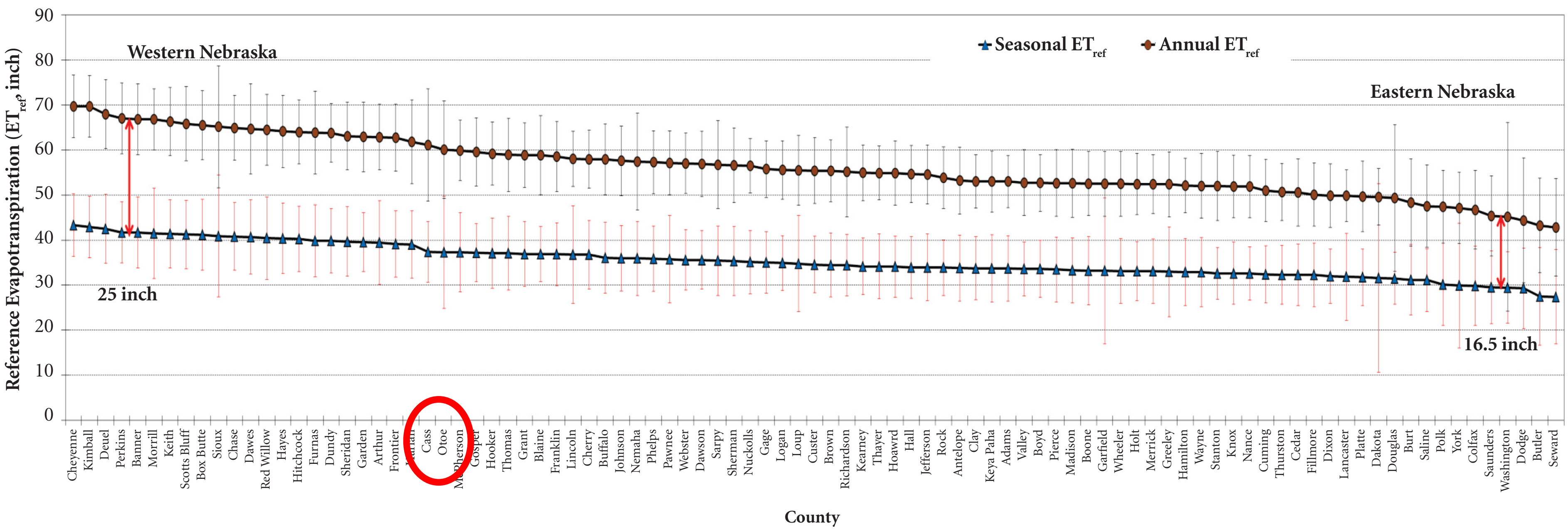


Figure 3. Graphical representation of long-term (1986-2012) average annual and seasonal (May 1-September 30) alfalfa-reference (potential) evapotranspiration (ET_{ref}) values along with standard deviations for all 93 counties across Nebraska.

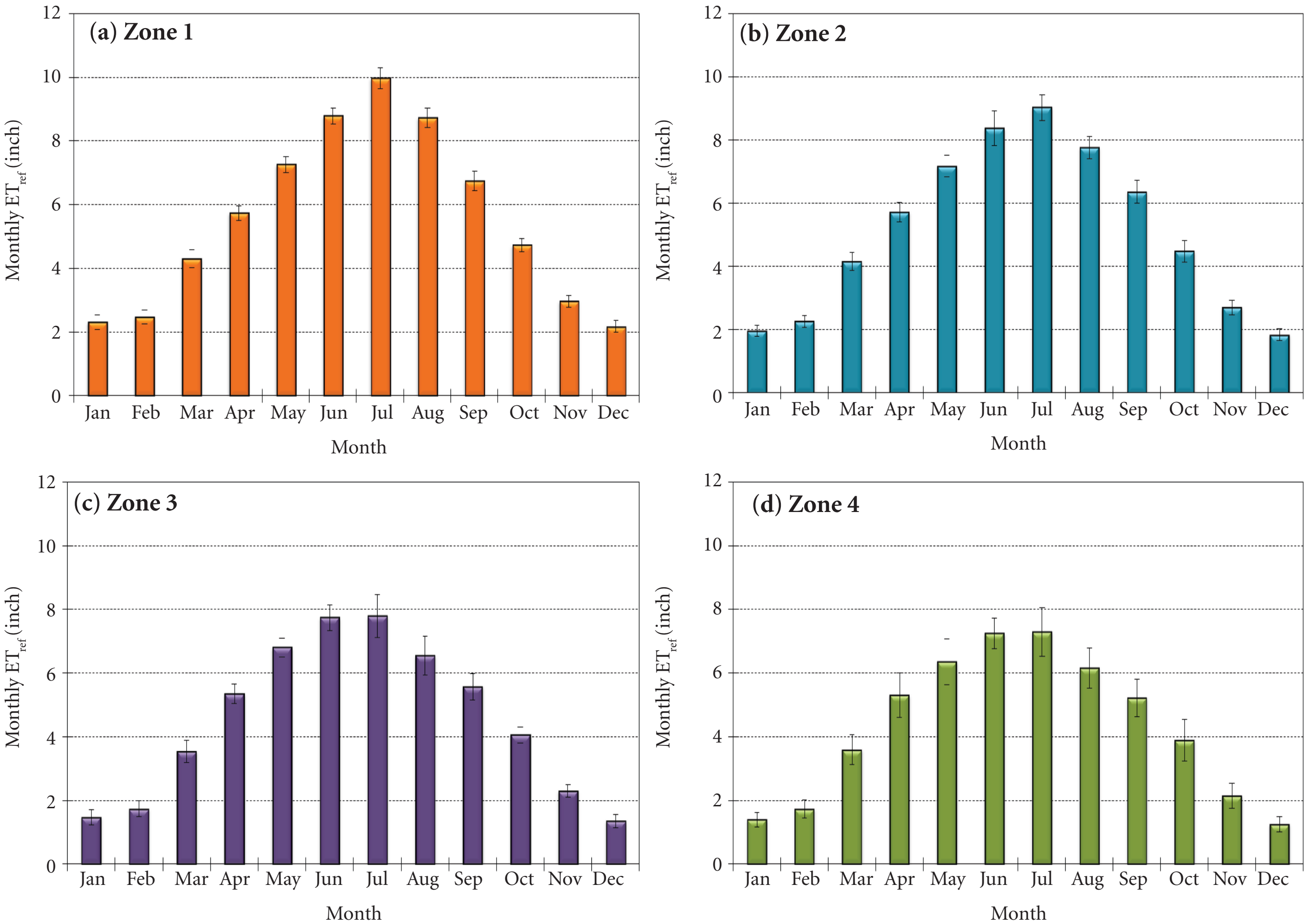


Figure 4. Long-term average monthly alfalfa-reference (potential) evapotranspiration (ET_{ref}) for Zone 1 (a), Zone2 (b), Zone 3 (c), and Zone 4 (d). Each bar represents the average of 27 years (1986-2012) of monthly totals of ET_{ref}. Vertical lines on each bar represent the standard deviation (SD) in each zone for a given month.

2, and Zone 3, respectively. A similar pattern of ET_{ref} was described in the UNL Extension publication *Magnitude and Trends of Reference Evapotranspiration Rates in South Central Nebraska: Daily, Monthly, Growing Season Total, and Annual Total* (EC765), which describes the detailed analysis of ET_{ref} at Clay Center, Nebraska.

Temporal Variation of Annual and Seasonal Total Alfalfa-Reference (Potential) Evapotranspiration

Figure 5 represents the statewide annual and seasonal (May 1 to September 30) ET_{ref} along with SD values from 1986 to 2012. In each figure, a dotted black line represents the long-term average line, and the red line shows the ET_{ref} trend line over the period of 27 years. For both annual and seasonal time steps, a small increasing trend was observed for ET_{ref}, with an overall increase of 3.7 inches for annual and 2.7 inches for growing season periods over the period of 27 years. The maximum of 75.8 inches and 47.1 inches was observed in 2012 for both annual and seasonal ET_{ref}, which is about 27 percent greater than annual and seasonal long-term average values. The increasing trend might be due to high ET_{ref} value in 2012, both annually and seasonally. However, no trend was observed when year 2012 was excluded from the analysis.

The lowest amount of annual and seasonal ET_{ref} was observed in the wettest years, 1993 and 1996, respectively, with a statewide average of 45.5 inches (SD = 8.63 inches) and 26.6 inches (SD = 6.68 inches), which is 19 percent and 24 percent lower than the long-term average value for annual and seasonal, respectively. From 1986 to 2012, there were 13 years (1987, 1988, 1989, 1990, 1999, 2000, 2002, 2003, 2005, 2006, 2010, 2011, and 2012) when the annual ET_{ref} was higher than the long-term average. On the other hand, for seasonal ET_{ref}, there were 14 years, including 1997, when the seasonal ET_{ref} was higher than the long-term average. The maximum SD of 11.83 inches (annual) and 8.69 inches (seasonal) was

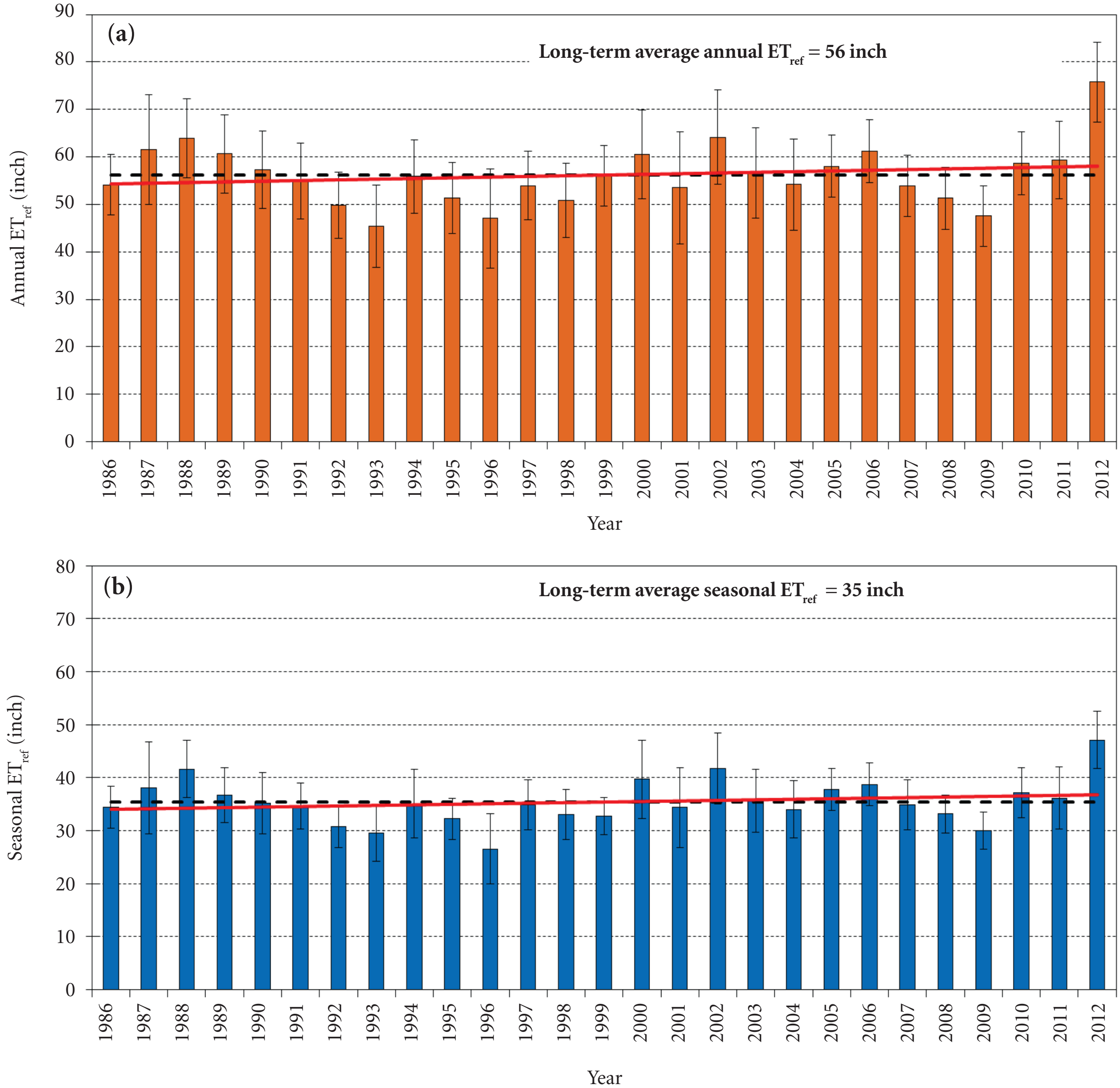


Figure 5. Long-term average statewide annual and seasonal (May 1 to September 30) alfalfa-reference (potential) evapotranspiration (ET$_{ref}$) trend from 1986-2012 across Nebraska. Dotted black and red lines represent the long-term average and ET$_{ref}$ trend from 1986-2012.

observed in 2001 and 1987, respectively, indicating more variation in annual and seasonal ET$_{ref}$ in 2001 and 1987.

Figure 6a-6d and *7a-7d* represent the annual (January 1-December 31) and seasonal (May 1- September 30) ET$_{ref}$ totals from 1986 to 2012 for Zone 1, Zone 2, Zone 3, and Zone 4, respectively. The long-term average annual ET$_{ref}$ of 66.2 inches (range: 84.5 inches in 2012 to 48.2 inches in 2009), 62.1 inches (range: 82.6 inches in 2012 to 48.6 inches in 1993), 54.3 inches (range: 75 inches in 2012 to 41.5 inches in 1993), and 51.6 inches (range: 69.1 inches in 2012 to 42.2 inches in 1996) was observed for Zone 1, Zone 2, Zone 3, and Zone 4, respectively. In all cases, the highest ET$_{ref}$ was observed in 2012 and the lowest was observed 1993 and 1996, which were very wet years in Nebraska. Over the 27-year period, maximum annual ET$_{ref}$ was observed in Zone 1, except in 1998, 2000, 2002, 2003, and 2006, where maximum ET$_{ref}$ was observed in Zone 2. In the 27-year period, there were almost 10 years in Zone 1 and 13 years in Zone 2, Zone 3, and Zone 4 where annual ET$_{ref}$ was greater than long-term average value.

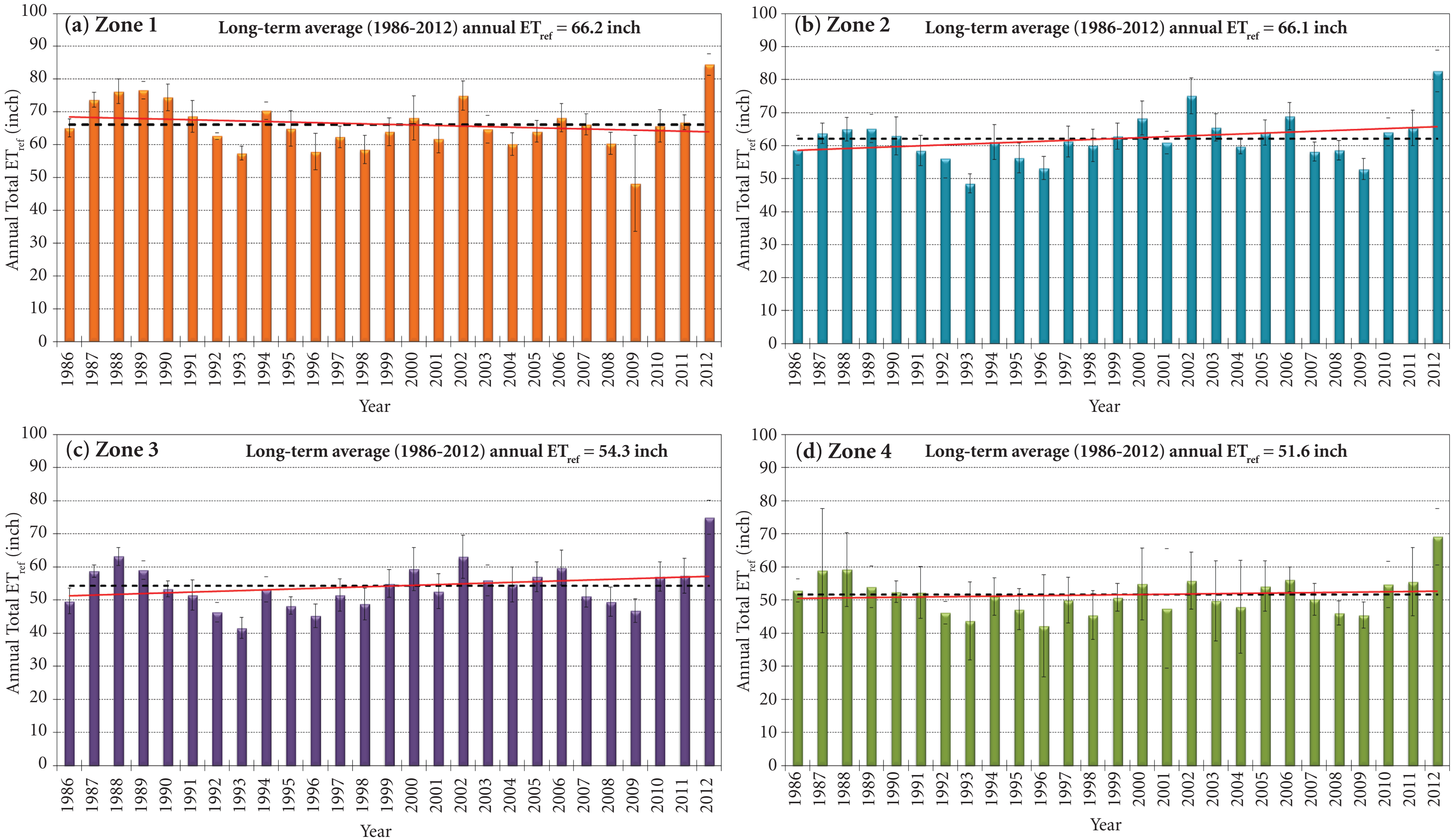


Figure 6. Long-term (1986-2012) average annual alfalfa-reference (potential) evapotranspiration (ET$_{ref}$) trend for Zone 1 (a), Zone 2 (b), Zone 3 (c) and Zone 4 (d). The vertical lines on each bar represent the standard deviation (SD) in annual ET$_{ref}$ in a given year. Dotted black and red lines represent the long-term average and ET$_{ref}$ trend from 1986-2012.

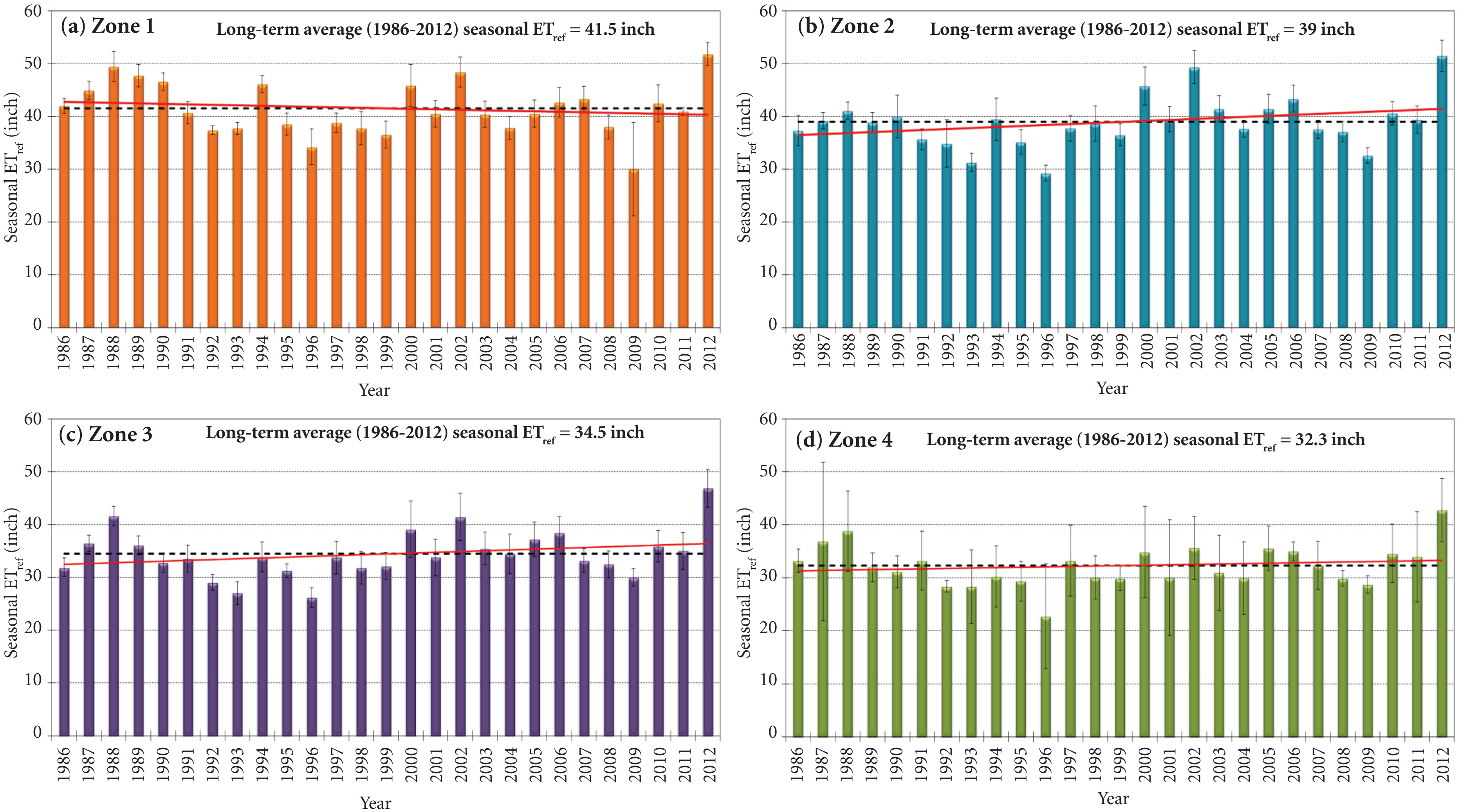


Figure 7. Long-term (1986-2012) average seasonal (growing season: May 1 to September 30) alfalfa-reference (potential) evapotranspiration (ET_{ref}) trend for Zone 1 (a), Zone 2 (b), Zone 3 (c) and Zone 4 (d). The vertical lines on each bar represent the standard deviation (SD) in seasonal ET_{ref} in a given year. Dotted black and red lines represent the long-term average and ET_{ref} trend from 1986-2012.

Temporal trend analysis (red line in *Figure 6*) shows that for all zones, except Zone 1, there is an increasing trend of ET_{ref} with an average increase of 11 percent, 10 percent, and 4 percent in Zone 2, Zone 3, and Zone 4, respectively. However, in Zone 1, there is a gradual decrease in ET_{ref} annual totals from 1986 to 2012, with an average reduction of 7 percent. This decreasing trend might be due to small annual ET_{ref} totals in Zone 1 in recent years. For example, after 2000, the number of years having ET_{ref} more than the long-term average value is four; however, in other zones, after 2000, there are eight years in Zone 2 and seven years in Zone 3 and Zone 4 where annual ET_{ref} is greater than the long-term average value, which might result in an increasing trend in these zones. Maximum SD of 14.67 inches, 6.29 inches, 6.57 inches, and 18.75 inches was observed in 2009, 2012, 2000, and 1987 in Zone 1, Zone 2, Zone 3, and Zone 4, respectively, representing the years with maximum variation in ET_{ref} over 27 years.

Similar to annual total trends, *Figure 7a-7d* represents the temporal variation in seasonal ET_{ref} from 1986 to 2012. The long-term average seasonal ET_{ref} of 41.5 inches (range: 30 to 51.7 inches), 38.94 inches (range: 29.24 to 51.43 inches), 34.45 inches (26.17 to 46.84 inches), and 32.29 inches (22.77 to 42.79 inches) was observed in Zone 1, Zone 2, Zone 3, and Zone 4, respectively. For all years, maximum seasonal ET_{ref} was observed in 2012, which was the record drought year in Nebraska, and minimum was observed in 1996 in all zones. Similar to the annual ET_{ref} trend, Zone 1 represents the decreasing trend (red line in *Figure 6*) in ET_{ref} with a total reduction of 2.6 inches from 1986 to 2012. However, in Zone 2, Zone 3, and Zone 4 an increasing trend in seasonal ET_{ref} was observed with an average increase of 12 percent, 11 percent, and 5 percent, respectively.

Trends for Individual Counties

Figure 8a and *8b* represent the trend analysis of each county. Orange circles in each figure represent the counties with increasing ET_{ref} trends, and blue circles represent the counties with decreasing trends in ET_{ref}. The increasing size of the orange circles represent increasing annual and seasonal ET_{ref} trends, and the increasing size of the blue circles represent the decreasing trend in annual and seasonal ET_{ref}. Both annually and seasonally, about 75 percent Nebraska shows the increasing trend in ET_{ref} from 1986 to 2012. The majority of counties in Zone 2 and Zone 3 are showing an overall increasing trend. The maximum increasing trend was observed in Douglas and Washington Counties with an overall increase of 39 percent from 1986 to 2012. In seasonal trends, the maximum increase of 63 percent was observed in Washington County. The maximum decreasing trend in ET_{ref}, both annually and seasonally, was observed in Zone 4 counties, with maximum reduction of 25 percent and 24 percent in Sioux County, respectively. The high increasing trend might be due to high 2012 ET_{ref} values. However, the same increasing trend, although lower in magnitude, was observed when 2012 was not included in the analysis. For example, from 1986 to 2012, the total increasing trend in Douglas County was 39 percent which reduced to 27 percent when 2012 year was excluded from the analysis.

Summary

Reference (potential) evapotranspiration is often used as one approach to quantify crop water requirements. ET_{ref} can have substantial spatial and temporal distribution due to differences and changes in terrain climatic and microclimatic characteristics as well as elevation across Nebraska. It is important to quantify/monitor the changes in ET_{ref} over time for all locations in a given state so that accurate water resources management decisions specific for each location can be developed and implemented to meet crop water demands under changing climatic conditions. This Extension Circular quantified and mapped monthly, seasonal (typical growing season: May 1 to September 30), and annual ET_{ref} across Nebraska from 1986 to 2012. Some of the key observations are summarized below.

A gradual decrease in ET_{ref} totals from the western to eastern part of the state was observed. The statewide long-term average annual ET_{ref} value was 56.2 inches with significant differences across the state, with average ET_{ref} of 66.2 in Zone 1 (SD = 2.30 inches), 62.1 in Zone 2 (SD = 3.64 inches), 54.30 in Zone 3 (SD = 3.38 inches), and 51.6 inch in Zone 4 (SD = 5.23 inches). On a statewide scale, the long-term maximum and minimum values of annual ET_{ref} of 69.8 inches and 42.83 inches were observed in Kimball County (Zone 1) and in Seward County (Zone 4), respectively. There was about a 39 percent difference in the annual ET_{ref} amounts between the western and eastern parts of the state. On average, there is about a 37 percent difference in seasonal ET_{ref} from eastern to western part of the state.

Maximum and minimum monthly ET_{ref} values ranged from 2.4 inches to 10.5 inches and 0.59 inches to 6.31 inches, with maximum values being in July and June and minimum values in December. Higher SD values were observed in the middle of the year (from May to September) and lower in winter months. The monthly ET_{ref} ranged from 2.18 inches to 9.97 inches in Zone 1, from 1.84 inches to 9.03 inches in Zone 2, from 1.36 inches to 7.79 inches in Zone 3, and from 1.25 inches to

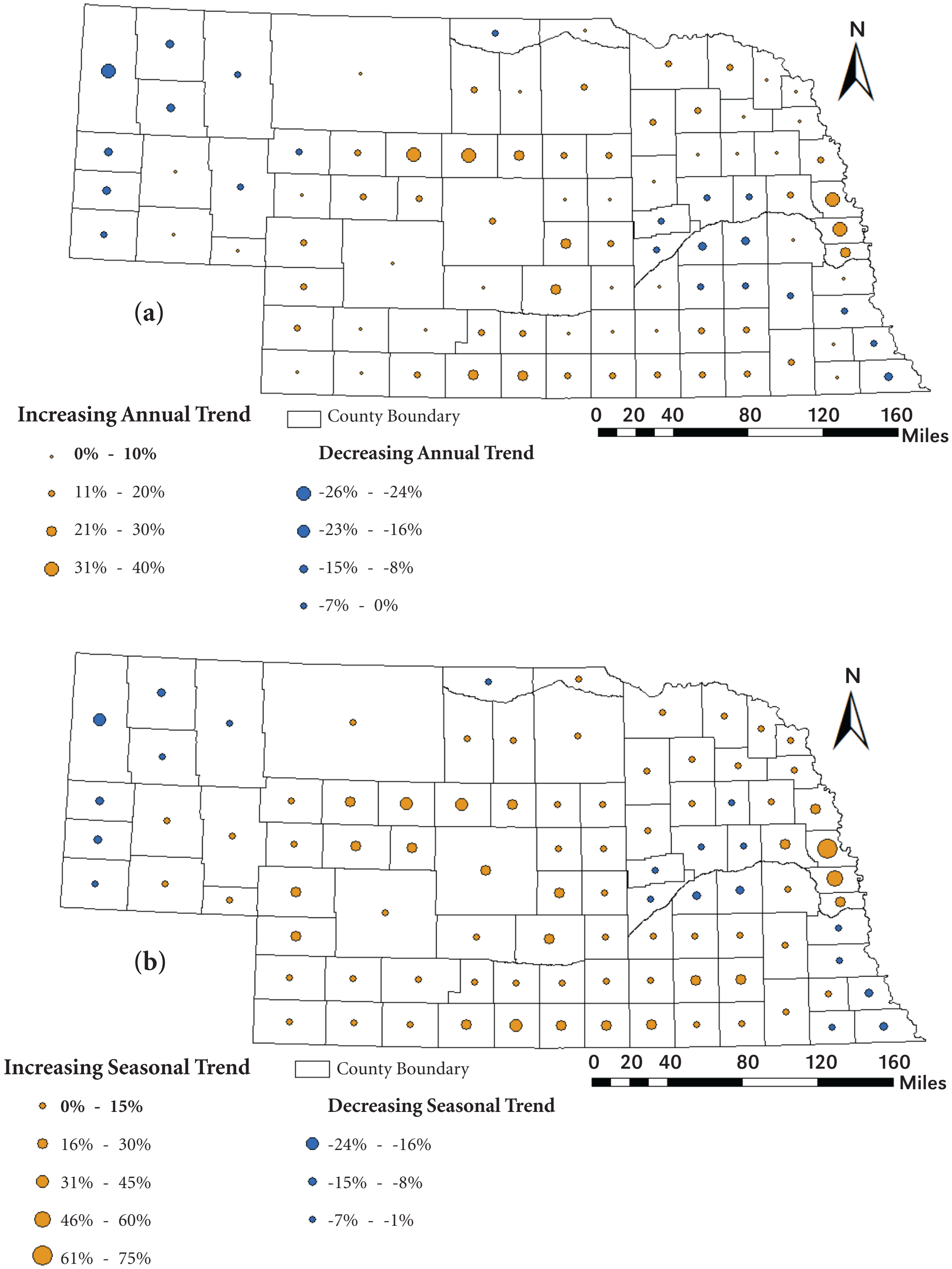


Figure 8. Alfalfa-reference (potential) evapotranspiration (ET_{ref}) annual (a) and seasonal (b) trends from 1986-2012 for all 93 counties across Nebraska. Orange and blue circles in each county represent the increasing and decreasing trend in annual and seasonal ET_{ref} for each county in the state.

7.30 inches for Zone 4. In all Zones, as well as on a statewide basis, the maximum values were observed in July and minimum values were observed in December.

For both annual and seasonal time steps, a small increasing trend was observed statewide for ET_{ref}, with an overall increase of 3.7 inches for annual and 2.7 inches for growing season over the period of 27 years. The lowest amount of annual and seasonal ET_{ref} was observed in the wettest years, 1993 and 1996, respectively, with a statewide average of 45.5 inches (SD = 8.63 inches) and 26.6 inches (SD = 6.68 inches), which is 19 percent and 24 percent lower than long-term average value for annual and seasonal, respectively.

Temporal trend analysis (red line in *Figure 6*) shows that for all Zones except Zone 1 there is an increasing trend of annual ET_{ref} with an average increase of 11 percent, 10 percent, and 4 percent in Zone 2, Zone 3, and Zone 4, respectively. However, in Zone 1, there was a gradual decrease in ET_{ref} annual totals from 1986 to 2012, with an average reduction of 7 percent. Similar to annual ET_{ref} trend, Zone 1 represents the decreasing trend (red line in *Figure 7*) in seasonal ET_{ref} with a total reduction of 2.6 inches from 1986-2012. However, in Zone 2, Zone 3, and Zone 4 an increasing trend in seasonal ET_{ref} was observed with an average increase of 12 percent, 11 percent and 5 percent, respectively. For all years, maximum seasonal ET_{ref} was observed in 2012, which was the record drought year in Nebraska, and a minimum was observed in 2009 and 1996 in all zones.

Both annually and seasonally, about 75 percent Nebraska shows the increasing trend in ET_{ref} from 1986 to 2009. The maximum increasing trend was observed in Douglas and Washington Counties with an overall increase of 39 percent from 1986 to 2012. The maximum decreasing trend in ET_{ref}, both annually and seasonally, was observed in Zone 4 counties, with maximum reduction of 25 percent and 24 percent in Sioux County, respectively. These datasets and information can be useful when developing spatial and temporal water resources and related management strategies for specific locations.

Resources

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This publication has been peer reviewed.