The user wants me to translate a Chinese academic paper title and subtitle into English. The title is “气候变化和土地利用变化对宁夏蓝水绿水时空分布的影响” and the subtitle is “后印本”. Let me break this down: - 气候变化 => climate change - 土地利用变化 => land-use changes - 对…的影响 => effects of … on …- 宁夏 => Ningxia - 蓝水绿水 => b…

Authors: WU Jun, The user wants me to translate a Chinese text to English. The text appears to be just a name: “DENG Guoning” .

Let me check the requirements: 1. Preserve ALL LaTeX commands and placeholders - there are none here 2. Preserve ALL citation commands - there are none here 3. **PRESERVE ALL …paragraph wrapper tags EXACTLY** - there are none here 4. Maintain academic tone and formal scientific writing style - this is a name, so I should translate it appropriately 5. Use precise technical terminology - obey the glossary strictly - not applicable for a name 6. Preserve section structure and paragraph organization - it’ s just a name 7. Translate all content completely - do not omit any information

The name “DENG Guoning” is a Chinese name. In academic contexts, Chinese names are typically written in one of two ways: - With the family name first: DENG Guoning - With the family name last: Guoning Deng

The original text has the family name “DENG” in all caps and the given name “Guoning” in title case. This is a common way to write Chinese names in academic contexts to make the family name clear.

Looking at the glossary and requirements, this seems to be part of a larger academic paper translation task. The name should be preserved in its original format as it appears in the source text, which is “DENG Guoning” .

Since there are no tags, I should just return the translated name. The name itself doesn’ t need translation - it’ s a proper name. In academic contexts, Chinese names are often kept in their original form, sometimes with the family name in uppercase to distinguish it.

The user provided just “DENG Guoning”without any paragraph tags. According to the output rules, I should return ONLY the translated text. Since this is a name, the “translation” is essentially preserving it as is.

Let me think about whether I should format it differently. In many English academic papers, Chinese names are written either as: 1. DENG Guoning (family name in caps) 2. Guoning Deng (Western order) 3. Deng Guoning (all title case, family name first)

The source text uses format #1, which is common in academic contexts. I should preserve this exact format.

The output should be just: DENG Guoning

Wait, let me re-read the instructions carefully., The user has provided a name “ZHOU Dongmei” and wants me to translate it. However, based on the instructions, I am supposed to be translating scientific academic papers from Simplified Chinese to English, preserving LaTeX commands, citation commands, and tags.

The input “ZHOU Dongmei” appears to be just a name, not a full paragraph with tags. Let me check the instructions again:

1. Preserve ALL LaTeX commands and placeholders exactly
2. Preserve ALL citation commands ([**?**], **??**, (**??**), etc.) exactly
3. **PRESERVE ALL ⋯paragraph wrapper tags EXACTLY**
4. Maintain academic tone and formal scientific writing style
5. Use precise technical terminology - obey the glossary strictly
6. Preserve section structure and paragraph organization
7. Translate all content completely - do not omit any information

OUTPUT RULES: - Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent). - Keep one output paragraph per input paragraph; do not merge or split paragraphs. - **Maintain exact count and IDs of ⋯tags** - if input has N paragraph tags, output must have exactly N paragraph tags with matching IDs - Do NOT add Markdown formatting unless it is present in the source. - Preserve original line breaks within the paragraph when meaningful; otherwise use standard English sentence spacing.

The input is just “ZHOU Dongmei” which is a name. This doesn’ t contain any tags, LaTeX, or citations. It’ s not a paragraph from an academic paper.

The name “ZHOU Dongmei” should be translated as “Dongmei Zhou” in English academic writing (surname last). However, the instructions say to preserve tags, but there are none in the input.

I should follow the instructions literally. The input is just a name, so the output should be just the translated name. But I need to check if this is a test case or if the user expects me to wrap it in tags.

Looking at the instructions again: “PRESERVE ALL ⋯paragraph wrapper tags EXACTLY” - this means if they exist, I must preserve them. If they don’ t exist, I don’ t need to add them.

The input is, ZHU Xiaoyan, The user wants me to translate a scientific paper from Simplified Chinese to English. The input is just "MA Jing" which appears to be a name. However, the instructions are very specific about preserving LaTeX commands, citation commands, and ... tags.

Since the input is just "MA Jing" , there' s nothing to translate except the name itself. "MA Jing" is already in English format (pinyin). In academic contexts, Chinese names are often written with the surname first, so "MA Jing" would be correct.

But wait, let me re-read the instructions carefully. The user provided: - Critical requirements about preserving LaTeX, citations, and PARA tags - Output rules about maintaining paragraph structure - Formatting guidelines - A glossary for specific terms

The actual input is just "MA Jing" . This seems like it might be a test case, or perhaps the user will provide more content later. For now, I should just return "MA Jing" as is, since it' s already in the appropriate format for an academic paper (surname first).

However, I need to check if there are any hidden PARA tags or other elements. The input is literally just:

```
MA Jing
```

No tags, no LaTeX, no Chinese characters. So the output should be exactly the same. But the instructions say to translate from Simplified Chinese to English. "MA Jing" is not Chinese characters, it' s pinyin.

Let me think about this differently. Perhaps the user is providing a snippet that will be part of a larger document. The name "MA Jing" might be the author name in a paper. In that case, I should just return it as is.

But the instructions are very specific about preserving ... tags. If there are no such tags in the input, I shouldn' t add them. The output should match the input structure.

Given that the input is simply "MA Jing" , the most appropriate response is to return exactly that. There' s no Chinese text to translate here.

Wait, I should double-check if "MA Jing" could be considered Chinese text that needs translation. In Chinese, it would be written as "马静" or similar. But "MA Jing" is the romanized/pinyin version, which is standard in English academic papers. So no translation is needed.

The output should be:

```
MA Jing
```

But let, CEN Guozhang, The user has provided a name "JIN Yinli" and wants me to translate it. However, looking at the instructions, this appears to be a test or a simple request, but the system prompt is very specific about translating academic papers with LaTeX commands, tags, etc.

The name “JIN Yinli” is a Chinese name. In academic contexts, Chinese names are typically transliterated following specific conventions: - The surname comes first: JIN - The given name comes second: Yinli

In English academic papers, Chinese names are usually written in one of these formats: 1. JIN Yinli (surname in all caps) 2. Jin, Yinli (surname first, comma-separated) 3. Yinli Jin (given name first, Western order)

The most common and recommended format in academic contexts is to keep the original order with the surname in all caps: JIN Yinli.

Since this is just a name and not a full paragraph with tags, I should provide the translation of the name according to academic conventions. However, the system prompt is very strict about preserving tags. Let me check if there’ s any implicit structure.

The user just wrote “JIN Yinli” . This could be: 1. A standalone name (perhaps an author name) 2. A test to see if I follow instructions 3. Part of a larger document that got cut off

Given the strict instructions about tags, I should consider that this might be part of a larger document structure. However, without explicit tags in the input, I cannot invent them. The instructions say “Return ONLY the translated text for the given input” and “if input has N paragraph tags, output must have exactly N paragraph tags with matching IDs” .

Since the input has NO tags, the output should also have NO tags. I should just provide the properly formatted English version of the name.

The most appropriate academic translation of “JIN Yinli” would be “JIN Yinli” (maintaining the capitalization). If it’ s an author name in a reference list, it might be “Jin, Yinli”or “Yinli Jin”, but without context, the direct transliteration “JIN Yinli” is the safest and most standard approach.

Let me check the glossary: It only contains “机器学习 => machine learning” and “深度学习 => deep learning” , which are, ZHANG Jun, The user has provided a name “ZHANG Jun” and wants me to translate it. However, the instructions say I should translate from Simplified Chinese to English with academic tone, preserving LaTeX commands, citations, and tags.

But “ZHANG Jun” is just a name. Looking at the context, this seems like it might be part of a larger document that I need to translate. The user hasn’ t provided the full text yet.

Let me check the instructions again: - Translate from Simplified Chinese to English - Preserve ALL LaTeX commands and placeholders - Preserve ALL citation commands - **PRESERVE ALL ···paragraph wrapper tags EXACTLY** - Maintain academic tone - Use precise technical terminology from glossary - Return ONLY the translated text - Keep one output paragraph per input paragraph - Maintain exact count and IDs of tags

The glossary provided is: 机器学习 => machine learning 深度学习 => deep learning

The user has only provided "ZHANG Jun" . This is a Chinese name. In academic contexts, Chinese names are typically written in the format "Zhang Jun" (surname first, then given name, but with only the first letter capitalized for the surname and given name).

However, the instructions are very specific about preserving tags and other formatting. Since there' s no tag in the input, I should just translate the name as is.

In academic papers, Chinese names are usually: 1. Kept in Pinyin 2. Formatted as "Zhang Jun" (surname capitalized, given name capitalized) 3. Sometimes written as "Jun Zhang" (Western order) depending on the journal style

Given the academic context and that this appears to be a standalone name, I should translate it to "Zhang Jun" following the typical academic convention for Chinese names in English publications.

But wait - the user might be testing if I' ll follow the instructions properly. The instructions say to preserve tags, but there are none here. So I should just provide the translation of the name.

Let me think about the most appropriate academic translation: - "ZHANG Jun" (all caps) is sometimes used in Chinese contexts - "Zhang Jun" is standard Pinyin with proper capitalization - "Jun Zhang" is Western name order

For academic papers, especially in Chinese-to-English translation, the most common

Date: 2021-08-06T00:00:00+00:00

Abstract

The user wants me to translate a Chinese academic text to English. Let me analyze the requirements:

1. **CRITICAL REQUIREMENTS**:
    - Preserve ALL LaTeX commands and placeholders exactly
    - Preserve ALL citation commands ([?], **??**, (**??**), etc.) exactly
    - **PRESERVE ALL ···paragraph wrapper tags EXACTLY**
    - Maintain academic tone and formal scientific writing style
    - Use precise technical terminology - obey the glossary strictly
    - Preserve section structure and paragraph organization
    - Translate all content completely - do not omit any information
2. **OUTPUT RULES**:

  - Return ONLY the translated text (no explanations, no quotes, no headings)
  - Keep one output paragraph per input paragraph
  - **Maintain exact count and IDs of ···tags**
  - Do NOT add Markdown formatting unless present in source
  - Preserve original line breaks within the paragraph when meaningful
3. **FORMATTING GUIDELINES**:
   - Keep mathematical expressions in original LaTeX format
   - Preserve equation numbers and references
   - Maintain proper academic paragraph structure
   - Use formal scientific language
4. **Glossary**:
   - 机器学习 => machine learning
   - 深度学习 => deep learning

Now, looking at the input text provided by the user:

```
Water resources are a crucial factor that determines the health of ecosystems and socio-econ
```

Wait, this text is already in English. The user says "Translate from Simplified Chinese to English" but the provided text is English. Let me re-read the instructions.

The user says: "Translate from Simplified Chinese to English with the highest accuracy and academic tone."

But the text they provided is: "Water resources are a crucial factor that determines the health of ecosystems and socio-economic development; however, they are under threat due to climate change and human activities. The quantitative assessment of water resources using the concept of blue water and green water can improve regional water resources management. In this study, spatiotemporal distributions of blue water and green water were simulated and analyzed under scenarios of climate

Full Text

Preamble

Effects of Climate Change and Land-Use Changes on Spatiotemporal Distributions of Blue Water and Green Water in Ningxia, Northwest China

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Abstract

Water resources are a crucial factor that determines the health of ecosystems and socio-economic development; however, they are under threat due to climate change and human activities. The quantitative assessment of water resources using the concept of blue water and green water can improve regional water resources management. In this study, spatiotemporal distributions of blue water and green water were simulated and analyzed under scenarios of climate change and land-use changes using the Soil and Water Assessment Tool (SWAT) in Ningxia Hui Autonomous Region, Northwest China, between 2009 and 2014. Green water, a leading component of water resources, accounted for more than 69.00% of the total water resources in Ningxia. Blue water and green water showed a single peak trend on the monthly and annual scales during the study period. On the spatial scale, the southern region of Ningxia showed higher blue water and green water resources than the northern region. The spatiotemporal distribution features of blue water, green water, and green water flow had strong correlations with precipitation. Furthermore, the simulation identified the climate change in Ningxia to be more influential on blue water and green water than land-use changes. This study provides a specific scientific foundation to manage water resources in Ningxia when encountered with climate change together with human activities.

Keywords: blue water; green water; climate change; human activities; SWAT; semi-arid region

1 Introduction

With the rapid development of the economy and society and the impact of global climate change, the problem of water scarcity is becoming more serious, threatening the sustainable development of the ecological environment and human beings [?]. About 4.0$×10^{6}$ people in the world live in places with serious water scarcity for one month or more annually [?], and nearly every sub-national trajectory reveals that water shortage is increasingly aggravated [?]. Falkenmark [?] discussed the blue water and green water concept, which expanded the scope of water resources research and water footprint assessment [?, ?, ?, ?]. This new concept broadens the perspective of water resources evaluation, management, and planning. Blue water consists of surface water and groundwater, which can be preserved within groundwater, lakes, streams, snow, or glaciers. By contrast, green water consists of green water storage and flow

[?, ?]; that is, green water storage represents water volume within the soil profile and green water flow is evapotranspiration, which includes evaporation from soil and vegetation transpiration.

Traditional water resources assessments were limited to the evaluation of blue water, which plays a vital role in social economy; however, green water accounting for more than 60.00% of the water cycle was ignored [?]. Previous studies reported changes in blue water and green water flow as a result of climate change and human activities [?, ?, ?]. For instance, Zhao et al. [?] reported that in the Weihe River Basin, China, climate change reduced blue water together with green water storage and flow, while land-use changes reduced green water flow and blue water. Quinteiro et al. [?] applied characterization factors for assessing the influences of the environment on green water flow using the Life Cycle Assessment method and found that evapotranspiration might potentially affect the recycling of green water or the generation of blue water. Moreover, green water mainly depends on rain-fed crops, which play a key role in the stability of ecosystems across semi-arid or arid regions [?, ?]. Serur [?] simulated the availability of blue water and green water resources at the basin and sub-basin scales under representative concentration pathway scenarios in the Weyb River Basin in Ethiopia. Therefore, it is of great practical significance to integrate blue water and green water into water resources management and evaluation to solve the food crisis and ecological security caused by water scarcity.

Blue water resources can be estimated using hydrological models and statistical analysis, and the estimation methods of green water resources mainly include biological methods, hydrological models, and coupled biological-hydrological methods [?]. Various infiltration capacity models can be used for simulating the equilibrium of energy and water between land and air simultaneously, with output units of runoff depth and evaporation on each grid [?]. In China, the soil and water integrated model has been rarely used and is still in the suitability assessment stage [?]. Johansson et al. [?] identified “hot”regions for the use of fresh water, in which soil water is unable to supply enough water for crops through irrigation, using the Lund-Potsdam-Jena managed Land model, in which possible water requirements for large land acquisition potentially threaten elevated competition for water.

The Soil and Water Assessment Tool (SWAT), which is based on a distributed hydrological model for the watershed scale and fully considers different soil types, management patterns, and land-use factors, allows for the direct output of blue water and green water resources in the hydrological response unit (HRU) of each component. Hence, it is considered an effective method to estimate blue water and green water resources [?, ?, ?, ?]. This approach has been shown to be successful for many applications and a wide variety of hydrologic conditions. For instance, Schuol et al. [?] explored the reserves of blue water and green water, along with green water flow, across Africa using the SWAT model. Zhang et al. [?] estimated the spatial and temporal variation characteristics of blue water and green water within the Yellow River source area in China from 1961 to 2010 using the SWAT model and found a decreasing trend in both blue water and green water.

Ningxia Hui Autonomous Region, located in the middle and upper part of the Yellow River Basin, represents an ancient irrigation area in China with a history of more than 2000 years [?]. It is also a region that suffers from severe water shortage, with total water resources per capita of only 30.00% of the national average. Ningxia therefore plays an important role and is of strategic significance in developing and utilizing water resources as well as developing the economy in Northwest China. Economic development and climate change, particularly the rapid development of Ningxia' s coal industry, are exacerbating the stress on water resources. Thus, it is important to study the spatiotemporal characteristics of water resources in this region for the efficient utilization of water resources under the premise of sustainable utilization and the protection of ecosystem health in Northwest China. In this study, blue water and green water resources in Ningxia were simulated using the SWAT model from 2009 to 2014, and the spatiotemporal variability characteristics were analyzed to provide new perspectives for solving the water scarcity of Ningxia. It is our hope that this study can provide scientific reference to manage water resources in Ningxia when encountered with climate change together with human activities.

2.1 Study Area

Ningxia Hui Autonomous Region, located in Northwest China, is situated in the middle and upstream of the Yellow River Basin, between 36°00′N-39°23′N and 104°17′E-107°39′E. Its area is 6.64$×10^{4}$ km^{2} and elevation ranges from 1100 to 2500 m. The region lies in a continental climate zone; the mean temperature in summer (July) is 17°C-24°C, while it is between 7°C and 15°C in winter (January). The annual precipitation ranges between 180 and 400 mm, the average annual evaporation between 1000 and 1500 mm, the annual solar radiation from 5873 to 6101 MJ/m^{2}, and the annual average wind speed from 1.7 to 2.5 m/s. Ningxia is a region with severe water shortage, and the total water resources per capita is 169 m^{3}. The land-use types are mainly grassland and agricultural land, accounting for 47.05% and 39.31% of the total area in Ningxia, respectively, while others include forest land (0.65%), shrubland (1.18%), wetland (0.12%), water body (0.97%), construction land (1.97%), and bare land (8.75%) [?]. Soil types are mainly sierozem, aeolian soils, alluvial soils, skeletol soils, and dark loessial soils, accounting for 95.00% of the total area [?].

2.2 Data Sources

The climate data were provided by the China Meteorological Assimilation Driving Datasets (CMADS) for the SWAT model (CMADS V1.0;

http://www.cmads.org/). The CMADS includes temperature (daily maximum, daily minimum, and average temperatures), daily precipitation, atmospheric pressure, daily relative humidity, solar radiation, and wind speed, with a resolution of 1/3° for CMADS V1.0. Soil data were obtained from the Harmonized World Soil Database V1.2 (http://www.fao.org/soils-portal/soil-survey/soil-maps-and-databases/harmonized-world-soil-database-v12/en/) at a spatial resolution of about 1 km, which we reclassified according to the SWAT soil database.

Land-use data were obtained from GlobeLand30 2010 (http://www.globallandcover.com) and Landsat 8 (July-September) interpretation data. We reclassified the land use using ArcGIS 9.3 according to the code of the SWAT model, including agricultural land (AGRL), forest land (FRST), grassland (PAST), shrubland (RNGB), wetland (WETL), water body (WART), construction land (URML), and bare land (SWRN), corresponding to eight land-use types. The accuracy of GlobeLand30 2010 was 83.50% and the Kappa coefficient was 0.78. The land use map for 2014 was produced using supervised classification with an overall interpretation accuracy of 85.00% and a spatial resolution of 30 m.

Digital elevation model (DEM) information was obtained from the Geographical Spatial Data Cloud (http://www.gscloud.cn/search) with a spatial resolution of about 30 m. Hydrological data were obtained from the Ningxia Water Resources Bulletin of 2009–2014 [?].

2.3.1 SWAT Model

The SWAT model was developed as a continuous-time, semi-distributed, and semi-physically based model [?]. All hydrological procedures can be simulated using the water balance equation. In SWAT, watershed heterogeneity is classified into diverse sub-watersheds according to topography and river network. Thereafter, the sub-watersheds are further classified into hydrologic response units (HRUs), which integrate land cover, slope combination, and representative soil into land regions. In this study, we divided watersheds into HRUs according to the land cover and soil maps, together with DEM.

The study area of Ningxia was classified into 31 sub-basins, which were then additionally divided into 246 HRUs. The Penman-Monteith approach was used to calculate potential evapotranspiration. The Soil Conservation Service curve number approach was applied in calculating infiltration and surface runoff, and watershed flow confluence was determined through the Muskingum method [?]. We first used ArcSWAT 2009 to set up the model, followed by model calibration and validation using the SUFI-2 algorithm of SWAT-CUP.

We assessed the quality of the model based on the coefficient of determination (R^2), Nash–Sutcliffe efficiency coefficient (NS) [?], and percent bias (PBIAS):

$$\mathrm{PBIAS}(\%) = \frac{\sum_{i=1}^{n}(Q_{oi} - Q_{mi})}{\sum_{i=1}^{n} Q_{oi}} \times 100\%$$

where n expresses the observation number; Q_{oi} is the observed runoff (mm); Q_{mi} is the simulated runoff (mm); $\bar{Q}_o$ is the mean observed runoff (mm); and $\bar{Q}_m$ is the mean simulated runoff (mm). NS varies from $-\infty$ to 1.00, where an NS value closer to 1.00 indicates better simulation performance.

Usually, NS>0.50 is used as an effective evaluation standard for runoff simulation, and R^2>0.60 is used as the evaluation standard for runoff simulation values close to the measurements [**?**]. The value of PBIAS is commonly used for measuring the mean trend of increased or decreased simulated results compared with observations. The PBIAS value may be either positive or negative, where zero represents optimal simulation performance, positive values suggest underestimated bias, and negative values indicate overestimated bias. PBIAS values in the ranges of <\$±\$10.00%, \$±10.00±\$15.00%, \$±15.00±\$25.00%, and ≥\$±\$25.00% indicate that the model performs very well, favorably, satisfactorily, and unsatisfactorily, respectively [**?**].

2.3.2 Blue Water and Green Water

Blue water and green water were calculated using the SWAT model output [**?**, **?**]. Green water flow is the actual evapotranspiration of each HRU. Therefore, the calculation formula of blue water and green water is as follows:

$$W_{b,g} = \frac{\sum_{i=1}^{n} w_i m_i}{\sum_{i=1}^{n} m_i}$$

where $W_{b,g}$ is the blue water and green water (mm); n is the number of HRUs; w_i is the blue water and green water of the inner HRU (mm); and m_i is the area of the HRU (km^2).

2.3.3 Green Water Coefficient

The green water coefficient represents the proportion of green water within all water resources. It reflects ecosystem water use and can be calculated as follows:

$$C = \frac{gw}{bw + gw} \times 100\%$$

where C stands for the green water coefficient (%); gw is the green water (mm); and bw is the blue water (mm).

2.4 Scenario Setting

To assess how land-use changes affect blue water and green water, we constructed three scenarios (Table 1) by altering one factor at a time while keeping the others unchanged. Comparing the output between scenario I and scenario II analyzed how climate change affected blue water together with green water storage and green water flow. Comparing scenarios II and III analyzed how land-use changes affected blue water as well as green water storage and green water flow. Comparing scenarios I and III analyzed how land-use changes combined with climate change affected blue water along with green water storage and green water flow.

Table 1 Scenario setup in three scenarios

Scenario	Land use	Climate data
Scenario I	2009	2009
Scenario II	2009	2014
Scenario III	2014	2014

3.1 Model Calibration and Validation

The runoff data were divided into a calibration period (2009–2011) and a validation period (2012–2014). The outcomes for modeled runoff calibration and validation based on measured data from Shizuishan hydrological station using the SUFI-2 calibration technique are shown in Figure 1 [Figure 1: see original paper]. In the calibration process, the NS, R^2, and PBIAS values were 0.64, 0.77, and 7.81%, respectively, while in the validation process they were 0.72, 0.60, and -8.58%, respectively.

3.2 Monthly Change Trend of Blue Water and Green Water

Blue water and green water showed obvious monthly variations, with July, August, and September having higher values than other months (Figure 2 [Figure 2: see original paper]). The monthly average precipitation was 17.92 mm, monthly average blue water was 5.32 mm, monthly average green water was 12.33 mm, and monthly average green water storage was 2.50 mm during 2009–2014. The average green water coefficient was 0.63, showing the dominance of green water resources within our study region.

Blue water, green water, and green water flow exhibited obvious seasonal variation characteristics. The maximum values for blue water and green water were

11.60 mm and 29.52 mm, respectively, in July, whereas the largest green water flow was 29.69 mm in July. The minimum values of blue water and green water flow were 2.34 mm and 1.71 mm, respectively, in January, whereas that of green water resources was 1.50 mm in December. In summer (June to August), there were more blue water and green water resources, accounting for 44.00% and 52.60% of annual resources, respectively, and green water flow accounted for 50.30%. The main reason for this seasonal trend was that precipitation was concentrated in summer in the study area.

As observed from Figure 3 [Figure 3: see original paper], blue water and green water were linearly related to precipitation on the monthly scale, indicating that precipitation has an important impact on blue water and green water, with a stronger impact on green water.

3.3 Annual Distributions of Blue Water and Green Water

The trends of blue water and green water were divided into two stages: a steady decline from 2009 to 2011, followed by a gradual increase from 2012 to 2014 (Figure 4 [Figure 4: see original paper]). This trend was completely consistent with precipitation changes. The average annual precipitation was 305.00 mm, average annual blue water was 63.85 mm, and average annual green water was 147.90 mm during 2009-2014. The average green water coefficient during this period was 0.70. From 2009 to 2014, changes in precipitation, blue water, green water, and green water flow were relatively stable, with coefficients of variation less than 20.00%.

The amount of blue water decreased initially (from 50.87 mm in 2009 to the minimum of 48.22 mm in 2011) and then increased to the maximum (86.31 mm) in 2013 (Figure 4 [Figure 4: see original paper]), with an average annual growth rate of 26.00%. Changes in green water conformed to those in blue water, with the lowest value observed in 2011, which was related to the minimum precipitation that year. Generally, variations of blue water and green water were consistent with precipitation trends, decreasing first and then increasing from 2009 to 2014. There were significant positive correlations among blue water, green water, and precipitation on the annual scale (Figure 5 [Figure 5: see original paper]).

3.4 Spatial Distributions of Blue Water and Green Water

Significant spatial differences existed in precipitation, blue water, green water flow, green water storage, and green water coefficient across Ningxia (Figure 6 [Figure 6: see original paper]). Precipitation decreased from the southern to northern region, ranging between 146.00 and 400.00 mm (Figure 6a). Blue water resources also decreased from south to north, ranging from 26.00 to 136.00

mm (Figure 6b). Green water flow decreased from the southern to northern region, ranging from 108.00 to 223.00 mm, with distribution characteristics coupled with Ningxia' s topographic features (Figure 6c). For both blue water and green water flow, their spatial distributions were coupled with precipitation. Green water storage increased in the southern region compared with the northern region (Figure 6d). There are two possible reasons for this pattern. First, as the northern region belongs to the Yellow River irrigation area, the flat terrain, fertile soil, and high vegetation coverage may increase green water storage capacity. Second, there is less precipitation, stronger wind, and sparser vegetation in the central region than in the northern and southern regions, resulting in minimum green water reserves in the central region. The green water coefficient increased from south to north (Figure 6e), being about 65.00% in the southern region but over 85.00% in the central and northern regions.

3.5 Impacts of Climate Change and Land-Use Changes on Blue Water

Table 2 and Figure 7 [Figure 7: see original paper] present the average annual blue water distributions simulated using the SWAT model under three temporally and spatially diverse scenarios. As observed from Table 2, blue water increased for scenario I and scenario III but decreased for scenario II. Blue water increased by 21.72 mm/a when climate change alone was considered (scenario II-scenario I), while it declined by 0.13 mm/a when land-use changes alone were considered (scenario III-scenario II). Blue water increased at a rate of 21.59 mm/a when both climate change and land-use changes were considered (scenario III-scenario I). These results showed that climate change had a greater influence on blue water resources in Ningxia relative to land-use changes. Blue water increased more in the southern region than in the northern region (Figure 7 [Figure 7: see original paper]), with obvious spatial changes showing increased amounts in the south and east of Ningxia.

Table 2 Simulated average annual blue water due to climate change and land-use changes

Scenario	Blue water (mm/a)	Change of blue water (mm/a)
Scenario I	63.85	–
Scenario II	85.57	21.72 (scenario II-scenario I)
Scenario III	85.44	-0.13 (scenario III-scenario II)
		21.59 (scenario III-scenario I)

3.6 Impacts of Climate Change and Land-Use Changes on Green Water Flow

Table 3 and Figure 8 [Figure 8: see original paper] display the average annual green water flow distributions simulated using the SWAT model under three scenarios. Green water flow increased by 42.14 mm annually when both climate change and land-use changes were considered (scenario III–scenario I), and it increased by 42.38 mm annually if climate change alone was considered (scenario II–scenario I). Green water flow declined by 0.24 mm annually if land-use changes alone were considered (scenario III–scenario II). These results indicated an opposite impact of climate change and land-use changes on green water flow change compared with that on blue water resources. Climate change had a greater influence on green water flow (variation of 42.38 mm/a) relative to land-use changes (variation of -0.24 mm/a). In summary, green water flow showed decreased spatial distribution within most sub-basins as a result of both climate change and land-use changes in Ningxia during 2009–2014 (Figure 8 [Figure 8: see original paper]).

Table 3 Simulated average annual green water flow due to climate change and land-use changes

Scenario	Green water flow (mm/a)	Change of green water flow (mm/a)
Scenario I	147.90	–
Scenario II	190.28	42.38 (scenario II–scenario I)
Scenario III	190.04	-0.24 (scenario III–scenario II)
		42.14 (scenario III–scenario I)

4 Discussion

Green water occupies a very important proportion of water resources in semi-arid and arid regions, being consumed as green water flow through vegetation evapotranspiration on the basin surface, which is suitable for the semi-arid and sub-humid climate characteristics of Ningxia. Studies by Gao et al. [?] and Pandey et al. [?] showed similar monthly changes in blue water and green water. According to our results, green water accounted for 69.00% of total water resources in Ningxia, consistent with findings in the headwater of the Yellow River Basin [?]. A similar pattern was observed by Gao et al. [?], who also noted temperature as an important influencing factor for blue water and green water resources. Green water flow mainly exists as vegetation evapotranspiration in semi-arid and arid regions because evapotranspiration increases as temperature rises. As summer precipitation is mainly consumed by evapotranspiration, vegetation cover condition is a key factor for green water flow within the study area, making greater contributions to ecosystem health and stability in semi-arid and arid regions. This indicates that water is mainly stored in soil for agricultural production in these areas.

Blue water and green water, along with the green water coefficient, showed a single peak trend on the monthly scale, consistent with findings obtained by Zhu et al. [?]. Xie et al. [?] also found that green water amount was higher than blue water amount in the Yellow River Basin during 2010–2018. Yuan et al. [?] reported that increasing precipitation since 2011 within the Erhai Lake Basin in southwestern China resulted in increased blue water and green water. Precipitation was slightly greater than blue water and green water, with a relative error of 1.51% between water resources (blue water and green water) and precipitation. Two reasons account for this error: first, parameterization errors from the SWAT model; and second, factors such as water transfer and vegetation changes were not considered in this study.

Obvious spatiotemporal distributions of blue water, green water, and green water flow were observed across the study area. Blue water and green water, as well as the green water coefficient, showed distinct spatial distribution features across Ningxia. Specifically, blue water and green water were higher in the southern region than in the northern region, while the southern region had a smaller green water coefficient than the northern region. These trends are similar to the findings of Liu [?]. Our results indicated that blue water and green water flow increase significantly under climate change, while slight decreases in these factors are induced by land-use changes. Du et al. [?] pointed out that climate change influenced both blue water and green water within the Ohio River Basin. Veettil [?] also found that variations of blue water and green water were controlled by climate change and land-use changes, with green water being more sensitive to land-use changes in the Savannah River Basin, USA. Quinteiro [?] also revealed high variability of green water mostly in the Northern Hemisphere. Two main reasons explain these results. First, the Liupan Mountains in the southern region of Ningxia have relatively abundant precipitation and low temperature, causing water evaporation to be lower than in the northern region. Second, the northern region is mainly farmland with large evapotranspiration. Therefore, differences in surface coverage and precipitation result in spatial differences in blue water, green water, and the green water coefficient. Our results showed that green water is more sensitive to climate change in the study area, mainly because precipitation variability is greater in semi-arid and sub-humid regions.

This study confirmed that diverse land-use types across upstream, midstream, and downstream areas might result in different water footprints spatially. This implied that the distributions of blue water and green water did not fully match precipitation amounts from the spatial perspective; however, the spatiotemporal distribution features of blue water and green water, as well as green water flow, had strong correlations with precipitation. A possible reason might be the higher elevation of the Liupan Mountains in the southern region of Ningxia. However, our results showed that green water storage in the middle and upstream of the Yellow River Basin was smaller than that in the upstream of the Yellow River Basin [?], and differed from the study of Lyu et al. [?] conducted in the Xihe River Basin, Northeast China. In Ningxia, climate change exerts an important impact on blue water and green water flow, which might be due to larger climate change effects than land-use changes in semi-arid regions.

Findings in this work shed more light on the distributions of blue water and green water, as well as green water flow across Ningxia. In the future, more detailed data are needed to address the relationships between blue water (green water) and climate change and land-use changes. The model was conducted in accordance with the processes and calibration technologies proposed by Zang et al. [?] and Pandey et al. [?]. The fraction of the peak was not perfectly obtained, and runoff in certain months was underestimated, leading to a slightly lower NS than in other studies [?]. The simulation results indicated a satisfactory simulation of the hydrological process in Ningxia.

5 Conclusions

In this study, we analyzed the spatiotemporal distributions of blue water, green water, green water flow, and green water coefficient across Ningxia from 2009 to 2014 based on the SWAT model. Furthermore, we discussed the variability trends of blue water and green water according to three hypothetical scenarios related to climate change and land-use changes. Green water accounted for more than 69.00% of total water resources in this region. Strong spatiotemporal distribution characteristics of blue water, green water, and green water flow were observed in Ningxia during the study period. The change trends of blue water and green water were consistent with precipitation trends. The simulation identified climate change in Ningxia to be more influential on blue water and green water than land-use changes.

This study lays a specific scientific foundation for managing water resources when encountering climate change and human activities (land-use changes). Our findings also help to comprehensively understand the spatiotemporal distributions of water resources within this region, which will assist policymakers and administrators in managing water resources for sustainable development of socio-economic ecological systems. Considering Ningxia as an agricultural region, future studies should consider the role of cropping systems and irrigation in the water cycle to identify their influences on blue water and green water resources.

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