Article

Changes of Reference Evapotranspiration and Its Relationships to Dry/Wet Conditions Based on Aridity Index in Songnen Grassland, Northeast China

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Abstract: Reference evapotranspiration (ET_0) plays an irreplaceable role in regional dry/wet conditions under the background of climate change. Based on the FAO Penman-Monteith method and daily climate variables, ET_0 was calculated for 22 stations in and around Songnen Grassland, northeast China, during 1960-2014. The temporal and spatial variations of ET_0 and precipitation (P) were comprehensively analyzed at different time scales by using the Mann-Kendall test, Sen's slope estimator, and linear regression coupling with break trend analysis. Sensitivity analysis was used to detect the key climate parameter attributed to ET_0 change. Then, the role of ET_0 in regional dry/wet conditions was discussed by analyzing the relationship between ET_0, P and aridity index (AI). Results shown a higher ET_0 in the southwest and a lower in the northeast, but P was opposite to that of ET_0. Evidently decreasing trend of ET_0 at different time scales was detected in almost the entire region, and the significant trend mainly distributed in the eastern, northeastern and central. For the whole region, sensitivity analysis indicated decreasing trend of ET_0 was primarily attributed to relative humidity and maximum air temperature. The positive contribution of increasing temperature rising to ET_0 was offset by the effect of significantly decreasing relative humidity, wind speed and sunshine duration. In addition, the value of ET_0 shown higher in drought years and lower in wet years.

Keywords: reference evapotranspiration; climatic change; drought/wet; Songnen Grassland

1. Introduction

Climate change becomes an indisputable fact, and it may accelerate hydrological cycle and redistribute global water resources [1]. Researches on climate change were identified not only in isolated temperature or precipitation, but also on integrated parameters [2], like reference evapotranspiration (ET_0). *ET_0* is one of the vital components of hydrological cycle and controls energy and mass exchange between terrestrial ecosystems and atmosphere [2, 3], influenced by many factors including climate factors, crop factors, environmental conditions and management [4]. Changes in ET_0 would affect agricultural production, water resource programming and irrigation scheme. Under present global warming and climate change conditions, to identify the spatial and temporal variation and to determine the dominant climatic variables affecting ET_0 trends are significant for revealing the impacts of climate change on hydrologic cycle. In addition, it can be helpful in determining appropriate adaptation measures for mitigating the potential damage from climate change bad effects

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[5-7]. However, relationship between changing ET_0 and dry/wet tendency is not quite clear yet, but it is crucial for water resource management.

Studies that investigate changes in climate factors have yielded mixture of results and conclusions about the trends of ET_0 for specific locations during last decades. Contrary to the general expectations that increase in temperature would lead to an increase in evapotranspiration, some previous studies concluded that evaporation have diminished in the last decades [2]. In the upper and mid-lower Yangtze River basin, Wang, et al. [1] reported decreasing trend in ET_0 during 1961-2000 based on daily data of 115 meteorological stations. Irmak, et al. [8] found over 116-year period there was a significant decreasing in ET_0 in the Platter river basin, USA. The same decline trends also found in other regions throughout the world such as Canadian, New Zealand and India [9-11]. ET_0 has identified an increasing trend in some regions for the same period, however, such as Iran, Northern Eurasia, and parts of Romania [12-14].

Being a typical farming-pastoral ecotone, located in the central part of northeast China, Songnen Grassland have experienced highly spatial and temporal variability in ET_0 and precipitation. This makes the management of water resources difficult in the region. However, to the best of our knowledge, there was no comprehensive study of the relationships between changes in ET_0 and dry/wet conditions has been done, and especially, the sensitivity of ET_0 to climatic variables has not been done in this region. Water is the lifeline for the socioeconomic development of Songnen Grassland, because agriculture and animal husbandry, which heavily depend on precipitation and irrigation, are the pillar industry in the area. Therefore, understanding ET_0 trend and its role in regional dry/wet conditions are important to address water shortage in this region and give a scientific basis for regional water resources management.

In this case, the objectives of this study were (1) to evaluate spatial distribution of the ET_0 and precipitation at different time scales in Songnen Grassland over the period of 1960-2014; (2) to investigate temporal variability of ET_0 by using the Mann-Kendall test and liner regression coupling with break trend analysis and the slopes of trend lines using the Sen's slope estimator; (3) to analyze temporal trends of the climatic parameters needed to calculate ET_0, and the sensitivity and its trends of ET_0 to the climatic parameters by sensitivity analysis method; (4) to explore the role of changing ET_0 in regional drying or wetting conditions based on AI index. Results of this study will improve our understanding the impact of climate change on hydrological process and agriculture irrigation management.

2. Materials and Methods

2.1. Study area

Songnen Grassland is located in central northeast China. It lies from 43°30′ N to 48°05′ N and from 122°12′ E to 126°20′ E, and covers an area of approximately 22,350,000 km^2 (Fig. 1). Generally, it is distributed in the meadow steppe belt of China and is the important grassland in Eurasian steppe zone. The region is more dominated by temperate continental monsoon climate, with four distinct seasons: quite dry, windy springs, warm, rainy summers, sunny, mild autumns, and often long, freezing and dry winters. Mean annual temperature ranges from 1.9 °C in the southwest to 6.2 °C in the northeast region, while the mean annual precipitation amount varies from 350 mm in the southwest to 500 mm in the northeast region. Meanwhile, the mean annual amount of evaporation is roughly two or three times than precipitation.

Songnen Grassland forms a typically agricultural area at the east and an agro-pastoral transition zone at the west region, determined by various physical geographical features and regional climatic differences. The current ecological environment tend to be deteriorated due to the recent and ongoing climate change and land use change in the region. Since the agriculture and animal husbandry development are the main priorities within the general economic strategy of the region, investigation on changes in ET_0 and its role in regional dry/wet conditions are needed for agriculture managers and stakeholders.

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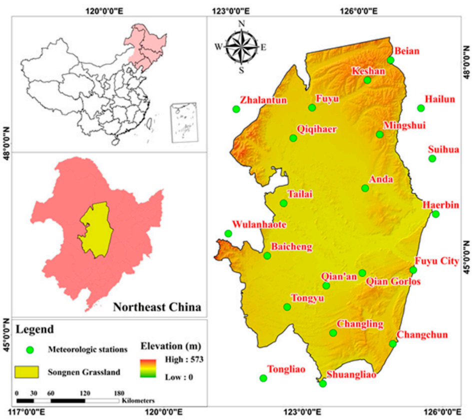

Figure 1. Location of Songnen Grassland in China and meteorological stations considered.

2.2. Climate data and quality control

Climate data from 21 meteorological observatory stations is provided by the National Meteorological Information Centre of China, including daily observations of maximum air temperature (Max T, °C), minimum air temperature (Min T, °C), average air temperature (Ave T, °C), average relative humidity (Ave RH, %), wind speed (Win S, m/s), sunshine duration (Sun H, h) and precipitation (P, mm), for the period of 1960-2014. Regional of seasonal, growing season of vegetation (from April to October) and annual values of these climatic variables are then calculated by the weighted average or sum method. The weight of every station is obtained by Thiessen polygon method which assigns weight in proportion to the study area that is closest to that station. Thermic seasons are considered as winter that contains December, January and February; spring: March, April and May; summer: June, July and August; and autumn: September, October and November.

The chosen meteorological stations are showed in Figure 1. They are all distributed inside or adjacent the study area in order to cover the entire region. All selected stations have good-quality data and meet the QA/QC requirements, and the missing data was substituted with the corresponding long-term mean value.

2.3. Methods

2.3.1. Calculation of Reference Evapotranspiration (ET_0)

The FAO-56 Penman-Monteith (FAO-PM) equation was recommended as the sole and global standard method for ET_0 calculation [4, 15]. The method had been widely verified its accuracy and reliability under various climatologic zones around the world [16-18]. Accordingly, the FAO-PM method was used to estimate daily ET_0 in this study, and subsequently seasonal, growing season and annual ET_0 values were derived from daily values. The FAO-PM equation was expressed as:

$$ET_0 = \frac{0.408\Delta\left(R_n - G\right) + \gamma \frac{900}{\left(T+273\right)} U_2 \left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34U_2\right)} \tag{1}$$

where ET_0 is reference evapotranspiration (mm/d), Δ is the slope of the saturation vapour pressure curve at a given air temperature (kPa/°C), R_n is the net radiation at the crop surface (MJ/(m²•d)), G is the soil heat flux density (MJ/(m²•d)), γ is the psychrometric constant (kPa/°C), T is the mean daily air temperature at 2 m height (°C), U_2 is wind speed at 2 m height (m/s), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), and $(e_s - e_a)$ is the saturation vapour pressure deficit (kPa).

R_n is the difference between the incoming net shortwave radiation (R_{ns}) and the net outgoing longwave (R_{nl}). R_{ns} is calculated as

$$R_{ns} = \left(1 - \lambda\right) R_s \tag{2}$$

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where R_s is the incoming solar radiation (MJ/(m²•d)) and λ (=0.23) is the albedo of the hypothetical grass reference crop (dimensionless). And it was estimated based on sunshine duration record according to the calibration equation by Croitoru, et al. [2]. At the same time, R_{nl} is given by

$$R_{nl} = \sigma\left[\frac{T_{\max,K}{}^{4} + T_{\min,K}{}^{4}}{2}\right]\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad (3)$$

where σ is Stefan–Boltzmann constant (=4.903×10⁹ MJ/(K⁴•m²•d)); $T_{max,K}$ is the maximum absolute temperature during the 24-h period (K=°C+273.16); $T_{min,K}$ is the minimum absolute temperature during the 24-h period (K=°C+273.16); and, R_{so} is the clear - sky radiation (MJ/(m²•d)). All the variables in Eq. (1) were calculated using the standard procedure outlined by Allen, et al. [15]. Calculation of ET_0 was based on CROPWAT 8.0 software developed by FAO during 1960-2014.

2.3.2. Trend analysis

To calculate trends, six data sets including one annual, four seasonal and one growing season were conducted for each meteorological station. In this study, the Mann-Kendall (MK) test, a non-parametric test, recommended by the World Meteorological Organization, was used to detect trends [19, 20]. The MK test had been widely used for trend detecting in hydrologic and climatic research owing to it does not need to conform any distribution form for the data and can allow the missing data [21-23]. Besides, Sen's slope estimator was used to measure the magnitude of the trend [24]. The MK test and Sen's slope estimator calculations for various time series of SPI and ET_0 were performed using the Excel-based template MAKESENS 2.0 beta, developed by researchers of Finnish Meteorological Institute [17].

2.3.3. Sensitivity analysis

Sensitivity analysis was a quantitative description method of the important degree of input variables to the output [25]. In present study, it was performed to evaluate the effect of climatic variables on ET_0. Because of the different approaches used in conducting ET_0, there were no standard or common procedure for carrying out the sensitivity analyses on ET_0 [16, 26]. This study applied the sensitivity analysis method which has the advantages of simple procedures and clear outcome was developed from Li and T J [27]. The measure S_x is the sensitivity of the FAO-PM method to a meteorological parameter, defined as:

$$S_{xij} = \left|\frac{ET_0\langle 1.1xij\rangle - ET_0\langle 0.9xij\rangle}{ET_0\langle xij\rangle}\right| \quad (4)$$

where x_i is one of a meteorological parameters needed calculation of ET_0, j is the parameter at year, and xij, $\langle 1.1x_{ij}\rangle$ and $\langle 0.9x_{ij}\rangle$ are the estimated ET_0 when the parameter x_i equals its reference value or is $1.1x_{ij}$ and $0.9x_{ij}$ at j year, respectively.

2.3.4. Aridity index (AI index)

Aridity was usually expressed as a comprehensive function of precipitation, temperature, and/or potential evapotranspiration, and reflects the level of meteorological drought [28]. There are many AI indexes have been proposed. Among these indexes, following Thornthwaite [29] and Huo, et al. [3] defined the AI index as the ratio of difference between P and ET_0 to ET_0. The definition can express the arid degree in any arid or semiarid region, and can be understood as the dearth of water availability at the surface and subsurface levels.

In this study, based on the previous study, the AI value was calculated as:

$$AI = \left(ET_0 - P\right)/ET_0 \quad (5)$$

where ET_0 is reference evapotranspiration, and P is precipitation. If AI be equal to or close to 1, it indicate that there is no precipitation and aridity in the highest. In contrast, if the precipitation be equal to or higher than ET_0, the AI will be equal to 0 or be negative. The AI values of growing season

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at each station were calculated, and the average AI in the whole Songnen Grassland was expressed by the arithmetic average from stations in and around the region.

2.3.5. Spatial interpolation

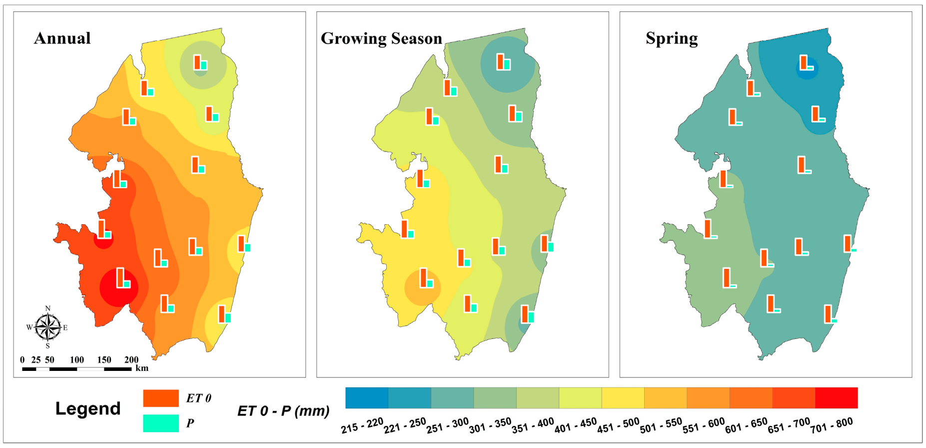
For analyzing of spatial patterns of trends and its magnitudes, the method of IDW was used to the whole region. This method was a simple deterministic interpolation, which was extensively used for mapping the spatial extent of climatic and hydrological point data [30]. All the procedures were made using ArcGIS 10.2 software.

3. Results

3.1. Spatial distribution of ET_0, P and their difference over the period 1960-2014

The spatial distributions of ET_0 and P at annual, seasonal and growing season from 1960 to 2014 were shown in Fig. 2, and their difference was displayed using the IDW interpolation as well. Fig.2 shows strong variability and marked difference between the northeastern ranges and the southwestern region. From the visual inspection, it was observed that the spatial pattern of high and low values of annual ET_0, P and the difference all shows similarities to other time scales. The spatial pattern of ET_0 and the difference indicated higher values corresponding to the southwest and lower values was distributed in the northeast areas, but precipitation was opposite, which the minimum value was in western and the highest value was in eastern. Generally, ET_0 value was more than double the precipitation amounts at all of the time scales considered, especially during annual and growing season.

For ET_0, the average of annual and growing season increased from northeast to southwest from less than 850 and 750 mm respectively, to more than 1100 and 980mm respectively. And seasonally, it presented that all of stations showed higher ET_0 in summer, followed by spring, autumn and winter. For P, the value of annual and growing season increased from western to eastern, ranges from 381 to 577 mm and from 352 to 511 mm respectively, and both the minimum was found in Tongyu and the maximum was in Changchun. Seasonally, higher the amount of precipitation was exhibited during summer, followed by autumn, spring and winter. For their difference, the maximum was distributed in the southwest at every time scales (Fig.2), especially at annual, that the difference has reached 700-800 mm in southwestern region. From seasonal perspective, the spring was experienced the maximum value of the difference ranged from 215 to 350 mm, followed by summer, autumn and winter.



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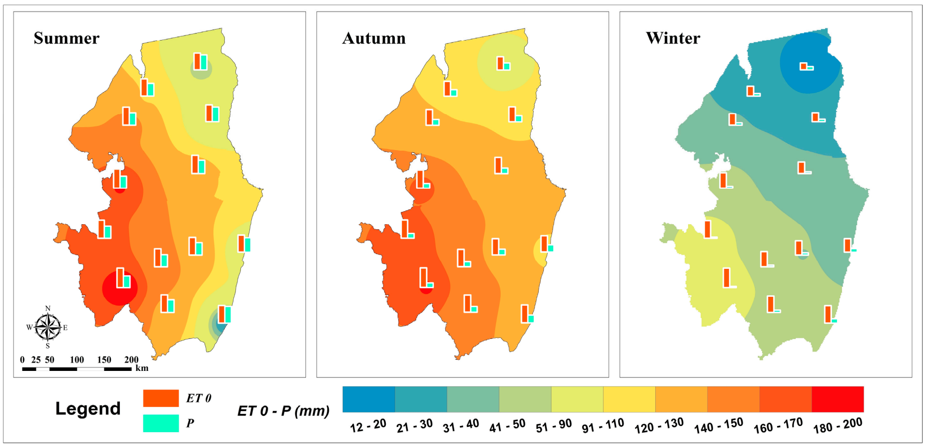


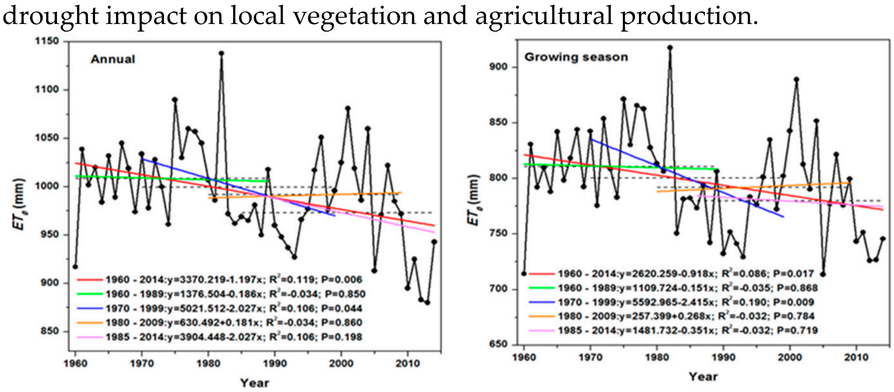
Figure 2. Spatial distribution of ET_0, P and their difference for the period 1960-2014.

3.2. Temporal variations of ET_0

To calculate temporal trends of ET_0 for different time scales, the linear regression coupling with break trend analysis as well as the MK test and the Sen's slope estimator were applied for the period 1960-2014. The period of break trend analysis was chosen every 30 years, which was considered as the climatological normal according to the recommendation of WMO [31]. In this paper, the climatological normal ranged from 1960 to 1989, from 1970 to 1999, from 1980 to 2009 and from 1985 to 2014, respectively. The values of the linear regression coupling with break trend analysis at 21 were shown in Fig. 3, and those of the MK test and Sen's slope estimator were shown in Table 1.

Fig. 3 indicated an evidently decreasing trend in ET_0 at every time scales, especially in annual, growing season and spring which all had passed the significance test at the 0.05 level. Besides, it was shown that almost all considered time scales had experienced decreasing trend of ET_0 at every climatological normal with a rate ranging from -2.415 to -0.003 mm/a. The dropping at the sharpest rate was detected from 1970 and 1999, and the maximum was in growing season (-2.415 mm/a). However, it was noteworthy that the region was experienced an increasing trend of ET_0 in all time scales during 1980-2009, with a rate ranging from 0.085 to 0.296 mm/a, except in spring and winter, although the increasing trend was not significant.

The results of trend analysis were almost identical with the nonparametric methods exhibited in Table 1. It was showed that ET_0 had a decreasing trend in different time scales at the 21 stations inside and around the region. More than 90 % for the total number of analyzed stations at every time scales were reported decreasing trends except during autumn, and among them 50 % were statistically significant during annual, growing season and spring. Increasing trends were found in less than 10 % of data sets, especially during autumn of approximately 38 %, but none of them were significant. In terms of magnitude of the trend, the highest decrease of ET_0 was recorded in Haerbin (around the region) and Fuyu City (inside the region) at annual, with an average decrease rate of -4.45 and -2.86mm/a, respectively. On the basis of this results, there is no doubt that Songnen Grassland experienced an evidently decrease of ET_0 in the last 55 years. The variations of ET_0 rates may mitigate drought impact on local vegetation and agricultural production.



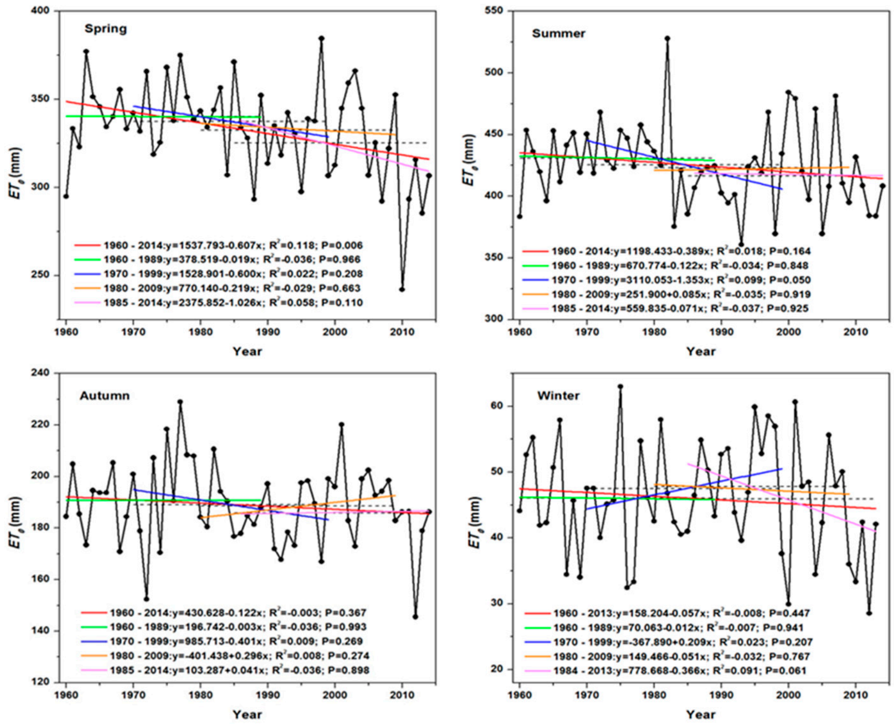


Figure 3. Linear trend and break trend analysis (for every 30 years) of ET_0 from 1960 to 2014.

Table 1. Results of the MK test and Sen's slope estimator for ET_0 at different time scales.

Station	Annual		Growing season		Spring		Summer		Autumn		Winter	
	Z	β	Z	β	Z	β	Z	β	Z	β	Z	β
Keshan[a]	-2.19*	-1.11	-1.89	-0.78	-2.37*	-0.65	-1.52	-0.38	-0.86	-0.11	-1.89	-0.08
Fuyu[a]	-1.47	-0.86	-1.15	-0.61	-1.48	-0.49	-0.94	-0.35	-0.44	-0.10	-0.66	-0.05
Qiqihaer[a]	-0.83	-0.41	-0.52	-0.30	-1.28	-0.35	-0.83	-0.27	0.60	0.10	-0.39	-0.04
Mingshui[a]	-2.82*	-2.01	-2.82*	-1.65	-2.52*	-0.83	-1.90	-0.74	-1.21	-0.20	-0.66	-0.04
Tailai[a]	-2.77*	-1.77	-2.19*	-1.14	-2.48*	-0.74	-1.45	-0.58	-1.73	-0.24	-1.22	-0.13
Anda[a]	-4.30*	-2.70	-4.17*	-2.23	-2.89*	-0.87	-3.22*	-1.25	-2.69*	-0.46	-1.42	-0.11
Baicheng[a]	-2.61*	-1.71	-2.24*	-1.29	-2.13*	-0.58	-2.08*	-0.66	-0.28	-0.06	-0.54	-0.03
Qian'an[a]	-3.27*	-1.50	-2.94*	-1.19	-2.86*	-0.67	-1.95	-0.56	-0.16	-0.02	-0.45	-0.04
QianGorlos[a]	-2.26*	-0.95	-2.27*	-0.83	-1.87	-0.42	-1.33	-0.38	-0.23	-0.04	0.32	0.03
Tongyu[a]	0.09	0.05	-0.12	-0.05	-0.65	-0.17	0.38	0.10	1.47	0.22	0.34	0.04
Changling[a]	-0.83	-0.40	-1.05	-0.41	-1.21	-0.22	-0.83	-0.23	1.81	0.26	-0.53	-0.08
FuyuCity[a]	-4.98*	-2.86	-4.52*	-2.33	-3.52*	-1.12	-3.51*	-1.21	-2.19*	-0.43	-1.58	-0.15
Changchun[a]	-0.74	-0.40	-0.68	-0.37	-2.04*	-0.60	-0.06	-0.03	1.02	0.17	-0.15	-0.01
Zhalantun[b]	-0.44	-0.14	0.29	0.15	-1.31	-0.30	0.83	0.18	-0.58	-0.10	-0.90	-0.07
Wulanhaote[b]	-1.71	-0.83	-1.23	-0.62	-2.24*	-0.70	-0.29	-0.10	0.12	0.02	-0.56	-0.05
Tongliao[b]	0.83	0.66	0.00	0.00	-0.83	-0.26	-0.16	-0.05	1.93	0.39	0.89	0.15
Beian[b]	-1.03	-0.40	-0.63	-0.24	-1.64	-0.33	-0.38	-0.08	0.04	0.01	-1.01	-0.04
Hailun[b]	-0.89	-0.53	-1.12	-0.58	-1.33	-0.39	-0.95	-0.29	0.41	0.08	-0.37	-0.02
Suihua[b]	-2.50*	-1.47	-2.69*	-1.30	-2.47*	-0.79	-1.78	-0.59	-1.00	-0.20	-0.61	-0.02
Haerbin[b]	-5.36*	-4.45	-5.11*	-3.39	-4.59*	-1.64	-3.48*	-1.50	-4.68*	-1.04	-1.72	-0.19
Shuangliao[b]	-2.86*	-1.91	-2.82*	-1.54	-2.19*	-0.52	-2.89*	-0.89	-2.03*	-0.32	-0.89	-0.13

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Region[a]	-2.23*	-1.28	-2.04*	-1.01	-2.10*	-0.59	-1.48	-0.50	-0.37	-0.07	-0.68	-0.05
Region[b]	-1.74	-1.13	-1.66	-0.94	-2.07*	-0.62	-1.14	-0.41	-0.73	-0.14	-0.65	-0.05
Region[a,b]	-2.83*	-1.32	-2.57*	-1.04	-2.41*	-0.59	-1.77	-0.53	-0.65	-0.10	-0.45	-0.06

The Z value of more than 1.96 represent significant upward trend, while values less than -1.96 show a decreasing trend at $\alpha < 0.05$. a represents station in Songnen Grassland; b represents station around Songnen Grassland; a,b represents station in and around Songnen Grassland; * represents significant trend at the 0.05 level.

3.3. Spatial variations of ET_0

The spatial variations of ET_0 at different time scales from 1960 to 2014 were displayed in Fig. 4. All considered time scales had experienced similar changing pattern, which presented a majority of time series of ET_0 have witnessed downward trends in the whole region, except during autumn. The most stations with significant decreasing trend of ET_0 were mainly distributed in the eastern, northeastern and central region frequently occurred at annual, spring and growing season. These region were distributed the highest decrease rate of ET_0 ranged from -0.2 to -4.0 mm/a as well. However, the positive changes were mainly recorded in the southwestern and southern regions at autumn and winter, but they were statistically insignificant with the increasing rate ranging from 0.01 to 0.40 mm/a (Table 1). Overall, the spatial changing pattern of ET_0 in Songnen Grassland is that a significant downward trend across the central part region with a gradually reduced intensity from the eastern parts to the western areas.

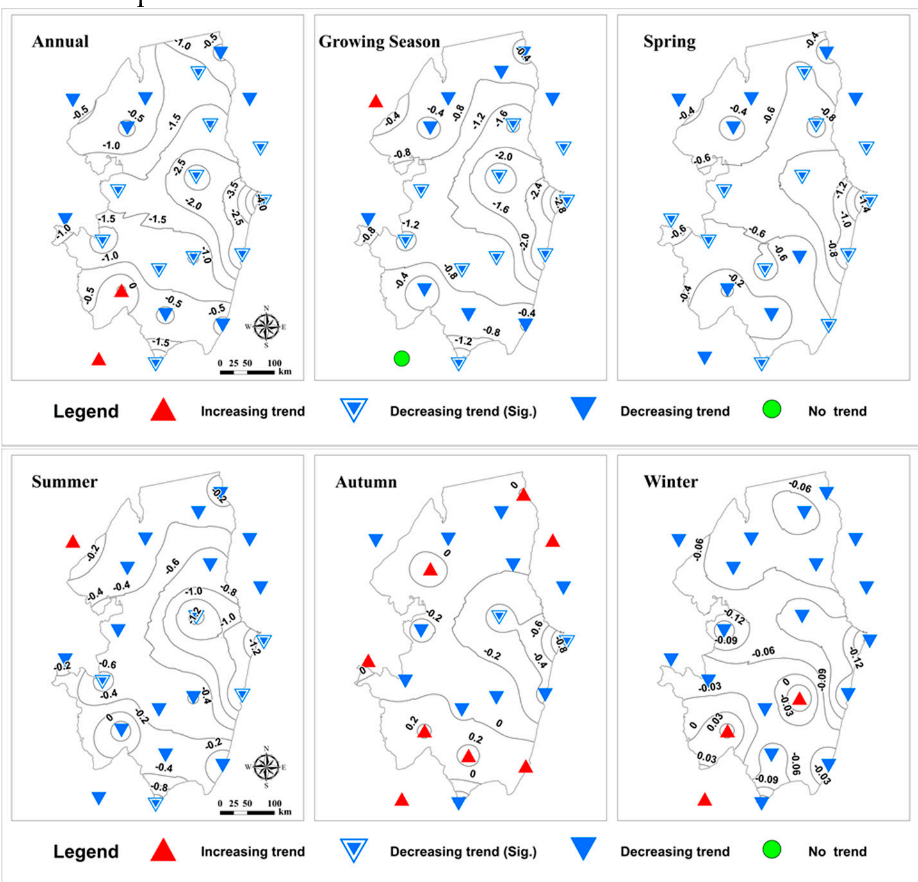

Figure 4. Spatial distribution of trends and its magnitude in ET_0 over the period 1960-2014.

3.4. Changes in the climatic parameters

The changes in basic climatic parameters that played a considerable role in ET_0 change have been investigated on 21 stations across Songnen Grassland during 1960-2014. With the increase of air temperature (Ave T, Max T and Min T), region averaged annual of Ave RH, Sun H and Win S all significantly decreased during the study period (Fig. 5). All the climatic parameters experienced

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consonant changes at every climatological normal. All the increase trends of Ave T, Max T and Min T and the decrease trends of Sun H and Win S had passed the significance test at 0.01 level, while the Ave RH had passed the significance test at 0.05 level.

The MK test, then, was used for detecting the statistical significant trend at 21 stations in various time scales, and the results were shown in Fig. 6. The percentage value of the statistical significant increasing (α = 0.05) was 100 % for Ave T and Min T at all considered time scales, except during winter 95 % in Min T and more than 70 % in Ave T. In the case of Sun H, all of the series illustrated downward trends, especially at annual, among them between 52 % and 71 % were statistically significant. As for Win S, significant decreasing trends were found in roughly 100 % at all the analyzed locations. For Ave RH, an overwhelming majority of data series have seen negative trends, but in spring the positive trends were detected more than 50 %.

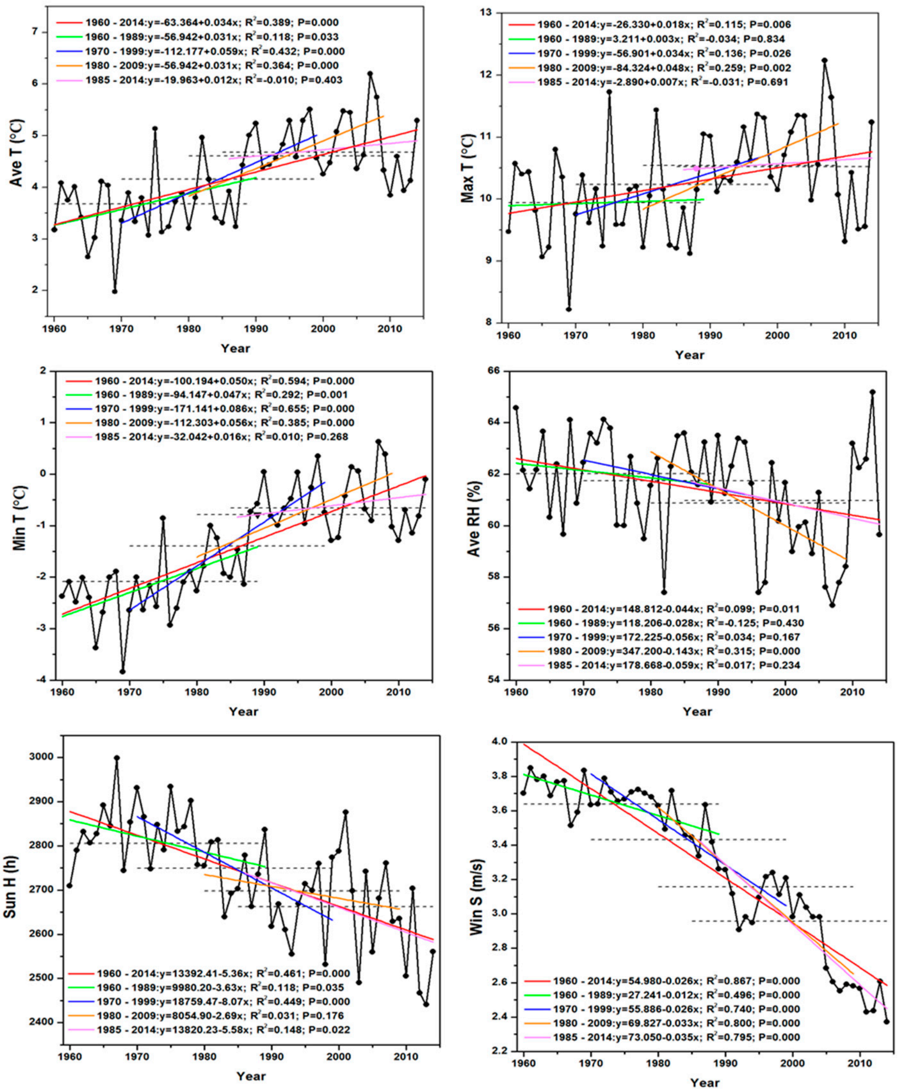

Figure 5. Linear trend and break trend analysis (for every 30 years) of climatic parameters from 1960 to 2014.

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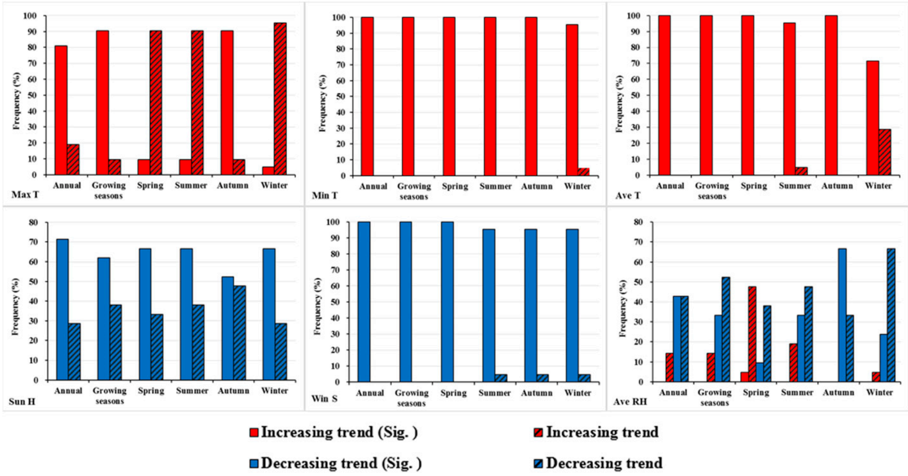

Figure 6. Frequency of climatic parameters trends in Songnen Grassland over the period 1960-2014 (%).

3.5. Attribution of climatic variables

Results of the sensitivity analysis for annual ET_0 to the climatic variables were performed in Fig. 7 and Table 2 for the 13 stations (inside the Songnen Grassland). It can be seen from Fig. 7 that the Ave RH and Max T were the most sensitive variables in change of ET_0 over the whole region, followed by Win S, Sun H, Min T and Ave T. However, there was a little difference in the northeast region at Keshan and Mingshui stations, mainly because there have a higher elevation and distributed small hills. The most sensitive climatic variables at this two stations was Ave T and Min T, respectively. The summary of dominant climatic variables and the temporal trends of their sensitivities were given in Table 2. Results indicated that Ave RH shown a significant decreasing trend except in Anda station which shown a significant increasing trend, and trend of Max T was the same as Ave RH that experienced significant downward trend at almost the whole region besides significant upward trends in Changchun. For Win S and Min T, a majority of stations witnessed a significant increasing trend. The Sun H shown the same temporal trend with Win S and Min T, but in the southwest region, Tongyu and Changling, shown no significant decreasing trend. As for the Ave T, results shown it had slight impact on changing ET_0 in Songnen Grassland, expect in Keshan. In short, the sensitivity of Ave RH, Max T, Ave T and Min T experienced a significant decreasing trends, whereas that of Win S and Sun H shown a significant increasing trends in the whole region.

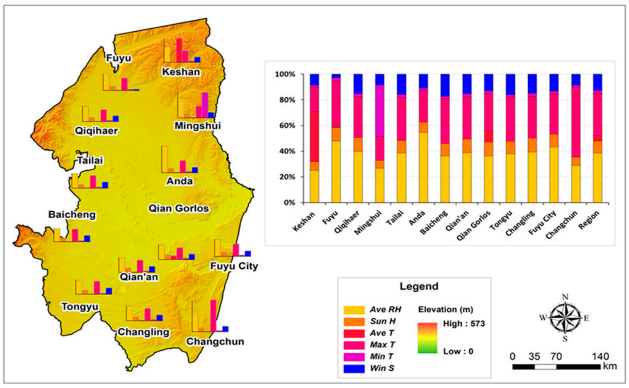

Figure 7. Spatial distribution of average sensitivity in annual comparison of various climatic variables.

Table 2. Summary of dominant climatic variables that caused changes in ET_0 at the inside stations.

Station	Order and trend of importance for the climatic variables in ET_0											
Keshan[a]	*Ave T*	-5.55*	*Ave RH*	-3.54*	*Max T*	-3.59*	*Win S*	-0.81	*Sun H*	3.85*	*Min T*	0.94
Fuyu[a]	*Ave RH*	-2.38*	*Max T*	-3.17*	*Sun H*	2.06*	*Min T*	1.56	*Win S*	0.07	*Ave T*	1.10

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Qiqihaer[a]	*Ave RH*	-4.56*	*Max T*	-4.15*	*Win S*	1.31	*Sun H*	2.06*	*Min T*	4.24*	*Ave T*	0.00
Mingshui[a]	*Min T*	-6.90*	*Ave RH*	-3.96*	*Max T*	-4.85*	*Win S*	0.64	*Sun H*	1.51	*Ave T*	0.00
Tailai[a]	*Ave RH*	-3.89*	*Max T*	-3.12*	*Win S*	4.02*	*Sun H*	1.29	*Min T*	3.66*	*Ave T*	0.00
Anda[a]	*Ave RH*	2.83*	*Max T*	-3.56*	*Win S*	0.20	*Sun H*	4.07*	*Min T*	0.40	*Ave T*	0.00
Baicheng[a]	*Ave RH*	-3.05*	*Max T*	-3.03*	*Win S*	1.19	*Sun H*	1.80	*Min T*	2.08*	*Ave T*	0.00
Qian'an[a]	*Ave RH*	-2.90*	*Max T*	-2.87*	*Win S*	2.53*	*Sun H*	0.28	*Min T*	1.68	*Ave T*	0.00
Qian Gorlos[a]	*Ave RH*	-6.27*	*Max T*	-4.66*	*Win S*	0.96	*Sun H*	3.53*	*Ave T*	-4.72*	*Min T*	2.31*
Tongyu[a]	*Ave RH*	-2.95*	*Max T*	-1.74	*Win S*	3.03*	*Sun H*	-0.15	*Min T*	1.06	*Ave T*	0.00
Changling[a]	*Ave RH*	-3.27*	*Max T*	-2.63*	*Win S*	4.01*	*Sun H*	-1.26	*Min T*	2.42*	*Ave T*	0.00
Fuyu City[a]	*Ave RH*	-5.62*	*Max T*	-4.37*	*Win S*	2.42*	*Sun H*	1.28	*Min T*	3.14*	*Ave T*	0.00
Changchun[a]	*Max T*	3.11*	*Ave RH*	-6.11*	*Win S*	1.97*	*Sun H*	3.47*	*Min T*	2.24*	*Ave T*	0.00
Region[a]	*Ave RH*	-4.07*	*Max T*	-4.18*	*Win S*	2.90*	*Sun H*	3.92*	*Ave T*	-6.94*	*Min T*	-7.93*

3.6. The role of ET_0 in regional dry/wet conditions

ET_0 accounts for more than 80 % of the total annual amount in growing season within a year, besides, this period is critical for crops and vegetation growing which effect directly regional socioeconomic. Therefore, this paper only considered what role ET_0 may play in regional dry/wet conditions during growing season. Regional trend and its magnitude of ET_0, AI and P were analyzed on both the inside 13 stations and the total 21 stations, but here have presented only the results of the former in Fig. 8, owing to the similarity in results.

Fig. 8 shown the interannual variations of growing season's ET_0, AI and P over Songnen Grassland for the period 1960 to 2014. From the visual inspection, ET_0, AI and P have all experienced the decreasing trends, but only the trend of ET_0 passed the significance test. As for the fluctuation of temporal evolution, results indicated that the fluctuating pattern of ET_0 was similar to AI, but opposite to that of P. Then, the simple regression equation is established as follows:

$$AI = 63.81 - 0.125P + 0.046ET_0 \quad (R^2 = 0.98, P = 0.00) \tag{6}$$

Eq. (6) shown there was a positive correlation between AI and ET_0 and a negative correlation between AI and P. The regression residual standard error displayed in Fig.8. Thus, the upward trends of ET_0 and AI were associated with downward trends of P and vice versa.This character was highly explicit during drought and wet years in particular. As shown in Fig. 8, during the severe drought years D1 (1982), D2 (2001), D3 (2004) and D4 (2007), the values of ET_0 and AI had reached or were about to the maximum in the last decades, however, the values of P had nearly attained the minimum at the same time. Similarly, the wet years such as W1 (1960), W2 (1998), and W3 (2013) had witnessed lower values of ET_0 and AI (Fig. 9).

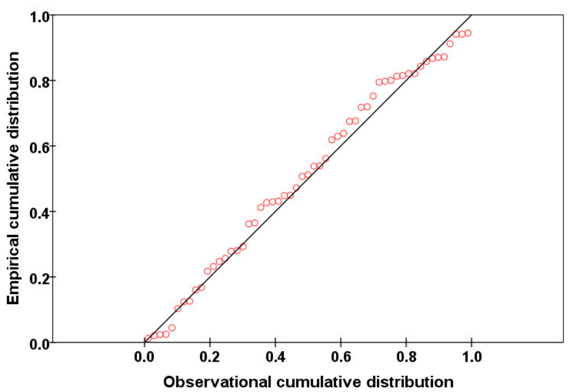

Figure 8. P-P plot of regression residual standard error.

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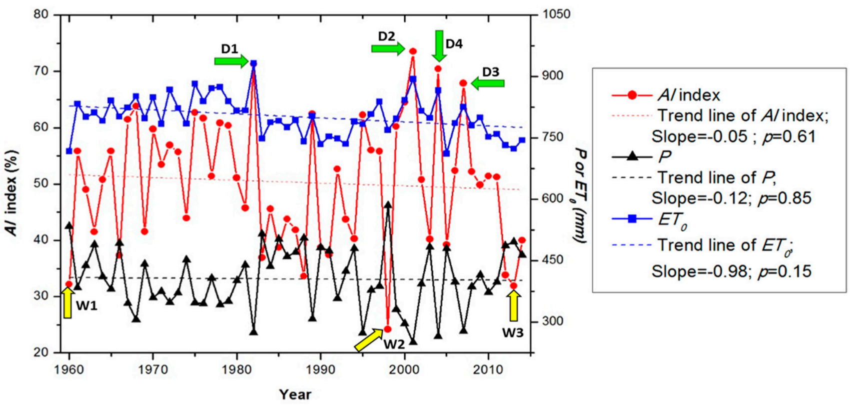

Figure 9. Comparison of temporal trend of ET_0, AI and P during 1960-2014. D, the drought year; W, the wet year.

4. Discussion

Songnen Grassland shows obviously spatial variations of ET_0 rates from northeast to southwest at different time scales (Fig. 2). It was influenced by both of the different regional climate and local topography. In the north region, there was distributed some valleys and the stations located in relatively high latitude area, while in the south, the topography was relatively flat with lower latitude (Fig. 1). Moreover, ET_0 rates over Songnen Grassland have been obviously decreasing over the last decades (Fig. 3 and 4). The results were consistent with a decreasing trends in the lower reaches in Taoer River basin of Northeast China investigated by Liang, et al. [32]. Huo, et al. also reported that a decreasing trend in the arid area of northwest China during 1955-2008 [3]. However, as discussed in introduction, some studies has identified an increasing trends in some regions for the last decades. One of the reasons for inconsistent findings in ET_0 trends is due to the fact that some studies on climate change utilize divergent climatic parameters, potentially providing incomplete or artificial trends and magnitudes in ET_0 [8].

During the study period, observed variations in Max T, Min T and Ave T were similar to the global pattern of increasing minimum, mean and maximum temperature [9], and the results of analyzing on other climatic factors were consistent with the finding reported from Yunnan Province in China [4]. Then, attribution analyses for changes in annual ET_0 shown that Ave RH and Max T were the most sensitive climate variables over the whole Songnen Grassland, which was in agreement with Yin, et al. [33] studied at the whole China. However, Liu, et al. has been reported that Win S and Sun H were the most sensitive factors in other part of China [11]. Thus, it can be concluded that ET_0 has different responses to climate variables in different regions and climate conditions. What's more, this study indicated the increase of ET_0 induced by rising air temperature can be compensated by reduced ET_0 as significant decrease of Ave RH, Win S and Sun H. As a result, regional ET_0 appeared to show a declining trend. Remarkably, human activity should take upon some of the responsibility about local climate change [28], such as GHG emissions and rapid urbanization, which should be further studied in Songnen Grassland.

ET_0 variations and its response to regional dry/wet conditions are of great importance for crop growing and natural vegetation [2, 34]. For this purpose, the present paper analyzed long term variations of ET_0, AI and P at growing season during 1960-2014. Results shown that ET_0 and AI decreased as the P increased, especially during drought or wet years, and vice versa (Fig. 8). This was consistent with Madhu, et al. [35] who reported that higher ET values were detected in the moderate and severe droughts years. Contrary to the Eq. (5), notably, the trends of ET_0, AI and P were both experiencing decrease trend during the study period in this paper. This could be due to the changes of precipitation was not significant. However, the decreasing rate of ET_0 and AI was higher than that of P. Faced with this, the climate in Songnen Grassland gets slightly wetter from 1960-2014, and the trend would be continued if the decreasing trend of ET_0 persists. In short, regional climate change brings positive influence for vegetation growth, agricultural production and ecological environment.

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5. Conclusions

In this study, spatial distributions of ET_0, P and their difference were obtained at different time scales. The temporal and spatial variations of ET_0 were performed for 55 years of data from 22 stations in and around Songnen Grassland, northeast China, during 1960-2014. Then, the interannual variability of climatic variables was investigated during the study period, and sensitivity analysis was conducted in this context. The role of ET_0 in regional dry/wet conditions, ultimately, was discussed based on analyzing relationships between ET_0, P and AI. The following conclusions can be drawn from this study.

(1) Trend analysis of ET_0 at different time scales shown an evidently decreasing trend in the last 55 years, especially in annual and spring. Break trend analysis shown that almost all considered climatological normals had experienced the decreasing trend, with a range of -2.415 to -0.003 mm per year. Spatial variations of ET_0 indicated that most significant decreasing trends were mainly distributed in the eastern, northeastern and central region during annual, spring and growing season.

(2) The interannual variability of climatic parameters shown the annual Max T, Ave T and Min T experienced significant increasing trend and significant decreasing trends were found for Ave RH, Win S and Sun H. Ave RH was the dominant climate variable for the declining annual ET_0 over the complete region, followed by Max T, Win S, Sun H, Min T and Ave T.

(3) In general, the results of this study indicated that drought/wetness condition was getting slightly wetter with decreasing ET_0 during growing season. Regional climate drought has been alleviated in recent several decades. The findings could be contribute to a better planning and efficient use of agricultural water resources in Songnen Grassland.

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