International Journal of Natural Resource Ecology and Management
2024, Vol. 9, No. 2, pp. 34-50
https://doi.org/10.11648/j.ijnrem.20240902.12

Research Article

Study on Ecological Water Demand Pressure of Forest and Grass Vegetation Construction in Northwest Loess Plateau Based on Fitting Verification

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Abstract

In this paper, the minimum ecological water requirement of forest and grass vegetation in different types and regions and small basins in Pingliang City was analyzed and evaluated by using the quota of water consumption for ecological construction. The actual evapotranspiration water consumption of different types of vegetation was used as the quota to calculate the appropriate ecological water demand of vegetation, and the actual evapotranspiration water consumption of vegetation was used as the quota to calculate the appropriate ecological water consumption of vegetation in this region. At the same time, in order to make the calculation result more accurate, the water consumption per unit area after the actual evapotranspiration of different regions and different types of vegetation is used as the calculation quota. In addition, according to the principles of similar vegetation types, similar site conditions and similar climate environment, the research results of He Wentao et al., Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, on the ecological water requirement of forest in the whole Jinghe River basin (He Wentao et al. Determination and calculation of ecological water requirement of forest vegetation, Journal of Soil and Water Conservation, 2004, 18(6)) were selected and compared with this study. This study verifies the reliability of the calculation results of evapotranspiration water consumption of vegetation in this area. It should be noted that He Wentao et al. also evaluated the ecological water requirement of vegetation in the whole Jinghe River basin by calculating the evapotranspiration water consumption of vegetation, and analyzed the vegetation ecological water requirement deficit in 2020 by comparing the calculated minimum ecological water requirement of vegetation in the region, so as to reflect the ecological water demand pressure faced by vegetation construction in the region. It provides a basic basis for coordinating the relationship between vegetation construction and water resources in this region.

Keywords

Forest and Grass Vegetation Construction, Ecological Water Requirement, Pressure Analysis, Loess Plateau

1. Introduction

The Loess Plateau is a typical ecologically sensitive area in China. Most areas of the Loess Plateau are arid and semi-arid areas, and water is the main factor restricting vegetation restoration [1-5]. According to the basic principle of "determining trees (grasses) by water", the balance between precipitation and evapotranspiration water consumption of vegetation should be maintained to the maximum extent, so as to meet the basic demand of water resources for vegetation construc-

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Received: 23 March 2024; **Accepted:** 6 May 2024; **Published:** 10 May 2024

tion [6-17]. Therefore, ensuring a certain supply of ecological water demand becomes the basic condition for regional ecological restoration [18, 22, 26, 32]. In many literatures [1-5, 17, 24, 25], ecological water demand is called ecological water or environmental water or ecological environmental water, which is classified according to the three levels of ecological elements. The micro-ecological water use in a region includes two parts: the ecological water use inside the river channel (basic river runoff, underground ecological water level, wetland water, evaporation leakage) and the ecological water use outside the river channel (urban ecological water use and artificial vegetation construction ecological water use). In general, ecological water demand (water use) can be completed by the natural water cycle under normal circumstances, but with the intensification of human activities and the enhancement of human interference on nature, it will inevitably lead to environmental destruction and degradation, and a large number of domestic and foreign studies agree that the restoration and reconstruction of degraded ecosystems first depends on vegetation restoration and reconstruction. And vegetation restoration must be guaranteed by water; At the same time, the shortage of water resources in degraded ecosystems has become powerless in nature, and objectively, human beings must be required to reallocate and adjust local water resources. Therefore, by analyzing and assessing the ecological water demand (water consumption) of vegetation restoration in this region, the purpose is to further understand the possible impact of vegetation restoration and construction on regional water resources and ecohydrology, as well as the impact of intra-regional water resources on vegetation restoration potential, so as to provide further support for the optimal allocation of regional and watershed water resources and the optimization of vegetation restoration structure.

Generally speaking, the ecological water requirement of vegetation includes the minimum ecological water requirement and the appropriate ecological water requirement [2-5, 25, 34]. Under specific climatic conditions, the water consumption necessary for the basic maintenance of the growth of different types of vegetation is called the minimum ecological water requirement. If the water consumption can maintain the natural growth of vegetation, stabilize the structure of vegetation, maintain the ecological process, and normally play the ecological functions of vegetation, it is called the suitable ecological water requirement of vegetation. That is to say, the amount of water that must be consumed to maintain the virtuous cycle of the vegetation ecosystem in the region [2-5, 21, 24, 25, 34]. According to the research on the relationship between vegetation water consumption and soil water content [8-10, 20, 34], the soil water content of forest and grassland is in the lower limit of wilting water content or growth retarding water content respectively under the conditions of minimum ecological water requirement and suitable ecological water requirement. Since evapotranspiration water consumption is the main water consumption expenditure item in vegetation ecosystem, the evapotranspiration water consumption of vegetation is regarded as the appropriate ecological water consumption for vegetation ecosystem to maintain structural stability and play normal ecological functions (Wang Yujuan et al., 2009, Geographical Research). In this study, the minimum ecological water requirement of different types of forest and grass vegetation in different regions and small watersheds in Pingliang City was analyzed and evaluated by using water quota - area method for ecological construction, and the actual evapotranspiration water consumption of different types of vegetation was used as the quota to calculate the appropriate ecological water requirement of vegetation [1-4, 13, 35].

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, a tributary of Weihe River system in the Yellow River Basin, and Hulu River Basin in the west. 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. Analysis and Assessment at Regional Scale

3.1. Minimum Ecological Water Consumption Quota of Vegetation in This Region

According to the research results of "Ecological Water Use and Vegetation Construction in the Loess Plateau Area" by Professor Wang Lixian of Beijing Forestry University [1], through a comprehensive analysis of the research results on

the impact of forest vegetation on water yield in the Yellow River Basin, it is concluded that: In the Loess Plateau, the ecological water used for the construction of forest in hilly areas is 15mm, equivalent to 150m^3/hm^2; the ecological water used for the construction of forest in plain areas above 400mm is 100mm, equivalent to 1000m^3/hm^2; and the ecological water used for artificial grass planting on the Loess Plateau is 5mm, equivalent to 50m^3/hm^2. As this research result has been verified by the practice of vegetation construction on the Loess Plateau with high reliability, it has been adopted by many scholars in the industry as the quota for calculating the minimum ecological water consumption of vegetation in this study. At the same time, according to Yu Xinxiao et al.'s 5-year observation study on the water consumption of choir-rigated forest land in Hantai District of western Shanxi [4, 8, 13], the results showed that the water consumption of shrub land in the growing season was 0.8 times that of tree land. Based on the climatic characteristics and geomorphic types of mountain areas in this region, the minimum ecological water consumption quota of vegetation in the Middle East Loess Plateau region of Longong is determined as follows (see Table 1):

Table 1. Minimum ecological water consumption quota (m^3/hm^2) for vegetation in different landforms in different river basins.

Vegetation type	Loess hilly and gully region (Hulu River Basin)	Loess Plateau gully region (Jinghe and Qianhe River basins)
high-forest	150	200
shrubbery	120	160
meadow	50	50
High cover grassland	50	50
Medium coverage grassland	40	45
Low cover grassland	30	40

3.2. Forest and Grass Vegetation Resource Data

Table 2. Different types of forest and grass vegetation resources in different basins and tributaries.

catchment	tributary	Total area of land (km^2)	Woodland (hm^2)	trees (hm^2)	shrubs (hm^2)	grassland	High Coverage Grassland (coverage greater than 50%) (hm^2)	Medium coverage grassland (20-50%) (hm^2)	Low Cover grassland (5-20%) (hm^2)
Jinghe river basin	Jing River main stream	2421.94	103721.45	67833.83	35887.62	17159.18	5147.75	8579.59	3431.84
	Houxia river	31.10	1550.42	1013.97	536.45	229.72	68.92	114.86	45.94
	Jie He	141.90	5761.67	3768.13	1993.54	1040.86	312.26	520.43	208.17
	The Rui River	1568.37	89314.66	58411.79	30902.87	11804.84	3541.45	5902.42	2360.97
	Honghe River	228.00	9148.43	5983.07	3165.36	1425.42	427.63	712.71	285.08
	Puhe	35.72	1144.98	748.82	396.16	366.04	109.81	183.02	73.21
	The Black River main	1406.82	71574.51	46809.73	24764.78	14509.20	4352.76	7254.60	2901.84

catchment	tributary	Total area of land (km^2)	Woodland (hm^2)	trees (hm^2)	shrubs (hm^2)	grassland	High Coverage Grassland (coverage greater than 50%) (hm^2)	Medium coverage grassland (20-50%) (hm^2)	Low Cover grassland (5-20%) (hm^2)
	Stream								
	Daxi River	1386.44	86990.16	56891.56	30098.60	11301.39	3390.42	5650.70	2260.28
	subtotal	7220.30	369206.28	241460.91	127745.37	57836.65	17351.00	28918.33	11567.33
	The main stream of the Hulu River	770.94	14660.30	9587.84	5072.46	3625.92	1087.78	1812.96	725.18
	Longtail	85.60	2689.92	1759.21	930.71	345.90	103.77	172.95	69.18
	Yuhe River	171.00	5093.77	3331.33	1762.44	273.26	81.98	136.63	54.65
	The dog baby River	210.40	5795.07	3789.98	2005.09	753.88	226.16	376.94	150.78
	High-boundary river	385.79	9951.47	6508.26	3443.21	1371.24	411.37	685.62	274.25
Hulu river basin	Gangou River	270.00	6997.29	4576.23	2421.06	616.98	185.09	308.49	123.40
	Ganwei River	161.83	3474.69	2272.45	1202.24	246.21	73.86	123.11	49.24
	Nanhe	422.67	12331.43	8064.76	4266.67	1052.70	315.81	526.35	210.54
	Trang Lang Ha	339.18	6089.70	3982.66	2107.04	920.75	276.23	460.38	184.15
	Shuiluo River	837.55	26315.35	17210.24	9105.11	2644.71	793.41	1322.36	528.94
	Qingshui River	61.70	1106.88	723.90	382.98	55.68	16.70	27.84	11.14
	subtotal	3716.66	94505.86	61806.83	32699.03	11907.24	3572.17	5953.62	2381.45
Qianhe river basin	Chihe	182.12	11624.34	7602.32	4022.02	1097.23	329.17	548.62	219.45
	subtotal	182.12	11624.34	7602.32	4022.02	1097.23	329.17	548.62	219.45
combination		11119.08	475336.49	310870.06	164466.43	70841.13	21252.34	35420.57	14168.23

* Note: The proportion of forest forest and shrub forest in the table is determined according to the proportion of shrub irrigation in the three adjustment data, the total area of forest land is 65.4% of forest forest, and the total area of shrub forest and other forest land is 34.6%; The proportion of high coverage grassland (coverage greater than 50%), medium coverage grassland (20-50%) and low coverage grassland (5-20%) were 30%, 50% and 20%, respectively.

Table 3. Different types of forest and grass vegetation resources in different administrative regions.

Administrative region	Total area of land (km^2)	Woodland (hm^2)	trees (hm^2)	shrubs (hm^2)	grassland	High Coverage Grassland (coverage greater than 50%) (hm^2)	Medium coverage grassland (20-50%) (hm^2)	Low Cover grassland (5-20%) (hm^2)
Kongtong District	1930.31	83460.38	54583.09	28877.29	15585.16	4675.55	7792.58	3117.03
Jingchuan county	1461.20	69850.82	45682.44	24168.38	8644.42	2593.33	4322.21	1728.88
Lingtai county	1976.16	108536.51	70982.88	37553.63	20909.22	6272.77	10454.61	4181.84
Chongxin county	848.41	49034.47	32068.54	16965.93	6378.31	1913.49	3189.16	1275.66
Huating City	1201.32	69083.99	45180.93	23903.06	7712.79	2313.84	3856.40	1542.56
Zhuanglang county	1513.61	37555.86	24561.53	12994.33	5498.36	1649.51	2749.18	1099.67
Jingning county	2188.06	57814.46	37810.66	20003.80	6112.87	1833.86	3056.44	1222.57
Pingliang City	11119.08	475336.49	310870.06	164466.43	70841.13	21252.34	35420.57	14168.23

3.3. Calculation Results of the Minimum Ecological Water Consumption of Vegetation in the Region

3.3.1. Minimum Ecological Water Consumption Structure of Vegetation in the Basin

According to the area quota method, the total minimum ecological water consumption of vegetation in the whole basin of Pingliang City is 87.260,000 m^3, of which the minimum ecological water consumption of vegetation in the Jinghe River basin is 71,363 million m^3, accounting for 81.83%, and the minimum ecological water consumption of vegetation in the Hulu River basin is 13.6836 million m^3, accounting for 15.69%. The Qianhe river basin is 2,213,900 m^3, accounting for 2.48%. In the distribution of minimum ecological water consumption, the total water consumption of forest land was 84,0903,300 m^3, accounting for 96.37% of the total water consumption, among which, the ecological water consumption of forest land was 5908.37m^3 and that of shrub land was 2500.67m^3. The total ecological water consumption of grassland was 3.169,700 m^3, accounting for 3.63% of the total ecological water consumption, among which: The ecological water consumption of the high coverage grassland (more than 50%) was 1,0662,600 m^3, accounting for 33.52% of the total ecological water consumption of the grassland; the ecological water consumption of the medium coverage grassland (20-50%) was 1,564,200 m^3, accounting for 49.35% of the total ecological water consumption of the grassland; the ecological water consumption of the low coverage grassland (5-20%) was 542,900 m^3. It accounted for 17.13% of the total ecological water consumption of grassland.

The ecological water consumption of vegetation in the Jinghe River Basin is 20.89 million m^3, Houxia River 299,100 million m^3, Jie River 1,121 million m^3, Rui River 17,163,900 million m^3, Honghe 1,7679,900 million m^3, Puhe 229,800 million m^3, Heihe main stream 13,9845 million m^3, Daxi River 16,708,300 million m^3. The ecological water consumption of vegetation in the Jinghe River basin is mainly in the Jinghe River, Daxi River, Rui River and Heihe River.

The ecological water consumption of each tributary in the Hulu River Basin is as follows: The main stream of the Hulu River is 2.195,500 m^3, the Changwei River is 389,700 m^3, the Yuhe River is 722,400 m^3, the Guwazi River is 842,400 m^3, the Gaojie River is 1.445,600 m^3, the Gangou River is 100.23 million m^3, the Ganwei River is 495,200 million m^3, the Nanhe River is 1.764,900 million m^3, the Zhuanglang River is 888,800 m^3, and the Shuiluo River is 378. 260,000 m^3, Qingshui River 156,800 m^3. The water consumption of vegetation in the Hulu River basin is mainly in the main stream of the Hulu River, Shuiluo River, Nanhe River, Gaojie River, Gangou River, Zhuanglang River and Guwazi River.

The minimum ecological water consumption of vegetation in Qianhe River Basin is 2,213,900 m^3.

The minimum ecological water consumption of different types of vegetation in different river basins is shown in Table 4.

Table 4. *Minimum ecological water consumption of different types of vegetation in different river basins (10,000 m^2).*

catch-ment	tributary	Minimum total eco-logical water use	Minimum ecological water consumption of different types of vegetation						
			Woodland	trees	shrubs	grassland	High Coverage Grassland (coverage greater than 50%)	Medium cover-age grassland (20-50%)	Low Cover grassland (5-20%)
Jinghe river basin	Jing River main stream	2008.95	1930.88	1356.68	574.20	78.07	25.74	38.61	13.73
	Houxia river	29.91	28.86	20.28	8.58	1.05	0.34	0.52	0.18
	Jie He	112.00	107.26	75.36	31.90	4.74	1.56	2.34	0.83
	The Rui River	1716.39	1662.68	1168.24	494.45	53.71	17.71	26.56	9.44
	Honghe River	176.79	170.31	119.66	50.65	6.49	2.14	3.21	1.14
	Puhe	22.98	21.31	14.98	6.34	1.67	0.55	0.82	0.29
	The Black River main Stream	1398.45	1332.43	936.19	396.24	66.02	21.76	32.65	11.61
	Daxi River	1670.83	1619.41	1137.83	481.58	51.42	16.95	25.43	9.04
	subtotal	7136.30	6873.14	4829.22	2043.93	263.16	86.75	130.13	46.27
Hulu river basin	The main stream of the Hulu River	219.55	204.69	143.82	60.87	14.87	5.44	7.25	2.18
	Longtail	38.97	37.56	26.39	11.17	1.42	0.52	0.69	0.21
	Yuhe River	72.24	71.12	49.97	21.15	1.12	0.41	0.55	0.16
	The dog baby River	84.00	80.91	56.85	24.06	3.09	1.13	1.51	0.45
	High-boundary river	144.56	138.94	97.62	41.32	5.62	2.06	2.74	0.82
	Gangou River	100.23	97.70	68.64	29.05	2.53	0.93	1.23	0.37
	Ganwei River	49.52	48.51	34.09	14.43	1.01	0.37	0.49	0.15
	Nanhe	176.49	172.17	120.97	51.20	4.32	1.58	2.11	0.63
	Trang Lang Ha	88.80	85.02	59.74	25.28	3.78	1.38	1.84	0.55
	Shuiluo River	378.26	367.41	258.15	109.26	10.84	3.97	5.29	1.59
	Qingshui River	15.68	15.45	10.86	4.60	0.23	0.08	0.11	0.03
	subtotal	1368.31	1319.49	927.10	392.39	48.82	17.86	23.81	7.14
Qianhe river basin	Chihe	221.39	216.40	152.05	64.35	4.99	1.65	2.47	0.88
	subtotal	221.39	216.40	152.05	64.35	4.99	1.65	2.47	0.88
combination		8726.00	8409.03	5908.37	2500.67	316.97	106.26	156.42	54.29

3.3.2. Minimum Ecological Water Consumption Structure of Vegetation in Administrative Region

According to the calculation, the minimum ecological water consumption of vegetation in Kongtong District, Jingchuan County, Lingtai County, Chongxin County, Huating City, Zhuanglang County and Jingning County are as follows: 16,246,100 million m^3, 13,396,700 million m^3, 21.156,500 million m^3, 9,418,500 million m^3, 13,216,160 million m^3, 6,697,100 million m^3 and 8,322,700 million m^3, accounting for: 18.37%, 15.15%, 23.92%, 10.65%, 14.94%, 7.57%, 9.41%. It can be seen that the ecological water consumption of vegetation is mainly concentrated in Lingtai County, Kongtong District, Jingchuan County and Huating City in the Jinghe River basin, among which the ecological water consumption of vegetation is the largest in Lingtai County and the smallest in Jingning County. The minimum ecological water consumption of vegetation in each administrative region is shown in Table 5.

Table 5. Minimum ecological water consumption of different types of vegetation in administrative regions (10,000 m^2).

Administrative region	Minimum total ecological water use	Minimum ecological water consumption of different types of vegetation						
		Woodland	trees	shrubs	grassland	High Coverage Grassland (coverage greater than 50%)	Medium coverage grassland (20-50%)	Low Cover grassland (5-20%)
Kongtong District	1624.61	1553.70	1091.66	462.04	70.91	23.38	35.07	12.47
Jingchuan county	1339.67	1300.34	913.65	386.69	39.33	12.97	19.45	6.92
Lingtai county	2115.65	2020.52	1419.66	600.86	95.14	31.36	47.05	16.73
Chongxin county	941.85	912.83	641.37	271.45	29.02	9.57	14.35	5.10
Huating City	1321.16	1286.07	903.62	382.45	35.09	11.57	17.35	6.17
Zhuanglang county	669.71	647.16	491.23	155.93	22.54	8.25	11.00	3.30
Jingning county	832.27	807.21	567.16	240.05	25.06	9.17	12.23	3.67
Pingliang City	8844.92	8527.82	6028.35	2499.47	317.10	106.26	156.49	54.35

Note: Although the total area of forest and grass vegetation is the same, due to the cross-watershed boundary problem of vegetation distribution, the ecological water consumption calculated by administrative region and watershed area is slightly different, and the total ecological water consumption of vegetation is 1,189,200 m^3. The average minimum ecological water consumption of forest and grass in Pingliang City was 87,854,600 m^3.

3.4. Analysis and Assessment of Suitable Ecological Water Use of Forest and Grass Vegetation at Regional Scale

3.4.1. Determination of Appropriate Ecological Water Consumption Quota for Vegetation

As mentioned above, the suitable ecological water consumption of vegetation refers to the water that must be consumed to maintain the normal growth of vegetation and enable the vegetation ecosystem to perform its ecological functions normally, and the actual evapotranspiration water consumption of vegetation can best reflect the transpiration water consumption that must be consumed during the normal growth of vegetation and the evaporation consumption of forest and grassland soil. Therefore, the actual evapotranspiration water consumption of vegetation is taken as the quota to calculate the suitable ecological water consumption of vegetation in this region. In order to make the calculation results more accurate, the water consumption per unit area after the actual evapotranspiration of different regions and different types of vegetation is used as the calculation quota, and the data in Table 6 is converted to the data in Table 7, and the unit

of ecological water consumption is m^3/hm^2.

Table 6. Actual evapotranspiration (mm) of different vegetation types in different regions and different river basins in different growth periods.

Vegetation type	Kongtong District	Jingchuan County	Lingtai County	Chongxin County	Huating City	Zhuanglang County	Jingning County	Jing River basin	Hulu river basin
high-forest	217.46	232.85	234.35	227.18	203.89	204.28	195.80	223.15	200.04
shrubbery	203.17	217.68	219.00	212.32	190.60	190.65	182.86	208.56	186.75
High cover grass-land	168.56	180.51	181.83	175.87	159.91	158.55	151.41	173.34	154.98
Medium coverage grassland	164.54	176.14	177.51	171.60	156.47	154.91	147.75	169.25	151.33
Low cover grass-land	160.39	171.63	173.06	167.18	152.96	151.18	143.99	165.05	147.58
Grassland average	164.50	176.09	177.47	171.55	156.45	154.88	147.72	169.21	151.30

Table 7. Suitable ecological water consumption per unit area of vegetation in different regions and different river basins (m^3/hm^2).

Vegetation type	Administrative						watershed		
	Kongtong District	Jingchuan County	Lingtai County	Chongxin County	Huating City	Zhuanglang County	Jingning County	Jing River basin	Hulu river basin
high-forest	2174.61	2328.48	2343.55	2271.82	2038.89	2042.82	1958.01	2231.47	2000.41
shrubbery	2031.74	2176.81	2190.03	2123.20	1906.04	1906.45	1828.59	2085.57	1867.52
meadow	1644.97	1760.94	1774.66	1715.51	1564.47	1548.81	1477.17	1692.11	1512.99
High cover grassland	1685.60	1805.06	1818.30	1758.73	1599.07	1585.49	1514.12	1733.35	1549.80
Medium cover-age grassland	1645.38	1761.42	1775.11	1715.97	1564.73	1549.11	1477.55	1692.52	1513.33
Low cover grassland	1603.93	1716.33	1730.59	1671.81	1529.62	1511.83	1439.85	1650.46	1475.84

3.4.2. Calculation Results of Suitable Ecological Water Consumption of Vegetation

(i). Suitable Ecological Water Consumption Structure of Vegetation in Watershed

According to the area quota method, the total amount of suitable ecological water consumption for vegetation in the region was 1133,325,800 m^3 (see Table 8), among which, the suitable ecological water consumption for vegetation in the Jinghe River basin was 903,346,300 m^3, accounting for 79.71%, and the suitable ecological water consumption for vegetation in the Hulu River basin was 202,765,700 m^3, accounting for 17.89%. The Qianhe river basin is 27.2138 million m^3, accounting for 2.40%. In the allocation of suitable ecological water consumption, the total water consumption of forest land was 1015.2923 million m^3, accounting for 89.59% of the total water consumption, among which: the ecological water consumption of forest forest was 67941.61 m^3, and that of shrub forest was 33587.62 m^3. The total ecological water consumption of grassland was 118,033,500 m^3, accounting for 10.41% of the total ecological water consumption, among which: The ecological water consumption of high coverage grassland (more than 50%) was 36.1821 million m^3, that of medium coverage grassland (20-50%) was 58.8832 million m^3, and that of low coverage grassland (5-20%) was 22.96882 million m^3. It accounted for 30.65%, 49.89% and 19.46% of the ecological water consumption of grassland, respectively.

Table 8. Suitable ecological water consumption of different types of vegetation in different river basins (10,000 m^3).

catch-ment	tributary	Total amount of water suitable for eco-logical use	Minimum ecological water consumption of different types of vegetation						
			Woodland trees		shrubs	grassland	High Coverage Grassland (cover-age greater than 50%)	Medium cov-erage grassland (20-50%)	Low Cover grassland (5-20%)
Jinghe river basin	Jing River main stream	25532.34	22621.53	15136.92	7484.61	2910.81	892.29	1452.11	566.41
	Houxia river	377.11	338.14	226.27	111.88	38.97	11.95	19.44	7.58
	Jie He	1433.18	1256.61	840.85	415.77	176.57	54.13	88.08	34.36
	The Rui River	21481.95	19479.43	13034.42	6445.01	2002.52	613.86	999.00	389.67
	Honghe River	2237.06	1995.26	1335.10	660.16	241.80	74.12	120.63	47.05
	Puhe	311.81	249.72	167.10	82.62	62.09	19.03	30.98	12.08
	The Black River main Stream	18071.60	15610.32	10445.45	5164.87	2461.28	754.49	1227.86	478.94
	Daxi River	20889.57	18972.45	12695.18	6277.27	1917.12	587.68	956.39	373.05
	subtotal	90334.63	80523.47	53881.28	26642.19	9811.16	3007.53	4894.48	1909.14
Hulu river basin	The main stream of the Hulu River	3415.22	2865.25	1917.96	947.29	549.97	168.58	274.36	107.03
	Longtail	578.19	525.73	351.91	173.81	52.47	16.08	26.17	10.21
	Yuhe River	1036.99	995.54	666.40	329.14	41.45	12.70	20.68	8.07
	The dog baby River	1246.95	1132.61	758.15	374.46	114.35	35.05	57.04	22.25
	High-boundary river	2152.93	1944.95	1301.92	643.03	207.99	63.75	103.76	40.47
	Gangou River	1461.15	1367.57	915.43	452.14	93.58	28.69	46.68	18.21
	Ganwei River	716.45	679.10	454.58	224.52	37.34	11.45	18.63	7.27
	Nanhe	2569.76	2410.09	1613.28	796.81	159.67	48.94	79.65	31.07
	Trang Lang Ha	1329.85	1190.19	796.70	393.49	139.66	42.81	69.67	27.18
	Shuiluo River	5544.29	5143.15	3442.75	1700.40	401.14	122.96	200.12	78.06
	Qingshui River	224.78	216.33	144.81	71.52	8.45	2.59	4.21	1.64
	subtotal	20276.57	18470.51	12363.90	6106.61	1806.06	553.61	900.98	351.46
Qianhe river basin	Chihe	2721.38	2535.25	1696.43	838.82	186.13	57.06	92.85	36.22
	subtotal	2721.38	2535.25	1696.43	838.82	186.13	57.06	92.85	36.22
combination		113332.58	101529.23	67941.61	33587.62	11803.35	3618.21	5888.32	2296.82

(ii). Suitable Ecological Water Consumption Structure of Vegetation in Different Administrative Zones

According to the calculation, the total amount of suitable ecological water consumption for vegetation in Pingliang City is 1135.87800 million m^3, among which, the suitable ecological water consumption for vegetation in Kongtong District, Jingchuan County, Lingtai County, Chongxin County, Huating City, Zhuanglang County and Jingning County are: 203,076,600 m^3, 174,242,400 m^3, 285,796,100 m^3, 119,846,600 m^3, 149,772,800 m^3, 83,484,300 m^3 and 119,665,200 m^3, accounting for: 17.88%, 15.34%, 25.16%, 10.55%, 13.19%, 7.35%, 10.54%. It can be seen that the ecological water consumption of vegetation is mainly concentrated in Lingtai County, Kongtong District, Jingchuan County and Huating City within the Jinghe River basin, of which Lingtai County is the largest and Zhuanglang County is the smallest. The suitable ecological water consumption of vegetation in each administrative region is shown in Table 9.

As the minimum ecological water consumption of vegetation is the same, due to the fact that some vegetation crosses the watershed boundary, the suitable ecological water consumption of vegetation calculated by administrative area is different from that calculated by subwatershed area. According to the average value of the two, the total suitable ecological water consumption of forest and grass vegetation in Pingliang City is 1134,601,900 m^3 (see Table 9).

Table 9. Suitable ecological water consumption of different types of vegetation in different administrative regions (10,000 m^3).

Administrative region	Total amount of water suitable for ecological use	Minimum ecological water consumption of different types of vegetation						
		Woodland	trees	shrubs	grassland	High Coverage Grassland (coverage greater than 50%)	Medium coverage grassland (20-50%)	Low Cover grassland (5-20%)
Kongtong District	20307.06	17736.82	11869.70	5867.12	2570.24	788.11	1282.18	499.95
Jingchuan county	17424.24	15898.07	10637.06	5261.01	1526.17	468.11	761.32	296.73
Lingtai county	28579.61	24859.53	16635.16	8224.37	3720.08	1140.57	1855.80	723.71
Chongxin county	11984.66	10887.61	7285.41	3602.20	1097.05	336.53	547.25	213.27
Huating City	14977.28	13767.90	9211.88	4556.03	1209.37	370.00	603.42	235.95
Zhuanglang county	8348.43	7494.77	5017.47	2477.31	853.66	261.53	425.88	166.25
Jingning county	11966.52	11061.21	7403.35	3657.87	905.30	277.67	451.60	176.03
Pingliang City	113587.80	101705.92	68060.02	33645.90	11881.87	3642.53	5927.45	2311.89

3.4.3. Difference Analysis at Regional Scale

Due to the difference in the concept and calculation quota of ecological water use, the same area quota method leads to great differences in the calculation results of the two kinds of ecological water use, and the suitable ecological water use of vegetation is much larger than the minimum ecological water use. By calculation, the optimum ecological water consumption is 12.85 times of the minimum ecological water consumption, of which the average difference of forest ecological water consumption is 11.97 times, the average difference of forest ecological water consumption is 11.29 times, the average difference of shrub water consumption is 13.72 times, and the difference of grassland is the largest, reaching 37.23 times.

3.4.4. Verification and Analysis of Ecological Water Consumption of Forest and Grass Vegetation

In order to verify the reliability of the calculation results of evapotranspiration water consumption of vegetation in this

study, according to the principles of similar vegetation types, similar site conditions, and similar climate environment, we selected the research results of He Wentao et al., Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences, on the ecological water requirement of woodland in the whole Jinghe River basin (Determination and Calculation of ecological water requirement of forest vegetation, Journal of Soil and Water Conservation). 18 (6), 2004) was compared with this study [24, 25]. He Wentao et al. also evaluated the ecological water requirement of vegetation in the whole Jinghe River basin by calculating evapotranspiration water consumption of vegetation.

(i). Ecological Water Consumption During the Growth Period of Forest in Jinghe River Basin (He Wentao et al.)

Table 10. Ecological water consumption data of arbor forest in the whole Jinghe River basin (He Wentao et al.).

Regiona	Forest area (km^2)	April	May	June	July	August	Septem-ber	October	total growth period
Jing River main stream	3464.8	10860	13160	18740	18880	18150	11340	8490	99620
Tributaries of the Jing River	3577.8	11750	14150	19580	19440	18400	12020	9010	104350
total	7042.6	22610	27310	38320	38320	36550	23360	17500	203970
Monthly water consumption coefficient (%)		11.08	13.39	18.79	18.79	17.92	11.45	8.58	100.00
Ecological water requirement per unit area (m^3/hm^2)		321.05	387.78	544.12	544.12	518.98	331.70	248.49	2896.23

(ii). Evapotranspiration Water Consumption in Vegetation Growth Period Was Studied

Table 11. Monthly evapotranspiration water consumption of forest and grass vegetation in Pingliang City.

Vegetation type	April	May	June	July	August	September	October	Cumulative quantity (mm)
high-forest	18.43	25.24	32.13	39.06	36.48	27.26	17.87	196.47
shrubbery	17.24	23.58	29.99	36.45	34.05	25.52	16.66	183.50
High coverage grassland (more than 50% coverage)	14.18	19.41	24.71	30.60	28.61	21.73	13.84	153.08
Medium coverage grassland (20% ~ 50% coverage)	13.81	18.91	24.09	29.97	28.02	21.33	13.52	149.64
Low coverage grassland (coverage 5% ~ 20%)	13.43	18.40	23.44	29.32	27.42	20.92	13.19	146.12
Grassland average	13.81	18.91	24.08	29.96	28.02	21.32	13.52	149.62

(iii). Fitting Analysis and Verification of Vegetation Water Consumption Coefficient

Firstly, by calculating the water consumption coefficient (%) of the vegetation growth period in each month of the vegetation in this study and the control area, the difference of the water consumption characteristics of the vegetation in this area and the control vegetation was tested.

Table 12. *Comparison between evapotranspiration water consumption coefficient (%) of vegetation growth period in Pingliang City and forest and grassland ecological water consumption coefficient (%) in the control area (the whole Jinghe River basin).*

Comparative	Vegetation type	Monthly water consumption coefficient (%)							
		April	May	June	July	August	September	October	subtotal
Control 1	Jing River whole basin woodland	11.08	13.39	18.79	18.79	17.92	11.45	8.58	100.00
Control 2	Jinghe river whole basin grassland	8.50	8.60	21.40	21.50	20.00	12.00	8.00	100.00
This study	high-forest	9.38	12.85	16.35	19.88	18.57	13.87	9.10	100.00
	shrubbery	9.40	12.85	16.34	19.87	18.56	13.91	9.08	100.00
	meadow	9.23	12.64	16.09	20.03	18.73	14.25	9.03	100.00
	High coverage grassland (more than 50% coverage)	9.27	12.68	16.14	19.99	18.69	14.19	9.04	100.00
	Medium coverage grassland (20% ~ 50% coverage)	9.23	12.64	16.10	20.02	18.73	14.25	9.03	100.00
	Low coverage grassland (coverage 5% ~ 20%)	9.19	12.59	16.05	20.06	18.77	14.32	9.03	100.00

Through one-way ANOVA, Shapiro-Wilk test was not passed ($P < 0.050$), which fully indicated that the monthly evapotranspiration water consumption of different types of vegetation in this area was not significantly different from the monthly water consumption coefficient of forest and grassland in the Jinghe River basin in the control area. It can also be seen from the figure (see Figure 1) of evapotranspiration water consumption coefficient (%) of forest and grass vegetation in the growth period (April to October) in the Jinghe River Basin and that of the control area (the whole Jinghe River Basin), except that the ecological water consumption of grassland in the Jinghe River Basin in April and May is different from that of vegetation in the Jinghe River Basin, the monthly water consumption of other types of vegetation is basically the same. In the vegetation growth period, evapotranspiration was the lowest in early April and before hibernation in October, and water consumption increased greatly in May and June with the gradual increase of temperature and precipitation, and reached the maximum in July and August, with no significant difference in the ecological water consumption coefficient of each month. It shows that the water consumption characteristics of vegetation in this study are almost similar to that of forest and grassland in the whole Jinghe River basin.

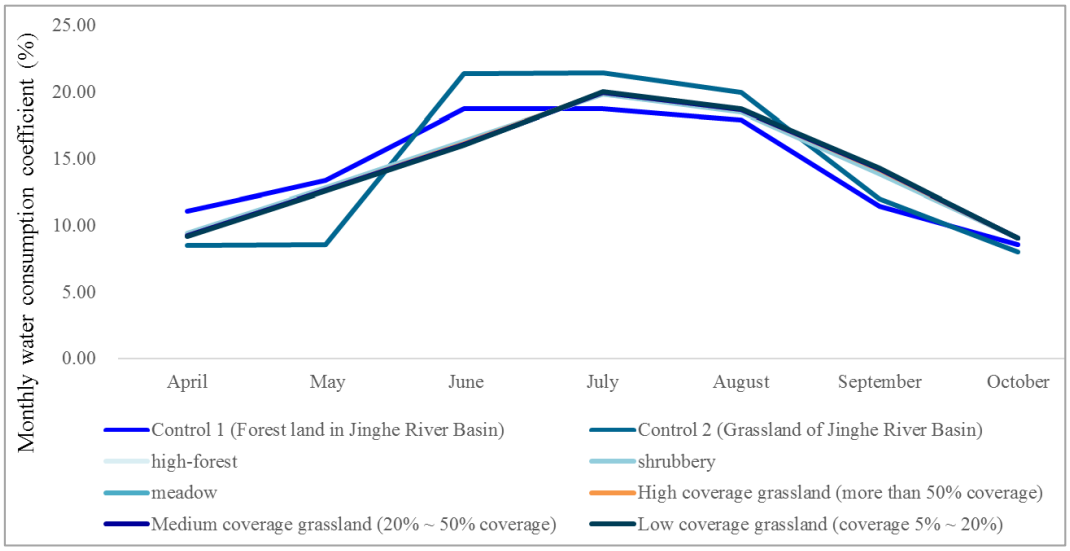

Figure 1. *Evapotranspiration water consumption coefficient of vegetation growth period (April to October) and ecological water consumption coefficient of forest and grassland in the control area (the whole Jinghe River Basin) (%).*

(iv). Comparative Analysis and Verification of Ecological Water Consumption of Vegetation

In this study, the actual evapotranspiration of forest in different regions calculated by Zhang's climate model was converted into evapotranspiration water consumption, which was compared with the results of He Wentao et al. 's research on ecological water consumption of forest in the whole Jinghe River basin (see Table 13): The average evapotranspiration water consumption per unit area in Pingliang City is not significantly different from the ecological water demand per unit area in Jinghe River Basin. The difference is large from April to August, and there is almost no difference from September to October. The difference of total water consumption in growth period is 730.78m^3/hm^2, which is mainly caused by the higher climate characteristic values of temperature and precipitation in Jinghe River basin than that in Jinghe River basin. The total area of the Jinghe River basin is more than 76,000 km^2, and the average annual rainfall reaches more than 600mm, which runs through 31 counties (cities) in Ningxia, Gansu and Shaanxi. It can be seen from Table 13 that the water consumption of Kongtong District, Jingchuan County, Chongxin County, Lingtai County and Huating City is close to the ecological water consumption of the whole Jinghe river basin, especially Lingtai County, where the water consumption per unit area is only 552.68m^3/hm^2. As mentioned above, due to the small variable decreasing trend of vegetation ecological water consumption from southeast to northwest of the whole basin, the ecological water consumption of vegetation growth period in this area is slightly lower than that of forest land ecological water consumption of Jinghe River basin in the control area is completely reasonable. It can be inferred that the results of ecological water consumption of vegetation calculated in this study are reliable and accord with the characteristics of vegetation types and climate in this region.

Table 13. *Comparison of ecological water requirement per unit area (m^3/hm^2) between the whole Jinghe River basin and the local area.*

Comparative		April	May	June	July	August	September	October	Growing period
Jing River Basin (control)		321.05	387.78	544.12	544.12	518.98	331.7	248.49	2896.23
This study	Kongtong District	203.42	267.64	348.98	439.79	409.14	305.56	200.08	2174.61
	Jingchuan county	213	282.82	355.49	475.67	455.16	335.05	211.29	2328.48
	Lingtai county	207.2	282.82	383.85	468.76	446.11	339.22	215.6	2343.55
	Chongxin county	213.45	277.43	351.29	463.51	435.22	325.41	205.52	2271.82
	Huating City	190.63	256	332.28	403.25	379.48	286.29	190.96	2038.89
	Zhuanglang county	191.48	252.68	334.69	398.62	385.99	289.29	190.07	2042.82
	Jingning county	176.27	253.33	319.72	388.58	368.17	271.61	180.32	1958.01
	Average in Pingliang City	199.35	267.53	346.61	434.03	411.32	307.49	199.12	2165.45
Difference between average in Pingliang City and control		-121.70	-120.25	-197.51	-110.09	-107.66	-24.21	-49.37	-730.78

(v). Relationship Between Ecological Water Use of Forest and Grass Vegetation and Regional Water Resources

Generally speaking, the water resources of a region are consumed in two aspects: first, the precipitation forms surface runoff, soil flow and underground flow and forms river runoff, which is discharged to the outside of the region through the horizontal direction; The second is the vertical return to the atmosphere in the form of evaporation and emission. Because of the close relationship between natural river runoff and human production and life, natural river runoff is generally regarded as a narrow sense of water resources. The relationship between ecological water consumption and water resources is based on two aspects: first, ecological water consumption includes natural ecological water and artificial ecological water; Second, the amount of water resources is natural river runoff. As a result:

a) Natural Ecological Water Consumption Has Been Included in the Amount of Water Resources.

The amount of water resources deducted from the natural ecological water consumption, the amount of water resources obtained is called the amount of available water resources, then the artificial ecological water consumption needs to be considered in the amount of available water resources.

b) The amount of water resources is the runoff of rivers in the natural state, while the artificial ecological water use

is the result of human activities. Its water consumption should be guaranteed from the amount of available water resources. Therefore, the artificial ecological water consumption should be considered in the process of water resource allocation.

c) Generally speaking, ecological environmental water use includes urban green space ecological water use and ecological water use for vegetation construction. This study focuses on ecological water use for vegetation construction, which is mainly used for soil and water conservation forest and grass and shelter forest construction.

4. Analysis of Ecological Water Requirement of Artificial Forest and Grass in This Region

Table 14. Minimum ecological water requirement of different types of artificial forest and grass in Pingliang City.

Artificial vegetation type		Minimum ecological water consumption ($104m^3$)	proportion (%)
Artificial forest land	Artificial arboreal forest	4762.15	91.07
	Artificial shrub	362.60	6.93
	subtotal	5124.74	98.00
Artificial grassland	High coverage (coverage greater than 50%)	27.50	0.53
	Medium coverage (20-50%)	67.48	1.29
	Low coverage (5-20%)	9.37	0.18
	subtotal	104.34	2.00
total		5229.08	100.00

According to the area quota method, the minimum ecological water requirement of various types of vegetation in the total minimum ecological water requirement of vegetation in the whole basin of Pingliang City and the proportion of artificial vegetation in the data of the third National land survey of Pingliang City, the minimum ecological water requirement of artificial forest and grass vegetation in the region was deduced, as shown in the table. Among them, the proportion of different coverage (coverage greater than 50%), medium coverage (20-50%) and low coverage (5-20%) in artificial grassland is calculated according to 30%, 50% and 20% respectively. By calculation, the total minimum ecological water requirement of artificial vegetation is 52.2908 million m^3, accounting for 59.93% of the total minimum ecological water requirement of total vegetation of 87.26 million m^3 in Pingliang City. Among the minimum ecological water requirement allocation of artificial vegetation, artificial forest land was 5.2474 million m^3, accounting for 98% (among which, artificial forest was 47.621,500 m^3, accounting for 91.07%; 69,300 m^3 (6.93%) of artificial shrubland; Artificial grassland was 1.0434 million m^3, accounting for 2.0% (among which, high coverage grassland was 275,000 m^3, accounting for 0.53%; medium coverage grassland was 674,800 m^3, accounting for 1.29%; low coverage grassland was 93,700 m^3, accounting for 0.18%). The minimum ecological water requirement of different types of artificial vegetation in Pingliang City is shown in Table 14.

As can be seen from Table 14, the ecological water consumption of the artificial forest and grass vegetation in Pingliang City is mainly concentrated in the artificial tree forest and shrubland, and the ecological water consumption of artificial grassland is very small.

5. Analysis of Allocation of Ecological Water in Water Resources

5.1. Water Resources of Pingliang City

According to the Water Resources Development Plan of Pingliang City, the average annual inflow of natural water resources in Pingliang City is 591 million m^3, the amount of self-produced water resources is 647 million m^3, the total amount of surface water resources is 1.238 billion m^3, the amount of groundwater resources is 357 million m^3, and the total amount of surface water and groundwater resources is 15.95m^3, that is, the total amount of generalized water resources. Surface water resources amounted to 647 million m^3, accounting for 91.90%; groundwater resources

(without double counting) amounted to 57 million m^3, accounting for 8.10%; total water resources amounted to 704 million m^3, of which 516 million m^3 was in Jinghe River basin, accounting for 73.30%; and 188 million m^3 was in Hulu River basin, accounting for 26.10%; The surface water resources can be used by 587 million m^3, with a utilization rate of 47.40%, among which the Jinghe River basin is 477 million m^3, with a utilization rate of 51.85%, and the Hulu River is 110 million m^3, with a utilization rate of 34.70%.

5.2. Planning Value of Ecological Water Use in the Comprehensive Water Resources Planning of Pingliang City

According to the comprehensive water resources planning of Pingliang City, the ecological water consumption of the city in the base year is only 5.01 million m^3, the ecological water consumption in 2020 is 9 million m^3, and the ecological water consumption in 2030 is 12.6 million m^3. The planned values of ecological water consumption in different river basins and administrative districts are 0 and 0 in different level years (see Table 15).

Table 15. Planned annual ecological water consumption of different levels in Pingliang City (10,000 m^3).

subzone			Base year	2020	2030
catchment	Jinghe river basin	Jing River main stream	394	570	726
		river	49	89	129
		Heihe	10	21	32
		Daxi River	11	40	65
		subtotal	465	720	951
	Hulu river basin	The main stream of the Hulu River	19	86	143
		Nanhe Zhuanglang River Luo River	18	95	167
		subtotal	37	180	310
subzone	Kongtong District		359	500	611
	Jingchuan county		53	91	143
	Lingtai county		11	43	70
	Chongxin county		10	26	42
	Huating City		31	60	84
	Zhuanglang county		18	87	151
	Jingning county		19	93	159
	Pingliang City		501	900	1260

* Note: Data from Pingliang Comprehensive Water Resources Planning

5.3. Pressure Analysis of Ecological Water Demand for Vegetation Construction

According to the comparison of the minimum ecological water requirement of vegetation in the city, without considering the ecological water consumption for urban green space construction and maintenance and the fact that the coverage rate of forest and grass will no longer increase, the ecological water requirement of vegetation in 2020 will be 432,290,800 m^3, and the ecological water requirement of vegetation in 2030 will be 39.690,800 m^3.

If the forest and grass coverage rate of the whole city (the whole basin) is increased by 1%, the forest and grass measure area will be correspondingly increased by 111.19km^2. Under the condition that the vegetation type and structure ratio of each small watershed remain basically unchanged, the ecological water consumption will be increased by 1,595,800 m^3 according to the minimum ecological water demand quota of different watershed and different vegetation types. For the increased ecological water consumption of different types of vegetation in each watershed zone.

6. Conclusion

Through the analysis of ecological water consumption of forest and grass vegetation in this area, the results show that:

1) The total minimum ecological water requirement of vegetation in the whole basin of Pingliang City is 87.26 million m^3, of which the minimum ecological water requirement of vegetation in the Jinghe River basin is 71.63 million m^3, accounting for 81.83%; the minimum ecological water requirement of vegetation in the Hulu River basin is 13.6836 million m^3, accounting for 15.69%; the minimum ecological water requirement of vegetation in the Qianhe River basin is 2,213,900 million m^3. The proportion was 2.48%. In the distribution of minimum ecological water demand, the total water demand of forest land was 84,0903,300 m^3, accounting for 96.37% of the total water demand, among which: the ecological water demand of forest land was 5908.37m^3, and that of shrub land was 2500.67m^3. The total ecological water demand of grassland was 3.169,700 m^3, accounting for 3.63% of the total ecological water demand, among which: The ecological water requirement of the high coverage grassland (more than 50%) was 1,0662,600 m^3, accounting for 33.52% of the total ecological water requirement of the grassland; the ecological water requirement of the medium coverage grassland (20-50%) was 1,564,200 m^3, accounting for 49.35% of the total ecological water requirement of the grassland; the ecological water requirement of the low coverage grassland (5-20%) was 542,900 m^3. It accounted for 17.13% of the total ecological water demand of grassland.
2) The total minimum ecological water demand of artificial vegetation in Pingliang City is 52.2908 million m^3, accounting for 59.93% of the total minimum ecological water demand of total vegetation in Pingliang City is 87.26 million m^3. Among the minimum ecological water requirement allocation of artificial vegetation, artificial forest land was 5.2474 million m^3, accounting for 98% (among which, artificial forest was 47.621,500 m^3, accounting for 91.07%; 69,300 m^3 (6.93%) of artificial shrubland; Artificial grassland was 1.0434 million m^3, accounting for 2.0% (among which, high coverage grassland was 275,000 m^3, accounting for 0.53%; medium coverage grassland was 674,800 m^3, accounting for 1.29%; low coverage grassland was 93,700 m^3, accounting for 0.18%).
3) According to the analysis of ecological water demand pressure for vegetation construction, the ecological water demand deficit of vegetation in 2020 is 432,298,800 m^3, and that in 2030 is 39,698,800 m^3, without considering the ecological water consumption for urban green space construction and maintenance and the no longer increasing coverage rate of forest and grass. If the city's forest and grass coverage rate is increased by 1%, the minimum ecological water consumption that needs to be increased every year is 1,595,800 m^3, which is used as a reference basis for ecological water allocation in the future optimal allocation of water resources.

Acknowledgments

This paper is one of the phased achievements of the 2023 Gansu Science and Technology Plan project "Study on Evapotranspiration Characteristics of Forest and grass Vegetation based on Water Resources Coupling Relationship" (23JRRL0006) and 2021 Pingliang City science and technology plan project "Research and Demonstration of Key Technologies for Forest and Grass Vegetation Restoration and Reconstruction based on ecological protection with high quality development in Pingliang City ([2021] No. 2).

Conflicts of Interest

The authors declare no conflicts of interest.

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