Spatiotemporal Characteristics of Wheat Water Requirement and Water Deficit in Gansu Province, 1967–2017: Postprint

Authors: Zhang Hua, Wang Hao, Zhang Hua

Date: 2019-09-11T00:00:00+00:00

Abstract

Based on daily meteorological data from 28 weather stations in Gansu Province during 1967–2017, wheat water requirement was calculated using the Penman-Monteith formula and crop coefficients. Effective precipitation was computed using the method recommended by the United States Department of Agriculture Soil Conservation Service, and wheat water deficit was subsequently derived. The temporal trends and spatial distribution characteristics of wheat water requirement and water deficit were analyzed, and the relative importance of influencing factors was discussed. The results indicate that: during 1967–2017, the annual average water requirement for spring wheat and winter wheat throughout their entire growth periods in Gansu Province was 517.03 mm and 436.70 mm, respectively, while the annual average water deficit was 468.24 mm and 301.54 mm, respectively. Temporally, over the 51-year period, no significant trend was observed in water requirement and water deficit in spring wheat cultivation areas overall, whereas both water requirement and water deficit in winter wheat cultivation areas exhibited a significant upward trend. Spatially, water requirement and water deficit in spring wheat cultivation areas generally decreased from northwest to southeast, while those in winter wheat cultivation areas generally decreased from west to east. Sunshine duration and daily mean temperature during the wheat growth period were the primary factors influencing wheat water requirement in Gansu Province.

Full Text

Abstract

Using daily meteorological data from 28 stations in Gansu Province, China, spanning 1967–2017, this study calculated wheat water requirements during the growing period using the Penman-Monteith formula. Effective precipitation

during the entire wheat growing period was calculated based on the method recommended by the USDA Soil Conservation Bureau, allowing determination of wheat water deficits throughout its life cycle. The analysis examined variation trends and spatial distribution characteristics of water requirements and deficits for both spring and winter wheat, as well as the factors influencing water demand. Results showed that from 1967 to 2017, the annual average water requirement for spring wheat and winter wheat in Gansu Province was 517.03 mm and 436.70 mm, respectively, while the annual average water deficit was 468.24 mm and 301.54 mm, respectively. Over the past 51 years, no significant change occurred in water requirements and deficits in spring wheat planting areas, whereas winter wheat planting areas exhibited a significant increasing trend. Spatially, water requirements and deficits in spring wheat areas gradually decreased from northwest to southeast, while those in winter wheat areas gradually decreased from west to east. Sunshine hours and daily average temperature during the wheat growth period in Gansu Province were the primary factors affecting wheat water requirements.

Keywords: Penman-Monteith formula; water requirement; water deficit; effective precipitation; Gansu Province

1. Introduction

Accurate calculation of crop water requirements is fundamental for efficient agricultural water management and irrigation system design. The Penman-Monteith formula, recommended by the Food and Agriculture Organization (FAO), has become the standard method for calculating reference evapotranspiration (ET) worldwide. In arid and semi-arid regions like Gansu Province, understanding spatial-temporal variations in wheat water requirements is crucial for sustainable water resource allocation.

Previous studies have examined crop water requirements in various regions of China. Cao et al. [**?**] analyzed effective rainfall and water demand characteristics for major crops in Hebei Province. Liu et al. [**?**] investigated changes in water requirements for main crops in North China over 50 years. Hu et al. [**?**] studied water requirements in the Shiyang River Basin. Yang et al. [**?**] examined water balance and spatial-temporal distribution patterns of wheat in Gansu Province. However, systematic analysis of long-term trends and spatial patterns for both spring and winter wheat across Gansu Province remains limited.

2. Data and Methods

2.1 Data Sources

The study utilized daily meteorological data from 28 meteorological stations in Gansu Province from 1967 to 2017, including precipitation, temperature, sunshine hours, wind speed, and relative humidity. Phenological data for wheat growth stages were obtained from agricultural observation stations.

2.2 Calculation Methods

2.2.1 Reference Evapotranspiration (ET)

The FAO-56 Penman-Monteith equation was employed to calculate daily ET :

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where R_n is net radiation, G is soil heat flux, T is mean daily air temperature, u_2 is wind speed at 2 m height, e_s is saturation vapor pressure, e_a is actual vapor pressure, Δ is the slope of the vapor pressure curve, and γ is the psychrometric constant.

2.2.2 Crop Water Requirement (ETc)

Crop water requirement was calculated using the crop coefficient method:

$$ET_c = K_c \times ET_0$$

where K_c is the crop coefficient varying by growth stage. Table 1 presents the phenological information and K_c values for meteorological stations in Gansu Province.

2.2.3 Effective Precipitation

Effective precipitation during the wheat growing period was calculated using the USDA Soil Conservation Bureau method, which considers precipitation intensity and soil water storage capacity.

2.2.4 Water Deficit

Water deficit was calculated as the difference between crop water requirement and effective precipitation.

2.2.5 Trend Analysis

The Mann-Kendall test was used to detect trends in water requirements and deficits at a significance level of $\alpha = 0.01$. The test statistic and its significance were calculated for each station.

3. Results

3.1 Temporal Variation Characteristics

3.1.1 Spring Wheat

From 1967–2017, the average water requirement for spring wheat in Gansu Province was 517.03 mm, with a maximum of 572.97 mm in 1974 and a minimum of 462.80 mm in 1993. The Mann-Kendall test showed no significant trend (%

+ (% 9& £*Æ, ‰Œ 0.01 5H@ (cid:242)(cid:243) R%&). The UF and UB statistics intersected in 2002, indicating a potential change point.

3.1.2 Winter Wheat

The average water requirement for winter wheat was 436.70 mm, with a maximum of 539.24 mm and a minimum of 353.56 mm. Unlike spring wheat, winter wheat showed a significant increasing trend (% & |/¸!012¡@ Q(cid:238)). The water deficit also increased significantly, particularly after 2002.

3.2 Spatial Distribution Characteristics

3.2.1 Spring Wheat

Water requirements and deficits for spring wheat decreased gradually from northwest to southeast across Gansu Province. The northwestern arid regions showed the highest values, exceeding 600 mm, while southeastern areas had relatively lower requirements around 400 mm.

3.2.2 Winter Wheat

For winter wheat, water requirements and deficits decreased from west to east. Western regions including Wuwei, Jinchang, and Zhangye showed higher values (450–500 mm), while eastern areas like Qingyang and Pingliang had lower requirements (350–400 mm).

3.3 Correlation with Meteorological Factors

Correlation analysis revealed that sunshine hours and daily average temperature during the growth period were the primary factors affecting wheat water requirements. Table 3 shows the correlation coefficients between water requirements and major meteorological factors.

Table 3. Correlation degree of wheat water requirement and major meteorological factors

Factor	Spring Wheat	Winter Wheat
Sunshine hours	0.822	0.786
Temperature	0.825	0.843
Precipitation	-0.0435**	0.0352**
Wind speed	0.0003	0.0005

Note: ** indicates significance at $P < 0.01$ level.

3.4 Propensity Rate of Meteorological Factors

The propensity rates of meteorological factors during the wheat growing period were analyzed (Table 4). Sunshine hours showed decreasing trends in most

stations, while temperature exhibited significant increasing trends, particularly in winter wheat growing areas.

4. Discussion

The spatial distribution patterns align with Gansu Province' s climatic zones. Northwestern regions have an arid climate with high evapotranspiration, leading to greater water requirements. The increasing trend in winter wheat water requirements reflects climate change impacts, particularly rising temperatures during the growth period.

The FAO-56 methodology provides reliable estimates, but local calibration of crop coefficients could improve accuracy. Previous studies in the Heihe River Basin [**?**] and Shiyang River Basin [**?**] reported similar spatial patterns, validating our results.

Water deficit calculations indicate that precipitation meets less than 20% of spring wheat water requirements in most areas, highlighting the critical role of irrigation. For winter wheat, effective precipitation contributes 30–40% of water needs, particularly in eastern regions.

5. Conclusions

(1) From 1967–2017, the annual average water requirement for spring wheat and winter wheat in Gansu Province was 517.03 mm and 436.70 mm, respectively, while water deficits were 468.24 mm and 301.54 mm, respectively.

(2) No significant trend was detected in spring wheat water requirements, whereas winter wheat showed a significant increasing trend, particularly after 2002.

(3) Spatially, spring wheat water requirements decreased from northwest to southeast, while winter wheat requirements decreased from west to east.

(4) Sunshine hours and daily average temperature were the dominant meteorological factors influencing wheat water requirements.

(5) The substantial water deficits underscore the need for improved irrigation management and water-saving agricultural practices in Gansu Province.

References

[1] Cao Yongqiang, Zhu Mingming, Li Weijia. Characteristics of effective rainfall and water demand of main crops in typical areas of Hebei Province[J]. Acta Ecologica Sinica, 2018, 38(2): 560–570.

[2] Liu Xiaoying, Li Yuzhong, Hao Weiping. Changes and causes of water demand of main crops in North China in recent 50 years[J]. Transactions of the Chinese Society of Agricultural Engineering, 2005, 21(10): 155–159.

[3] Hu Zhiqiao, Tian Xiaohong, Zhang Jiudong, et al. Study on water requirement and water requirement of main crops in Shiyang River Basin[J]. Agricultural Research in the Arid Areas, 2011, 29(3): 1-6.

[4] Yang Yanzhao, Feng Zhiming, Lin Yaoming. Water balance and spatial-temporal distribution pattern of wheat in Gansu Province[J]. Geographical Research, 2005, 24(6): 853-859.

[5] Gansu Provincial Bureau of Statistics. Gansu development yearbook 2017[M]. Beijing: China Statistics Press, 2018.

[6] Katerji N, Rana G. FAO-56 methodology for determining water requirement of irrigated crops: Critical examination of the concepts, alternative proposals and validation in Mediterranean region[J]. Theoretical & Applied Climatology, 2014, 116(3-4): 515-536.

[7] Song Ni, Sun Jingsheng, Wang Jinglei, et al. Spatial and temporal changes of water requirement of winter wheat in Henan Province and its influencing factors[J]. Chinese Journal of Applied Ecology, 2014, 25(6): 1693-1700.

[8] Fu Na, Liu Xigang, Zhang Yan, et al. Changes of rice irrigation water requirement in Southwest China[J]. Chinese Journal of Ecology, 2014, 33(7): 1895-1901.

[9] Chen Chao, Pang Yanmei, Pan Xuebiao, et al. Characteristics of China' s cotton water requirement from 1961 to 2012[J]. Journal of Natural Resources, 2015, 30(12): 2107-2119.

[10] Provenzano G, González-Altozano P, Manzano-Juárez J, et al. Using FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region[C]//European Geosciences Union General Assembly, 2015.

[11] Zheng Dongfang, Xu Jiayang, Lu Xiuping, et al. Spatial and temporal characteristics of water requirement and irrigation demand index of flue-cured tobacco in Yunnan Province[J]. Chinese Journal of Applied Ecology, 2015, 26(7): 2091-2098.

[12] Wang Mei, Yang Qian, Zheng Jianghua, et al. Temporal and spatial distribution characteristics of cotton water demand in Xinjiang from 1963 to 2012[J]. Acta Ecologica Sinica, 2016, 36(13): 4122-4130.

[13] Luo Nana, Barker B. Temporal and spatial evolution of cotton crop water demand and its meteorological impact factors in Northern Xinjiang[J]. Chinese Journal of Applied Ecology, 2017, 28(10): 3305-3313.

[14] Er-Raki S, Chehbouni A, Guemouria A, et al. Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region[J]. Agricultural Water Management, 2007, 87(1): 0-54.

[15] Song Ge, Zeng Jicai, Wang Yan, et al. Estimation of water requirement of winter wheat in North China Plain based on NDVI[J]. Journal of Irrigation and

Drainage, 2014, 33(6): 1-5.

[16] Drerup P, Brueck H, Scherer H W. Evapotranspiration of winter wheat estimated with the FAO56 approach and NDVI measurements in a temperate humid climate of NW Europe[J]. Agricultural Water Management, 2017, 192: 180-188.

[17] Ma Lingling, Zhang Chesheng, Tang Lingli, et al. Review and prospect of research progress on crop water demand[J]. Arid Land Geography, 2005, 28(4): 115-121.

[18] Gansu Yearbook Editorial Board. Gansu yearbook[M]. Beijing: China Statistics Press, 2009: 34-35.

[19] Deng Zhenyong, Yin Dong, Zhang Yi. Study on wheat ecological climate suitable planting area in Gansu Province[J]. Meteorological Science and Technology, 2000, 24(1): 36-40.

[20] Department of Economic Geography, Institute of Geography, Chinese Academy of Sciences. Distribution of agricultural production in China[M]. Beijing: Agricultural Press, 1983: 30-53.

[21] Yang Qi, Zhang Bo, Yin Haixia, et al. The change trend and influence factors of wheat water requirement in Hedong area of Gansu Province in the past 50 years[J]. Chinese Journal of Ecology, 2013, 32(11): 3074-3081.

[22] Gansu Provincial Meteorological Bureau Business Management Office. Gansu Province agricultural meteorological observation data collection (1981—1985)[M]. Lanzhou: Lanzhou University Press, 1988: 7-97.

[23] Allen RG, Pereira LS, Raes D, et al. Crop evapotranspiration guidelines for computing crop water requirements. FAO irrigation and drainage paper 56[M]. Rome: Food and Agriculture Organization of the United Nations, 1998: 37-58.

[24] Liu Yu, Pereira LS. Verification of the calculation method of crop coefficient recommended by FAO[J]. Transactions of the Chinese Society of Agricultural Engineering, 2000, 16(5): 26-30.

[25] Brouwer C, Heibloem M. Irrigation water management: Irrigation water needs[J]. Training Manual, 1986.

[26] Smith M. CROPWAT: A computer program for irrigation planning and management[M]. Rome: Food and Agriculture Organization of the United Nations, 1992: 20-21.

[27] Döll P, Siebert S. Global modeling of irrigation water requirements[J]. Water Resources Research, 2002, 38(4): 8-1-8-10.

[28] Sneyers R. On the statistical analysis of series of observations[R]. Geneva, 1990.

[29] Wei Fengying. Modern climate statistical diagnosis and prediction technology[M]. Beijing: Meteorological Press, 1999: 62-76.

[30] Xu Jianhua. Mathematical methods in modern geography[M]. Beijing: Higher Education Press, 2002: 133-290.

[31] Chen Yaning, Xu Changchun, Yang Yuhui, et al. Changes of hydrology and water resources in Xinjiang and their responses to regional climate change[J]. Acta Geographica Sinica, 2009, 64(11): 1331-1341.

[32] Yin Yunhe, Wu Shaohong, Chen Gang. Regional differences of climate change trends and mutations in China from 1961 to 2006[J]. Journal of Natural Resources, 2009, 24(12): 2147-2157.

[33] Liu Sifeng, Xie Naiming. Grey system theory and its application[M]. 4th ed. Beijing: Science Press, 2008: 40-47.

[34] Ren Yuzhong, Dong Xingguang, Wang Zhiguo. Analysis of factors affecting reference crop evapotranspiration based on grey correlation analysis[J]. Chinese Agricultural Science Bulletin, 2010, 26(12): 376-379.

[35] Hao Zhenchun, Yang Rongrong, Chen Xinmei, et al. Temporal and spatial variation characteristics of potential evaporation in the Yangtze River Basin from 1960 to 2011[J]. Journal of Glaciology and Geocryology, 2013, 35(2): 408-419.

[36] Yin Haixia, Zhang Bo, Wang Yamin, et al. Analysis of the change trend of crop water requirement in the middle area of the Heihe River Basin in recent 43 years[J]. Resources Science, 2012, 34(3): 409-417.

[37] Wang Yao, Zhao Chuanyan, Tian Fengxia, et al. Spatial distribution of spring wheat water requirement in the middle reaches of the Heihe River[J]. Acta Ecologica Sinica, 2011, 31(9): 2374-2382.

Note: Figure translations are in progress. See original paper for figures.