ChinaRxiv

AI translation · View original & related papers at
chinarxiv.org/items/chinaxiv-202112.00108

Spatiotemporal Variation Characteristics of Water Surplus-Deficit in Xinjiang over the Past 53 Years (Postprint)

Authors: Lu Baobao

Date: 2021-12-12T00:00:00+00:00

Abstract

Based on daily meteorological data from 58 meteorological stations in Xinjiang during 1965–2017, potential evapotranspiration was calculated using the Penman-Monteith (P-M) model, and water surplus/deficit was derived by incorporating precipitation; the spatiotemporal variation characteristics of water surplus/deficit in Xinjiang and their influencing factors were analyzed using the Mann-Kendall (M-K) abrupt change test, wavelet analysis, and Pearson correlation analysis. The results indicate that: (1) Over the past 53 years, the interannual variation of water surplus/deficit in Xinjiang exhibited an overall increasing trend, with the highest increase rate south of the Tianshan Mountains, followed by north of the Tianshan Mountains, and the lowest in the Tianshan mountainous region, with an average increase rate of 72.28 mm · (10a)-1 across the entire region; seasonal variation of water surplus/deficit followed the order summer > spring > autumn > winter, with the greatest linear change rate in summer and the smallest in winter. (2) Spatially, the maximum seasonal water deficit occurred primarily in the Turpan Basin and surrounding areas, Hami region, and northern Bayingolin Mongol Autonomous Prefecture, while the minimum values were mainly located in the Ili River Valley and Altay region. Regarding trends, annual water surplus/deficit in most areas exhibited an increasing trend, whereas decreasing trends were mainly observed in areas north of the Tianshan Mountains and parts of the Tarim Basin. (3) An abrupt change in the time series of average water surplus/deficit in Xinjiang occurred in 1985; except for areas north of the Tianshan Mountains, other regions have shown a significant decreasing trend in water surplus/deficit since 2000, varying with a 28 a period as the first principal period.

ChinaRxiv 中X

Full Text

Spatiotemporal Variation Characteristics of Water Budget in Xinjiang During the Latest 53 Years

LU Baobao[1], SUN Huilan[1], JIANG Quanquan[2], CAO Lijun[1], LAN Xiaoli[1], ZHANG Lele[1], LIU Tianyi[1]

[1]College of Geography Science and Tourism, Xinjiang Normal University, Urumqi, Xinjiang, China
[2]State Energy Group Xinjiang Jilintai Hydropower Development Co. Ltd, Ili, Xinjiang, China

Abstract

Based on daily meteorological data from 58 stations in Xinjiang spanning 1965–2017, potential evapotranspiration was calculated using the Penman-Monteith (P-M) model, and water budget was derived by combining precipitation data. Mann-Kendall (M-K) mutation test, wavelet analysis, and Pearson correlation analysis were employed to examine spatiotemporal variation characteristics and influencing factors of water budget in Xinjiang. The results indicate: (1) Over the past 53 years, interannual water budget variation in Xinjiang showed an overall increasing trend. The maximum increasing rate occurred south of the Tianshan Mountains at 93.69 mm$\cdot$(10a)$^{-1}$, followed by north of the Tianshan Mountains, with the minimum rate in the Tianshan area itself. The average increasing rate for entire Xinjiang was 72.28 mm$\cdot$(10a)$^{-1}$. Seasonal variation followed the pattern: summer > spring > autumn > winter, with maximum linear change rate in summer (18.82 mm$\cdot$(10a)$^{-1}$) and minimum in winter (2.64 mm$\cdot$(10a)$^{-1}$). (2) Spatially, maximum seasonal water deficit occurred primarily in the Turpan Basin and surrounding areas, Hami region, and northern Bayingolin Mongolian Autonomous Prefecture, while minimum values were located in the Yili River Valley and Altay area. Most regions exhibited increasing annual water budget trends, with decreasing trends mainly in areas north of the Tianshan Mountains and parts of the Tarim Basin. (3) A significant abrupt change in Xinjiang' s average water budget time series occurred around 1985. Since 2000, water budget has shown a clear decreasing trend in all areas except north of the Tianshan Mountains, with a 28-year periodicity identified as the primary oscillation cycle.

Keywords: Xinjiang; water budget; Penman-Monteith model; climate change; spatiotemporal characteristics

Introduction

Global climate warming has induced significant changes in regional precipitation, evapotranspiration, and other climatic elements, altering regional dry-wet conditions and triggering extreme meteorological events. In recent years, Northwest China' s arid region has experienced pronounced climate change. As a crucial component of Central Asia' s large-scale arid climate zone, although the overall pattern of dry-wet climate zones remains unchanged, notable climate fluctuations have emerged in local arid areas. Xinjiang, as a major part of Northwest China's arid region, has witnessed rapid temperature and precipitation increases since the mid-1980s, though this upward trend has moderated since 2000. The warming rate in Xinjiang is 1.6 times the national average. From 1965 to 2017, Xinjiang' s temperature increased at 0.32 ℃ $\cdot$ $(10a)^{-1}$ while precipitation rose at mm $\cdot$ $(10a)^{-1}$, presenting new challenges for sustainable development of regional water resources, agriculture, and animal husbandry.

Under global warming, most Xinjiang areas have experienced warming and precipitation increases over the past 53 years, exhibiting a "warm-humidification" trend to varying degrees. This pattern appears mainly in the western Tianshan region and northern Xinjiang. Water budget serves as a critical indicator of regional dry-wet conditions, comprehensively incorporating precipitation and evaporation effects to realistically reflect regional water balance status. It has been widely applied across China, with studies examining the Huai River Basin, Yellow River Basin, and other major river systems.

1.1 Study Area Overview

Xinjiang is located in the hinterland of the Eurasian continent between 34°25 - 48°10 N and 73°40 -96°18 E, far from oceans, and classified as arid and semi-arid region [Figure 1: see original paper]. Water vapor primarily originates from westerly circulation (Mediterranean Sea, Caspian Sea, Black Sea, Atlantic Ocean) and Arctic airflows. Winter and spring moisture comes from the Mediterranean and Caspian Seas, summer from the North Atlantic and Arctic Ocean, and autumn from the Black and Caspian Seas. Xinjiang features complex topography characterized by "three mountains surrounding two basins." Due to the Tianshan Mountains' barrier, moisture from the Arctic Ocean cannot reach southern Xinjiang, and westerly circulation fails to transport water vapor to Turpan, Hami, and vast southern Xinjiang areas, resulting in substantial regional water differences.

1.2 Data Sources

Meteorological data were obtained from the China Meteorological Data Center (http://data.cma.cn), comprising daily observations from 58 stations selected based on data completeness and quality control. The dataset includes daily mean temperature, precipitation, relative humidity, mean wind speed, and sunshine duration. Seasons were defined meteorologically as spring (March–May), summer (June–August), autumn (September–November), and winter (December–February).

1.3 Methods

1.3.1 Water Budget Calculation

Water budget (K) represents regional water balance using precipitation (P) and potential evapotranspiration (ET_0):

$$K = P - ET_0$$

where positive K indicates water surplus, negative K indicates water deficit, and zero K represents water balance.

Potential evapotranspiration was calculated using the FAO Penman-Monteith model, a mechanistic model integrating atmospheric, soil, and vegetation factors that has been extensively applied in arid region climate studies:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273.15} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_0 is potential evapotranspiration ($mm \cdot d^{-1}$), R is net radiation ($MJ \cdot m^{-2} \cdot d^{-1}$), G is soil heat flux ($MJ \cdot m^{-2} \cdot d^{-1}$), T is mean air temperature at 2 m height (℃), u_2 is wind speed at 2 m height ($m \cdot s^{-1}$), e is saturation vapor pressure (kPa), e is actual vapor pressure (kPa), Δ is the slope of the saturation vapor pressure curve ($kPa \cdot ℃^{-1}$), and γ is the psychrometric constant ($kPa \cdot ℃^{-1}$).

1.3.2 Wavelet Analysis

As an indicator of dry-wet climate variation, water budget exhibits periodic oscillations. Wavelet analysis, compared to Fourier transform, provides refined time-frequency and multi-scale decomposition, enabling analysis of temporal-frequency variations from any signal detail. This study employed the Morlet wavelet function to analyze periodic variation patterns of Xinjiang' s water budget over the past 53 years.

1.3.3 Mann-Kendall Test

The Mann-Kendall test is a non-parametric statistical method that is computationally simple and insensitive to outliers. It was applied to detect abrupt changes in regional average water budget time series. For time series T, a sequence S is constructed to calculate cumulative counts of values where the i-th observation exceeds the j-th observation. The UF statistic is computed as:

$$UF_k = \frac{S_k - E(S_k)}{\sqrt{Var(S_k)}}$$

where E(S) is the mean and Var(S) is the variance of S . For backward calculation (UB), the time series is reversed.

1.3.4 Inverse Distance Weighting Interpolation

Inverse Distance Weighting (IDW) is a common spatial interpolation method that estimates values at unknown points using weighted averages of known points, where weights are proportional to the inverse distance raised to a power. Closer points exert greater influence. The weight coefficient is:

$$\lambda_i = \frac{d_i^{-p}}{\sum_{i=1}^{n} d_i^{-p}}$$

where p is the power parameter and d is the distance between estimation and known points.

2.1 Interannual Variation of Precipitation and Potential Evapotranspiration

Water budget is influenced by concurrent precipitation and potential evapotranspiration. Precipitation across Xinjiang regions showed a slow upward trend, with greater interannual variability in the Tianshan area and north of the Tianshan Mountains. Potential evapotranspiration exhibited an overall increasing trend, though with fluctuating decreases after 2000 in the Tianshan area and south of the Tianshan Mountains, most notably in the southern region.

2.2 Spatial Distribution Characteristics

Annual and seasonal water budget distributions show distinct spatial patterns [Figure 3: see original paper]. As seasonal precipitation consistently remains below potential evapotranspiration, all seasons experience water deficit, generally increasing from west to east. Maximum deficit occurs in Hami and eastern Bayingolin Mongolian Autonomous Prefecture, exceeding 500 mm in summer. Minimum deficits in spring and summer appear in the Yili Prefecture and southern Aksu area; in autumn, minima concentrate in Hotan, Shache, and Aksu; in winter, minima occur in Yili Prefecture and Altay area. Summer and autumn deficits are smaller south than north of the Tianshan Mountains. Annual water budget variation is substantial, with maximum values (Hami area) differing from minima (Yili River Valley, Aksu) by approximately 600 mm.

2.3 Interannual Variation of Water Budget

Regional water budgets show overall increasing trends with decreasing deficits. Average water budgets for the Tianshan area, north of Tianshan, south of Tianshan, and entire Xinjiang increased at rates of 34.36 mm · $(10a)^{-1}$, 88.78 mm · $(10a)^{-1}$, 93.69 mm · $(10a)^{-1}$, and 72.28 mm · $(10a)^{-1}$ respectively, with the most significant deficit reduction south of the Tianshan Mountains. The 1965–1985 mean water deficit was greater than the long-term average, while the Tianshan area showed larger water budget values than regions north and south.

2.4 Intra-annual Variation

Autumn and winter water deficits are significantly lower than spring and summer deficits across Xinjiang, following the pattern: summer > spring > autumn > winter. Summer shows the greatest fluctuation, indicating unstable climate and frequent extreme events, most pronounced in the Tianshan area. Seasonal water budgets exhibit increasing trends, with rates of 11.59 $mm \cdot (10a)^{-1}$ (spring), 18.82 $mm \cdot (10a)^{-1}$ (summer), 9.99 $mm \cdot (10a)^{-1}$ (autumn), and 2.64 $mm \cdot (10a)^{-1}$ (winter). Summer increasing rates are most significant south and north of the Tianshan Mountains, while winter trends are insignificant.

2.5 Mutation Characteristics and Periodic Analysis

2.5.1 Mutation Test

Mann-Kendall test and cumulative anomaly curves identified abrupt changes in regional water budget. UF and UB curves intersect within critical lines (\$±\$1.96) in 1986 for the Tianshan area and 1985 for regions south of the Tianshan Mountains, with corresponding inflection points in cumulative anomaly curves shifting from decreasing to increasing trends. These results indicate a significant mutation in Xinjiang' s average water budget around 1985, with decreasing trends evident after 2000 except north of the Tianshan Mountains.

2.5.2 Periodic Characteristics

Morlet wavelet analysis revealed periodic oscillation characteristics in Xinjiang' s annual water budget. Wavelet coefficient real-part contours show alternating positive-negative patterns, with the 28-year period showing the most significant oscillation. Wavelet variance confirms 28 years as the primary period and 15 years as the secondary period. The wavelet coefficient has not closed by 2017, suggesting water budget will remain relatively low for some time after 2017.

2.5.3 Spatial Variation Trends

Given Xinjiang' s large topographic variation and spatial heterogeneity, spatial trend analysis is essential. Positive values indicate increasing trends, negative values decreasing trends. Most Xinjiang regions show non-significant increasing trends in annual water budget, with decreasing trends concentrated in southern Altay, Changji Hui Autonomous Prefecture, Turpan, and northern Hami. Summer shows the largest trend variation, with most significant increases in western Tianshan and decreases in eastern Tianshan. Annual decreasing trends appear in eastern Junggar Basin, Turpan, and parts of Tarim Basin.

3 Discussion

Xinjiang' s water budget showed an overall increasing trend from 1965–2017, but a decreasing trend emerged after 2000, consistent with potential evapotranspiration changes. The decreasing rate is -1, more pronounced south of the Tianshan Mountains (-1), shifting from increasing to clearly decreasing trends. This shift is not entirely consistent with precipitation patterns, suggesting other influencing factors.

Correlation analysis reveals water budget is most strongly associated with precipitation and mean wind speed, with wind speed as the dominant factor, and least correlated with temperature. This aligns with previous research indicating global potential evapotranspiration decreases due to reduced sunshine duration and wind speed. Studies show asymmetric warming between high and low latitudes reduces pressure gradients, weakening near-surface wind speeds. The "warm-dry shift" in Xinjiang' s climate since the mid-1990s, transitioning from "warm-humidification" to "warm-drying," correlates negatively with the Atlantic Multidecadal Oscillation. Thus, Xinjiang' s water budget variation is influenced by both large-scale atmospheric circulation and regional warming.

4 Conclusions

Water budget effectively reflects regional dry-wet climate variation. This study comprehensively analyzed Xinjiang' s 1965–2017 water budget considering topography and multiple meteorological factors, with main conclusions:

1) **Temporal distribution:** Interannual water budget variation shows an overall increasing trend, with rates decreasing from south of Tianshan (93.69 mm $\cdot$ $(10a)^{-1}$) to north of Tianshan (88.78 mm $\cdot$ $(10a)^{-1}$) and Tianshan area (34.36 mm $\cdot$ $(10a)^{-1}$). The whole Xinjiang average increase is 72.28 mm $\cdot$ $(10a)^{-1}$. Seasonally, summer deficit is maximum with linear change rate of 18.82 mm $\cdot$ $(10a)^{-1}$, followed by spring, autumn, and winter (minimum at 2.64 mm $\cdot$ $(10a)^{-1}$).

2) **Spatial distribution:** Water deficit increases from west to east, with maximum deficit (>500 mm) in summer across Turpan Basin, Hami, and northern Bayingolin Mongolian Autonomous Prefecture. Minimum deficit (-16 mm) occurs in winter in Yili and Altay regions. Most areas show increasing water budget trends, while decreasing trends appear in eastern Junggar Basin and parts of Tarim Basin (Yutian, Alar, Qiemo, Luntai).

3) **Mutation and periodicity:** An abrupt change occurred around 1985. Wavelet analysis identifies 28-year and 15-year periods, with 28 years as the primary oscillation cycle.

References

[1] Yan Yaqiong, Shen Shuanghe. Spatial and temporal changes of climatic

water deficit in the Huaihe River Basin over past 50 years. *Journal of the Meteorological Sciences*, 2019, 39(4): 457-465.

[2] Shi Jianguo, Yan Changrong, He Wenqing, et al. Study on spatial and temporal variation of water surplus and deficiency in Yellow River basin. *Journal of Natural Resources*, 2008, 23(1): 113-119.

[3] Xu Dongping, Bu Jinyang, Yang Junhui. Spatiotemporal change of water budget and its affecting factors in the Yellow River basin. *Arid Zone Research*, 2016, 33(4): 739-746.

[4] Gao Ge, Xu Chongyu. Characteristics of water surplus and deficit change in 10 major river basins in China during 1961 to 2010. *Acta Geographica Sinica*, 2015, 70(3): 380-391.

[5] Yao Yulong, Liu Puxing, Zhuoma Lancao, et al. Spatiotemporal change of water budget in Gansu province in recent 51 years. *Arid Zone Research*, 2014, 31(2): 202-208.

[6] Yao Xiaojun, Zhang Xiao, Sun Meiping, et al. Spatial-temporal characteristics of water deficit in Northwest China from 1960 to 2010. *Geographical Research*, 2013, 32(4): 607-616.

[7] Chen Yaning, Yang Qing, Luo Yi, et al. Ponder on the issues of water resources in the arid region of Northwest China. *Arid Land Geography*, 2012, 35(1): 1-9.

[8] Li Jiaxiu, Chen Yaning, Liu Zhihui. Variations in temperature and precipitation and their influences on surface water resource in different climate zones of Xinjiang. *Journal of University of Chinese Academy of Sciences*, 2018, 35(3): 371-380.

[9] Liu Wei, Jiang Fengqing, Li Xiaolan. Spatiotemporal evolution of adaptive capacity to climate change in Xinjiang. *Arid Zone Research*, 2017, 34(3): 531-540.

[10] Zhang Yang, Chu Xinzheng, Yang Shaomin. Climate change in North Xinjiang in recent 56 years. *Arid Zone Research*, 2019, 36(1): 212-219.

[11] Zhang Yin, Tuerxunbai Gulixian, Su Litan, et al. Spatial and temporal characteristics of climate change at different altitudes in Xinjiang in the past 60 years. *Arid Land Geography*, 2019, 42(4): 822-829.

[12] Pu Zongchao, Zhang Shanqing, Wang Shenglan, et al. The spatial-temporal variation characteristic of dry-wet climate in recent 48 years in Xinjiang Province, China. *Journal of Desert Research*, 2011, 31(6): 1563-1572.

[13] Song Jia, Xu Changchun, Yang Yuanyuan, et al. Temporal and spatial variation characteristic of evapotranspiration and dry-wet climate in Xinjiang based on MODIS16. *Research of Soil and Water Conservation*, 2019, 26(5): 210-221.

[14] Jiapaer G L, Liang S L, Yi Q X, et al. Vegetation dynamics and responses to recent climate change in Xinjiang using leaf area index as an indicator. *Ecological Indicators*, 2015, 58(5): 64-76.

[15] Guo Xiaojiao, Shi Jiansheng. Global review of the research progress and trend of evapotranspiration. *Geological Review*, 2019, 65(6): 1473-1486.

[16] Deng Xingyao, Liu Zhihui, et al. Temporal-spatial dynamic change characteristics of evapotranspiration in arid region of Northwest China. *Acta Ecologica Sinica*, 2017, 37(9): 2994-3008.

[17] Liu Xianfeng, Pan Yaozhong, Zhang Jinshui, et al. Spatiotemporal variation patterns of potential evapotranspiration in five provinces of Northwest China in 1966-2011. *Chinese Journal of Applied Ecology*, 2013, 24(9): 2564-2570.

[18] Yao Junqiang, Yang Qing, Liu Zhihui, et al. Spatiotemporal change of precipitation in arid region of the Northwest China. *Acta Ecologica Sinica*, 2015, 35(17): 5846-5855.

[19] Yang Lianmei, Liu Jing. Some advances of water vapor research in Xinjiang. *Journal of Natural Disasters*, 2018, 27(2): 1-13.

[20] Yao Junqiang, Mao Weiyi, Chen Jing, et al. Signal and impact of wet-dry shift over Xinjiang, China. *Acta Geographica Sinica*, 2021, 76(1): 57-72.

[21] Liu Huiying, Ren Hongyu, Zhang Pingcang, et al. Analysis of characteristics of variation and abrupt change of precipitation in Xiangxi River Watershed over the past 60 years. *Research of Soil and Water Conservation*, 2015, 22(4): 282-286.

[22] Liu Youcun, Hou Langong, Jiao Keqin, et al. On the teleconnection patterns to air temperature in the Tianshan Mountain, China. *Mountain Research*, 2016, 34(6): 679-689.

[23] Chen Ying, Jiazila Baishan. Annual variation of winter temperature and its causes in Xinjiang. *Arid Land Geography*, 2019, 42(2): 223-231.

[24] Liu Hui. Changes in the Extreme Weather Events and the Responses to the North Atlantic Oscillation Index in the Arid Northwest China. Master' s thesis, Xinjiang University, 2016.

[25] Huang Jianping, Ji Mingxia, Guo Jianping, Xu Jingwen, et al. Trends of Chinese dry-wet condition based on wetness index. *Transactions of the Chinese Society of Agricultural Engineering*, 2010, 26(8): 18-24.

[26] Zeng Lihong, Song Kaishan, Zhang Bai. Spatial and temporal structure of water deficit over Northeast China during the period of 1951-2008. *Journal of Natural Resources*, 2011, 26(5): 858-870.

[27] Li Hongying, Xue Yu, Cao Erjia, et al. Spatiotemporal variation characteristics of water deficit in Ulanqab during the latest 50 years. *Journal of Arid Land Resources and Environment*, 2019, 33(12): 145-151.

[28] Xu Ronglu, Li Baofu, Lian Lishu. Quantitative relationship between the spatiotemporal change of relative humidity and climatic factors in the arid region of Northwest China from 1960 to 2015. *Research of Soil and Water Conservation*, 2020, 27(6): 233-239.

[29] Liu Yan, Liu Youcun, Chen Ming, et al. Analysis on the variation characteristics of surface water in the Jiangnan Hills based on the Penman-Monteith method. *Journal of Anhui Agricultural University*, 2019, 46(4): 680-688.

[30] Chen Jingming, Liu Jingxian, Luo Xiangzhong. Improving the Penman-Monteith evapotranspiration model based on the coupling principle of carbon and water fluxes. *Transactions of Atmospheric Sciences*, 2020, 43(1): 59-75.

[31] Garcia M, Raes D, Allen R, et al. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano). *Agricultural and Forest Meteorology*, 2004, 125(1-2): 67-82.

[32] Torrence C, Compo G P. A practical guide to wavelet analysis. *Bulletin of the American Meteorological Society*, 1998, 79(1): 61-78.

[33] Yue S, Pilon P, Cavadias G. Power of the Mann-Kendall and Spearman' s rho tests for detecting monotonic trends in hydrological series. *Journal of Hydrology*, 2002, 259(1): 254-271.

[34] Zhang Hongfang, Ju Xiaoxuan, Lu Shan, et al. Comparison of parsing methods for fine grid precipitation forecasting. *Advances in Meteorological Science and Technology*, 2019, 9(3): 7-14.

[35] Li Y, Chen Y, Li Z, Fang G. Recent recovery of surface wind speed in Northwest China. *International Journal of Climatology*, 2018, 38(12): 4445-4458.

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

Source: ChinaXiv —Machine translation. Verify with original.