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Temporal Variations in Rice Water Requirements and the Impact of Effective Rainfall on Irrigation Demand: Strategies for Sustainable Rice Cultivation

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Abstract: In response to increasing global food demand and the significant water requirements of rice cultivation, this study aims to enhance water use efficiency in rice farming. Focusing on Jiayu County, a subtropical humid region in China, where rice is grown as a single crop every year, we investigated temporal variations in rice water requirements and the influence of effective rainfall on irrigation strategies. Data were collected from an experimental station within the Sanhulianjiang Reservoir in Jiayu County. Utilizing the Mann–Kendall trend test and the Seasonal–Trend Decomposition using the LOESS (STL) method, we analyzed historical data on rice water requirement (ET_c) and effective rainfall (R_e). Our findings reveal that annual water requirements for rice range between 432 mm and 746 mm, with peaks corresponding to critical growth stages such as tillering and jointing–booting. Effective rainfall contributes significantly to meeting these needs, providing 27–35% of the total water requirement during specific periods. Developed water-saving irrigation strategies, including optimized irrigation scheduling and the introduction of drought-resistant rice varieties, demonstrate a potential reduction in irrigation demands by approximately 33.84%. This study underscores the importance of integrating effective rainfall data into irrigation practices to enhance water use efficiency and promote sustainable rice production amidst climate variability challenges.

Keywords: rice cultivation; water use efficiency; the Mann–Kendall trend test; Seasonal–Trend Decomposition using LOESS; sustainable agriculture; Jiayu County

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1. Introduction

As the global population continues to rise, the demand for food production intensifies, necessitating effective strategies for water management, particularly in rice cultivation [1,2]. Rice is one of the most important staple foods worldwide, serving as a primary source of nutrition for over half of the global population [3]. However, the cultivation of rice is characterized by its considerable water requirements, with a significant part of its life cycle demanding sustained irrigation [4,5]. In dynamic climates where fluctuations in temperature, precipitation, and humidity can drastically affect crop yields, understanding the temporal variations in rice water requirements during the whole growing stage is crucial for optimizing irrigation strategies.

Water requirements for crops, particularly rice, refer to the total amount of water needed to grow the plant successfully and achieve optimal yields. This need is typically expressed as ET_c, which comprises the combined volume of water transpired by the plant and evaporated from the soil. The water requirements vary significantly across different growth stages of rice, including germination, tillering, jointing, heading, flowering, and ripening [6,7]. The tillering and jointing–booting stages typically represent the periods of highest water demand as they are critical for stem and grain development [8], whereas reduced water levels may suffice during maturation [9]. Studies have shown that inadequate water supply during these stages can severely diminish rice yields [10,11]. For instance, the water requirement during the tillering stage is approximately 165 mm, while the demand during the heading stage can peak at around 170 mm [12]. The annual water requirement for rice production can range from 4000 to over 6000 m^3/ha, depending on numerous factors including local climate, soil type, cultivar selection, and management practices [13].

As traditional flooding methods of irrigation present numerous challenges, including excessive water consumption and adverse environmental impacts, the exploration of innovative irrigation methods becomes paramount. Data from various growing stages affirm that through optimized irrigation schedules integrating effective rainfall, notable improvements in water use efficiency can be achieved [14–16]. The implications are far-reaching—not only do they promise economic benefits for farmers, but they also contribute to broader environmental sustainability goals amidst concerns about global water scarcity. Effective rainfall refers to precipitation that contributes beneficially to soil moisture, and it plays a crucial role in determining overall irrigation demand. Depending on the local climate, effective rainfall can significantly reduce irrigation needs. Several studies have shown that regions with adequate rainfall can potentially meet up to 35% of rice's total water requirements through effective rainfall, thereby conserving numerous resources previously allocated to irrigation [12,17]. For instance, in some years characterized by ample effective rainfall, rice crops have been shown to require little to no additional irrigation, effectively reducing reliance on artificial sources. Conversely, in periods of low effective rainfall, the reliance on artificial irrigation systems increases, leading to higher costs and potential sustainability concerns [18]. These findings underline the importance of rainwater harvesting techniques, which can optimize the use of local precipitation in conjunction with rice cultivation.

Understanding the relationship between effective rainfall and rice irrigation demand is imperative for achieving sustainable rice production and ensuring food security in an era marked by climate variability and increasing water scarcity. The Seasonal–Trend Decomposition using LOESS (STL) is a decomposition technique that separates a time series into seasonal, trend, and residual components. This method is particularly beneficial for analyzing agricultural data because it allows for the visualization and understanding of underlying patterns and relationships [19,20]. The LOESS approach used in STL does not assume linear relationships, making it suitable for capturing complex interactions between effective rainfall and irrigation demand [21]. Furthermore, the STL effectively isolates seasonal components, allowing researchers to see how seasonal fluctuations in effective rainfall align with rice irrigation demands [22,23]. By decomposing the time series data, researchers can identify long-term trends and provide insights into how effective rainfall impacts irrigation requirements over time [24]. Recent studies have shown that in regions like the Mekong Delta, effective rainfall can account for substantial portions of rice water needs. By employing STL, researchers were able to identify specific months where effective rainfall peaked, allowing farmers to plan irrigation more effectively [9]. In regions of India, effective rainfall has been linked to a notable decrease in groundwater extraction for irrigation. The use of STL facilitated an understanding of seasonal trends, revealing

critical periods to conserve water [25]. In West Africa, researchers have used STL to analyze the impact of shifting rainfall patterns on irrigation requirements. Findings indicated that regions experiencing irregular rainfall patterns required more robust irrigation practices to maintain rice yields [22,23].

Rice has been a staple crop in Jiayu County for centuries, underlining the area's agricultural significance. Rice is well suited to the region's climate, which provides ample rainfall in the summer months. Irrigation in the Sanhulianjiang Reservoir area involves a combination of traditional knowledge and modern technology. The system leverages gravity-fed canals and piped water systems to ensure that fields receive adequate moisture, particularly during dry spells. Despite the advancements in irrigation and rice cultivation, the Sanhulianjiang Reservoir area faces several challenges related to water resources. Climate change poses a significant threat, leading to unpredictable weather patterns, including droughts and heavy rainfall. These fluctuations can disrupt the timely application of water needed for rice cultivation, potentially harming crop yields. Another critical challenge is the management of water resources. Inefficient irrigation practices can result in significant water wastage. Some traditional methods still in use may not adequately account for modern agricultural demands, leading to water scarcity during critical growth periods. Additionally, competing demands for water between agricultural, industrial, and domestic users create conflicts and require careful management and coordination. Therefore, sustainable water management practices are essential to ensure that Jiayu County remains a thriving agricultural area in the face of ongoing challenges.

This study aims to explore the temporal variations and seasonal patterns of rice water requirements in Jiayu County, with a focus on the impact of effective rainfall on irrigation demand. By employing advanced decomposition methods such as STL, we seek to develop efficient irrigation strategies that maximize the utilization of effective rainfall. These strategies are essential for enhancing water use efficiency and promoting sustainable agricultural practices. Integrating these insights, our research aims to deepen the understanding of water management dynamics in rice cultivation, contributing to the development of resilient and adaptable agricultural systems capable of addressing climate variability challenges.

2. Materials and Methods

2.1. Study Area

Jiayu County is located between the Mufu Mountains and the Jianghan Plain, with a total area of about 123.67 km^2. The Sanhulianjiang irrigation experimental station is in the west of the Sanhulianjiang Reservoir in Jiayu County, and the geographical location is at 113°55′ E, 29°59′ N (Figure 1). It is 2 km from the Yangtze River to the west and has a geomorphological pattern of "one mountain, three rivers and four fields". It records daily weather data (i.e., temperature, precipitation, wind speed, etc.), soil moisture levels, and crop growth stages. The experimental station covers an area of 4666.67 m^2, with 1333.33 m^2 dedicated to paddy field experimental plots, and includes 8 measurement pits. The dimensions of the measurement pits are 2 m × 2 m, all of which are bottomed pits. The rice water requirement experiment was conducted in the measurement pits, and a comparison was made with the experimental paddy fields.

Jiayu County belongs to a subtropical humid monsoon climate. The annual average temperature is 17.5 °C, and the annual average rainfall is 1412 mm, characterized by uneven spatial and temporal distribution, significant interannual variability, and abnormal fluctuations between drought and flooding, with the maximum historical rainfall difference reaching 970 mm. The flooding season each year is concentrated from March to June, while the dry season occurs from July to October. Rice is indeed cultivated during the summer

season in the study area, although it may extend into early autumn depending on local climatic conditions. Jiayu County has long been a significant rice production area, with its climate being particularly suitable for rice cultivation, especially during the summer when rainfall is abundant.

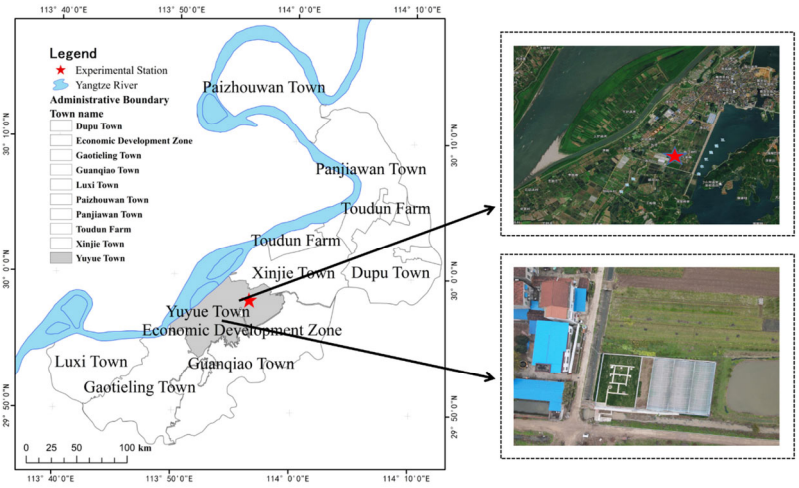


Figure 1. Location of the Sanhulianjiang irrigation experimental station.

2.2. Available Data

The meteorological data used in this study were obtained from the actual measurements at the experimental station in Figure 1. Daily meteorological data from 1982 to 2021 were selected, including precipitation, average temperature, maximum temperature, minimum temperature, average vapor pressure, average relative humidity, sunshine duration, and average wind speed at a height of 2 m above the ground. Data information is provided in the Supplementary Materials, and the statistical values of the data series are shown in Table 1.

Table 1. The statistical values of the meteorological data series from 1982 to 2021.

Item	Maximum Temperature (°C)	Average Temperature (°C)	Minimum Temperature (°C)	Relative Humidity (%)	Wind Speed (m/s)	Sunshine Duration (h)	Rainfall (mm/d)	ET_0 (mm/d)
Daily Average	21.88	18.11	13.65	78.20	1.64	3.93	11.80	2.99
Standard Deviation	8.55	8.56	8.68	5.50	0.69	1.71	19.09	1.30
Coefficient of Variation	0.39	0.47	0.64	0.07	0.42	0.44	1.62	0.44

2.3. The Matching Degree of Effective Rainfall and Rice Water Requirement

The matching degree of effective rainfall and rice water requirements (λ) refers to the relationship between the amount of rainfall that contributes to soil moisture and the water needed for rice cultivation [15]. It is crucial for optimizing irrigation practices. When effective rainfall meets or exceeds rice water requirements, it reduces the need for additional irrigation. Therefore, understanding and managing this relationship is vital for enhancing rice production and ensuring water resource efficiency in agriculture. The calculated equation is described by

$$\lambda = \frac{R_{ei}}{ET_{ci}}$$

where λ is the matching degree of effective rainfall and rice water requirements; R_{ei} is the effective rainfall of different rice growth stages (mm); ET_{ci} is the water requirement of different rice growth stages (mm).

2.3.1. Effective Rainfall (R_e)

The effective rainfall (R_e) refers to the portion of total precipitation that contributes to soil moisture and is available for plant use. Accurately assessing effective rainfall enables farmers to optimize crop yields while conserving water resources, ultimately supporting sustainable agricultural practices. In this study, the effective rainfall is determined according to the recommended method by the USDA [26,27] as follows:

$$R_e = \begin{cases} P \times (4.17 - 0.2P)/4.17 & (P \leq 8.3\ mm) \\ 4.17 + 0.1P & (\mathrm{P} > 8.3\ mm) \end{cases}$$

where R_e is the daily effective rainfall (mm); P is the daily precipitation (mm).

2.3.2. Rice Water Requirement (ET_c)

The rice water requirement amounts to the rice evapotranspiration (ET_c), which equals the reference crop evapotranspiration (ET_0) multiplied by the crop coefficient (K_c) [28]:

$$ET_c = ET_0 \times K_c$$

where ET_c is the daily water requirement of rice (mm); ET_0 is the daily reference crop evapotranspiration (mm); K_c is the crop coefficient of rice.

Crop coefficient (K_c) values are not static; they vary depending on factors such as crop type, variety, planting density, management practices, and weather conditions. In this research, the crop coefficients (K_c) were calculated based on field experiments conducted at the experimental stations. For each growth stage, we measured the actual evapotranspiration (ET_c) using lysimeters and calculated the reference crop evapotranspiration (ET_0) according to the FAO Penman–Monteith equation. The K_c values were then derived by dividing ET_c by ET_0. The average K_c value over a selected period of 20 years was ultimately chosen as the K_c value for this study (Table 2). This approach utilizes long-term data to obtain a more stable and representative K_c estimate, helping to mitigate the impact of interannual variability and providing an indicator that better reflects the crop's water requirements under long-term average conditions.

Table 2. Crop coefficient of rice of the Sanhulianjiang irrigated area.

Crop Coefficient	Returning Green Stage	Tillering Stage	Jointing–Booting Stage	Heading–Flowering Stage	Milk Stage	Yellow Ripening Stage
K_c	1.08	1.32	1.57	1.57	1.37	0.88

2.3.3. Reference Crop Evapotranspiration (ET_0)

The reference crop evapotranspiration (ET_0) is calculated using the Penman–Monteith model [29] as follows:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_a - e_d)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_0 is the daily reference crop evapotranspiration (mm); Δ is the rate of saturated water vapor pressure curve; R_n is the net radiation reaching the crop surface (MJ·m^{-2}); G is the heat flux of soil (MJ·m^{-2}); γ is the constant value of the moisture tester (kPa·°C^{-1}); T is the daily mean temperature at two meters high (°C); u_2 is the mean air velocity at two meters high (m·s^{-1}); e_a is the saturated vapor pressure (kPa); e_d is the actual water vapor pressure (kPa).

2.4. The Mann–Kendall Trend Test

The Mann–Kendall (MK) trend test is a non-parametric statistical test used to determine if there is a monotonic trend in a time series data [29]. It evaluates whether there is a statistically significant trend over time by comparing each data point with every other data point in the series. Specifically, it calculates the number of times a later value is greater than an earlier value (indicating an increasing trend) or less than an earlier value (indicating a decreasing trend). By applying the Mann–Kendall trend test, we can assess whether the time series data of rice water requirement are statistically significant, as well as identify the mutation point in rice water requirement over time.

2.5. The Seasonal–Trend Decomposition Procedure Based on Loess (STL)

The STL method, originally invented by Cleveland et al. [30], is a filtering procedure that decomposes a time series into three additive components such as trend, seasonal, and remainder. The STL is beneficial for its flexibility, allowing for varying seasonal patterns and adapting to changes in trends. In this study, the STL method is applied to identify seasonal patterns and long-term trends of the rice water requirement and the effective rainfall, which provide insights into how effective rainfall impacts irrigation requirements over time. Given a time series Y_t, the STL decomposes it into the following three components:

$$Y_t = S_t + T_t + R_t$$

where X_t is the original time series at time t; S_t is the seasonal component at time t, capturing periodic fluctuations with the time series; T_t is the trend component at time t, identifying long-term movements over time; R_t is the remainder component at time t, accounting for random noise or irregularities that are not captured by the seasonal and trend components.

3. Results and Discussions

3.1. Temporal Variations in the Rice Water Requirement

In recent decades, we have found that the annual rice water requirement (ET_c) has ranged from 432 mm to 746 mm, with an average value of about 565 mm. The long-term tendency of the ET_c series showed some random characteristics as displayed by the trend curve directly (Figure 2). Therefore, a Mann–Kendall trend test was conducted to excavate the variation characteristics from a statistical point of view. The results of the Mann–Kendall trend test indicated a 19.9 mm/10·a decline of the ET_c series, as was supported by the value of Z equaling −2.2 at 95% reliability. Moreover, two mutation points of the ET_c series were marked out through the intersection of the UB and UF curves, which indicated that sudden change in the ET_c that appeared in the years 1993 and 2004 (Figure 2).

As has been demonstrated by numerous researchers, rice water requirements (ET_c) exhibit fluctuations in response to climatic variables, cultivar renovation, and management standards [31–36]. In the Sanhulianjiang irrigation area, cultivar renovation has been implemented as a successful adaptation strategy to climate change over nearly 40 years. Figure 3 provides detailed information on the evolution of rice varieties in the Sanhulianjiang irrigation area from 1982 to 2021. As shown in Figure 3, two adaptive rice cultivars have emerged over time. Prior to 2016, decades of field trials indicated that "Shanyou63" was an ideal variety due to its relatively low ET_c values (as indicated in Figure 2). Since 2017, "Longping" has been selected as a superior option, also demonstrating low ET_c values.

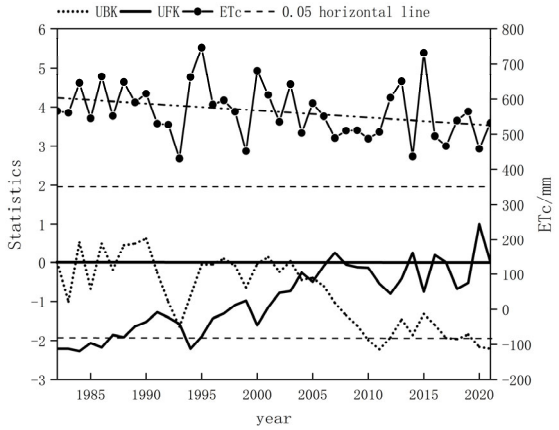


Figure 2. The interannual variation in rice water requirements from 1982 to 2021.

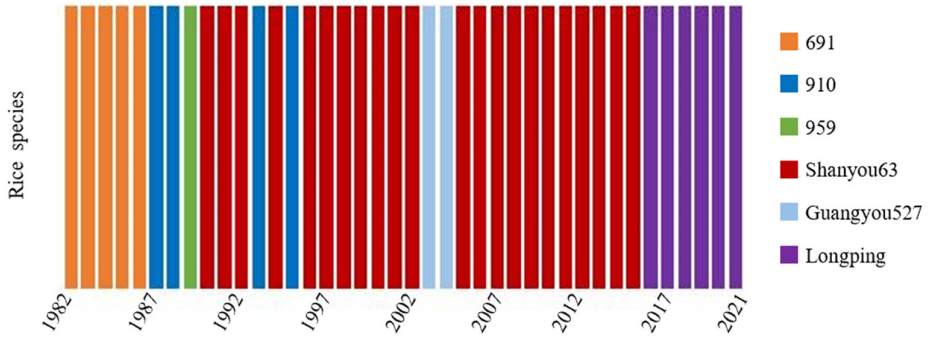


Figure 3. Evolution of rice varieties in the study area from 1982 to 2021.

The development and change in rice varieties represent a significant factor contributing to the observed changes in ET_c [37,38]. Specifically, the Mann–Kendall trend test identified mutation points in 1993 and 2004, coinciding with shifts in rice varieties. During these years, the varieties were changed to "910" and "Guangyou527", respectively. However, these varieties ("910" and "Guangyou527") lacked the broad adaptability required for climate change and were subsequently replaced by "Shanyou63" and "Longping". The introduction of drought-resistant rice varieties could be an important approach, demonstrating a potential reduction in irrigation demands.

3.2. Seasonal Patterns of the Rice Water Requirement

Figure 4 depicts the decomposition results of the rice water requirement (ET_c) from 1982 to 2021 using the above-mentioned STL technique. It can be seen that the original ET_c time series was decomposed into seasonal, trend, and remainder components. The original ET_c time series is graphed in the top panel. It was not difficult to find that the original ET_c time series had a significant cyclical characteristic, which was mainly determined by the seasonality of rice water consumption through different growth stages [39].

In our research, the rice water requirement (ET_c) ascended with the growth of rice at the early stage, and then showed a decreasing tendency (Figure 4). According to the obtained results, the ET_c series trends followed a 6-period seasonal pattern, with the highest value occurring from the tillering stage to the jointing–booting stage (Figure 5). As a crop with high water consumption, many studies have confirmed that water stress in the tillering stage could result in decreased rice yields [40,41]. Therefore, rice was normally irrigated to a great extent at the tillering stage, whereas it was irrigated a small amount at the returning green stage for both water savings and yield improvements [12,42]. However, the long-term changes in the rice water requirement (ET_c) did not change distinctly after

eliminating the quarterly fluctuation. This may indicate that the cultivar renovation in the Sanhulianjiang irrigation area is adaptive to climate change.

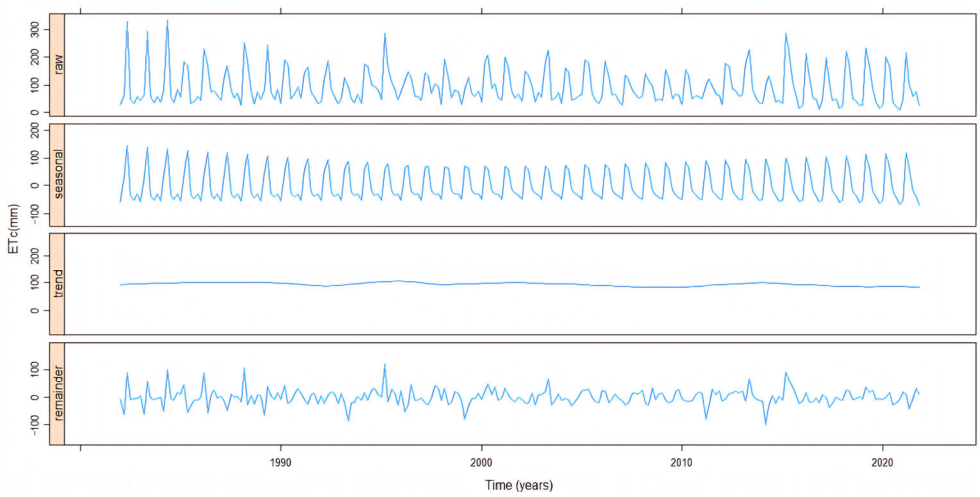


Figure 4. Decomposition plot of the rice water requirement during the whole growth period.

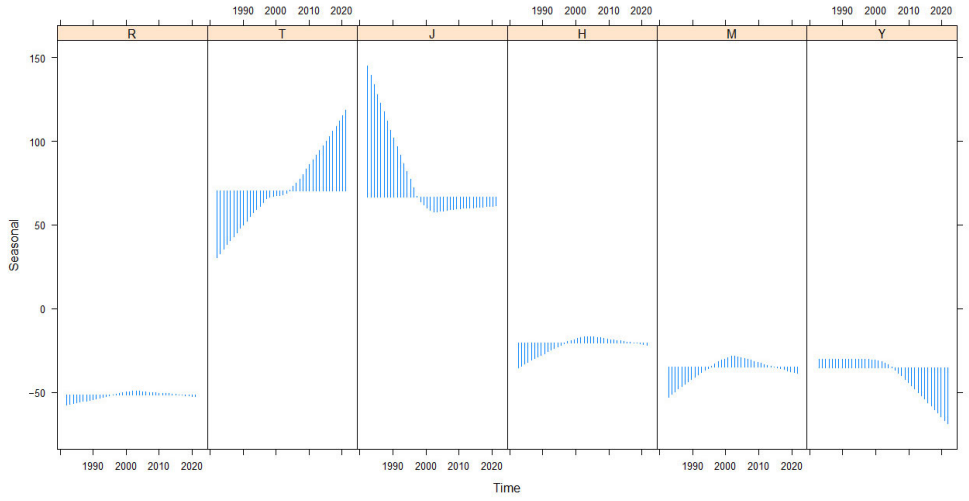


Figure 5. Cycle subseries of the rice water requirement for each growing stage. (R: returning green stage; T: tillering stage; J: jointing–booting stage; H: heading–flowering stage; M: milk stage; Y: yellow ripening stage.)

3.3. The Impact of the Effective Rainfall on the Irrigation Demand of Rice

The trend change of the effective rainfall, as obtained from the STL technique, is shown in Figure 6. The results revealed that most of the abundant effective rainfall was concentrated at the tillering stage, which was highly consistent with the trend change of the rice water requirement (ET_c). The amount and distribution characteristics of effective rainfall can be the key driving factors for making intelligent decisions about the irrigation demands, such as that less water or even no irrigation is required in some wet years [12,17]. The matching degree of the effective rainfall and the rice water requirement (ET_c) from 1982 to 2021 is presented in Figure 7, which ranges from 0.00 to 1.52. Specifically, the matching degree of the effective rainfall and the rice water requirement (ET_c) at certain growing stages was higher than 1.00 during some wet years. For example, the matching degrees of the effective rainfall and the rice water requirement (ET_c) at the returning green stage in 1988, 1992, 1995, and 1999 were 1.29, 1.09, 1.05, and 1.47, respectively, implying that there was sufficient effective rainfall to fulfill the rice water requirement (ET_c), and thus, no more irrigation water was required. However, nearly half of the matching degree values were

smaller than 0.20, which meant the irrigation demand should be increased with reduced effective rainfall.

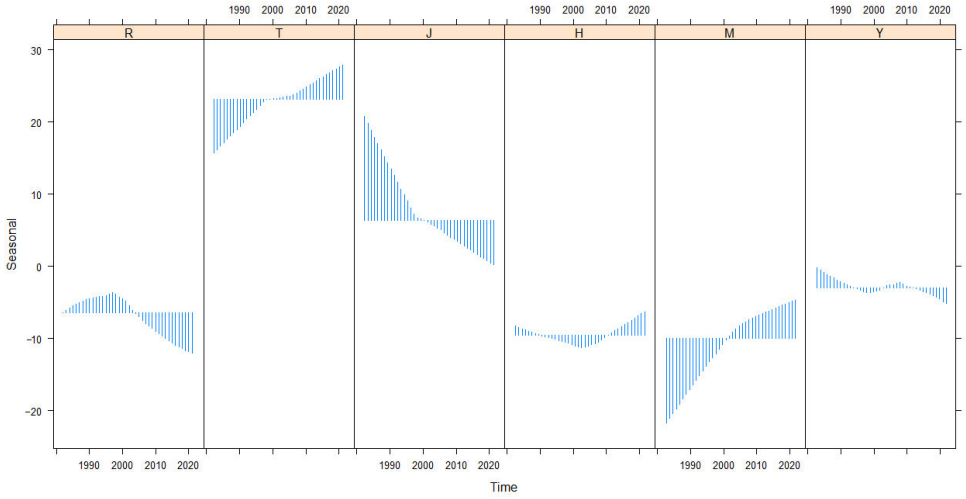


Figure 6. Cycle subseries of the effective rainfall for each growing stage. (R: returning green stage; T: tillering stage; J: jointing–booting stage; H: heading–flowering stage; M: milk stage; Y: yellow ripening stage.)

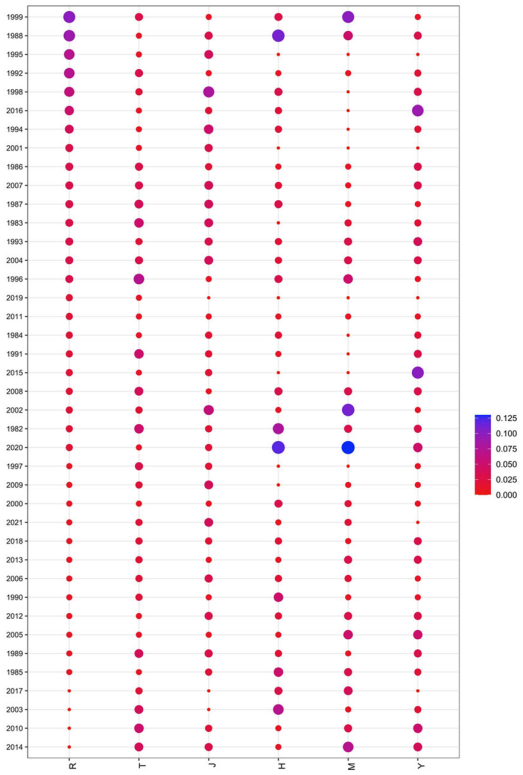


Figure 7. The contribution of effective rainfall to the rice water requirement for each growing stage. (R: returning green stage; T: tillering stage; J: jointing–booting stage; H: heading–flowering stage; M: milk stage; Y: yellow ripening stage.)

The annually averaged rice water requirements (ET_c) at the returning green stage, the tillering stage, the jointing–booting stage, the heading–flowering stage, the milk stage, and the yellow ripening stage are 42.62 mm, 165.69 mm, 169.25 mm, 72.86 mm, 58.93 mm, and 55.51 mm, respectively. For the returning green stage, the tillering stage, and the yellow ripening stage, the effective rainfall could meet about 27% to 35% of the rice water requirement (ET_c), and thus, less irrigation water was required. However, that of the

jointing–booting stage, the heading–flowering stage, and the milk stage was about 16% to 18%, indicating greater irrigation water demand to meet the rice water requirement (ET_c).

These findings reveal an intricate relationship between effective rainfall distribution and rice irrigation demand. From a long-term perspective, achieving an agreement between the rice water requirement (ET_c) and the effective rainfall distribution is crucial to developing the most effective irrigation strategies for water saving during climate change.

3.4. Irrigation Strategies with Efficient Utilization of the Effective Rainfall

Rice is a water-intensive crop; traditional flooded paddy field planting has been used widely to produce large amounts of rice. However, the traditional irrigation schedule of rice is facing many challenges such as excessive water consumption, severe soil water contamination, and low economic benefits [43]. In particular, continuous flooding to maintain a stable water coverage of rice has greatly reduced the water use efficiency, and intensified local and global water scarcity. In this research, the effective rainfall is taken to partially substitute the water used for field irrigation. Compared to the traditional irrigation schedule, the irrigation water demand of rice was reduced from 658.68 mm to 435.78 mm after increasing the use of effective rainfall. In this case, the water-saving rate was about 33.84% for all growing stages, with the rainwater use efficiency reaching 27.92% (Table 3). Under the combined action of such factors as crop growing circumstances, soil physical chemistry properties, and weather situations, the water-saving rates across different rice growth periods showed obvious discrepancy, which ranged from 15.20% to −316.59%. It was noted that the order of the water-saving rate for different growing stages was the returning green stage (i.e., 66.77%) > the tillering stage (i.e., 50.25%) > the milk stage (i.e., 40.40%) > the heading–flowering stage (i.e., 26.75%) > the jointing–booting stage (i.e., 15.20%) > the yellow ripening stage (i.e., −316.59%).

Table 3. Optimized irrigation schedule after increasing the use of effective rainfall.

Growing Stage	Traditional Irrigation (mm)	Optimized Irrigation (mm)	Water Saving Rate	Rainwater Use Efficiency
Returning green stage	74.83	24.86	66.77%	30.78%
Tillering stage	254.11	126.43	50.25%	20.27%
Jointing–booting stage	180.65	153.20	15.20%	35.23%
Heading–flowering stage	62.61	45.86	26.75%	22.59%
Milk stage	75.72	40.59	46.40%	32.63%
Yellow ripening stage	10.76	44.84	−316.59%	50.08%
Whole growing stage	658.68	435.78	33.84%	27.92%

In the growth period of rice, the largest water requirement appears at the tillering stage and the jointing–booting stage (i.e., 126.43 mm and 153.20 mm, respectively). During this period, the nutritional requirement and growth rate of rice are very high, and rice needs sufficient water to increase stems and support the pollination process. Therefore, reasonable water management is essential for improving the yield and quality of rice. In our research, the tillering stage and the jointing–booting stage usually start in mid-July and last for nearly two months. The rainy season is concentrated from June to September annually, which has the natural advantage of providing water for field irrigation. Accordingly, the rainwater use efficiency of these two stages was 20.27% and 35.23%, respectively.

During the returning green period, it is important to maintain a certain water level to meet the water needs of the rice plants and reduce leaf transpiration, which promotes the early development of new roots in seedlings and accelerates greening. It is best to irrigate with deep water during the day to protect the seedlings and drain the fields at night to encourage greening and rooting. The returning green period would last one week, during

which the water-saving rate was the highest (i.e., 66.77%) under the optimized irrigation schedule, and the rainwater use efficiency was 30.78%. As for the heading–flowering stage, rice plants have strong photosynthesis and vigorous metabolism, making them sensitive to water needs. At this stage, the soil moisture content in the field is generally in a saturated state, with a thin water layer being preferable. The heading–flowering stage also lasts for about one week, although the water requirement rate was second only to that during the jointing–booting stage; the optimized irrigation amount was 45.86 mm, with the water-saving rate and rainwater use efficiency being 26.75% and 22.59%, respectively.

The milk stage represents the highest net photosynthetic productivity for rice, while root vitality begins to decline. It is essential to ensure that the soil maintains high moisture while also allowing for good aeration. Generally, a shallow wet alternate irrigation method is preferred, which involves irrigating → letting it dry → irrigating again → and letting it dry again. In our research, the optimized irrigation amount of the milk stage was 40.59 mm, and the water-saving rate and rainwater use efficiency were 46.40% and 32.63%, respectively. Until the yellow ripening stage, the water consumption of the rice decreases sharply. It was noteworthy that the optimized irrigation amount was nearly four times the traditional irrigation amount. Although crops have a low water demand during this period, to ensure grain plumpness, it is advisable to adopt an alternating dry–wet irrigation method and reduce the frequency of irrigation. About a week before harvesting, the fields should be drained and allowed to dry out.

4. Conclusions

This research has demonstrated the significant impact of effective rainfall on irrigation strategies for rice cultivation in Jiayu County. By employing the Mann–Kendall trend test and the Seasonal–Trend Decomposition using LOESS (STL) method, we identified distinct temporal variations in rice water requirements throughout the growing season, particularly during critical stages such as tillering and jointing–booting. Our analysis reveals that integrating effective rainfall into irrigation planning can substantially reduce water usage while maintaining crop yields. Specifically, optimized irrigation scheduling and the introduction of drought-resistant rice varieties have shown potential to decrease irrigation demands by approximately 33.84%. Additionally, our findings highlight that effective rainfall contributes between 27% and 35% of the total water requirement during certain periods, emphasizing its crucial role in water management. These insights underscore the importance of adaptive management practices that align with fluctuating climatic conditions. Moving forward, it is essential to continue monitoring the impacts of climate change on rainfall patterns and irrigation demands. This will facilitate the development of innovative practices that enhance resilience and resource efficiency, ensuring sustainable rice production amidst increasing climate variability. The proposed strategies not only promote efficient water use but also contribute to building more adaptable and resilient agricultural systems.

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