# Postprint: Assessing Climate and Hydrological Effects of Land Use/Cover Change Using the WRF Model

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## Abstract

Currently, numerous studies have focused on changes in hydrological processes such as runoff generation and concentration (direct hydrological effects) caused by Land Use/Cover Change (LUCC), whereas research on runoff changes induced by regional climate change resulting from LUCC (indirect hydrological effects) is rarely reported. The indirect hydrological effects of LUCC in the Yi River Basin from 1990 to 2010 were investigated using the Weather Research and Forecasting Model (WRF) and elasticity coefficient methods. The results indicate that the WRF model demonstrates good capability in simulating temperature in the study area, with high correlation coefficients between simulated and observed values (0.86-0.97, $P<0.001$); although the model' s simulation accuracy for precipitation is lower than that for temperature, the correlation coefficients between simulated and observed values (0.41-0.91) all reached the significance level of $P<0.05$. Over the past 20 years, LUCC in the study area has primarily been a process of conversion from dryland to construction land (747.3 km$^2$) and bare land (132.4 km$^2$). LUCC caused temperature increases of 0.2°C in January and October 2013, led to a temperature decrease of 0.2°C in July, while temperature in April remained essentially stable. LUCC had a weak influence on precipitation changes in January, April, and October, while it significantly affected precipitation change in July, manifested as a reduction of 23.7 mm. Elasticity analysis shows that during 1960-2013, a 1% change in annual average precipitation and temperature in the basin would cause annual runoff to change by 2.4% and 1.8%, respectively. From 1990-2010, precipitation and temperature changes in the Yi River Basin caused by LUCC resulted in runoff changes of 18.4% and 1.7%, respectively, in 2013.

# Full Text

## Preamble

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### Quantifying the Climatic and Hydrological Effects of Land Use/Cover Change Based on the Weather Research and Forecasting Model

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## Abstract

Currently, most studies have focused on determining the direct hydrological effects of land use/cover change (LUCC) on runoff yield and confluence processes, while few have investigated the indirect hydrological effects—namely, runoff changes caused by LUCC-induced regional climate change. This study employs the Weather Research and Forecasting (WRF) model and elasticity coefficient methods to investigate the indirect hydrological effects of LUCC in the Yi River basin from 1990 to 2010. The results demonstrate that the WRF model simulates temperature well in the study area, with high correlation coefficients (0.86–0.97, $p < 0.001$) between modeled and measured values. Although precipitation simulation accuracy is lower than for temperature, correlation coefficients remain statistically significant (0.41–0.91, $p < 0.05$). The primary land use transformation involves conversion from dry farmland to urbanized land (747.3 km$^2$) and bare/sparse vegetation (132.4 km$^2$). LUCC caused January and October temperatures to increase by 0.2°C, while July temperatures decreased by 0.2°C; April temperatures remained basically stable. The largest temperature changes occurred in mixed forests and water bodies (0.4–1.3°C), while the smallest changes (<0.1°C) occurred in deciduous broadleaf forests and wetlands. LUCC showed weak impacts on precipitation changes in January, April, and October, but substantially affected July precipitation, causing a decrease of 23.7 mm. Elasticity analysis revealed that during 1960–2013, a 1% change in annual precipitation and temperature induced runoff changes of 1.8% and 2.4%, respectively. During 1990–2010, LUCC-induced changes in precipitation and temperature caused runoff to change by 18.4% and 1.7%, respectively.

**Keywords:** LUCC; runoff; WRF; climate effect; indirect hydrological effect

## Introduction

Land use/cover change (LUCC) represents one of the most important aspects of the Earth system and constitutes a significant driver of global change. Alterations in land use types affect surface properties such as albedo, ground roughness, and soil thermal characteristics, thereby exerting critical influences on climate and land surface processes. LUCC can substantially impact surface energy and water balance, and at regional scales, internal climate variability contributions often exceed those of external forcings, making the mechanisms of regional temperature change more complex than at global scales. The impact of LUCC on regional climate change is now unequivocal, with vegetation cover changes significantly affecting regional climate dynamics.

Two primary approaches dominate regional climate effect research: statistical analysis of observational and reanalysis data, and application of land-atmosphere coupled models. The latter is widely used due to its solid physical basis and ability to reveal mechanisms of regional climate change. Previous studies have shown that agricultural expansion has minimal large-scale temperature effects, but significant local impacts. For instance, Zhang et al. [15] simulated the effects of cropland expansion in central-eastern China, while Wang et al. [5] analyzed impacts on surface temperature in northern China' s semi-arid regions. Dong et al. [16] simulated LUCC effects on seasonal temperatures across China. Most research indicates that positive and negative temperature effects cancel out during regional averaging, resulting in negligible mean temperature changes. However, these effects manifest differently across land use types, temporal scales, and spatial scales, with LUCC impacts primarily limited to local areas.

Most existing studies focus on larger regions with spatial resolutions typically 30 km and temporal resolutions between seasonal and annual scales, with more research on temperature than precipitation effects. This limits result precision. Since LUCC significantly affects hydrological processes both directly (through runoff yield and confluence) and indirectly (through climate change), investigating indirect hydrological effects is crucial. This study addresses this gap by employing high-resolution (3 km) satellite observations of LUCC in southern Shandong, analyzing impacts on local temperature and precipitation at monthly and daily scales, and using elasticity coefficients to quantify indirect hydrological effects. The findings provide important scientific guidance for accurately interpreting hydrological process changes and clarifying underlying mechanisms.

# 1. Study Area

The Yi River is a major tributary in the Yishu-Sishui system of the Huai River basin, located between 33.5°–36.5°N and 117°–119.0°E. Originating in Yiyuan County, Shandong Province, and flowing to Wulou Village in Pixian County, Jiangsu Province, before entering the Yellow Sea at Yanwei Port, the river is known as the "mother river" of the Linyi region. The basin covers an area of $1.7 \times 10$ km$^2$.

[Figure 1: see original paper] shows the study area location and distribution of hydrological and meteorological stations in the Yi River basin.

# 2. Methods

## 2.1 Model Configuration and Experimental Design

This study employs WRF model version 3.7 to assess regional climate effects induced by LUCC. Since precipitation and temperature are the dominant climatic factors affecting runoff, we focus on analyzing LUCC-induced changes in these variables and their subsequent indirect hydrological effects. The simulation domain is centered at 35.8°N, 118.1°E with grid points of 91 × 130, 49 × 67, and 37 × 36 for domains 1, 2, and 3, respectively. Horizontal resolutions are 27 km (domain 1), 9 km (domain 2), and 3 km (domain 3). The control experiment uses NCEP-FNL reanalysis data (1° × 1°) as boundary conditions.

Considering data availability and the relative stability of LUCC over short periods, we simulate representative months (January, April, July, October) of 2013 to reflect seasonal climate characteristics and different weather dynamics. Sensitivity experiments replace 2010 land use data with 1990 data in domain 3, while keeping other settings identical to the control experiment. Differences between control and sensitivity experiments thus reflect LUCC impacts on regional climate elements.

Physics parameterizations include: Monin-Obukhov surface layer scheme, Kain-Fritsch (new Eta) cumulus parameterization, Dudhia shortwave radiation scheme, RRTM longwave radiation scheme, and YSU boundary layer scheme. Land use data for domains 1 and 2 are from USGS, while domain 3 uses 1 km × 1 km data from the Chinese Academy of Sciences' Resource and Environmental Science Data Center (http://www.resdc.cn) after resampling and format conversion. Meteorological validation data include daily temperature and precipitation from Yanzhou, Juxian, and Xuzhou stations. All simulations were conducted on a Sugon TIANUO 1620-G15 server (32 CPU).

## 2.2 Elasticity Coefficient Method

In climate change impact studies, elasticity coefficients quantify hydrological sensitivity to meteorological variables. The elasticity coefficient ( ) of annual runoff to precipitation or temperature change is calculated as:

$$= (\Delta Q/Q) \;/\; (\Delta X/X)$$

where X and Q are long-term mean meteorological and runoff values, respectively. The physical meaning is the percentage change in runoff caused by a 1% change in meteorological elements. The runoff change rate ( ) due to LUCC is:

$$= \quad \times \quad / \; X$$

where  is the annual temperature or precipitation change induced by LUCC, calculated as the sum of monthly changes from WRF simulations.

### 2.3 Trend Analysis

The Mann-Kendall test (significance level $= 0.05$) determines significant trends in runoff and climate variables. A positive Z-value indicates increasing trends, while $Z < 0$ indicates decreasing trends. When $|Z| > 1.96$, the trend is statistically significant.

## 3. Results

### 3.1 Model Validation

Comparison of control simulation with observations shows WRF reliably reproduces monthly temperature patterns, with correlations significant at $p < 0.001$. Simulated temperatures show slight biases: January and October are overestimated by 3.3% and 6.2%, respectively, while July is underestimated by 3.3%. Overall, the model captures temperature spatiotemporal variability well.

[Figure 2: see original paper] presents scatter plots of observed versus simulated daily temperatures for January, April, July, and October 2013.

Precipitation simulation accuracy is lower than temperature but still acceptable, with correlations significant at $p < 0.05$. January and October precipitation are underestimated by 14.3% and 17.1%, respectively, while July is overestimated. [Figure 3: see original paper] shows observed and simulated daily precipitation changes.

### 3.2 Land Use/Cover Change Analysis

From 1990 to 2010, dry farmland dominated the basin (70.3% and 68.6% of total area, respectively), followed by paddy fields (11.4% and 11.1%). Grassland and forest accounted for 5.4–7.2%. The most significant changes were dry farmland reduction (1089.8 $km^2$) and urban construction land increase (821.8 $km^2$), followed by bare land (207.8 $km^2$) and water bodies (214.2 $km^2$). The primary transformation was conversion from dry farmland to construction land

(747.3 km²) and bare land (132.4 km²). [Figure 4: see original paper] illustrates land use patterns in 1990 and 2010.

### 3.3 Climate Effects of LUCC

**Temperature Changes:** Differences between control and sensitivity simulations reveal LUCC-induced temperature changes. January and October temperatures increased by 0.2°C, July decreased by 0.2°C, and April remained stable. Mixed forests and water bodies showed the largest changes (0.4–1.3°C), while deciduous broadleaf forests and wetlands showed the smallest (<0.1°C). [Figure 5: see original paper] displays spatial temperature variations.

**Precipitation Changes:** LUCC had negligible effects on January, April, and October precipitation but substantially reduced July precipitation by 23.7 mm. This strong summer impact is attributed to abundant seasonal precipitation and altered moisture fluxes. Spatial precipitation variations were weakly associated with underlying surfaces. [Figure 6: see original paper] shows precipitation changes.

### 3.4 Indirect Hydrological Effects

Elasticity analysis using 1960–2013 data shows the Yi River runoff is highly sensitive to climate: a 1% change in precipitation and temperature induces 1.8% and 2.4% runoff changes, respectively. During 1990–2010, LUCC-induced precipitation and temperature changes caused runoff to change by 18.4% and 1.7%, respectively, demonstrating significant indirect hydrological effects.

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## 4. Discussion

The simulation results indicate that both temperature and precipitation effects can cancel out during regional averaging, consistent with previous findings [5,15]. This suggests the need for higher spatiotemporal resolution to scientifically reveal LUCC impacts. Interestingly, urban construction land showed slight temperature decreases in some months during 1990–2010, which may relate to urban spatial optimization and increased greening that mitigate heat island effects [22]. Similar weakening trends have been observed in Beijing [23], Chongqing [24], and Xining [25]. However, urban heat islands also manifest through spatial expansion, and whether this represents actual intensity reduction requires further investigation.

The indirect hydrological effects of LUCC primarily influence precipitation changes, which have greater impact on runoff than temperature. While LUCC directly affects interception and infiltration, its indirect effects through altered meteorological conditions warrant continued attention. Although WRF simulations passed significance tests, using only representative months introduces uncertainty; longer-term simulations are needed. Future work should couple climate models with physically-based hydrological models for more accurate assessment.

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## 5. Conclusions

(1) Significant LUCC occurred in the Yi River basin during 1990–2010, dominated by conversion from dry farmland to construction land (747.3 km$^2$) and bare land (132.4 km$^2$).

(2) WRF demonstrates good simulation capability, reliably reproducing temperature and precipitation patterns. LUCC exhibits clear spatiotemporal climate effects: January and October temperatures increased by 0.2°C, July decreased by 0.2°C, and April remained stable. Mixed forests and water bodies experienced the largest temperature changes (0.4–1.3°C), while deciduous broadleaf forests and wetlands showed minimal changes (<0.1°C). Precipitation effects were negligible in January, April, and October, but July precipitation decreased substantially by 23.7 mm.

(3) Yi River runoff is highly sensitive to climate variability. During 1960–2013, 1% changes in basin precipitation and temperature caused 1.8% and 2.4% runoff changes, respectively. During 1990–2010, LUCC-induced climate changes led to 18.4% and 1.7% runoff changes, respectively, highlighting significant indirect hydrological effects.

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## References

[1] IPCC. Climate Change 2013: The Physical Science Basis: Summary for Policymakers. Working Group I Contribution to the IPCC Fifth Assessment Report. Cambridge, UK: Cambridge University Press, 2013.

[2] Zhang X Z, Tang Q H, Zheng J Y, Ge Q S. Warming/cooling effects of cropland greenness changes during 1982-2006 in the North China Plain. Environmental Research Letters, 2013, 8(2): 024038.

[3] Pielke R Sr, Beven K, Brasserur G, Calvert J, Chahine M, Dickerson R R, Entekhabi D, Foufoula-Georgiou E, Gupta H, Gupta V, Krajewski W, Krider E P, Lau W K M, McDonnell J, Rossow W, Schaake J, Smith J, Sorooshian S, Wood E. Climate change: The need to consider human forcings besides greenhouse gases. EOS, Transactions American Geophysical Union, 2009, 90(45): 413–413.

[4] Pitman A J, Arnet A, Ganzeveld L. Regionalizing global climate models. International Journal of Climatology, 2012, 32(3): 321–337.

[5] Wang M N, Xiong Z, Yan X D. Modeling the climatic effects of land use/cover change in eastern China. Physics and Chemistry of the Earth, Parts A/B/C,

2015, 87-88: 97-107.

[6] [Chinese reference on natural and anthropogenic contributions to 20th century temperature changes]

[7] Peng S S, Piao S L, Zeng Z Z, Ciais P, Zhou L M, Li L Z X, Myneni R B, Yin Y, Zeng H. Afforestation in China cools local land surface temperature. Proceedings of the National Academy of Sciences of the United States of America, 2014, 111(8): 2915-2919.

[8] [Chinese reference on land cover change and climate effects]

[9] Gao X J, Zhang D F, Chen Z X, Pal J S, Giorgi F. Land use effects on climate in China as simulated by a regional climate model. Science in China Series D: Earth Sciences, 2007, 50(4): 620-628.

[10] [Chinese reference on land use change and regional warming effects]

[11] [Chinese reference on progress and methods of global climate impact studies]

[12] [Chinese reference on LUCC impacts on climate systems]

[13] [Chinese reference on numerical simulation of LUCC impacts on regional climate]

[14] Liu F S, Tao F L, Liu J Y, Zhang S, Xiao D P, Wang M, Zhang H, Bai H Z. Effects of land use/cover change on land surface energy partitioning and climate in Northeast China. Theoretical and Applied Climatology, 2016, 123(1/2): 141-150.

[15] [Chinese reference on cropland expansion effects in central-eastern China]

[16] Dong S Y, et al. [Reference on seasonal temperature effects of LUCC]

[17] Chen H S, et al. [Reference on numerical simulation of LUCC impacts]

[18] [Chinese reference on flood impacts of watershed land use change]

[19] [Chinese reference on LUCC and runoff impacts using SWAT model]

[20] [Chinese reference on land use and climate change impacts on runoff]

[21] Zheng H X, Zhang L, Zhu R R, Liu C M, Sato Y, Fukushima Y. Responses of streamflow to climate and land surface change in the headwaters of the Yellow River Basin. Water Resources Research, 2009, 45(7): W00A19, doi:10.1029/2007WR006665.

[22] [Chinese reference on urban vegetation and heat island changes]

[23] Ge R F, et al. [Reference on Beijing’ s thermal environment improvement]

[24] Zhang X L, et al. [Reference on Chongqing’s heat island intensity reduction]

[25] Han G F, et al. [Reference on Xining’ s heat island effect analysis]

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