Postprint: Evapotranspiration Study in the Jinghe River Basin Based on the SEBS Model

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Abstract

The Jinghe River basin, an ecologically fragile area in arid regions, was selected as the study area. Daily meteorological observation data from 1990–2016 and six scenes of Landsat imagery from the corresponding period were selected. Based on the surface energy balance system model method, the spatiotemporal patterns of evapotranspiration from 1990 to 2016 were studied. The results indicate that: (1) Against the backdrop of global warming, evapotranspiration in the study area has shown an overall increasing trend over the past 26 years, and Morlet wavelet analysis reveals the existence of variation cycles at scales of 5 years, 7 years, and 13 years. (2) The spatial distribution of evapotranspiration in the study area is characterized by high values in the south and low values in the north. Areas with decreased evapotranspiration are located in the northeastern unused land, while areas with significantly increased evapotranspiration are located in the northwest of Aibi Lake and the southern mountainous regions. (3) Evapotranspiration values for different land use types, in descending order, are: forest land > water body > grassland > cultivated land > construction land > unused land. (4) The meteorological factor that shows a highly positive correlation with surface evapotranspiration is wind speed, and the surface parameters are elevation (DEM) and surface emissivity ( ); the meteorological factor that shows a highly negative correlation with surface evapotranspiration is near-surface air relative humidity, and the surface parameters are Temperature Vegetation Drought Index (TDVI) and surface temperature (Ts).

Full Text

Evapotranspiration in the Jinghe River Basin Based on the SEBS Model

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Abstract

This study investigated evapotranspiration in the Jinghe Basin, an ecologically fragile area in an arid region, using daily meteorological observation data from 1990 to 2016 and six scenes of corresponding Landsat imagery. Based on the Surface Energy Balance System (SEBS) model, the spatiotemporal patterns of annual evapotranspiration were analyzed. The results reveal that against the backdrop of global warming, evapotranspiration in the study area has shown an overall increasing trend over the past 26 years, with Morlet wavelet analysis identifying periodic cycles at 5-year, 7-year, and 13-year scales. Spatially, evapotranspiration exhibits a pattern of high values in the south and low values in the north, with decreasing evapotranspiration observed in unused land in the northeast and significant increases in the northwestern part of Lake Aibi and the southern mountainous areas. Across different land use types, evapotranspiration rates decrease in the following order: forest land > water body > grassland > cultivated land > construction land > unused land. Among meteorological factors, wind speed shows the strongest positive correlation with surface evapotranspiration, while surface elevation and specific surface emissivity are the key positively correlated surface parameters. Near-surface air relative humidity demonstrates the strongest negative correlation, and the Temperature Vegetation Dryness Index (TVDI) and surface temperature are the primary negatively correlated surface parameters.

Keywords: SEBS model; evapotranspiration; spatiotemporal pattern; Jinghe River Basin; Xinjiang

1.1 Study Area Overview

The Jinghe River Basin (81°07 52 ~83°05 48 E, 44°00 21 ~45°00 56 N) is located at the northern foothills of the Borokonu Mountains in the Tianshan range, on the southwestern edge of the Junggar Basin. The terrain slopes from high in the south to low in the north, with an average elevation ranging from 300 to 3500 m. The region experiences scarce summer precipitation, dry and cold winters, and pronounced continental climate characteristics. Frequent sandstorms with long duration and abundant sunshine (summer sunshine hours exceeding 61%–64%) combine with the dry climate and active windy conditions to create intense evapotranspiration, making this area one of the typical regions with severely degraded ecosystems in the arid northwest of China (Fig. 1).

1.2 Data Sources

Meteorological data were obtained from the China Meteorological Data Service Center (http://data.cma.cn). Daily observation data were selected from the Jinghe meteorological station (station number: 51434) of the China Ground

International Exchange Stations, covering the period from 1990 to 2016. Remote sensing data were acquired from the Geospatial Data Cloud of China (www.gscloud.cn), including Landsat-5 TM images for 1990, 1995, and 2000; Landsat-7 ETM+ images for 2005 and 2010; and Landsat-8 OLI_TIRS images for 2015 and 2016. All images were from September–October (autumn), with path/row numbers of P146/R029 and cloud cover below 10%. ENVI 5.1 and ArcGIS 10.1 software were used for processing, with TM-destripe tool applied to repair striping issues in Landsat-7 ETM+ images.

2 SEBS Model Mechanism

The Surface Energy Balance System (SEBS), proposed by Dutch scholar Su, comprises three theoretical components: (1) retrieval of surface physical parameters, including surface albedo, surface emissivity, surface temperature, Normalized Difference Vegetation Index (NDVI), and surface roughness; (2) calculation of heat transfer roughness length, involving pressure, temperature, humidity, and wind speed at a reference height estimated using an atmospheric-scale meteorological model; and (3) computation of the evapotranspiration fraction, primarily incorporating downward solar radiation and longwave radiation (Fig. 2).

The mathematical foundation of the model is the surface energy balance equation:

$$Rn = \lambda E + H + G$$

where λE is the latent heat flux ($\mathrm{W \cdot m^{-2}}$), Rn is the net radiation flux ($\mathrm{W \cdot m^{-2}}$), H is the sensible heat flux ($\mathrm{W \cdot m^{-2}}$), and G is the soil heat flux ($\mathrm{W \cdot m^{-2}}$).

Net radiation flux is calculated as:

$$Rn = (1-\alpha)R_s\downarrow + R_L\downarrow - (1-\epsilon)R_L\uparrow - \epsilon\sigma T_s^4$$

where $R_s\downarrow$ is incoming shortwave radiation ($\mathrm{W \cdot m^{-2}}$), α is surface albedo, $R_L\downarrow$ is incoming longwave radiation ($\mathrm{W \cdot m^{-2}}$), ϵ is surface emissivity, σ is the Stefan-Boltzmann constant ($5.67 \times 10^{-8}\ \mathrm{W \cdot m^{-2} \cdot K^{-4}}$), and T_s is surface temperature (K).

Soil heat flux is computed as:

$$G = Rn[\Gamma_c + (1-F_c)(\Gamma_s - \Gamma_c)]$$

where Γ_c is the ratio of soil heat flux to net radiation under full vegetation cover (0.05), Γ_s is the ratio under bare soil (0.315), and F_c is fractional vegetation cover derived from NDVI.

Sensible heat flux calculation integrates surface parameters and atmospheric boundary layer parameters (wind speed, temperature, and surface potential temperature difference) through bulk parameterization to solve for the Monin-Obukhov length (L) and friction velocity (μ^*). The momentum roughness model, originally designed for uniformly distributed low vegetation, was adjusted in this study based on second-order closure theory to account for regional variations in land cover. Momentum roughness length (z_{0m}) and zero-plane displacement (d) were calculated differently for partially and fully vegetated surfaces using leaf area index (LAI).

3 Accuracy Verification

Model validation employed a combined "point" and "area" approach. Point validation used daily measured evaporation data from the Jinghe meteorological station (Table 1). Compared with pan evaporation data, the model showed a mean error rate of -8.39% for evapotranspiration, while surface temperature and air temperature had mean error rates of 11.22% and 12.79%, respectively.

For area validation, the Penman-Monteith model, with its robust physical basis and recognized as a standard calculation method requiring no regional calibration, was used for comparison. The regional evapotranspiration results from SEBS showed consistent multi-year trends with Penman-Monteith data (Fig. 3), demonstrating good applicability to the Jinghe region.

4.1 Temporal Variation of Evapotranspiration

Model-retrieved daily evapotranspiration in the study area showed an overall increasing trend from 1990 to 2016, with small annual fluctuations and mean values of 1.41 mm, 1.5 mm, and 1.647 mm for different periods. The period 1990–1995 saw a significant increase of 0.237 mm, primarily in Lake Aibi, southern and southeastern mountainous areas, and the upper-middle plains of the Jinghe Basin. Another increase occurred during 2000–2010 (mean increase of 0.821 mm), while 2015–2016 showed lower values (mean decrease of 1.316 mm).

To understand periodic characteristics, Morlet wavelet analysis was performed using data from the Jinghe meteorological station. The wavelet variance diagram revealed three peaks at 5-year, 7-year, and 13-year scales (Fig. 5). The 13-year cycle was particularly pronounced, undergoing three alternating wet-dry phases. The positive contour line appearing in 2015 remained unclosed in 2016, indicating that evapotranspiration will likely remain high in the near future, confirming the observed trends and suggesting continued increases.

The wavelet variance at the 5-year scale was slightly higher than at 7 years, indicating nested periodic structures within the 13-year cycle. Contour maps of wavelet coefficient real parts (Fig. 6) show oscillations between positive and negative phases at 5- and 7-year scales, demonstrating the complex multi-scale periodic structure of evapotranspiration in the Jinghe Basin, consistent with findings from other studies.

4.2 Spatial Characteristics of Evapotranspiration Under Land Use Types

Evapotranspiration shows uneven spatial distribution across the study area, with clear differences between lakes, river upstream/downstream areas, and mountains, generally presenting a south-high, north-low pattern. High values appear in southern forest land, while the lowest values occur in dry, bare unused land in the north. Areas with increased or stable evapotranspiration account for 74.54% of the total area, concentrated in the northern lake region, central oasis, and southern mountains. Decreasing evapotranspiration occurs in 25.46% of the area, mainly in northeastern unused land.

Based on China's land resource classification system, land use classification was performed. Using a center-of-gravity migration model (Fig. 8), spatial changes in evapotranspiration were analyzed. Over the past 26 years, cultivated land, forest land, and grassland have all migrated eastward. Cultivated land shifted 4.99 km east, while forest and grassland moved southeast by 13.96 km and 10.37 km, respectively, concentrating areas of slight evapotranspiration increase in water-rich regions around and south of Lake Aibi. Water bodies with high evapotranspiration migrated 7.21 km northwest, creating significant increases in the northwestern part of the lake. Construction land and unused land, characterized by low evapotranspiration, showed distinct differentiation. Oasis urban expansion drove construction land 3.08 km southwest, while unused land migrated 23.67 km northeast, causing evapotranspiration decreases in northeastern unused land and near Dandagai Village in Tuoli Township.

5.1 Natural Driving Factors

As a key climatic indicator, evapotranspiration is determined by the combined effects of meteorological factors. Correlation analysis was performed for temperature, relative humidity, precipitation, wind speed, solar radiation, sunshine hours, and diurnal temperature range (Table 2).

Wind speed shows the strongest positive correlation with evapotranspiration, influenced by the Alashankou pass in the northwestern part of the study area. Near-surface air relative humidity exhibits the strongest negative correlation. Although temperature shows lower significance in correlation compared to other factors, its direct effect cannot be ignored as it determines atmospheric water vapor capacity and diffusion rates. IPCC reports indicate global mean temperature increased by 0.85°C from 1880–2012 relative to pre-industrial levels. In the study area, the average temperature rose significantly at a rate of 0.33°C per decade ($\alpha = 0.05$) over the past 26 years, with increasing evapotranspiration partially responding to this warming. The low values in 1995 were mainly due to low temperature and wind speed from weather processes 10 days before image acquisition.

Surface temperature is negatively correlated with evapotranspiration. The negative correlation between TVDI and evapotranspiration indicates significant soil moisture effects—lower soil moisture leads to reduced evapotranspiration (Fig. 9).

5.2 Human Impact Factors

Different land use types alter soil moisture and surface temperature, thereby affecting regional evapotranspiration. Construction land, water bodies, and cultivated land increased overall, while forest land, grassland, and unused land decreased (Table 3). Driven by population growth and oasis agriculture, cultivated land expanded rapidly with a dynamic degree of 12.24%. Although forest and grassland decreased, areas have gradually recovered since the implementation of the "Three-North" Shelterbelt Program, Grain for Green project, and grassland ecological protection policies, making them high-evapotranspiration zones.

Correlation analysis between surface parameters (surface temperature T_s, emissivity ϵ, elevation DEM, and TVDI) and evapotranspiration revealed positive correlations with elevation and emissivity. Except for a slight decrease above 500 m where Tianshan spruce distribution occurs, evapotranspiration increases significantly with elevation. Terrain affects radiation absorption, so evapotranspiration also increases with surface emissivity.

Livestock numbers increase with population growth. Unused land consists mainly of rocks, Gobi desert, and saline-alkali soils with sparse vegetation and rapid surface warming, creating negative correlation between surface temperature and evapotranspiration. Livestock numbers, as an indicator of rational grassland use, directly affect grassland area changes, demonstrating that human transformation of natural surfaces influences land cover and consequently evapotranspiration.

Frequent human activities and overexploitation of natural resources caused Lake Aibi's water area to decrease through 2010, with the maximum retreat in 2006 exposing the lakebed and increasing unused land, leading to evapotranspiration decreases in the northeastern unused land. However, since the establishment of the Lake Aibi National Nature Reserve in 2007 and implementation of unified water resource management and water-saving irrigation, the lake area expanded by 328 km² by 2016, causing significant evapotranspiration increases in the northwestern reserve area.

6 Conclusion

Regional evapotranspiration is influenced by both natural and anthropogenic factors. Under global warming, northwestern Chinese river basins show overall increasing evapotranspiration, a trend confirmed by this study. The spatiotemporal distribution patterns are also changing. Despite natural surfaces being replaced by impervious artificial surfaces during economic development and urbanization, urban land with low evapotranspiration contribution cannot be ignored. From 1990–2016, newly added urban green space of 0.127 km^2 increased evapotranspiration from construction land.

Although evapotranspiration developed positively overall during 1990–2016, spatial imbalance may promote localized extreme hydrometeorological events and challenge water resource and risk management.

Key conclusions: (1) Under global warming, evapotranspiration in the Jinghe Basin showed fluctuating increases from 1990–2016, with periodic cycles at 5-year, 7-year, and 13-year scales. Spatially, it presents a south-high, north-low pattern, with decreases in northeastern unused land and significant increases in the northwestern Lake Aibi area and southern mountains.

(2) Across land use types, evapotranspiration decreases as: forest land > water body > grassland > cultivated land > construction land > unused land, indicating that evapotranspiration is affected not only by climate and physical geography but also by land use and vegetation coverage. Economic development's replacement of natural surfaces with artificial ones influences regional evapotranspiration.

(3) Wind speed is significantly positively correlated with evapotranspiration, while near-surface relative humidity is significantly negatively correlated. Surface parameter analysis shows that emissivity and elevation are significantly positively correlated, while surface temperature and TVDI are significantly negatively correlated with evapotranspiration.

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