Postprint: Study on the First Spring Soaking Rain in Northwest China Based on the Relative Moisture Index

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Abstract

Currently, the determination of the standard for the first spring soaking rain in the four northwestern provinces and autonomous regions mainly derives from the long-term accumulated operational experience of forecasters. To address this issue, utilizing daily data from 249 meteorological stations in Shaanxi, Gansu, Qinghai, and Ningxia from 1960 to 2016, the threshold for the first spring soaking rain was determined through analysis of the relative moisture index in Northwest China combined with potential evapotranspiration characteristics. Compared with existing studies, this method fully considers the climatic characteristics of the relative moisture index across various locations in the study area as well as local energy and water-heat balance, with clear theoretical underpinnings; the selected indicators can comprehensively reflect the integrated influence of various meteorological elements on climatic dry-wet conditions. Consequently, the determined soaking rain threshold is stable with minimal monthly variations. Subsequently, based on this indicator, the characteristics of the first spring soaking rain in Northwest China were analyzed. The results indicate that the first spring soaking rain in this region advances progressively from southeast to northwest. Southern Shaanxi appears earliest, mainly in March; Guanzhong and northern Shaanxi have a combined probability exceeding 80% for occurrence in March and April. Most of eastern Gansu, most of Ningxia, and eastern Qinghai show a combined probability exceeding 70% for occurrence in April and May. Western Qinghai is the latest region, with occurrences basically in June. Regarding interdecadal variations in occurrence dates, eastern Gansu shows the most stable timing, while Ningxia and Shaanxi exhibit the greatest variations; western Qinghai and western Gansu are relatively consistent, falling between the two extremes. Simultaneously, western Gansu, Guanzhong in Shaanxi, and southern Shaanxi demonstrate a significant delaying trend in the occurrence time of the first spring soaking rain, while other regions show no obvious trend. The research results can be applied to monitoring and forecasting of soaking

rain, and can also serve as a reference for establishing standards for the first spring soaking rain in Northwest China to facilitate regional climate assessment.

Full Text

The First Spring Saturating Rain in Northwest China Based on the Relative Humidity Index

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Abstract: Spring precipitation critically impacts agricultural production in northwest China (Shaanxi, Gansu, Qinghai, and Ningxia), where winter and spring wheat are major crops. This period coincides with crucial agricultural phases including winter wheat green-up and jointing, and sowing of spring wheat and autumn crops. Consequently, the first spring saturating rain that can alleviate drought represents a key concern for researchers and practitioners. Currently, identification of this event in the four northwestern provinces relies primarily on empirical methods accumulated through long-term operational experience. While some studies have explored this issue using spring drought indices, a theoretical foundation remains lacking. Using daily data from 249 meteorological stations across Shaanxi, Gansu, Qinghai, and Ningxia from 1960–2016, this study determines the threshold for the first spring saturating rain through theoretical calculation of potential evapotranspiration and the relative humidity index. The results indicate that a process precipitation of 22 mm is required, consistent with previous research. This threshold represents the precipitation amount needed for the relative humidity index to transition from "drought"to "no drought" conditions. Accordingly, the first spring saturating rain in northwest China can be defined as either 48-hour precipitation $ $22 mm or 24-hour precipitation $ $15 mm. The methodology explicitly considers regional characteristics of the relative humidity index, energy balance, and water-heat balance, providing clear theoretical justification. The selected indices comprehensively reflect the combined influence of meteorological factors on local dry-wet conditions, yielding a stable threshold with minimal monthly variation. This approach avoids the influence of rapidly increasing spring precipitation and temperature on threshold determination inherent in spring drought index methods, thereby compensating for deficiencies in current empirical identification practices. The results can be applied to monitoring and forecasting of saturating rain events

and facilitate regional climate assessment.

Keywords: relative humidity index; saturating rain; climate characteristics; northwest China

Introduction

Northwest China (encompassing Shaanxi, Gansu, Qinghai, and Ningxia) represents a major cultivation region for winter and spring wheat. Spring constitutes a critical agricultural period, coinciding with winter wheat green-up and jointing as well as sowing of spring wheat and major autumn crops. Precipitation during this season exerts profound impacts on agricultural production. Consequently, investigation of the first spring saturating rain capable of relieving drought represents a significant research priority. The timing of this event closely correlates with the occurrence and development of spring drought, and substantially influences winter wheat recovery, spring crop sowing, growth conditions, and ultimate yields. Previous research has examined this phenomenon from multiple perspectives, including formation mechanisms, physical quantity characteristics, climatic features, spatiotemporal variation patterns, relationships with spring and annual drought, and responses to sea surface temperature. These studies have yielded valuable insights regarding atmospheric circulation patterns in years with anomalously early or late saturating rain, interdecadal variations in occurrence dates, associations with sea temperature fields, and drought impacts of early versus late arrival. However, most research has been confined within individual provinces, limiting broader spatial understanding of saturating rain characteristics across the northwest region. From a drought mitigation perspective, saturating rain should constitute effective precipitation that alleviates drought conditions. While strict universal standards are impractical due to varying local climates and soil properties, the four northwestern provinces share adjacent territories and relatively consistent overall climatic characteristics, all belonging to arid and semi-arid climate zones. This provides a feasible premise for regional-scale investigation. Furthermore, current operational standards for identifying the first spring saturating rain in these provinces derive primarily from long-term experiential accumulation by forecasters, requiring theoretical foundation for regional climate assessment purposes.

Previous explorations by Zhang et al. combined spring drought indices for beneficial investigation, though this approach cannot fully reflect local water-heat balance across the vast Three-North region of China, and its applicability requires further verification. In summary, theoretical justification remains insufficient in current standard determination practices. This study therefore employs the relative humidity index—which effectively reflects local water-heat balance and evapotranspiration characteristics—to theoretically determine the threshold for the first spring saturating rain in northwest China, subsequently analyzing its characteristics using this calculated standard.

Data and Methods

1.1 Data

This study utilizes daily meteorological data from 249 stations across the four northwestern provinces for the period 1960-2016, with data sourced from the National Meteorological Information Center. All data correspond to 20:00 observations.

1.2 Methodology

1.2.1 Potential Evapotranspiration Potential evapotranspiration (PET) is widely applied in climate-humidity analysis, agricultural water demand and production management, rational water resource utilization and evaluation, and ecological environment studies such as desertification research. The FAO Penman-Monteith method is employed for PET calculation, as it is theoretically robust with clear physical meaning, comprehensively considering energy balance and water vapor diffusion theory. This method adequately reflects the combined influence of meteorological factors and yields accurate results applicable across different climate zones. The formula is:

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

where PE represents potential evapotranspiration ($\mathrm{mm \cdot d^{-1}}$), R_n is net radiation at the crop surface ($\mathrm{MJ \cdot m^{-2} \cdot d^{-1}}$), G is soil heat flux density ($\mathrm{MJ \cdot m^{-2} \cdot d^{-1}}$), T_{mean} is mean daily air temperature at 2 m height (°C), u_2 is wind speed at 2 m height ($\mathrm{m \cdot s^{-1}}$), e_s is saturation vapor pressure (kPa), e_a is actual vapor pressure (kPa), Δ is the slope of the vapor pressure curve ($\mathrm{kPa \cdot °C^{-1}}$), and γ is the psychrometric constant ($\mathrm{kPa \cdot °C^{-1}}$).

Key considerations in calculation include: (1) Mean daily temperature is calculated from daily maximum and minimum temperatures rather than averaged hourly observations; (2) Due to the nonlinearity of the saturation vapor pressure equation, average saturation vapor pressure for daily, decadal, or monthly periods should be computed as the mean of saturation vapor pressures derived from daily maximum and minimum temperatures; (3) For time scales of 1-10 days, soil heat flux (G) can be considered negligible, though at monthly scales it can be estimated using:

$$G = 0.14(T_{month,i} - T_{month,i-1})$$

where $T_{month,i}$ and $T_{month,i-1}$ represent mean temperatures for the current and previous months, respectively.

1.2.2 Relative Humidity Index Among commonly used meteorological drought indices, the relative humidity index incorporates potential evapotranspiration and is calculated as:

$$I_m = \frac{P - PE}{PE}$$

where I_m is the relative humidity index for a given period, P is precipitation for that period, and PE is potential evapotranspiration. This index is selected because it comprehensively reflects the influence of various climatic elements on drought conditions compared to other indices.

1.2.3 Criteria for the First Spring Saturating Rain The first spring saturating rain should be defined as the initial rainfall event following the first drought period in spring that transitions the relative humidity index from light drought or higher drought levels to no-drought conditions, thereby relieving spring drought. Referencing national standards, drought classifications based on the relative humidity index are defined in .

The threshold determination must account for the fact that prior to the first saturating rain, precipitation is not entirely absent. Rather, there are typically one or multiple small precipitation events whose cumulative effects partially alleviate drought. Therefore, in the calculation formula, P_{before} (precipitation before the saturating rain) should employ the climatological value for that month rather than being set to zero, which would be scientifically unreasonable and inconsistent with actual conditions. This approach represents a key advantage of the method, as it considers both the gradual increase in relative humidity index due to accumulating precipitation and the evolving water-heat balance associated with vegetation growth through the physical quantity of potential evapotranspiration.

The threshold calculation follows this principle: when the relative humidity index transitions from drought to no-drought conditions, the required precipitation amount can be derived from the index definition. For monthly threshold determination, PE_{before} uses the previous month' s value while $I_{climate}$ employs the current month' s climatological value. This yields stable monthly thresholds for saturating rain across northwest China (see).

Results

2.1 Spatial Distribution of Potential Evapotranspiration

2.1.1 Multi-year Average PET Spatial Pattern Calculated multi-year average potential evapotranspiration across northwest China ranges from 500–1263 mm, with higher values in the north than south. The maximum PET occurs in western Hexi Corridor, Gansu, exceeding 1100 mm, while the Qilian Mountains show lower values below 800 mm. Southern Qinghai, southern

Gansu, western Shaanxi, and southern Shaanxi exhibit values of 800 mm or less, consistent with previous research findings [14,21].

2.1.2 Annual Variation of PET The annual variation of PET shows distinct patterns, peaking in July for Shaanxi and Ningxia, and in June for Gansu and Qinghai. Monthly difference analysis (current month minus previous month) reveals March–May as the rapid increase period and August–October as the rapid decrease period across the four provinces, representing the times of fastest PET change.

2.2 Determination of the First Spring Saturating Rain Threshold

To determine the threshold, monthly relative humidity indices from February to June were calculated (). For Gansu, stations east of Wushaoling were used, while for Qinghai, eastern agricultural region stations were selected. The analysis shows that most of northwest China exhibits negative relative humidity index values (averaged over 1960–2016), indicating drought conditions ranging from severe to light. As precipitation gradually increases from March onward, the index rises toward or reaches the no-drought threshold.

The final thresholds for process precipitation during saturating rain events are presented in . These results are more stable than those derived from spring drought indices, primarily because the difference in potential evapotranspiration between consecutive months remains stable in northwest China. The method eliminates the influence of rapidly increasing precipitation and temperature on threshold determination, addressing deficiencies in current empirical practices.

2.3 Characteristics Analysis Using the New Threshold

Based on theoretical calculations, the first spring saturating rain in northwest China requires a process precipitation of 22 mm. Therefore, the standard can be defined as either 48-hour precipitation \$ \$22 mm or 24-hour precipitation \$ \$15 mm. Analysis using this standard reveals:

2.3.1 Daily Precipitation Threshold The multi-year average earliest date for daily precipitation \$ \$15 mm shows a southeast-to-northwest progression. The earliest occurrence appears in southeastern Shaanxi and Guanzhong, averaging early March (day sequence <65). Northern Shaanxi and most of eastern Gansu appear in late March (day sequence <85). Most of Ningxia, central-northern Gansu, and eastern Qinghai agricultural areas occur in late April (day sequence <115). Western Qinghai is the latest region, appearing in early June, though this has minimal agricultural impact as it lies in non-agricultural zones.

2.3.2 Temporal Distribution Characteristics Historical analysis of the earliest and latest dates for daily precipitation \$ \$15 mm over 57 years shows that in some parts of Shaanxi and eastern Gansu, the earliest occurrence can be before day 45, while most of Ningxia, Gansu, and eastern Qinghai experience earliest dates before day 65. The latest dates reveal that except for southern Shaanxi where it can extend to day 150, most of the four-province region can see the first $ $15 mm event as late as day 180. The difference between earliest and latest dates is most pronounced in eastern Gansu, most of Ningxia, and most of Shaanxi, reaching approximately 110 days, indicating significant interannual variability with important implications for agricultural production.

2.3.3 Monthly Probability Distribution Probability analysis of the first $ $15 mm precipitation event shows distinct regional patterns. In March, probability is highest in Guanzhong and southern Shaanxi, reaching 30–40%, while eastern Gansu and Ningxia show probabilities of 20–30%. By April, probabilities increase substantially, with eastern Gansu, Ningxia, and northern Shaanxi reaching 40–50%, and southern Shaanxi exceeding 50%. May sees further increases, with eastern Qinghai agricultural areas and central Gansu exceeding 50% probability.

2.3.4 Interdecadal Variation Interdecadal analysis of the first $ $15 mm event date reveals that eastern Gansu (east of Wushaoling) shows the most stable timing, while Ningxia and Shaanxi exhibit the greatest variability. Western Qinghai and western Gansu show intermediate consistency. Notably, western Gansu, Guanzhong, and southern Shaanxi demonstrate significant delaying trends, while other regions show no clear trend.

Discussion

The theoretically determined threshold of 22 mm for the first spring saturating rain shows good consistency with operationally determined standards based on forecaster experience, with typical differences of 10–15 days in occurrence timing. This alignment validates the practical applicability of the new standard.

The methodology developed here determines thresholds by analyzing the minimum required change in relative humidity index to transition from drought to no-drought conditions. This approach provides clear theoretical justification and comprehensively considers the combined influence of meteorological elements on local dry-wet conditions and energy-water balance across the four provinces. Consequently, the determined thresholds are stable with minimal monthly variation, avoiding the influence of rapidly increasing spring precipitation and temperature on threshold determination inherent in spring drought index methods. This addresses current deficiencies in empirically based operational standards and provides a tool for monitoring, forecasting, and regional climate assessment.

Future research should examine circulation characteristics and formation mechanisms in years with anomalously early or late saturating rain events to improve prediction capabilities and response measures, particularly given new climate change characteristics and their impacts on phenology and surface vegetation in northwest China.

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