Changes in Surface Moisture Conditions in the Shanxi Region Under Climate Warming (Postprint)

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Abstract

Using observational data from 67 meteorological stations in Shanxi Province from 1961 to 2017 and the FAO Penman-Monteith model, this study employs statistical methods to investigate the spatiotemporal variations of surface aridity in Shanxi Province over the past 57 years, analyze the interdecadal fluctuations and areal changes of dry/wet zone boundaries, and explore the primary influencing factors of aridity in this region. The results indicate that: based on an annual aridity index of 2. 0 as the criterion, the entire Shanxi Province can be classified into two sub-regions—semi-arid and semi-humid—which aligns closely with vegetation coverage patterns. The northern and southeastern regions of Shanxi exhibit a wetting trend, particularly pronounced after 2000, whereas most of the southwestern region shows a drying trend. The aridity index displayed a fluctuating upward trend from the 1960s to the 1990s, followed by a downward trend thereafter. Precipitation exhibited a declining trend before the 1990s and an increasing trend subsequently. Evapotranspiration changes occurred in three distinct phases: an upward trend from the 1960s to the 1970s, relative stability from the 1980s to the 2000s, and an increasing trend thereafter. The dry/wet zone boundary underwent two phases of displacement: a southeastward shift from the 1960s to the 1990s and a subsequent northwestward shift, with the proportion of arid area to total area expanding from 52% to 73 % and then contracting to 23 %. Both precipitation and evapotranspiration are significantly correlated with aridity, with the correlation between precipitation and aridity being stronger than that between evapotranspiration and aridity. Relative humidity, average wind speed, and sunshine duration are not significantly correlated with aridity but are significantly correlated with evapotranspiration. Maximum and minimum temperatures are not significantly correlated with either aridity or evapotranspiration. The interdecadal variation trend of desertification in northwestern Shanxi is consistent with the aridity variation trend, and dry/wet conditions constitute an important influencing factor on the desertification trend in northwestern Shanxi.

Full Text

Abstract

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Shanxi Province, China is located between 110.23°–114.55°E and 34.56°–40.73°N and has a total area of approximately 15.67×10 km^2. It is situated on the eastern Loess Plateau of China, with altitudes mostly above 1000 m. The province has a temperate continental monsoon climate with distinct seasons and is classified as a semiarid and semihumid zone according to dry-humid climate classification. Located on the northern margin of the East Asian monsoon, it is greatly affected by interannual variations in monsoon intensity, which causes frequent drought disasters and creates a fragile ecological environment. Surface dry/wet conditions exert important effects on local agriculture, forestry, and animal husbandry production.

Using statistical methods, this study analyzes the temporal and spatial characteristics of the aridity index (AI) and interdecadal changes of dry/wet areas, and investigates relationships between surface dryness and meteorological factors. The AI was calculated using the modified Penman-Monteith model from the Food and Agriculture Organization of the United Nations (FAO). Meteorological observation data from 67 stations in Shanxi Province from 1961 to 2017 were used, including annual precipitation, daily maximum and minimum temperatures, average wind speed, sunshine hours, and relative humidity, all obtained from the Shanxi Meteorological Information Center. Geographic information including longitude, latitude, and altitude for each station was also incorporated. Statistical methods used 主要包括 trend analysis, Pearson correlation analysis, and partial correlation analysis.

The results can be summarized as follows:
(1) Based on an annual AI threshold of 2.0, Shanxi Province can be divided into semiarid and semihumid zones, which shows good agreement with observed vegetation coverage.
(2) The northern and southeastern parts of Shanxi Province show a wetting trend, while most of the southwestern region shows a drying trend.
(3) The AI shows an overall increasing trend from the 1960s to the 1990s, followed by a decreasing trend. Precipitation exhibits an opposite trend, while evapotranspiration changes are divided into three stages: an upward trend from the 1960s to the 1970s, almost no trend from the 1980s to 2000, and then an upward trend after 2000.

(4) The boundaries between semiarid and semihumid lands moved southeastward from the 1960s to the 1990s, then northwestward after the 1990s. The proportion of semiarid area expanded from 52% to 73% and then decreased to 23%.
(5) Both precipitation and evapotranspiration exhibit prominent effects on aridity, with precipitation showing a stronger correlation with dryness than evapotranspiration. Relative humidity, average wind speed, and sunshine hours affect dryness primarily through evapotranspiration. Correlations between maximum/minimum temperatures and dryness/evapotranspiration are not significant.
(6) The interdecadal trend of desertification in northwestern Shanxi is consistent with dryness trends. These changes imply that dry/wet conditions are an important factor affecting desertification. The major difference from previous studies is the shift from drying to wetting in recent decades.

Our conclusions can be used to guide agricultural and animal husbandry production, forestry planning, desertification control, and ecological environmental construction, especially in northwestern Shanxi. A key problem to be solved is the accurate estimation of solar radiation in areas without radiation observations and modification of the Penman-Monteith formula for different reference crops or land use types to render calculated evapotranspiration values suitable for different surfaces. In the future, establishing an index similar to dryness and defining a threshold that can accurately depict spatial distribution of vegetation extent or desertification will be helpful for guiding agricultural production, ecological environmental construction, and desertification control.

Keywords: FAO Penman-Monteith; aridity; climate; Shanxi

1. Data and Methods

1.1 Data Sources

This study utilized meteorological observation data from 67 stations in Shanxi Province spanning from 1961 to 2017. The dataset, obtained from the Shanxi Meteorological Information Center and subjected to quality control, included annual precipitation, daily maximum and minimum temperatures, average wind speed, sunshine hours, and relative humidity. Geographic information including longitude, latitude, and altitude for each station was also incorporated.

1.2 Calculation Method

Reference evapotranspiration was calculated using the FAO Penman-Monteith equation. The Aridity Index (AI) was computed as the ratio of precipitation to reference evapotranspiration. The Penman-Monteith equation incorporates various meteorological parameters including temperature, humidity, wind speed, and radiation. The saturation vapor pressure component of the equation is calculated as:

$$e_s = 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right)$$

where T is the mean temperature (°C).

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