The user wants me to translate a Chinese academic paper title: “石羊河上游地面人工增雨效果统计检验分析后印本” Let me break this down: - 石羊河上游 => Upper Shiyang River (石羊河 is a proper name, should be Shiyang River) - 地面人工增雨 => ground-based artificial precipitation enhancement / ground-based cloud seeding - 效果 => effect…

Authors: The user just wrote “程鹏” which is a Chinese name. It could be “Cheng Peng” or “Peng Cheng” depending on the order. In academic contexts, Chinese names are often written with the surname first, so “程鹏” would be “Cheng Peng” where 程 (Cheng) is the surname and 鹏 (Peng) is the given name.

However, the user might be asking me to translate something about this person, or this might be a test. But there’ s no context provided. The instruction says to translate from Simplified Chinese to English with academic tone, but there’ s no paragraph with tags or any content to translate.

Wait, let me re-read the instructions. The user wrote “程鹏” and nothing else. This is not in the format I was instructed to handle. The instructions say I should expect input with …tags and translate the content inside them.

Since there’ s no such structure, I should probably just translate the name itself. But the instructions are very specific about preserving LaTeX commands, citations, and tags. There’ s none of that here.

I think the most reasonable interpretation is that the user wants me to translate this Chinese name into English. In academic contexts, the standard is to use pinyin. “程鹏” would be “Cheng Peng” . If it’ s a person’ s name, I should maintain the capitalization.

But wait - maybe the user is testing if I’ ll follow the instructions properly. The instructions say “Return ONLY the translated text for the given input (no explanations, no quotes, no headings you invent).” So I should just output the translation without any commentary.

Given that "程鹏" is just a name, the translation would be "Cheng Peng". In academic writing, Chinese names are typically rendered in pinyin with the surname first, so "Cheng Peng" is correct.

However, I should consider if there's any ambiguity. Could "程鹏" be something else? It's most definitely a name. Could it be a place? No, it's a person's name. Could it be a company? Unlikely.

So my answer should be simply: Cheng Peng

But wait - the instructions mention preserving tags. Since there are none, I don't need to add them. The user just gave me a name, so I should just give the translation of the name.

Actually, let me think about this more carefully. The user might have made a

Date: 2021-08-01T00:00:00+00:00

Abstract

The user wants me to translate a Chinese scientific text about artificial rain enhancement in the Shiyang River basin. Let me break down 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
    - 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

Looking at the input text, I notice: - There are no LaTeX commands or math placeholders in this text - There are no citation commands - There are no tags in

the input - The text is about weather modification/artificial rain enhancement - It' s a scientific abstract or summary of research results

Since there are no tags in the input, I need to check the requirements again. The user says "PRESERVE ALL ···paragraph wrapper tags EXACTLY" and "if input has N paragraph tags, output must have exactly N paragraph tags with matching IDs" . But the input doesn' t have any tags.

Wait, let me re-read the instructions. The user says "Translate from Simplified Chinese to English with the highest accuracy and academic tone." and gives me a block of text. The text appears to be a single paragraph. The instructions about tags seem to be general guidelines for when such tags are present. Since they' re not present in the input, I should just translate the text as is.

But let me double-check: The user says "Remember: Mathematical content, citations, and wrapper tags must remain untouched - only translate the Chinese text inside the tags." This suggests that if there were tags, I should only translate the content inside them. Since there are none, I should just translate the entire text.

The text is: "为深入了解石羊河上游的人工增雨效果，评估不同月份的人工增雨效果，利用统计方法对 2010

Full Text

Statistical Test and Analysis of Artificial Rainfall Enhancement Effect in the Upper Shiyang River Basin

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Abstract: The Shiyang River is an important inland river in the Hexi Corridor of northwestern China, where water resources are scarce and the ecological environment is fragile. Since 2010, the meteorological department has significantly expanded the scale of artificial precipitation enhancement operations in the basin, and observed meteorological and ecological data have shown increased local annual precipitation levels and sustained improvement in the ecological environment. To further evaluate the effects of artificial precipitation enhancement in the upper reaches of the Shiyang River, this study collected monthly precipitation data from 1960 to 2019 and applied various statistical analysis methods —including sequence analysis, regional comparison analysis, and regional historical regression analysis—to analyze and evaluate the effects of artificial rainfall enhancement operations conducted between April and October from 2010 to 2019 in the upper Shiyang River Basin, with statistical significance testing performed on the results. The findings demonstrate an average relative rainfall increase of 17.5% and an average monthly absolute rainfall increase of 4.7 mm, indicating that the artificial rainfall enhancement effect from April to October was statistically significant. All tests showed that the effects in spring (April–May) and autumn (September–October) were significantly better than in summer (June–August). Comparative analysis of the three test methods revealed that sequence analysis produced relatively smaller results, regional comparison analysis produced relatively larger results, and regional historical regression analysis yielded more objective and accurate outcomes.

Preliminary results indicate that artificial rainfall enhancement represents an effective measure for improving water resources in the Shiyang River Basin. Such operations have increased the annual mean precipitation by 13.5% and contributed a cumulative rainfall increase of 337 mm over the 10-year period. These results suggest that meteorological departments should seize the most favorable opportunities in spring and autumn to conduct artificial rainfall enhancement operations in order to successfully increase the total water resources in the basin.

Keywords: artificial rainfall enhancement; statistical test; sequence analysis; regional historical regression statistics; Shiyang River

1 Introduction

Through years of development, weather modification in China has played an increasingly important role in hail suppression, alleviation of water resource shortages, and other applications. With the continuous expansion of artificial rainfall enhancement operations, scientifically and objectively evaluating the effects of such operations has become an important task in weather modification research and an effective approach for advancing weather modification technology. Due to the high natural variability of precipitation, obtaining quantitative rainfall enhancement results through statistical methods has become a commonly used approach. Numerous technical and methodological explorations have been conducted around statistical testing, achieving significant progress.

Since the inception of weather modification work, evaluating the effects of artificial seeding operations has remained a scientific challenge, attracting widespread attention from researchers. Conducting randomized field seeding trials for artificial rainfall enhancement effect testing is a widely recognized approach internationally, as exemplified by the White Top Project in the central United States, the Wyoming orographic cloud seeding experiment, the North China stratiform cloud precipitation experiment, and the Gutian experiment in Fujian. Defelice et al. evaluated seeding effects and concluded that rainfall enhancement rates reached 5%–15%. Domestic scholars have used numerical analysis methods to examine the efficacy of non-randomized experiments, finding that regional historical regression statistical analysis offers the highest efficacy. In the Jianghuai convective cloud artificial rainfall enhancement effect test, combining regional historical regression statistical analysis with physical testing methods provided physical evidence corresponding to statistical test results, revealing convective cloud rainfall enhancement effects. Qian Li et al. used statistical testing methods to evaluate artificial rainfall enhancement, achieving good results.

With increasing regional population and economic development, the ecological environment of the Shiyang River Basin has become extremely fragile. Developing and utilizing atmospheric cloud water resources is an effective means to alleviate freshwater resource shortages, particularly in northwestern China. Since 2010, meteorological departments have increased the scale of artificial rainfall enhancement operations in the Shiyang River Basin, resulting in significantly increased annual precipitation and a sustained positive trend in ecological environment development. Objectively evaluating the effects of artificial rainfall enhancement in the Shiyang River Basin is crucial for improving operational plans and enhancing effectiveness. Based on these considerations, this paper uses data from artificial rainfall enhancement operations in the Shiyang River Basin from 2010 to 2019 as an example, employing sequence analysis, regional comparison analysis, and regional historical regression statistical testing methods to analyze the significance of artificial rainfall enhancement effects under changing climatic conditions, providing a reference basis for conducting artificial rainfall enhancement operations and effect testing in arid regions.

2 Study Area and Methods

2.1 Study Area Overview

The Shiyang River is the third largest inland river system in the Hexi Corridor of Gansu Province, originating from the Daxue Mountain on the northern side of the Lenglongling section of the Qilian Mountains. The river stretches approximately 250 km between 101°41′-104°16′E and 36°29′-39°27′N. The entire river system runs from east to west, with eight main tributaries distributed within Wuwei City and Jinchang City. The southern part of the Shiyang River is a water source conservation area in the Qilian Mountains, while the northern part borders the Tengger and Badain Jaran deserts. Precipitation distribution in the basin is uneven, with an average precipitation of 260 mm in the southern mountainous area, while the average precipitation in Minqin County in the north is only 113 mm, making it a typical resource-scarce water-deficient region.

The operational area and comparison area selected in this study are located in the upper reaches of the Shiyang River, spanning the semi-arid humid zone of the southern Qilian Mountains alpine region and the semi-arid to arid zone of the central corridor plain area. In recent years, meteorological departments have continuously increased the layout of ground-based artificial rainfall enhancement operations in the Shiyang River, continuously adding operational sites. By 2019, there were 32 operational sites covering a beneficial area of 6,000 km^2. The Shiyang River Basin conducts an average of 150 artificial rainfall enhancement operations annually, launching approximately 8,000 rain-inducing shells and 400 rockets each year. Each rocket contains 10 times the amount of silver iodide as a rain-inducing shell. When converted to rain-inducing shells, the annual average launch exceeds 12,000 shells. [Figure 1: see original paper] shows the operational sites and operational volume changes in the Shiyang River Basin.

2.2 Data

Based on the distribution of meteorological observation stations and ground-based artificial rainfall enhancement operational sites in the study area, and considering the completeness and reliability of data series, precipitation data from three meteorological stations (Wuwei, Gulang, and Yongchang) within the basin for the period 1960–2019 were selected, sourced from the China Meteorological Data Network. Information on artificial rainfall enhancement operational sites and operational conditions was provided by the Gansu Weather Modification Office.

2.3 Methods

2.3.1 Sequence Analysis The sequence analysis method uses only an operational area without a comparison area. The historical average rainfall in the operational area is used as the estimated value of natural precipitation during the operational period (Y_e), which is then compared with the measured rainfall during the operational period (Y) to determine the artificial influence effect (ΔR). Due to the large daily rainfall variability, monthly or seasonal rainfall is commonly used as the evaluation unit in effect testing. The relative rainfall enhancement rate (E) is calculated as follows:

$$E = \frac{Y - Y_e}{Y_e} \times 100\%$$

2.3.2 Regional Comparison Analysis A reasonable operational impact area and comparison area are selected, and the rainfall enhancement effect is determined by comparing precipitation between the comparison area and the operational impact area during the effect testing period. Assuming uniform spatial distribution of precipitation between the comparison area and operational area during the test period, the monthly precipitation correlation coefficient between the operational impact area and comparison area is calculated (formula 2), where the magnitude of the correlation coefficient serves as the basis for determining the correlation of average precipitation between the two areas. Using the natural rainfall in the comparison area during the same period as the estimated value (Y_e) for the operational impact area, and comparing it with the measured rainfall in the operational impact area (Y), the artificial rainfall enhancement effect is obtained.

The correlation coefficient is calculated as:

$$r = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \sum_{i=1}^{n}(y_i - \bar{y})^2}}$$

where r is the monthly precipitation correlation coefficient between the impact area and comparison area; $\bar{x}$ and $\bar{y}$ are the historical monthly average precipitation for the comparison area and operational impact area, respectively (mm); x_i and y_i are the monthly precipitation during the historical period (mm); n is the sample size; and $i = 1, 2, \ldots, n$.

2.3.3 Regional Historical Regression Statistical Analysis This method calculates the historical precipitation correlation relationship between the operational impact area and comparison area during non-operational periods, estimates precipitation in the operational impact area during the effect testing period, and compares it with measured values to obtain the rainfall enhancement effect. This approach is suitable for testing effects on longer-term cumulative operational samples, requiring reasonable selection of target and comparison areas. After normal transformation and testing of historical precipitation data, a simple linear regression equation between the comparison area (independent variable) and operational area (dependent variable) is established using the least squares method. The estimated rainfall during the target operational period is then calculated and compared with measured precipitation to determine rainfall increase and enhancement rate.

The monthly simple linear regression equation between the comparison area (x_i) and operational area (y_i) is:

$$y = a + bx$$

where the regression coefficients are:

$$b = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} = \frac{S_{xy}}{S_x^2}$$

$$a = \bar{y} - b\bar{x}$$

Here, $\bar{x}$ and $\bar{y}$ represent the average historical precipitation for the comparison area and operational area, respectively (mm); S_{xy} is the covariance; S_x^2 is the variance; n is the sample size; and $i = 1, 2, \ldots, n$.

3 Results and Analysis

3.1 Selection of Operational Target and Comparison Areas

According to the basic conditions specified in the "Technical Guidelines for Artificial Rainfall Enhancement Effect Testing" issued by the China Meteorological Administration' s Weather Modification Center, the operational impact area and comparison area were selected ([Figure 2: see original paper]). The national meteorological stations in the comparison area include Yongchang and Jinchang stations, while those in the operational impact area include Wuwei and Gulang stations. Since Jinchang station was established relatively recently with historical data series not synchronized with other stations, Yongchang station was selected as the representative station for the comparison area, and Wuwei and Gulang stations as representative stations for the operational target area, ensuring synchronized data series.

The distance between Wuwei station and Yongchang station, and between Wuwei station and Gulang station, is approximately 55 km, with similar geographical locations, climatic characteristics, and weather influence systems. The comparison area, represented by Yongchang station, is located upwind of the operational impact area represented by Wuwei and Gulang stations. When seeding operations are conducted in the operational impact area, the comparison area is not affected, making the selection of operational impact and comparison areas reasonable. The correlation coefficient of historical monthly average precipitation between the operational impact area and comparison area is 0.73, indicating good correlation.

3.2 Sequence Analysis

The historical data series used spans 1960–2019. Due to the long sample series, the natural precipitation in the test area can be considered a stable time series. Based on the historical precipitation in the operational area, the historical average precipitation was calculated and used as the natural precipitation expectation value (Y_e) for the test area, which was then compared with the measured precipitation during the operational period (Y) to determine the artificial influence effect (ΔR). The sequence analysis test results show that the average monthly absolute rainfall increase in the upper Shiyang River was 3.2 mm, with an average relative rainfall enhancement rate of 12.1%. Monthly relative rainfall enhancement rates ranged from 2.5% to 35.2%, with the best effect in April–May, reaching 35.2%, and relatively poor effects in June–August.

The rank-sum test method was used for significance testing of rainfall enhancement effects, as only results passing significance tests are considered credible. Historical monthly precipitation data from periods with and without artificial rainfall enhancement operations were ranked from smallest to largest. The rank sum of the smaller sample capacity was used for comparison, specifically the rank sum (T) of monthly precipitation during the operational period. When $n > 10$, the rank sum (T) can be considered to approximately follow a normal distribution $N\left(\frac{n_1(n_1+n_2+1)}{2}, \sqrt{\frac{n_1 n_2(n_1+n_2+1)}{12}}\right)$, allowing rank-sum test application. The calculation formula is:

$$u = \frac{T - \frac{n_1(n_1+n_2+1)}{2}}{\sqrt{\frac{n_1 n_2(n_1+n_2+1)}{12}}}$$

where u is the significance analysis value; T is the rank sum; n_1 is the sample capacity for rank sum calculation; and n_2 is the other sample capacity.

Significance testing of monthly rainfall enhancement effects using the rank-sum method shows that except for June–August, all other months passed the one-sided test ($|u| > 1.64$) at the 0.05 significance level, indicating significant rainfall enhancement effects. The sequence analysis method uses the historical average rainfall in the operational impact area as the estimated natural rainfall, which, while simple, can be significantly affected by whether the historical average precipitation is above or below normal, introducing certain biases in the results.

3.3 Regional Comparison Analysis

Based on the selected operational impact and comparison areas, the monthly correlation coefficients between the operational impact area and comparison area during the historical period were calculated (). Except for June–August, all monthly correlation coefficients reached 0.73 or higher, indicating good correlation; June–August coefficients were 0.52 and 0.58, respectively, indicating moderate correlation. Absolute rainfall increase and relative rainfall enhancement rate were calculated (). Regional comparison analysis shows an average monthly absolute rainfall increase of 5.5 mm in the upper Shiyang River, with an average relative rainfall enhancement rate of 30.2%. Monthly relative rainfall enhancement rates ranged from 1.6% to 79.5%, with the best effect in April-May, reaching 79.5%, and relatively poor effects in June–August at 1.6% and 3.6%, respectively.

Significance testing shows that all months passed the one-sided test ($|u| > 1.64$) at the 0.05 significance level, indicating significant monthly rainfall enhancement effects. However, for months with poorer correlation coefficients (June-August), using the comparison area' s precipitation as the natural precipitation estimate for the operational area introduces larger errors, particularly affecting the reliability of results for these months.

3.4 Regional Historical Regression Statistical Analysis

Following the regional historical regression statistical testing method, after normal transformation of the historical period datasets for the operational impact and comparison areas, the monthly correlation coefficients between the operational target area and comparison area ranged from 0.73 to 0.90, indicating good correlation between precipitation in the operational impact and comparison areas. Using comparison area rainfall (x_i) as the independent variable and impact area rainfall (y_i) as the dependent variable, monthly simple linear regression equations were established between the comparison and operational areas for April–October using the least squares method. The established monthly simple linear regression equations are shown in [Figure 3: see original paper].

The regression equations were tested for significance using the F-test method, with results showing that all monthly regression equations passed the test at the 0.05 significance level, indicating significant regression effects. By substituting monthly precipitation data from the comparison area into the monthly simple linear regression equations, the absolute and relative rainfall enhancement rates for the operational impact area were calculated.

Regional historical regression statistical analysis results show that the artificial rainfall enhancement effect in the upper Shiyang River was best in April–May, with enhancement rates and amounts of 37.4% and 5.9 mm, respectively. Due to poorer correlation, June–August had enhancement rates and amounts of only 22.8% and 3.7 mm, respectively, with lower credibility. September–October had relative rainfall enhancement rates between 32.4% and 36.8%, with good effects. The average monthly rainfall enhancement rate was 17.5%, and the average monthly rainfall increase was 4.7 mm. Significance testing using the t-test method shows that all months passed the test at the 0.05 significance level, indicating significant rainfall enhancement effects in the operational area.

3.5 Comparison of Testing Methods

Comparing the effects of artificial rainfall enhancement in the upper Shiyang River across the three statistical testing methods, the average relative rainfall enhancement rates from sequence analysis, regional comparison analysis, and regional regression analysis were 12.1%, 30.2%, and 17.5%, respectively, with average monthly absolute rainfall increases of 3.2 mm, 5.5 mm, and 4.7 mm, respectively. All three methods indicate significant artificial rainfall enhancement effects in the upper Shiyang River. Sequence analysis results were relatively small, regional comparison analysis results were relatively large, and regional historical regression analysis results fell between the two.

Numerous artificial rainfall enhancement statistical tests have shown that sequence analysis and regional comparison analysis have relatively high distortion rates and lower efficacy, with greater possibility of false effects. Regional historical regression statistical analysis, due to its high sensitivity and use of larger sample sizes, has a smaller distortion rate. If the comparison area is reasonably selected, it produces fewer false effects with higher testing efficacy and accuracy. The operational impact and comparison areas selected in this study are within the same weather system influence zone, at similar distances, with the comparison area located upwind of the impact area and unaffected by seeding operations. Therefore, the comparison area selection is reasonable, and regional historical regression statistical analysis can objectively and accurately reflect artificial rainfall enhancement results in the upper Shiyang River.

All three methods show that artificial seeding effects in spring (April–May) and autumn (September–October) are significantly better than in summer (June–August). April–May showed the best relative rainfall enhancement rates. This period features relatively stable precipitation, mostly stratiform cloud precipitation with abundant ice crystal particles, allowing full catalyst activation. In contrast, June–August has more convective precipitation with lower relative rainfall enhancement rates, indicating that artificial rainfall enhancement effects on stable precipitation in the Shiyang River Basin are far better than those on convective precipitation. Spring and autumn are periods of low precipitation and severe water resource shortage in the Shiyang River Basin. Therefore, favorable opportunities should be seized to increase weather modification operations during these seasons to help increase total water resources and alleviate water use conflicts.

3.6 Effect Analysis

Significance testing of rainfall enhancement effects shows that in regional historical regression analysis, all months passed the test at the 0.05 significance level. In sequence analysis, all months except June–August passed the test at the 0.05 significance level. In regional comparison analysis, all months passed the test at the 0.05 significance level. Based on the three statistical test results, preliminary conclusions indicate that artificial rainfall enhancement in the upper Shiyang River from April to October achieved an average relative rainfall enhancement rate of 17.5% and an estimated artificial rainfall increase of 337 mm, increasing annual precipitation by 13.5%. Current domestic and international artificial rainfall enhancement operations achieve effects of 8%–17%, and the Shiyang River Basin' s artificial rainfall enhancement effect reached 17.5%, demonstrating that the effect is significant and that artificial rainfall enhancement can serve as an effective measure for developing atmospheric cloud water resources and alleviating local water shortages in the Shiyang River Basin.

4 Conclusions

To develop and utilize atmospheric water resources and improve the ecological environment of the Shiyang River Basin, meteorological departments have continuously increased operational intensity in the upper Shiyang River since 2010. This paper used three statistical testing methods to conduct statistical test and analysis of artificial rainfall enhancement effects in the Shiyang River Basin. Through evaluation of operational effects, the following conclusions were reached:

1) Sequence analysis, regional comparison analysis, and regional historical regression analysis yielded average rainfall enhancement rates of 12.1%, 30.2%, and 17.5%, respectively, with average monthly rainfall increases of

3.2 mm, 5.5 mm, and 4.7 mm, respectively. Artificial rainfall enhancement significantly increased annual precipitation by 13.5% in the upper Shiyang River, demonstrating significant operational effects.

2) Comparative analysis of the three statistical testing methods shows that regional historical regression analysis results fall between those of sequence analysis and regional comparison analysis, providing relatively objective results. This method is suitable for rainfall enhancement effect testing and evaluation in the inland river basins of the Hexi Corridor. Regional historical regression statistical analysis shows monthly relative rainfall enhancement rates between 10.0% and 37.4%.

3) All three testing methods show that artificial seeding effects in spring (April–May) and autumn (September–October) are significantly better than in summer (June–August). April–May showed the best rainfall enhancement effects, with relative rainfall enhancement rates of 37.4%. This period features relatively stable precipitation, mostly stratiform cloud precipitation with abundant ice crystal particles, allowing full catalyst activation. In contrast, June–August has more convective precipitation with lower relative rainfall enhancement rates, indicating that artificial rainfall enhancement effects on stable precipitation in the Shiyang River Basin are far better than those on convective precipitation. Spring and autumn are periods of low precipitation and severe water resource shortage in the Shiyang River Basin. Therefore, favorable opportunities should be seized to increase weather modification operations during these seasons to help increase total water resources and alleviate water use conflicts.

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