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Research Article

Study on Response of Evapotranspiration Consumption of Forest and Grass Vegetation to Natural Precipitation in Northwest Loess Plateau

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Abstract

In this paper, the evapotranspiration balance of forest and grass vegetation in the Loess Plateau of Northwest China in different regions was analyzed using 6 indexes in 3 categoriess, namely, evapotranspiration ratio (Ea/Q, Ep/Q), evapotranspiration difference (Q-EA, Q-EP), and actual (potential) water supply ratio (1-Ea/Q, 1-Ep/Q). It is used to objectively reflect the suitability of different types of vegetation in different periods of growth based on precipitation. In another words this suitability reflects the support capacity of natural rainfall to vegetation consumed water through evapotranspiration under the specific climate environment of the Loess Plateau. The results show that: (1) The actual evapotranspiration water consumption of all types of vegetation in this region increased significantly in the first three months of the growth period from April to June, resulting in a relatively high moisture dryness index of vegetation with an average k value of 0.44. The main reason was that natural precipitation was less at this stage, and the gradually rising temperature strengthened the transpiration of most vegetation. The forest was the most stressed. At the end of May and the beginning of June, with the increase of natural precipitation, the average k value of all types of vegetation began to decline. From July to September, due to the flood season in this region, the precipitation increased sharply, and the moisture dryness index was in the lowest range of the whole growth period, and the average k value varied between 0.26 and 0.30 with the lowest value was 0.26 at the end of August and the beginning of September. (2) It is obvious that the water stress of forest is higher than that of shrub and grassland. It is fully indicated that the difference of transpiration caused by the difference of vegetation types leads to the difference of actual evapotranspiration water consumption of different vegetation types.

Keywords

Forest and Grass Vegetation, Precipitation, Evapotranspiration, Response, Loess Plateau

1. Introduction

The Loess Plateau is a typical ecologically sensitive area in China, which existed with two main ecological and environmental problems of drought and soil erosion, and the restoration of vegetation cover is a key measure to improve the ecological environment [1]. In recent years, with the continuous promotion of soil and water conservation and ecological environment construction, the soil erosion control degree in the Loess Plateau has been continuously improved, the veg-

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etation coverage rate has also been greatly improved, and the ecological environment quality has also been improved to a certain extent. However, most of the Loess Plateau is located in arid and semi-arid areas, and water is the main factor restricting vegetation restoration [2, 3, 16]. Maintaining the balance between precipitation and vegetation evapotranspiration and water growth according to the basic principle of "determining trees (grasses) by water" is an important basis for regional ecological restoration [1, 5, 9, 15]. Therefore, in the process of vegetation restoration and reconstruction, the response relationship between precipitation and evapotranspiration in the process of vegetation restoration must first be considered [4, 17]. Relevant studies have shown that large-scale vegetation restoration is or has caused an increase in regional evapotranspiration, resulting in a decrease in soil effective water storage and runoff, as well as an increase in ecological water demand, and the contradiction between vegetation restoration and water resources has become increasingly prominent [4, 17]. In this sense, the ecohydrological effects of large-scale vegetation restoration on the Loess Plateau are bound to have an impact on regional water balance, which may further aggravate the situation of regional water shortage. For a long time, there exist some problems in the process of vegetation restoration, such as improper selection of vegetation types, unbalance of the structure of vegetation, and excessive density. In fact, the heterogeneity of climatic resources and their spatial distribution in a region largely determines the type, pattern, quantity and structure of vegetation that can be supported [5, 17]. In order to provide a scientific and reasonable basis for vegetation restoration, it is necessary to first consider the balance relationship of precipitation evapotranspiration in the process of vegetation restoration, and analyze the water suitability of different vegetation types in different regions, so as to help select vegetation types with high suitability according to the climate resources in different regions, so as to improve the restoration effect of forest and grass vegetation in this region.

Vegetation evapotranspiration is an important process of water movement and balance in soil-plant-atmosphere circulatory system (SPAC), and it is also a complex physical and biological process. The evapotranspiration water consumption of vegetation includes the surface soil water evaporation of forest and grass land and the water evaporation of plant body [5, 6]. The climate in this region belongs to the temperate and warm temperate continental semi-arid and semi-humid climate. According to the biological characteristics of the vegetation in this region, more than 90% of the vegetation transpiration mainly occurs during the vegetation growth period (April to October). Although the surface soil water evaporation is still going on during the vegetation dormant period (November to March), the soil evaporation in this stage is very small. At the same time, the replenishment of soil water by precipitation in winter and early spring can fully achieve water balance, and the evaporation of soil can be ignored [7-12]. Therefore, vegetation evapotranspiration in this study refers to the evapotranspiration water consumption during the growth period of vegetation from April to October.

2. Study the Regional Profile

Pingliang City is located in the central and eastern part of Gansu Province, with a total land area of 11119.07km^2. It consists of Jinghe River Basin in the east and Hulu River Basin in the west, and. There are 1 city, 5 counties and 1 district in the Jinghe River Basin in the east, including Kongtong District, Jingchuan County, Lingtai County, Chong Xin County and Huating City, and Zhuanglang County and Jingning County in the Hulu River Basin in the west. The climate type is temperate semi-humid and semi-arid climate, the average annual precipitation is 533.1mm, the average annual drought index is 1.65, the vegetation type is temperate forest grassland, the main species are deciduous broad-leaved forest, mixed forest, forest grassland, etc.

According to the data of the third National land survey, the existing forest area of Pingliang City is 354,702.23 hm^2, including 305,166.14 hm^2 of forest and 49,536.09 hm^2 of shrub. The main tree species are *Robinia pseudoacacia L*., broad-leaved mixed forest, oak (*Quercus L.*), poplar (*PopulusL.*), *Larix gmelinii (Rupr. Kuzen.*), Chinese pine (*P. tabuliformis*) and other 29 species, the economic forest is mainly artificially planted red Fuji apple (*Malus pumila Mill*). Grassland area 68572.19hm^2, mostly for artificial grassland, there are more than 70 species, mostly for gramineae, compositae plants. The forest coverage rate reached 33.8%, higher than the average of 21.83%. The coverage rate of forest and grass reached 50.57%, which was close to the average vegetation coverage rate of 59.0% on the Loess Plateau.

3. Research Methods

In this study, vegetation evapotranspiration was analyzed by climatological method. Evapotranspiration climatological method, usually based on the temperature, rainfall, radiation, water pressure, wind speed and other meteorological data to estimate, such as Penman formula, Budko formula, Thornthwaite formula, Makkink formula, Morton formula. In addition, there are many improved empirical formulas and models suitable for calculating monthly or annual evapotranspiration over large areas or river basins. In this paper, the empirical model method of evapotranspiration climatology was adopted to calculate the potential evapotranspiration (Ep) value based on the improved HAMON model, and the empirical model Zhang et al [14] was introduced to calculate the actual evapotranspiration (Ea) of different vegetation types in the region. On this basis, 6 parameters, including evapotranspiration ratio (Ea/Q, Ep/Q), evapotranspiration difference (Q-EA, Q-EP), and actual (potential) water supply ratio (1-Ea/Q, 1-Ep/Q), were used to analyze the evapotranspiration balance of forest and grass vegetation in different basins in this region. It is used to objectively reflect the suitability of different types of vegetation in different periods of growth based on precipitation.

4. Basic Information and Calculation Method

4.1. Sources of Information

Based on the meteorological statistics of the region from 1997 to 2000, the climatic resources data are shown in Table 1, Table 2 and Table 3 respectively.

Table 1. *Meteorological elements of Pingliang City.*

.month	April	May	June	July	Augus	September	October
Mean temperature	10.5	15.2	19.0	21.1	19.9	14.8	8.7
Mean precipitation	31.4	45.6	64.1	109.2	96.9	61.5	38.3
Mean wind speed	2.4	2.2	0.9	1.9	1.9	1.7	1.8
Precipitation days	7.9	9.6	10.7	12.4	12.9	11.5	9.2

Table 2. *Annual average monthly temperature of each administrative region in Pingliang during vegetation growth period (April to October).*

Administrative region	Annual average monthly temperature (℃)						
	April	May	June	July	August	September	October
Kongtong District	13	17	21	23.5	22	17	11
Jingchuan county	13.5	18	22.5	25	24	18.5	12
Lingtai county	13.5	18	22.5	24.5	24	18.5	12
Chongxin county	13.5	17.5	22	24.5	23.5	18	11.5
Huating City	11	15	19.5	21.5	20.5	15.5	9.5
Zhuanglang county	11	15	19.5	21.5	21	16	10
Jingning county	10.5	15.5	19.5	21.5	20.5	15	9.5
Average of Pingliang City	10.5	15.2	19	21.1	19.9	14.8	8.7

Table 3. *Annual Mean Monthly Precipitation Scale (mm) for each administrative region of Pingliang during vegetation growth period (April to October).*

Administrative region	April	May	June	July	August	September	October	Annual	Growing season
Kongtong District	33	45.7	63.2	107	108.6	82.2	41.2	533.4	480.9
Jingchuan county	35.4	47.9	57	111.9	114.7	92.2	42.4	551.5	501.5
Lingtai county	33	47.9	70.9	119	101.2	106.6	46.3	578.8	524.9
Chongxin county	35.6	47.9	57.8	110.3	100.4	89.9	41.7	527.6	483.6
Huating City	34.5	52.5	66.4	122.5	111.7	120.1	49	607.4	556.7

Administrative region	April	May	June	July	August	September	October	Annual	Growing season
Zhuanglang county	35	49.8	68.4	108.1	102.1	81.5	40.8	518.4	485.7
Jingning county	29.2	46.5	57.9	90.2	87.2	74.9	36.1	451	422
Average of Pingliang City	33.2	48	63.4	108.5	102.7	91	42.1	533.1	488.9

4.2. Calculation Model

In this paper, the empirical model method of evapotranspiration climatology research by ZHANG (Zhang et al., 2012) is adopted. The model formula is as follows:

$$Ea=Q*(1+w*Ep/Q)/[(1+W*Ep/Q+(Ep/Q)-1] \quad (1)$$

Formula:

Ea: actual evapotranspiration (mm); Q: Precipitation (mm); w: Water use coefficient of non-dimensional plants (tree forest 2.0, shrub 1.5, grassland 0.5). In order to further distinguish grassland types, grassland was divided into high coverage grassland (coverage greater than 50%, w=0.5), medium coverage grassland (coverage 20% ~ 50%, w=0.3) and low coverage grassland (coverage 5% ~ 20%, W =0.5). w=0.2); Ep: Surface potential evapotranspiration (mm).

Ep calculated according to HAMON model:

$$Ep=0.1651*d1*TRHOSA \quad (2)$$

$$TRHOSA=216.7*TESA/(Tm+273.3) \quad (3)$$

$$TESA=6.108*\exp[17.27*Tm/(Tm+237.3)] \quad (4)$$

d1: sunshine number (h/d), this article takes d1=12h; TRHOSA: Saturated vapor density at monthly mean temperature ($g.m^{-3}$); TESA: Saturated vapor pressure (kpa) at a specific temperature; Tm: Average monthly temperature (℃).

5. Result Analysis

5.1. Analysis of Precipitation Evapotranspiration Balance in Different Vegetation Growth Periods

In this study, 6 parameters, including evapotranspiration ratio (Ea/Q, Ep/Q), precipitation evapotranspiration difference (Q-EA, Q-EP), and actual (potential) water supply ratio (1-Ea/Q, 1-Ep/Q), were used to analyze the evapotranspiration balance relationship of forest and grass vegetation in different ranges in this region. It is used to objectively reflect the suitability of different types of vegetation in different periods of growth based on precipitation. Among them, the evapotranspiration precipitation ratio reflects the dry or wet state of the vegetation growth environment. Due to different evapotranspiration types, the actual dryness and potential dryness of vegetation are divided. The higher the dryness value, the greater the water stress the vegetation is subjected to during growth. The relative surplus of water is reflected by the evapotranspiration difference (mm) of precipitation, which indicates the water surplus status during the growth of specific types of vegetation. The water supply rate reflects the rainfall support capacity of vegetation after it consumes water through evapotranspiration in a specific climate environment. The higher the water supply rate, the higher the water suitability of this type of vegetation in the region, and vice versa.

5.1.1. Forest

The moisture dryness coefficient (k), moisture relative surplus (mm) and water supply coefficient of trees in different regions of this region are shown in Table 4.

Table 4. *Analysis of monthly precipitation evapotranspiration balance during the growth period of forest in different regions.*

Administrative region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k) Evapotranspiration precipitation ratio		Moisture relative surplus (mm) Difference between precipitation and evapotranspiration		Water supply rate	
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
KT	4	20.34	22.46	33	0.62	0.68	12.66	10.54	0.38	0.32
	5	26.76	28.66	45.7	0.59	0.63	18.94	17.04	0.41	0.37
	6	34.90	36.28	63.2	0.55	0.57	28.30	26.92	0.45	0.43
	7	43.98	41.88	107	0.41	0.39	63.02	65.12	0.59	0.61
	8	40.91	38.44	108.6	0.38	0.35	67.69	70.16	0.62	0.65
	9	30.56	28.66	82.2	0.37	0.35	51.64	53.54	0.63	0.65
	10	20.01	19.82	41.2	0.49	0.48	21.19	21.38	0.51	0.52
	subtotal	217.46	216.19	480.9	0.98	0.45	263.44	262.44	0.55	0.55
JC	4	21.30	23.16	35.4	0.60	0.65	14.10	12.24	0.40	0.35
	5	28.28	30.42	47.9	0.59	0.64	19.62	17.48	0.41	0.36
	6	35.55	39.56	57	0.62	0.69	21.45	17.44	0.38	0.31
	7	47.57	45.59	111.9	0.43	0.41	64.33	66.31	0.57	0.59
	8	45.52	43.09	114.7	0.40	0.38	69.18	71.61	0.60	0.62
	9	33.51	31.33	92.2	0.36	0.34	58.69	60.87	0.64	0.66
	10	21.13	21.11	42.4	0.50	0.50	21.27	21.29	0.50	0.50
	subtotal	232.85	234.26	501.5	0.46	0.47	268.65	267.24	0.54	0.53
LT	4	20.72	23.16	33	0.63	0.70	12.28	9.84	0.37	0.30
	5	28.28	30.42	47.9	0.59	0.64	19.62	17.48	0.41	0.36
	6	38.38	39.56	70.9	0.54	0.56	32.52	31.34	0.46	0.44
	7	46.88	44.32	119	0.39	0.37	72.12	74.68	0.61	0.63
	8	44.61	43.09	101.2	0.44	0.43	56.59	58.11	0.56	0.57
	9	33.92	31.33	106.6	0.32	0.29	72.68	75.27	0.68	0.71
	10	21.56	21.11	46.3	0.47	0.46	24.74	25.19	0.53	0.54
	subtotal	234.35	232.99	524.9	0.45	0.44	290.55	291.91	0.55	0.56
CX	4	21.35	23.16	35.6	0.60	0.65	14.25	12.44	0.40	0.35
	5	27.74	29.53	47.9	0.58	0.62	20.16	18.37	0.42	0.38
	6	35.13	38.44	57.8	0.61	0.67	22.67	19.36	0.39	0.33
	7	46.35	44.32	110.3	0.42	0.40	63.95	65.98	0.58	0.60

Administrative region	month	Evapotranspiration (mm): Actual evapotranspiration Ea	Evapotranspiration (mm): Potential evapotranspiration Ep	Precipitation (mm) Q	Moisture dryness (k), Evapotranspiration precipitation ratio: Actual evapotranspiration precipitation ratio (Ea/Q)	Moisture dryness (k), Evapotranspiration precipitation ratio: Potential evapotranspiration precipitation ratio Ep/Q	Moisture relative surplus (mm), Difference between precipitation and evapotranspiration: Difference between precipitation and actual evapotranspiration Q-Ea	Moisture relative surplus (mm), Difference between precipitation and evapotranspiration: Difference between precipitation and potential evapotranspiration Q-Ep	Water supply rate: Actual water supply rate 1-Ea/Q	Water supply rate: Potential water supply rate 1-Ep/Q
	8	43.52	41.88	100.4	0.43	0.42	56.88	58.52	0.57	0.58
	9	32.54	30.42	89.9	0.36	0.34	57.36	59.48	0.64	0.66
	10	20.55	20.46	41.7	0.49	0.49	21.15	21.24	0.51	0.51
	subtotal	227.18	228.21	483.6	0.47	0.47	256.42	255.39	0.53	0.53
	4	19.06	19.82	34.5	0.55	0.57	15.44	14.68	0.45	0.43
	5	25.60	25.39	52.5	0.49	0.48	26.90	27.11	0.51	0.52
	6	33.23	33.24	66.4	0.50	0.50	33.17	33.16	0.50	0.50
HT	7	40.33	37.34	122.5	0.33	0.30	82.17	85.16	0.67	0.70
	8	37.95	35.24	111.7	0.34	0.32	73.75	76.46	0.66	0.68
	9	28.63	26.18	120.1	0.24	0.22	91.47	93.92	0.76	0.78
	10	19.10	18.03	49	0.39	0.37	29.90	30.97	0.61	0.63
	subtotal	203.89	195.24	556.7	0.37	0.35	352.81	361.46	0.63	0.65
	4	19.15	19.82	35	0.55	0.57	15.85	15.18	0.45	0.43
	5	25.27	25.39	49.8	0.51	0.51	24.53	24.41	0.49	0.49
	6	33.47	33.24	68.4	0.49	0.49	34.93	35.16	0.51	0.51
ZL	7	39.86	37.34	108.1	0.37	0.35	68.24	70.76	0.63	0.65
	8	38.60	36.28	102.1	0.38	0.36	63.50	65.82	0.62	0.64
	9	28.93	26.98	81.5	0.35	0.33	52.57	54.52	0.65	0.67
	10	19.01	18.61	40.8	0.47	0.46	21.79	22.19	0.53	0.54
	subtotal	204.28	197.67	485.7	0.42	0.41	281.42	288.03	0.58	0.59
	4	17.63	19.21	29.2	0.60	0.66	11.57	9.99	0.40	0.34
	5	25.33	26.18	46.5	0.54	0.56	21.17	20.32	0.46	0.44
	6	31.97	33.24	57.9	0.55	0.57	25.93	24.66	0.45	0.43
JiN	7	38.86	37.34	90.2	0.43	0.41	51.34	52.86	0.57	0.59
	8	36.82	35.24	87.2	0.42	0.40	50.38	51.96	0.58	0.60
	9	27.16	25.39	74.9	0.36	0.34	47.74	49.51	0.64	0.66
	10	18.03	18.03	36.1	0.50	0.50	18.07	18.07	0.50	0.50
	subtotal	195.80	194.63	422	0.46	0.46	226.20	227.37	0.54	0.54
Av-	4	18.43	19.21	33.2	0.56	0.58	14.77	13.99	0.44	0.42

Administrative region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k)		Moisture relative surplus (mm)		Water supply rate	
					Evapotranspiration precipitation ratio		Difference between precipitation and evapotranspiration			
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
erage of Pingliang City	5	25.24	25.71	48	0.53	0.54	22.76	22.29	0.47	0.46
	6	32.13	32.27	63.4	0.51	0.51	31.27	31.13	0.49	0.49
	7	39.06	36.49	108.5	0.36	0.34	69.44	72.01	0.64	0.66
	8	36.48	34.03	102.7	0.36	0.33	66.22	68.67	0.64	0.67
	9	27.26	25.09	91	0.30	0.28	63.74	65.91	0.70	0.72
	10	17.87	17.13	42.1	0.42	0.41	24.23	24.97	0.58	0.59
	subtotal	196.47	189.92	488.9	0.40	0.39	292.43	298.98	0.60	0.61

Remark: KT, JC, LT, CX, HT, ZL and JN in the table are abbreviations of Kongtong District, Jingchuan county, Lingtai county, Chongxin county, Huating City, Zhuanglang county and Jingning county respectively.

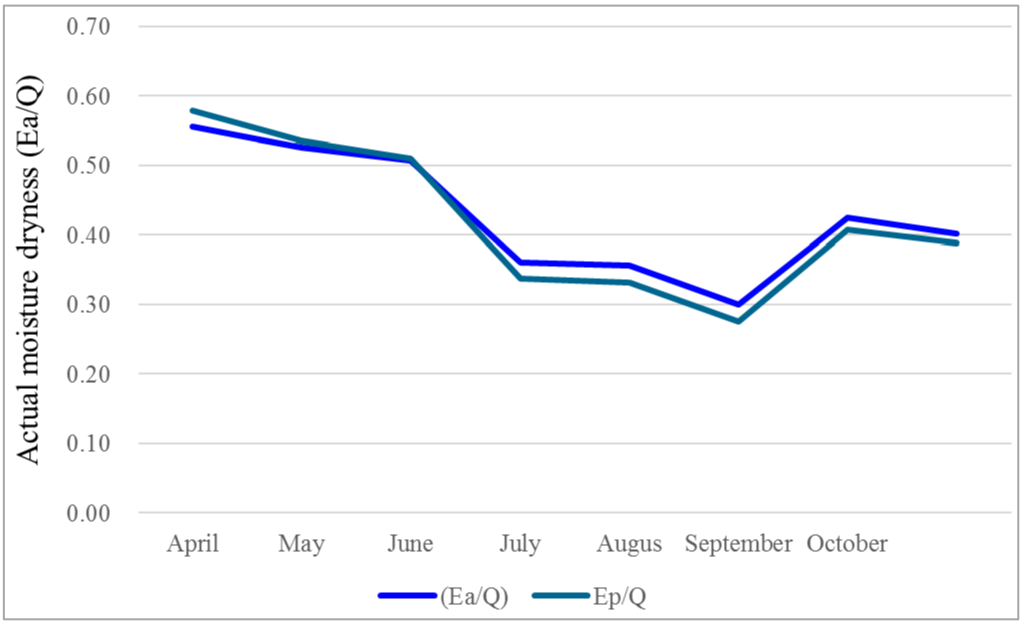

Figure 1. *Intermonthly variation of moisture dryness in growing period of forest in Pingliang City.*

Table 5. *Analysis of precipitation evapotranspiration balance during the growth period of forest in different regions.*

Administrative region	**Evapotranspiration (mm)**		**Precipitation (mm)**	**Moisture dryness (k)**		**Moisture relative surplus (mm)**		**Water supply rate**	
				Evapotranspiration precipitation ratio		**Difference between precipitation and evapotranspiration**			
	Actual evapotranspiration	**Potential evapotranspiration**		**Actual evapotranspiration precipitation ratio**	**Potential evapotranspiration precipitation ratio**	**Difference between precipitation and actual evapotranspiration**	**Difference between precipitation and potential evapotranspiration**	**Actual water supply rate**	**Potential water supply rate**
	Ea	**Ep**	**Q**	**(Ea/Q)**	**Ep/Q**	**Q-Ea**	**Q-Ep**	**1-Ea/Q**	**1-Ep/Q**
Kongtong District	217.46	218.46	480.90	0.98	0.45	263.44	262.44	0.55	0.55
Jingchuan county	232.85	234.26	501.50	0.46	0.47	268.65	267.24	0.54	0.53
Lingtai county	234.35	232.99	524.90	0.45	0.44	290.55	291.91	0.55	0.56
Chongxin county	227.18	228.21	483.60	0.47	0.47	256.42	255.39	0.53	0.53
Huating City	203.89	195.24	556.70	0.37	0.35	352.81	361.46	0.63	0.65
Zhuanglang county	204.28	197.67	485.70	0.42	0.41	281.42	288.03	0.58	0.59
Jingning county	195.80	194.63	422.00	0.46	0.46	226.20	227.37	0.54	0.54
The whole area	196.47	189.92	488.90	0.40	0.39	292.43	298.98	0.60	0.61

Table 6. *Linear regression relationship between forest evapotranspiration (y) and precipitation (x) in different administrative regions.*

Administrative area	**Actual evapotranspiration regression (y1)**	**Potential evapotranspiration regression (y2)**
Kongtong District	y1 = 11.680 +0.282x (R2 = 0.869)	y 2 = 15.345 +0.226x (R2 = 0.727)
Jingchuan county	y 1 = 12.518 + 0.290 x (R2 = 0.85)	y 2 = 16.963 + 0.230 x (R2 = 0.661)
Lingtai county	y 1 = 13.073 + 0.272 x (R2 = 0.781)	y 2 = 17.054 + 0.217 x (R2 = 0.628)
Chongxin county	y 1 = 11.473 + 0.304 x (R2 = 0.841)	y 2 = 15.504 + 0.247 x (R2 = 0.670)
Huating City	y 1 = 14.474 + 0.184 x (R2 = 0.655)	y 2 = 16.186 + 0.147 x (R2 = 0.529)
Zhuanglang county	y 1 = 9.775 + 0.280 x (R2 = 0.906)	y 2 = 11.696 + 0.238 x (R2 = 0.838)
Jingning county	y 1 = 8.760 + 0.319 x (R2 = 0.853)	y 2 = 11.586 + 0.269 x (R2 = 0.733)
The whole area of Pingliang City	y 1 = 11.314 + 0.240 x (R2 = 0.786)	y 2 = 13.406 + 0.197 x (R2 = 0.661)

From the Ea/Q curve in Figure 1, we can see: The curve of moisture dryness index in the growth period of forest in this region showed a process of first decreasing and then increasing, that is, in the first three months of April, May and June, the moisture dryness index was relatively high, and the average k value was 0.53, indicating that the forest in this stage was subjected to the strongest water stress. The k value began to decline at the end of May and early June, and the k value showed a rapid decline from the end of June to the beginning of July. From July to September, the moisture dryness index was in the lowest value range of the whole growth period, and the change range of k value was 0.30~0.36, and the lowest value was 0.30 in late August and early September. From the beginning of September to the end of October, the k value gradually increased, increasing to 0.42.

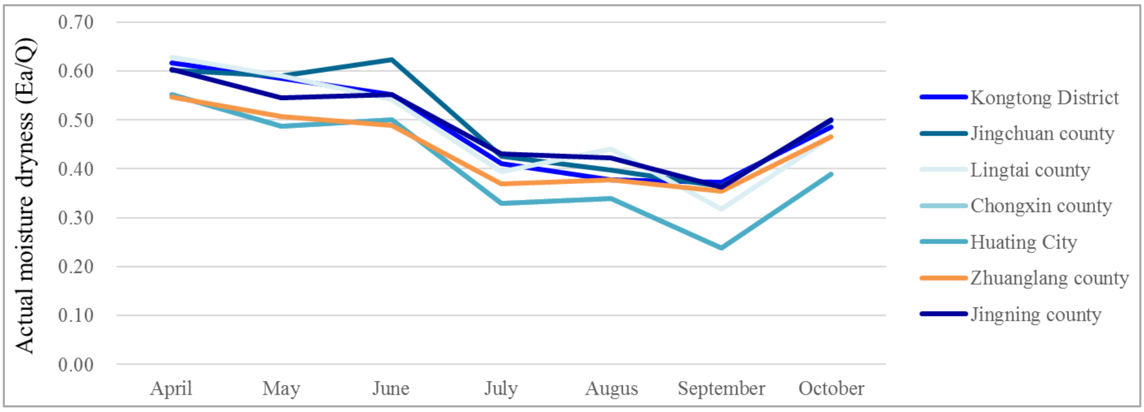

Figure 2. *Spatial-temporal heterogeneity of water firmness index in growing period of forest in Pingliang City.*

There were significant differences in the degree of water stress in different areas of forest in the region (see Figure 2), which were as follows: (1) Inter-monthly changes: the mean dryness index from April to October was 0.59, 0.54, 0.54, 0.38, 0.32, 0.46, respectively, as shown in Table 7; (2) Spatial and temporal differences: in April, the highest k value appeared in Lingtai County (0.63), followed by Kongtong District (0.62), Jingchuan County (0.60) and Jingning County (0.60), and the lowest K value appeared in Chongxin County (0.55), Huating City (0.55) and Zhuanglang County (0.55). In May, the highest k value appeared in Kongtong District (0.59), Jingchuan County (0.59) and Lingtai County (0.59), followed by Jingning County (0.54) and Zhuanglang County (0.51), and the lowest K value appeared in Chongxin County (0.49) and Huating City (0.49). In June, the highest value of k appeared in Jingchuan County (0.62), followed by Kongtong District (0.55), Jingning County (0.55), Lingtai County (0.54), Chongxin County (0.50) and Huating City (0.50), and the lowest value appeared in Zhuanglang County (0.49). In July, the maximum value of k appeared in Jingchuan County (0.43) and Jingning County (0.43), followed by Kongtong District (0.41), Lingtai County (0.39) and Zhuanglang County (0.37), and the minimum value appeared in Chongxin County (0.33) and Huating City (0.33). In August, the highest value of k appeared in Lingtai County (0.44), followed by Jingning County (0.42), Jingchuan County (0.40), Kongtong District (0.38) and Zhuanglang County (0.38), and the lowest value appeared in Chongxin County (0.34) and Huating City (0.34). In September, the highest value of k appeared in Kongtong District (0.37), followed by Jingchuan County (0.36), Jingning County (0.36), Zhuanglang County (0.35) and Lingtai County (0.32), and the lowest value appeared in Chongxin County (0.24) and Huating City (0.24). In October, k value increased rapidly, with the highest value appearing in Jingchuan County (0.50) and Jingning County (0.50), followed by Kongtong District (0.49), Lingtai County (0.47) and Zhuanglang County (0.47), and the lowest value appearing in Chongxin County (0.39) and Huating City (0.39), as shown in Table 7.

Table 7. *Temporal and spatial changes of k value in forest.*

Month	KT	JC	LT	CX	HT	ZL	JN	Average
April	0.62	0.60	0.63	0.55	0.55	0.55	0.60	0.59
May	0.59	0.59	0.59	0.49	0.49	0.51	0.54	0.54
June	0.55	0.62	0.54	0.50	0.50	0.49	0.55	0.54
July	0.41	0.43	0.39	0.33	0.33	0.37	0.43	0.38
Augus	0.38	0.40	0.44	0.34	0.34	0.38	0.42	0.38
September	0.37	0.36	0.32	0.24	0.24	0.35	0.36	0.32
October	0.49	0.50	0.47	0.39	0.39	0.47	0.50	0.46
Mean value	0.49	0.50	0.48	0.41	0.41	0.44	0.49	0.46

Remark: KT, JC, LT, CX, HT, ZL and JN in the table are abbreviations of Kongtong District, Jingchuan county, Lingtai county, Chongxin county, Huating City, Zhuanglang county and Jingning county respectively.

5.1.2. Shrubland

Water dryness coefficient (k), water relative surplus (mm) and water supply coefficient of shrub growth period in different regions of this region are shown in Table 8.

Table 8. Analysis of monthly evapotranspiration balance of shrub growth period in different regions.

R region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k) Evapotranspiration precipitation ratio		Moisture relative surplus (mm) Difference between precipitation and evapotranspiration		Water supply rate	
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
KT	4	20.34	22.46	33	0.62	0.68	12.66	10.54	0.38	0.32
	5	26.76	28.66	45.7	0.59	0.63	18.94	17.04	0.41	0.37
	6	34.90	36.28	63.2	0.55	0.57	28.30	26.92	0.45	0.43
	7	43.98	41.88	107	0.41	0.39	63.02	65.12	0.59	0.61
	8	40.91	38.44	108.6	0.38	0.35	67.69	70.16	0.62	0.65
	9	30.56	28.66	82.2	0.37	0.35	51.64	53.54	0.63	0.65
	10	20.01	19.82	41.2	0.49	0.48	21.19	21.38	0.51	0.52
	subtotal	203.17	216.19	480.9	0.42	0.45	277.73	264.71	0.58	0.55
JC	4	21.30	23.16	35.4	0.60	0.65	14.10	12.24	0.40	0.35
	5	28.28	30.42	47.9	0.59	0.64	19.62	17.48	0.41	0.36
	6	35.55	39.56	57	0.62	0.69	21.45	17.44	0.38	0.31
	7	47.57	45.59	111.9	0.43	0.41	64.33	66.31	0.57	0.59
	8	45.52	43.09	114.7	0.40	0.38	69.18	71.61	0.60	0.62
	9	33.51	31.33	92.2	0.36	0.34	58.69	60.87	0.64	0.66
	10	21.13	21.11	42.4	0.50	0.50	21.27	21.29	0.50	0.50
	subtotal	232.85	234.26	501.5	0.46	0.47	268.65	267.24	0.54	0.53
LT	4	20.72	23.16	33	0.63	0.70	12.28	9.84	0.37	0.30
	5	28.28	30.42	47.9	0.59	0.64	19.62	17.48	0.41	0.36
	6	38.38	39.56	70.9	0.54	0.56	32.52	31.34	0.46	0.44
	7	46.88	44.32	119	0.39	0.37	72.12	74.68	0.61	0.63
	8	44.61	43.09	101.2	0.44	0.43	56.59	58.11	0.56	0.57
	9	33.92	31.33	106.6	0.32	0.29	72.68	75.27	0.68	0.71
	10	21.56	21.11	46.3	0.47	0.46	24.74	25.19	0.53	0.54
	subtotal	234.35	232.99	524.9	0.45	0.44	290.55	291.91	0.55	0.56

R region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k)		Moisture relative surplus (mm)		Water supply rate	
					Evapotranspiration precipitation ratio		Difference between precipitation and evapotranspiration			
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
	4	21.35	23.16	35.6	0.60	0.65	14.25	12.44	0.40	0.35
	5	27.74	29.53	47.9	0.58	0.62	20.16	18.37	0.42	0.38
	6	35.13	38.44	57.8	0.61	0.67	22.67	19.36	0.39	0.33
CX	7	46.35	44.32	110.3	0.42	0.40	63.95	65.98	0.58	0.60
	8	43.52	41.88	100.4	0.43	0.42	56.88	58.52	0.57	0.58
	9	32.54	30.42	89.9	0.36	0.34	57.36	59.48	0.64	0.66
	10	20.55	20.46	41.7	0.49	0.49	21.15	21.24	0.51	0.51
	subtotal	227.18	228.21	483.6	0.47	0.47	256.42	255.39	0.53	0.53
	4	19.06	19.82	34.5	0.55	0.57	15.44	14.68	0.45	0.43
	5	25.60	25.39	52.5	0.49	0.48	26.90	27.11	0.51	0.52
	6	33.23	33.24	66.4	0.50	0.50	33.17	33.16	0.50	0.50
HT	7	40.33	37.34	122.5	0.33	0.30	82.17	85.16	0.67	0.70
	8	37.95	35.24	111.7	0.34	0.32	73.75	76.46	0.66	0.68
	9	28.63	26.18	120.1	0.24	0.22	91.47	93.92	0.76	0.78
	10	19.10	18.03	49	0.39	0.37	29.90	30.97	0.61	0.63
	subtotal	203.89	195.24	556.7	0.37	0.35	352.81	361.46	0.63	0.65
	4	19.15	19.82	35	0.55	0.57	15.85	15.18	0.45	0.43
	5	25.27	25.39	49.8	0.51	0.51	24.53	24.41	0.49	0.49
	6	33.47	33.24	68.4	0.49	0.49	34.93	35.16	0.51	0.51
ZL	7	39.86	37.34	108.1	0.37	0.35	68.24	70.76	0.63	0.65
	8	38.60	36.28	102.1	0.38	0.36	63.50	65.82	0.62	0.64
	9	28.93	26.98	81.5	0.35	0.33	52.57	54.52	0.65	0.67
	10	19.01	18.61	40.8	0.47	0.46	21.79	22.19	0.53	0.54
	subtotal	204.28	197.67	485.7	0.42	0.41	281.42	288.03	0.58	0.59
	4	17.63	19.21	29.2	0.60	0.66	11.57	9.99	0.40	0.34
	5	25.33	26.18	46.5	0.54	0.56	21.17	20.32	0.46	0.44
JN	6	31.97	33.24	57.9	0.55	0.57	25.93	24.66	0.45	0.43
	7	38.86	37.34	90.2	0.43	0.41	51.34	52.86	0.57	0.59
	8	36.82	35.24	87.2	0.42	0.40	50.38	51.96	0.58	0.60

R region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k)		Moisture relative surplus (mm)		Water supply rate	
					Evapotranspiration precipitation ratio		Difference between precipitation and evapotranspiration			
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
	9	27.16	25.39	74.9	0.36	0.34	47.74	49.51	0.64	0.66
	10	18.03	18.03	36.1	0.50	0.50	18.07	18.07	0.50	0.50
	subtotal	195.80	194.63	422	0.46	0.46	226.20	227.37	0.54	0.54
Average of Pingliang City	4	18.43	19.21	33.2	0.56	0.58	14.77	13.99	0.44	0.42
	5	25.24	25.71	48	0.53	0.54	22.76	22.29	0.47	0.46
	6	32.13	32.27	63.4	0.51	0.51	31.27	31.13	0.49	0.49
	7	39.06	36.49	108.5	0.36	0.34	69.44	72.01	0.64	0.66
	8	36.48	34.03	102.7	0.36	0.33	66.22	68.67	0.64	0.67
	9	27.26	25.09	91	0.30	0.28	63.74	65.91	0.70	0.72
	10	17.87	17.13	42.1	0.42	0.41	24.23	24.97	0.58	0.59
	subtotal	196.47	189.92	488.9	0.40	0.39	292.43	298.98	0.60	0.61

Remark: KT, JC, LT, CX, HT, ZL and JN in the table are abbreviations of Kongtong District, Jingchuan county, Lingtai county, Chongxin county, Huating City, Zhuanglang county and Jingning county respectively.

Table 9*. Analysis of evapotranspiration balance of precipitation in shrub growth period in different regions.*

Administrative region	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k)		Moisture relative surplus (mm)		Water supply rate	
				Evapotranspiration precipitation ratio		Difference between precipitation and evapotranspiration			
	Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
	Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
Kongtong District	203.17	216.19	480.90	0.42	0.45	277.73	264.71	0.58	0.55
Jingchuan county	217.68	234.26	501.50	0.43	0.47	283.82	267.24	0.57	0.53
Lingtai county	219.00	232.99	524.90	0.45	0.44	290.55	291.91	0.55	0.56

Administrative region	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k)		Moisture relative surplus (mm)		Water supply rate	
				Evapotranspiration precipitation ratio		Difference between precipitation and evapotranspiration			
	Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
	Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
Chongxin county	212.32	228.21	483.60	0.44	0.47	271.28	255.39	0.56	0.53
Huating City	190.60	195.24	556.70	0.34	0.35	366.10	361.46	0.66	0.65
Zhuanglang county	190.65	197.67	485.70	0.39	0.41	295.05	288.03	0.61	0.59
Jingning county	182.86	194.63	422.00	0.43	0.46	239.14	227.37	0.57	0.54
The whole area	183.50	189.92	488.90	0.38	0.39	305.40	298.98	0.62	0.61

Table 10. *Linear regression relationship between shrub evapotranspiration (y) and precipitation (x) in different administrative regions.*

Administrative area	Actual evapotranspiration regression (y1)	Potential Evapotranspiration regression (y2)
Kongtong District	y1 = 11.048 +0.262x (R2 = 0.865)	y 2 = 15.345 +0.226x (R2 = 0.727)
Jingchuan county	y 1 = 11.888 + 0.268 x (R2 = 0.844)	y 2 = 16.963 + 0.230 x (R2 = 0.661)
Lingtai county	y 1 = 12.356 + 0.252 x (R2 = 0.780)	y 2 = 17.054 + 0.217 x (R2 = 0.628)
Chongxin county	y 1 = 10.891 + 0.281 x (R2 = 0.835)	y 2 = 15.504 + 0.247 x (R2 = 0.670)
Huating City	y 1 = 13.453 + 0.173 x (R2 = 0.664)	y 2 = 16.186 + 0.147 x (R2 = 0.529)
Zhuanglang county	y 1 = 9.147 + 0.261 x (R2 = 0.905)	y 2 = 11.696 + 0.238 x (R2 = 0.838)
Jingning county	y 1 = 8.297+ 0.296 x (R2 = 0.850)	y 2 = 11.586 + 0.269 x (R2 = 0.733)
The whole area of Pingliang City	y 1 = 10.576 + 0.224 x (R2 = 0.788)	y 2 = 13.406 + 0.197 x (R2 = 0.661)

From the Ea/Q curve in Figure 3, we can see: The inter-monthly variation process of water dryness in the growth period of shrubbery in this region is basically the same as that of forest, and the curve of moisture dryness index presents a process of decreasing first and then increasing. That is, in the first three months of April, May and June, the moisture dryness index is relatively high, and the average value of k value reaches 0.49, indicating that shrubbery in this region is subjected to the strongest water stress at this stage, and the k value begins to decline at the end of May and beginning of June. From the end of June to the beginning of July, the k value decreased rapidly. From July to September, the moisture dryness index was in the lowest range of the whole growth period, and the change range of k value was 0.28~0.34, and the lowest value was 0.28 at the end of August to the beginning of September. From the beginning of September to the end of October, k value gradually increased to 0.40, and the degree of shrub growth subjected to water stress began to increase again.

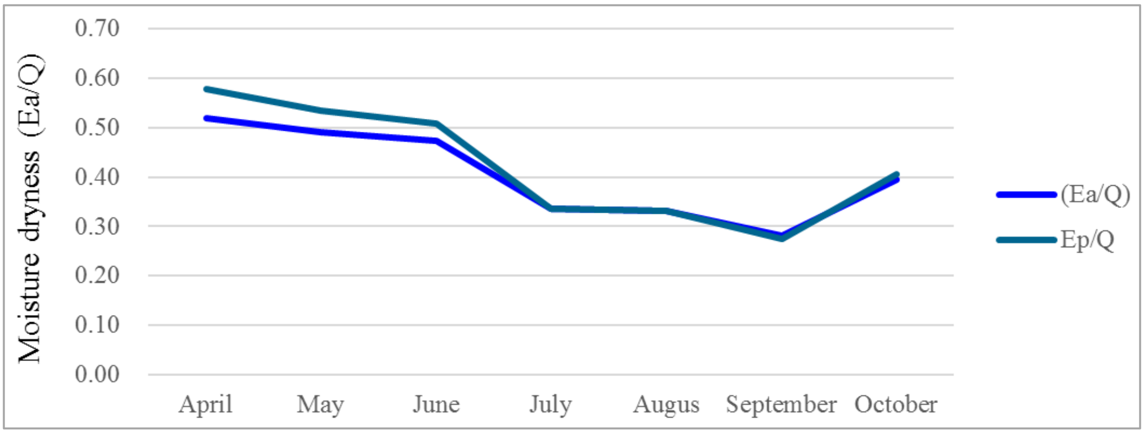

Figure 3. Intermonthly variation of moisture dryness during the growing period of shrubland in Pingliang City.

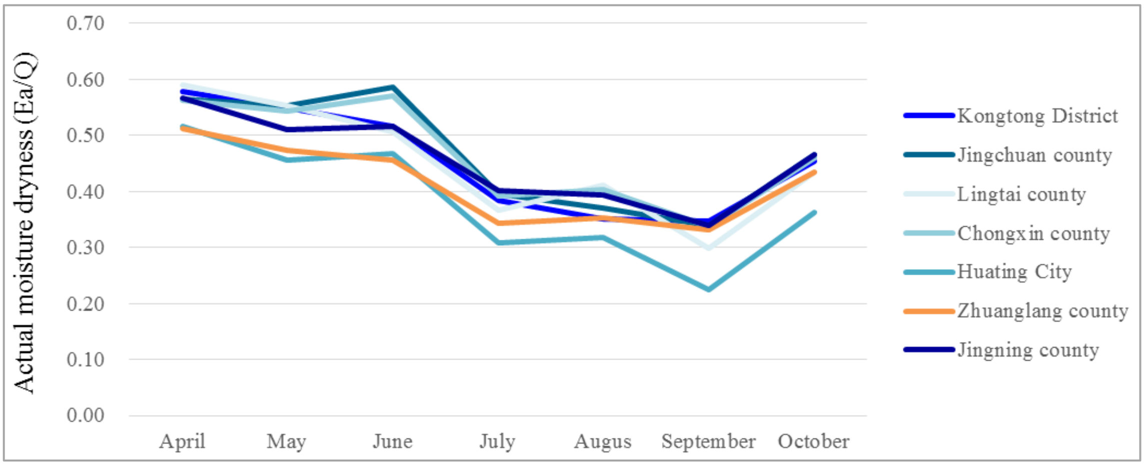

Figure 4. Spatial-temporal heterogeneity of actual moisture dryness in the growing period of shrubland in Pingliang City.

There were significant differences in the degree of water stress to shrubland in different ranges in this region (see Figure 4), which were as follows: (1) Inter-monthly changes: the mean dryness index from April to October was 0.56, 0.52, 0.52, 0.37, 0.37, 0.32 and 0.44, respectively, as shown in Table 11. (2) Spatiotemporal difference: in April, the highest value of k appeared in Lingtai County (0.59), followed by Kongtong District (0.58), Jingning County (0.57), Jingchuan County (0.56), Chongxin County (0.56) and Huating City (0.52), and the lowest value appeared in Zhuanglang County (0.51). In May, the highest value of k appeared in Kongtong District (0.55), Jingchuan County (0.55) and Lingtai County (0.55), followed by Chongxin County (0.54), Jingning County (0.51) and Zhuanglang County (0.47), and the lowest value appeared in Huating City (0.45). In June, the highest value of k appeared in Jingchuan County (0.59), followed by Chongxin County (0.57), Kongtong District (0.52), Jingning County (0.52), Lingtai County (0.51) and Huating City (0.47), and the lowest value appeared in Zhuanglang County (0.46). In July, the maximum value of k appeared in Jingchuan County (0.40) and Jingning County (0.40), followed by Chongxin County (0.39), Kongtong District (0.38), Lingtai County (0.37) and Zhuanglang County (0.34), and the minimum value appeared in Huating City (0.31). In August, the highest value of k appeared in Lingtai County (0.41), followed by Chongxin County (0.40), Jingning County (0.39), Jingchuan County (0.37), Kongtong District (0.35) and Zhuanglang County (0.35), and the lowest value appeared in Huating City (0.32). In September, the highest value of k appeared in Kongtong District (0.35), followed by Jingchuan County (0.34), Jingning County (0.34), Chongxin County (0.34), Zhuanglang County (0.33) and Lingtai County (0.30), and the lowest value appeared in Huating City (0.22). k value increased rapidly in October, with the highest value appearing in Jingchuan County (0.47) and Jingning County (0.47), followed by Chongxin County (0.46), Kongtong District (0.45), Lingtai County (0.43) and Zhuanglang County (0.43), and the lowest value appearing in Huating City (0.36).

***Table 11**. Temporal and spatial changes of shrub k value.*

Month	KT	JC	LT	CX	HT	ZL	JN	Average
April	0.58	0.56	0.59	0.56	0.52	0.51	0.57	0.56
May	0.55	0.55	0.55	0.54	0.45	0.47	0.51	0.52
June	0.52	0.59	0.51	0.57	0.47	0.46	0.52	0.52
July	0.38	0.40	0.37	0.39	0.31	0.34	0.40	0.37
Augus	0.35	0.37	0.41	0.40	0.32	0.35	0.39	0.37
September	0.35	0.34	0.30	0.34	0.22	0.33	0.34	0.32
October	0.45	0.47	0.43	0.46	0.36	0.43	0.47	0.44
Mean value	0.45	0.47	0.45	0.47	0.38	0.41	0.46	0.44

5.1.3. Grass

In this paper, the medium coverage grassland (20% ~ 50% coverage) was taken as an example. Water dryness coefficient (k), water relative surplus (mm) and water supply coefficient of grassland with medium coverage (20%-50% coverage) in different regions of this region are shown in Table 12.

***Table 12**. Analysis of monthly evapotranspiration balance of grassland with coverage of 20%-50% in different regions during the growing period.*

Ad-ministrative region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k) Evapotranspiration precipitation ratio		Moisture relative surplus (mm) Difference between precipitation and evapotranspiration		Water supply rate	
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
KT	4	15.31	22.46	33	0.46	0.68	17.69	10.54	0.54	0.32
	5	20.09	28.66	45.7	0.44	0.63	25.61	17.04	0.56	0.37
	6	26.15	36.28	63.2	0.41	0.57	37.05	26.92	0.59	0.43
	7	33.34	41.88	107	0.31	0.39	73.66	65.12	0.69	0.61
	8	31.25	38.44	108.6	0.29	0.35	77.35	70.16	0.71	0.65
	9	23.37	28.66	82.2	0.28	0.35	58.83	53.54	0.72	0.65
	10	15.02	19.82	41.2	0.36	0.48	26.18	21.38	0.64	0.52
	subtotal	164.54	216.19	480.9	0.34	0.45	316.36	264.71	0.66	0.55
JC	4	16.01	23.16	35.4	0.45	0.65	19.39	12.24	0.55	0.35
	5	21.23	30.42	47.9	0.44	0.64	26.67	17.48	0.56	0.36
	6	26.79	39.56	57	0.47	0.69	30.21	17.44	0.53	0.31
	7	35.97	45.59	111.9	0.32	0.41	75.93	66.31	0.68	0.59

Administrative region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k)		Moisture relative surplus (mm)		Water supply rate	
					Evapotranspiration precipitation ratio		Difference between precipitation and evapotranspiration			
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
	8	34.61	43.09	114.7	0.30	0.38	80.09	71.61	0.70	0.62
	9	25.68	31.33	92.2	0.28	0.34	66.52	60.87	0.72	0.66
	10	15.85	21.11	42.4	0.37	0.50	26.55	21.29	0.63	0.50
	subtotal	176.14	234.26	501.5	0.35	0.47	325.36	267.24	0.65	0.53
LT	4	15.62	23.16	33	0.47	0.70	17.38	9.84	0.53	0.30
	5	21.23	30.42	47.9	0.44	0.64	26.67	17.48	0.56	0.36
	6	28.76	39.56	70.9	0.41	0.56	42.14	31.34	0.59	0.44
	7	35.66	44.32	119	0.30	0.37	83.34	74.68	0.70	0.63
	8	33.66	43.09	101.2	0.33	0.43	67.54	58.11	0.67	0.57
	9	26.36	31.33	106.6	0.25	0.29	80.24	75.27	0.75	0.71
	10	16.21	21.11	46.3	0.35	0.46	30.09	25.19	0.65	0.54
	subtotal	177.51	232.99	524.9	0.34	0.44	347.39	291.91	0.66	0.56
CX	4	16.04	23.16	35.6	0.45	0.65	19.56	12.44	0.55	0.35
	5	20.81	29.53	47.9	0.43	0.62	27.09	18.37	0.57	0.38
	6	26.42	38.44	57.8	0.46	0.67	31.38	19.36	0.54	0.33
	7	35.08	44.32	110.3	0.32	0.40	75.22	65.98	0.68	0.60
	8	32.87	41.88	100.4	0.33	0.42	67.53	58.52	0.67	0.58
	9	24.95	30.42	89.9	0.28	0.34	64.95	59.48	0.72	0.66
	10	15.42	20.46	41.7	0.37	0.49	26.28	21.24	0.63	0.51
	subtotal	171.60	228.21	483.6	0.35	0.47	312.00	255.39	0.65	0.53
HT	4	14.28	19.82	34.5	0.41	0.57	20.22	14.68	0.59	0.43
	5	19.22	25.39	52.5	0.37	0.48	33.28	27.11	0.63	0.52
	6	24.92	33.24	66.4	0.38	0.50	41.48	33.16	0.62	0.50
	7	31.22	37.34	122.5	0.25	0.30	91.28	85.16	0.75	0.70
	8	29.28	35.24	111.7	0.26	0.32	82.42	76.46	0.74	0.68
	9	23.01	26.18	120.1	0.19	0.22	97.09	93.92	0.81	0.78
	10	14.54	18.03	49	0.30	0.37	34.46	30.97	0.70	0.63
	subtotal	156.47	195.24	556.7	0.28	0.35	400.23	361.46	0.72	0.65
ZL	4	14.35	19.82	35	0.41	0.57	20.65	15.18	0.59	0.43
	5	18.94	25.39	49.8	0.38	0.51	30.86	24.41	0.62	0.49

Administrative region	month	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k) Evapotranspiration precipitation ratio		Moisture relative surplus (mm) Difference between precipitation and evapotranspiration		Water supply rate	
		Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
		Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
	6	25.12	33.24	68.4	0.37	0.49	43.28	35.16	0.63	0.51
	7	30.51	37.34	108.1	0.28	0.35	77.59	70.76	0.72	0.65
	8	29.47	36.28	102.1	0.29	0.36	72.63	65.82	0.71	0.64
	9	22.22	26.98	81.5	0.27	0.33	59.28	54.52	0.73	0.67
	10	14.29	18.61	40.8	0.35	0.46	26.51	22.19	0.65	0.54
	subtotal	154.91	197.67	485.7	0.32	0.41	330.79	288.03	0.68	0.59
JN	4	13.25	19.21	29.2	0.45	0.66	15.95	9.99	0.55	0.34
	5	18.98	26.18	46.5	0.41	0.56	27.52	20.32	0.59	0.44
	6	23.96	33.24	57.9	0.41	0.57	33.94	24.66	0.59	0.43
	7	29.36	37.34	90.2	0.33	0.41	60.84	52.86	0.67	0.59
	8	27.86	35.24	87.2	0.32	0.40	59.34	51.96	0.68	0.60
	9	20.82	25.39	74.9	0.28	0.34	54.08	49.51	0.72	0.66
	10	13.52	18.03	36.1	0.37	0.50	22.58	18.07	0.63	0.50
	subtotal	147.75	194.63	422	0.35	0.46	274.25	227.37	0.65	0.54
Average of Pingliang City	4	13.81	19.21	33.2	0.42	0.58	19.39	13.99	0.58	0.42
	5	18.91	25.71	48	0.39	0.54	29.09	22.29	0.61	0.46
	6	24.09	32.27	63.4	0.38	0.51	39.31	31.13	0.62	0.49
	7	29.97	36.49	108.5	0.28	0.34	78.53	72.01	0.72	0.66
	8	28.02	34.03	102.7	0.27	0.33	74.68	68.67	0.73	0.67
	9	21.33	25.09	91	0.23	0.28	69.67	65.91	0.77	0.72
	10	13.52	17.13	42.1	0.32	0.41	28.58	24.97	0.68	0.59
	subtotal	149.64	189.92	488.9	0.31	0.39	339.26	298.98	0.69	0.61

Remark: KT, JC, LT, CX, HT, ZL and JN in the table are abbreviations of Kongtong District, Jingchuan county, Lingtai county, Chongxin county, Huating City, Zhuanglang county and Jingning county respectively.

Table 13. Analysis of evapotranspiration balance of precipitation in the growing period of grassland with coverage of 20%-50% in different regions.

Administrative region	Evapotranspiration (mm)		Precipitation (mm)	Moisture dryness (k) Evapotranspiration precipitation ratio		Moisture relative surplus (mm) Difference between precipitation and evapotranspiration		Water supply rate	
	Actual evapotranspiration	Potential evapotranspiration		Actual evapotranspiration precipitation ratio	Potential evapotranspiration precipitation ratio	Difference between precipitation and actual evapotranspiration	Difference between precipitation and potential evapotranspiration	Actual water supply rate	Potential water supply rate
	Ea	Ep	Q	(Ea/Q)	Ep/Q	Q-Ea	Q-Ep	1-Ea/Q	1-Ep/Q
Kongtong District	164.54	216.19	480.90	0.34	0.45	316.36	264.71	0.66	0.55
Jingchuan county	176.14	234.26	501.50	0.35	0.47	325.36	267.24	0.65	0.53
Lingtai county	177.51	232.99	524.90	0.34	0.44	347.39	291.91	0.66	0.56
Chongxin county	171.60	228.21	483.60	0.35	0.47	312.00	255.39	0.65	0.53
Huating City	156.47	195.24	556.70	0.28	0.35	400.23	361.46	0.72	0.65
Zhuanglang county	154.91	197.67	485.70	0.32	0.41	330.79	288.03	0.68	0.59
Jingning county	147.75	194.63	422.00	0.35	0.46	274.25	227.37	0.65	0.54
The whole area	149.64	189.92	488.90	0.31	0.39	339.26	298.98	0.69	0.61

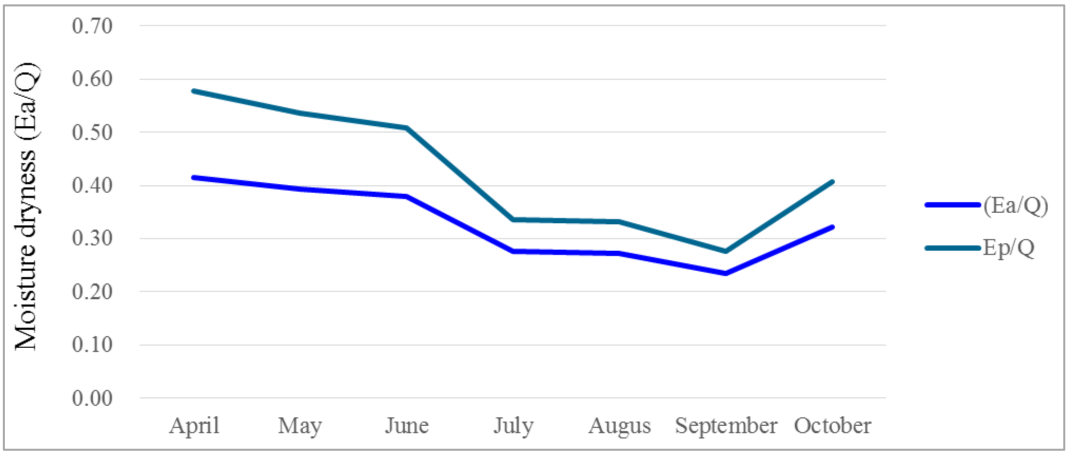

Figure 5. Intermonthly variation of moisture dryness in the medium coverage grassland (coverage 20% ~ 50%) during the growing period in Pingliang City.

Table 14. Linear regression relationship between evapotranspiration (y) and precipitation (x) of grassland with medium coverage (20%-50% coverage) in different administrative regions.

Administrative area	Actual evapotranspiration regression (y1)	Potential Evapotranspiration regression (y2)
Kongtong District	$y1 = 8.497 + 0.218x$ ($R^2 = 0.885$)	$y2 = 15.345 + 0.226x$ ($R^2 = 0.727$)
Jingchuan county	$y1 = 9.188 + 0.223x$ ($R^2 = 0.862$)	$y2 = 16.963 + 0.230x$ ($R^2 = 0.661$)
Lingtai county	$y1 = 9.499 + 0.215x$ ($R^2 = 0.812$)	$y2 = 17.054 + 0.217x$ ($R^2 = 0.628$)

Administrative area	Actual evapotranspiration regression (y1)	Potential Evapotranspiration regression (y2)
Chongxin county	y 1 = 8.410 + 0.233x (R^2 = 0.855)	y 2 = 15.504 + 0.247 x (R^2 = 0.670)
Huating City	y 1 = 10.186 + 0.153 x (R^2 = 0.728)	y 2 = 16.186 + 0.147 x (R^2 = 0.529)
Zhuanglang county	y 1 = 6.934+ 0.219 x (R^2 = 0.922)	y 2 = 11.696 + 0.238 x (R^2 = 0.838)
Jingning county	y 1 =6.377+ 0.244 x (R^2 = 0.870)	y 2 = 11.586 + 0.269 x (R^2 = 0.733)
The whole area of Pingliang City	y 1 = 8.320 + 0.191 x (R^2 = 0.826)	y 2 = 13.406 + 0.197 x (R^2 = 0.661)

From the Ea/Q curve in Figure 5, we can see: The inter-monthly variation process of moisture dryness in the growing period of medium coverage grassland (20% ~ 50% coverage) in this region is basically the same as that of forest and shrub, and the curve of moisture dryness index presents a process of decreasing first and then increasing, that is, in the first 3 months of April, May and June, the moisture dryness index is relatively high, and the average value of k value reaches 0.43. In this stage, the water stress was the strongest in the medium coverage grassland in this region, and the k value began to decline at the end of May and early June, and rapidly decreased from the end of June to the beginning of July. From July to September, the moisture dryness index was in the lowest range of the whole growth period, and the k value varied from 0.23 to 0.32, and the lowest value was 0.23 at the end of August and early September. From the beginning of September to the end of October, the k value gradually increased to 0.32, and the degree of water stress on the growth of medium coverage grassland began to increase again.

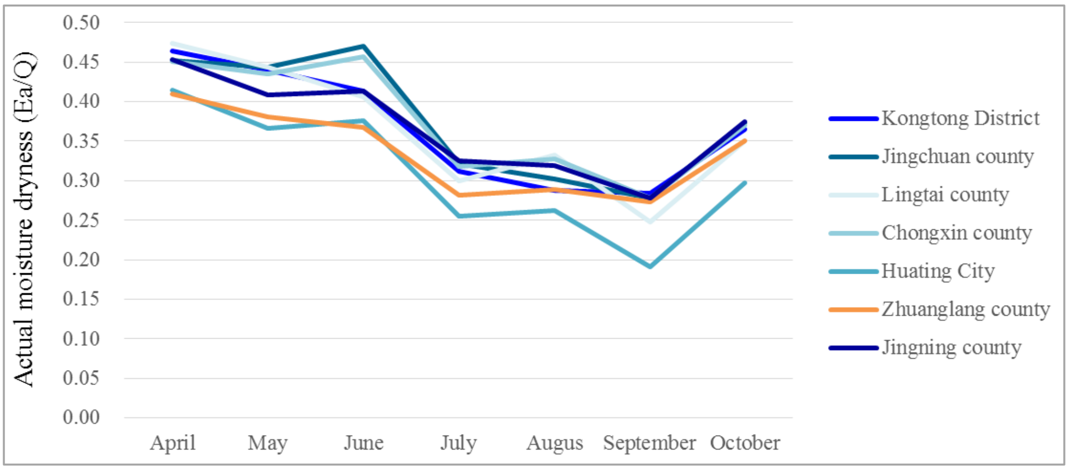

Figure 6. *Spatial-temporal heterogeneity of actual moisture dryness in the medium coverage grassland (20% ~ 50%) during the growing period in Pingliang City.*

There are obvious differences in the degree of water stress of grassland with medium coverage (20% ~ 50% coverage) in different areas of the region (see Figure 6), which are as follows: (1) Inter-monthly changes: the average dryness index from April to October is: 0.45, 0.42, 0.41, 0.30, 0.30, 0.26, 0.35, as shown in Table 15; (2) Spatial and temporal differences: in April, the highest k value appeared in Lingtai County (0.47), followed by Kongtong District (0.46), Jingning County (0.45), Jingchuan County (0.45), Chongxin County (0.45), and the lowest K value appeared in Huating City (0.41) and Zhuanglang County (0.41). In May, the highest k value appeared in Kongtong District (0.44), Lingtai County (0.44) and Jingchuan County (0.44), followed by Chongxin County (0.43), Jingning County (0.41) and Zhuanglang County (0.38), and the lowest K value appeared in Huating City (0.37). In June, the highest value of k appeared in Jingchuan County (0.47), followed by Chongxin County (0.46), Kongtong District (0.41), Lingtai County (0.41), Jingning County (0.41) and Huating City (0.38), and the lowest value appeared in Zhuanglang County (0.37). In July, the highest value of k appeared in Jingning County (0.33), followed by Jingchuan County (0.32), Chongxin County (0.32), Kongtong District (0.31), Lingtai County (0.30) and Zhuanglang County (0.28), and the lowest value appeared in Huating City (0.25). In August, the highest value of k appeared in Lingtai County (0.33) and Chongxin County (0.33), followed by Jingning County (0.32), Jingchuan County (0.30), Kongtong District (0.29) and Zhuanglang County (0.29), and the lowest value appeared in Huating City (0.26). In September, the highest k value appeared in Kongtong District (0.28), Jingchuan County (0.28), Jingning County (0.28) and Chongxin County (0.28), followed by Zhuanglang County (0.27) and Lingtai County (0.25), and the lowest K value appeared in Huating City (0.19). In October, k value increased rapidly, with the highest value appearing in Jingchuan County (0.37), Jingning County (0.37) and Chongxin County (0.37), followed by Kongtong District (0.36), Lingtai County (0.35) and Zhuanglang County (0.35), and the lowest value appearing in Huating City (0.30), as shown in Table 15.

Table 15. *Temporal and spatial changes of k value of grassland coverage.*

Month	KT	JC	LT	CX	HT	ZL	JN	Average
April	0.46	0.45	0.47	0.45	0.41	0.41	0.45	0.45
May	0.44	0.44	0.44	0.43	0.37	0.38	0.41	0.42
June	0.41	0.47	0.41	0.46	0.38	0.37	0.41	0.41
July	0.31	0.32	0.30	0.32	0.25	0.28	0.33	0.30
Augus	0.29	0.30	0.33	0.33	0.26	0.29	0.32	0.30
September	0.28	0.28	0.25	0.28	0.19	0.27	0.28	0.26
October	0.36	0.37	0.35	0.37	0.30	0.35	0.37	0.35
Mean value	0.37	0.38	0.36	0.38	0.31	0.34	0.37	0.36

5.2. Comparative Analysis of Moisture Dryness in the Growth Period of Different Types of Vegetation

Table 16. *Moisture dryness of different vegetation types during growth period in Pingliang City (Ea/Q).*

Month	Dryness of different types of vegetation			Average
	Woodland		Grassland	
	high-forest	shrubbery	Medium cover grassland	
April	0.56	0.52	0.42	0.46
May	0.53	0.49	0.39	0.44
June	0.51	0.47	0.38	0.42
∑April-June average	0.53	0.49	0.40	0.40
July	0.36	0.34	0.28	0.30
Augus	0.36	0.33	0.27	0.30
September	0.30	0.28	0.23	0.26
October	0.42	0.40	0.32	0.36
Mean value	0.43	0.40	0.33	0.36

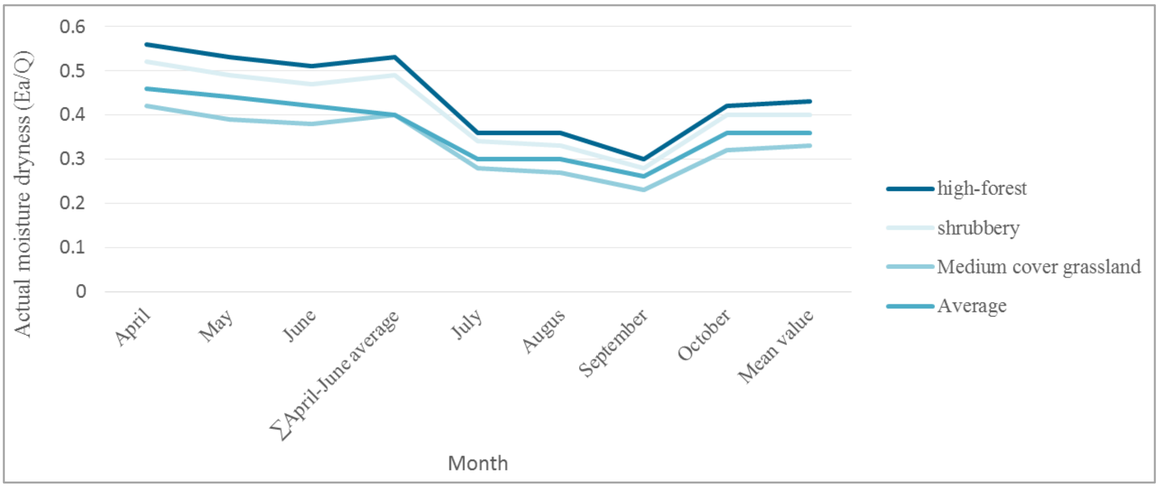

Figure 7. Monthly variation of moisture dryness index of different vegetation types in the growth period of Pingliang City.

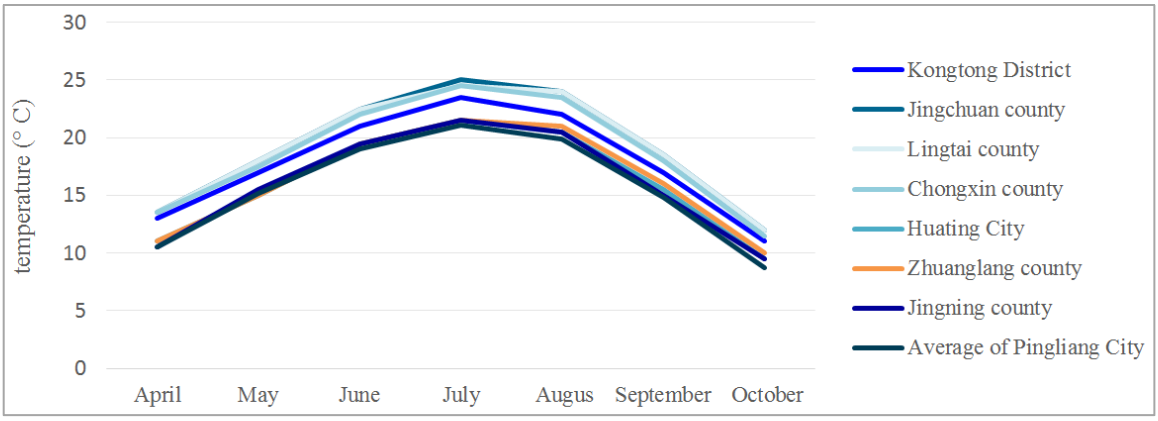

Figure 8. Annual average monthly temperature in various regions of Pingliang City during vegetation growth period.

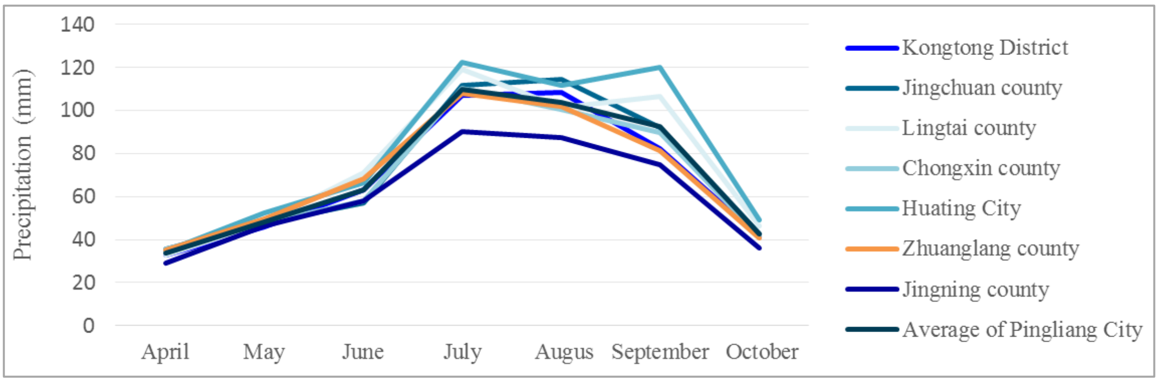

Figure 9. Annual average monthly precipitation of various regions in Pingliang City during vegetation growth period.

6. Conclusion

(1) The change trend and process of the moisture dryness index curve of all vegetation types in the growth period in this region are almost identical, showing a process of first decreasing and then increasing. That is to say, in the first three months of the growth period from April to June, most vegetation began to sprout and grow rapidly with the gradual increase of temperature due to the low natural precipitation. The enhanced transpiration of vegetation itself leads to a substantial increase in the actual evapo-transpiration water consumption of vegetation. Therefore, the moisture dryness index of vegetation is relatively high, with an average k value of 0.44. The average k value of

forest was 0.53, the average k value of shrub was 0.49, and the average k value of grassland was 0.40 (among which, the average k value of high-cover grassland was 0.41, the average k value of medium-cover grassland was 0.40, and the average k value of low-cover grassland was 0.39). In this stage, the forest forest suffered the strongest water stress in this region, followed by shrub and grassland. At the end of May and the beginning of June, with the increase of natural precipitation, the average k value of all types of vegetation began to decline, and from the end of June to the beginning of July, the average k value of all types of vegetation showed a rapid decline. From July to September, the flood season was fully entered in this region, the precipitation increased sharply, and the moisture dryness index was in the lowest value range of the whole growth period. The average k value ranges from 0.26 to 0.30, and the lowest value is 0.26 at the end of August and the beginning of September. From the beginning of September to the end of October, with the gradual decrease of precipitation, the average k value gradually increased, increasing to 0.36.

(2) In the monthly variation of k value, k tree forest >k shrub forest >k grassland, it is obvious that the water stress of forest forest is higher than that of shrub forest and grassland. It is no doubt that the grassland: $k_{\text{high cover}} > k_{\text{medium cover}} > k_{\text{low cover}}$, but the difference was not significant, relatively speaking, the grassland with high cover was more susceptible to environmental water stress. It is fully indicated that the difference of transpiration caused by the difference of vegetation types leads to the difference of actual evapotranspiration water consumption of different vegetation types. As can be seen from Figure 7.

Abbreviations

SPAC: Soil-plant-Atmosphere Circulatory System
Ea: Actual Evapotranspiration (mm)
Ep: Potential Evapotranspiration (mm)
Ea/Q: The ratio of Actual Evapotranspiration to Precipitation
Ep/Q: Ratio of Potential Evapotranspiration to Precipitation
TRHOSA: Saturated Vapor density at monthly Mean Temperature ($g.m^{-3}$)
TESA: Saturated Vapor Pressure (kpa) at a Specific Temperature
Tm: Average Monthly Temperature (℃)
KT: Kongtong Distric
JC: Jingchuan County
LT: Lingtai County
CX: Chongxin County
HT: Huating City
ZL: Zhuanglang County
JN: Jingning County

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Conflicts of Interest

The authors declare no conflicts of interest.

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