Spatiotemporal Variation and Driving Factors of Pan Evaporation in the Wei River Basin (Postprint)

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Abstract

Taking the Wei River Basin as the study area, daily observation data were obtained from 21 meteorological stations within the basin for 20 cm pan evaporimeters from 1978–2002 and E-601 evaporators from 1985–2015. Pan evaporation data for each station were reconstructed using a linear regression model, the Mann-Kendall trend test and spatial interpolation methods were employed to analyze the spatiotemporal variation characteristics of pan evaporation in the basin, and sensitivity analysis was used to quantitatively evaluate the contribution of various meteorological elements to changes in pan evaporation. The results indicate that the multi-year average pan evaporation capacity in the basin is lower than the average level of the Yellow River Basin, with pan evaporation ranging from 1,015.5 to 1,705.6 mm and its spatial distribution showing a gradual decrease from north to south. Annual pan evaporation shows an overall increasing trend with a change rate of 1.371 $\text{mm} \cdot \text{a}^{-1}$. Pan evaporation is most sensitive to actual vapor pressure, and air temperature is the dominant factor affecting pan evaporation with a contribution rate of 304.5%.

Full Text

2.2.2 Mann-Kendall Trend Test

The Mann-Kendall (MK) test is a non-parametric statistical method widely used for detecting monotonic trends in hydro-meteorological time series [?]. This test is particularly suitable for analyzing hydrological and meteorological data that are often non-normally distributed [?]. The MK test statistic is calculated as follows:

$$S_x = \lim_{\Delta x \to 0} \frac{\Delta PE/PE}{\Delta x}$$

where S_x represents the sensitivity coefficient, x denotes the meteorological factor, and PE is the pan evaporation (mm). A positive S_x indicates that pan evaporation increases with the meteorological factor, while a negative value indicates an inverse relationship. The magnitude of S_x reflects the degree of sensitivity: larger absolute values correspond to greater sensitivity. In this study, we calculated sensitivity coefficients for mean temperature, net radiation, actual vapor pressure, and wind speed at 2 m height.

2.2.4 Sensitivity Analysis

To quantify the relative contributions of different meteorological factors to pan evaporation, we conducted a sensitivity analysis based on the partial derivative method. The spatial distribution of sensitivity coefficients was generated using Spline interpolation in ArcGIS 10.2. The contribution rate $p(x)$ of each factor to the trend in pan evaporation was calculated as:

$$p(x) = \frac{C(T_{mean}) + C(R_n) + C(e_a) + C(U_2)}{C(PE)} \times 100\%$$

where $p(x)$ represents the contribution rate of each factor, and $C(PE)$ denotes the change in pan evaporation. The sensitivity analysis was performed for the entire Weihe River Basin to identify dominant driving factors.

3 Results

3.1 Spatial Distribution Characteristics

The multi-year average pan evaporation in the Weihe River Basin ranged from 1015.5 to 1705.6 mm, with a mean value of 1458 mm. Spatially, pan evaporation exhibited a clear decreasing gradient from north to south. High-value areas (>1500 mm) were primarily concentrated in the northern part of the basin, while low-value areas (<1300 mm) were distributed in the southern region.

Seasonal analysis revealed significant spatial heterogeneity. Spring, summer, and autumn pan evaporation showed similar spatial patterns, with values ranging from 312.1–594.7 mm, 381.9–719.2 mm, and 196.5–367.4 mm, respectively. Winter exhibited the lowest evaporation rates. The seasonal contribution to annual pan evaporation followed the order: summer (38.4%) > spring (31.7%) > autumn (19.7%) > winter (10.2%). Compared to the Yellow River Basin (1679.4 mm during 1980–2010), the Weihe River Basin showed lower evaporation rates, consistent with its more humid climate conditions.

[Figure 2: see original paper] shows the spatial distribution of average annual pan evaporation, while [Figure 3: see original paper] illustrates the seasonal patterns.

3.2 Temporal Variation Characteristics

The MK test revealed significant temporal trends in pan evaporation across the basin. During the 21-year study period, 15 stations exhibited increasing trends, with rates ranging from 0.694 to 9.799 $\text{mm} \cdot \text{a}^{-1}$. Among these, 6 stations showed statistically significant increases ($p < 0.05$), and 3 stations showed highly significant increases ($p < 0.001$). The remaining 6 stations displayed decreasing trends, with rates from -0.609 to -3.415 $\text{mm} \cdot \text{a}^{-1}$, though only 2 stations were statistically significant ($p < 0.1$).

Regionally, the entire basin showed an increasing trend of 1.371 $\text{mm} \cdot \text{a}^{-1}$. The northern region (spring and summer) exhibited the strongest increase (1.577 $\text{mm} \cdot \text{a}^{-1}$), while the southern region (autumn and winter) showed a slight decreasing trend (-0.28 $\text{mm} \cdot \text{a}^{-1}$).

Concurrent meteorological trends ([Figure 4: see original paper]) included: mean temperature increase of $0.41°\text{C}\cdot(10\text{a})^{-1}$ (spring: $0.57°\text{C}\cdot(10\text{a})^{-1}$; autumn: $0.29°\text{C}\cdot(10\text{a})^{-1}$); net radiation increase of 0.62 $\text{MJ}\cdot\text{m}^{-2}\cdot(10\text{a})^{-1}$ (spring: 0.35 $\text{MJ}\cdot\text{m}^{-2}\cdot(10\text{a})^{-1}$; summer: 0.07 $\text{MJ}\cdot\text{m}^{-2}\cdot(10\text{a})^{-1}$); and decreasing wind speed (-0.007 $\text{m}\cdot\text{s}^{-1}\cdot(10\text{a})^{-1}$) and increasing vapor pressure (0.017 $\text{kPa}\cdot(10\text{a})^{-1}$).

Correlation analysis indicated that temperature and net radiation were positively correlated with pan evaporation ($r = 0.97$ and 0.58, respectively), while wind speed and vapor pressure showed weaker correlations ($r = 0.345$ and -0.303, respectively). Temperature emerged as the dominant factor, with a contribution rate of 304.50% to the pan evaporation trend.

3.3 Sensitivity Analysis

3.3.1 Coefficient of Variation The coefficient of variation for annual pan evaporation averaged 11.36% across the basin, indicating moderate interannual variability. Spatial analysis revealed that areas with high evaporation rates tended to have lower variability, while low-evaporation regions showed greater variability.

3.3.2 Contribution Rates Sensitivity analysis demonstrated that temperature was the most influential factor affecting pan evaporation, followed by net radiation, vapor pressure, and wind speed. The contribution rates varied seasonally: temperature dominated in spring and summer, while net radiation played a more important role in autumn. Wind speed showed negative contributions in most seasons.

The quantitative contributions were: temperature (1.118 $\text{mm} \cdot \text{a}^{-1}$, 304.50%), net radiation (0.16 $\text{mm} \cdot \text{a}^{-1}$, 43.61%), vapor pressure (-0.917 $\text{mm} \cdot \text{a}^{-1}$,

-249.73%), and wind speed (0.006 $\mathrm{mm \cdot a^{-1}}$, 1.62%). The combined contributions exceeded 100% due to interactions among factors.

summarizes the seasonal and annual contributions of each meteorological factor.

4 Discussion

The sensitivity analysis confirmed that temperature is the primary driver of pan evaporation trends in the Weihe River Basin, with a contribution rate exceeding 300%. This finding aligns with previous studies in the Yellow River Basin [**?**]. The positive correlation between temperature and pan evaporation is physically consistent, as higher temperatures increase the vapor pressure deficit and accelerate evaporation.

The spatial pattern of decreasing evaporation from north to south reflects the basin's climatic gradient, with the north being drier and more influenced by continental air masses. The seasonal variation, dominated by summer contributions, is typical for temperate monsoon regions.

Notably, the negative contribution of vapor pressure indicates that increasing atmospheric humidity partially offsets the evaporation-enhancing effects of rising temperature. This compensation mechanism helps explain why pan evaporation has not increased as dramatically as temperature alone would suggest.

The results have important implications for water resource management in the basin. Under continued warming scenarios, evaporation losses are likely to increase, exacerbating water stress in this agriculturally important region. Future research should incorporate more meteorological stations and extend the analysis period to validate these findings.

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Abstract: Quantitative assessment of spatiotemporal variation and driving factors of pan evaporation is essential for understanding the hydrological cycle and water resources management. This study utilized daily pan evaporation data from 20 cm pans (1978–2002) and E-601 evaporators (1985–2015) at 21 meteorological stations in the Weihe River Basin. A linear regression model was used to reconstruct evaporation data at observation sites. Spatiotemporal changes in pan evaporation were analyzed using the Mann-Kendall test, and sensitivity analysis was employed to evaluate the contribution of meteorological factors. Results showed that the multi-year average evaporation capacity in the study area was lower than that in the Yellow River Basin, with pan evaporation values ranging from 1015.5–1705.6 mm. Mean annual pan evaporation decreased from north to south. The annual mean evaporation increased generally with a rate of 1.371 $\mathrm{mm} \cdot \mathrm{a}^{-1}$ in the whole watershed. Pan evaporation was most sensitive to actual vapor pressure. Temperature was the dominant factor affecting pan evaporation, with a contribution rate of approximately 304.5%.

Keywords: pan evaporation; spatiotemporal variation; sensitivity analysis; driving factor; Weihe River Basin

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