

Spatio-temporal changes of rice cropping system in Anhui Province from 2010 to 2020

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Abstract. Monitoring changes in rice production is of significant importance for addressing food security concerns in China. However, obtaining long-term, high-resolution rice planting maps is challenging due to the influence of cloud cover and temporal resolution limitations. This study, conducted on the Google Earth Engine (GEE) platform, utilizes Landsat and Sentinel data and employs the difference in normalized difference vegetation index method (dNDVI) to extract the distribution in rice cultivation systems in Anhui Province over the past decade. The results indicate that, between 2010 and 2020, the area of single cropping rice cultivation in Anhui Province increased by 12513.612 km², while the area of double cropping rice cultivation decreased by 13527.892 km². The rice replanting index declined by 31%. With a notable shift observed in 2015, where a substantial area of double cropping rice was replaced by single cropping rice cultivation. Consequently, over the past decade, there has been a gradual decrease in the rice cultivation area in Anhui Province, accompanied by a significant shift from double to single cropping cultivation, and a continuous decline in the replanting index. This research provides vital clues for a deeper understanding of the rice planting pattern, offering scientific support for the sustainability of food production.

Keywords: Rice cropping, Anhui Province, Landsat, difference of NDVI (dNDVI), Google Earth Engine (GEE).

1. Introduction

Rice is a vital grain crop in China, feeding over 65% of the population and being the most significant crop in terms of sowing area, yield, and total output[1]. China experiences regional differences in rice maturity due to the uneven distribution of solar resources. There are two main types of rice cultivation in China: once-a-year and twice-a-year rice production, corresponding to single cropping rice (SCR) and double cropping rice (DCR). Paddy rice cultivation comprises over 60% of China's plantings in the south, which is a crucial production base for paddy rice, especially DCR[2].

In recent years, remote sensing imagery has been widely used to monitor changes in rice cultivation patterns. Vegetation indices derived from satellite images are powerful parameters for detecting rice growth information. The normalized difference vegetation index (NDVI) is currently the most commonly used method for monitoring vegetation changes[3]. This method has also been widely applied to monitor and map rice planting systems[4-6]. Landsat and Sentinel imagery is the image data source that was widely used to discriminate various rice planting systems in rice-growing regions and crop planting information extraction[7,8]. The pixel size of Landsat TM/ETM+ (0.09 hectares) is roughly equivalent to the average size of rice paddies in many regions of China. Therefore, Landsat and Sentinel imagery has been used extensively in recent years to study the pattern of rice paddies in China[2], [9].

This study employs Landsat and Sentinel satellite imagery to investigate the changes in the distribution of SCR and DCR crops in Anhui Province over the past decade. The purpose of this research is to unveil the characteristics of variations in farmers' motivation for crop production and regional land use intensity.

2. Methodology and Data

2.1 Study Area

Anhui Province (Figure 1) is an essential agricultural center in China with a rich history of agricultural practices. Its coordinates ranges from 114°54' E to 119°37' E longitude, and 29°41' N to 34°38' N latitude with a total land area of 139,400 square kilometers, occupying 1.45% of the total national area. It is strategically located in the central region of the Yangtze River Delta. Characterized by diverse terrains including plains, tablelands, hills, and mountains, Anhui Province produces rice and wheat as its dominant grain crops, with rice cultivation comprising both SCR and DCR varieties.

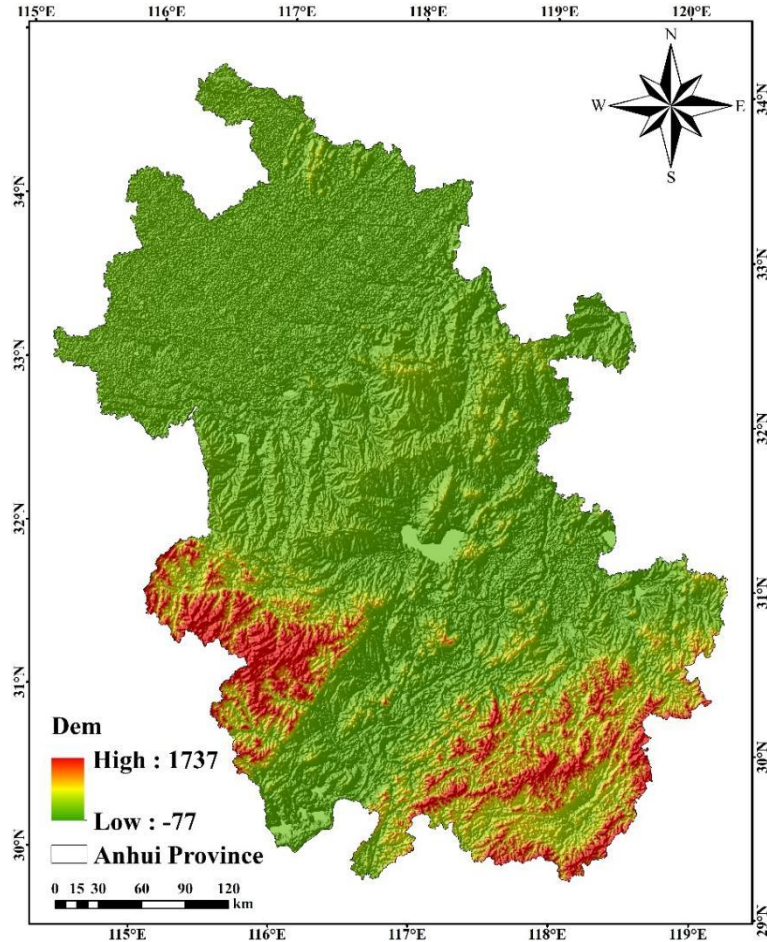


Fig. 1 Overview map of the study area

2.2 Data source and data preprocessing

For this study, 117 Landsat8 OLI/TIRS and Sentinel-2 images were utilized. The chosen remote sensing images were selected based on several factors, including time window, image quality, and atmospheric, radiometric and geometric calibration. Additionally, cloud and shadow removal were also performed. The Normalized Difference Vegetation Index was calculated, and land use data from 2010, 2015, and 2020 were used to create a rice field distribution mask. Information on the phenology and NDVI values for Anhui Province rice was also gathered as an essential data source for predicting agricultural activity. These values reveal the synchrony and order of growth events, which can be used as a prediction for future agricultural practices.

2.3 Rice Maturity Extraction Method

The study uses the difference in NDVI method (dNDVI) to identify rice maturity by assessing differences in the NDVI. This involves selecting remote sensing images during characteristic time

windows for SCR and DCR with varying NDVI changes, considering the plants' phenological background. Then, the NDVI and dNDVI during the characteristic time window are estimated. Distinguishing between SCR and DCR is achievable based on the positive or negative dNDVI values. As June and July exhibit faster NDVI changes and larger value discrepancies for SCR and DCR, they are the characteristic time window for rice maturity extraction. The dNDVI value is calculated by averaging the NDVI monthly during the start and end months of the characteristic time window ranging from -2 to 2. The formula is shown below:

$$dNDVI = NDVI_{t1} - NDVI_{t2} \quad (1)$$

where $NDVI_{t1}$ and $NDVI_{t2}$ denote the NDVI values for the starting and ending months within the same time window, respectively. In this study, $NDVI_{t1}$ denotes the NDVI value for June and $NDVI_{t2}$ denotes the NDVI value for July.

3. Results

3.1 Rice cropping system maps in 2010, 2015 and 2020

Figure 2 presents the distribution map of rice maturity in Anhui Province in 2010, 2015 and 2020, illustrating a small difference in sowing area between SCR and DCR in the primary rice producing areas. In terms of spatial distribution, SCR was prominently grown in the southeastern region, while DCR dominated in the northwestern area. Comparing the distribution maps of rice maturity in 2010 and 2015, there was a significant decrease in sowing area of DCR, which resulted in SCR occupying a much larger sowing area. This points towards a widespread phenomenon of the "double to single" transition across Tongling, Anqing, Hefei, and Wuhu cities. In 2015, this phenomenon was particularly evident in the southeast of the Yangtze River, where DCR distribution became scanty.

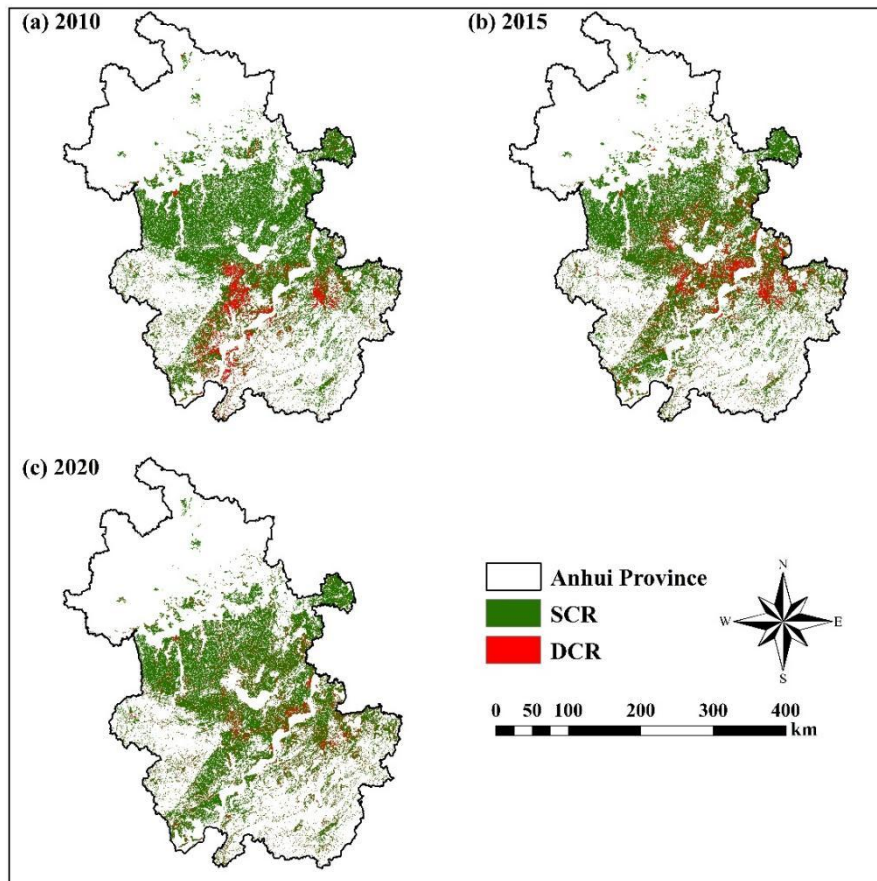


Fig. 2 Distribution of rice ripening in Anhui Province in 2010, 2015 and 2020

3.2 Accuracy Assessment

This study investigated the accuracy of rice planting area in Anhui Province, utilizing the ratio of SCR and DCR sown area to reflect rice planting patterns. The remote sensing images captured from 2010 to 2020 were compared with municipal-level rice sowing data to verify the extracted results. To increase the reliability of the results, data from three different years were integrated and compared. The findings revealed a strong correlation between the extracted and statistical data, with determination coefficients of 0.76, 0.81, and 0.68 for the extracted rice area, sowing ratio of SCR and DCR, respectively. These results indicate that the extracted data precisely reflect the distribution of rice planting in the region. In addition to that, a visual interpretation of Google Earth images in May further validated the extracted data, supporting the study's outcomes. Overall, these findings contribute to our understanding of rice planting management and support the use of remote sensing technology in rice cultivation management.

3.3 Spatiotemporal Changes in Rice Cropping System

Rice paddy area in Anhui Province has decreased gradually from 2010 to 2020. Planting area of rice decreased from 42892.12km² in 2010 to 41877.85km² in 2020, while the sowing area of SCR increased continuously from 23127.31km² in 2010 to 35640.92km² in 2020. The sowing area of DCR decreased gradually from 42892.12 km² in 2010 to 6236.92km² in 2020. Between 2010 and 2020, most cities in Anhui Province underwent a transition from utilizing rice paddies to other types of land use, primarily observed in Hefei, Chuzhou, Wuhu, and Ma'anshan. While some areas within the province saw instances of other land use types being converted to rice paddies, the overall trend evidenced a broad conversion from rice paddies to other types of use with primary production areas seeing the most significant conversion. Notably, from 2015 to 2020, a profound change in which paddy fields were transformed into other land use types from the previous period was observed, particularly in Hefei's center as a result of rapid urbanization.

An analysis of rice maturity changes in Anhui Province between 2010 and 2020, illustrated in Figure 3, highlighted an observable shift from DCR to SCR between 2010 and 2015. Significantly, a higher area, 12178.63km², was converted from DCR to SCR; whereas, there was a relatively lower conversion of 2977.99km² from SCR to DCR during this period. This shift led to a decrease in the replanting index from 146% to 124%. The period between 2015 and 2020, however, demonstrated a stable distribution pattern of rice maturity with minor changes, including a continued reduction in the area of DCR, and a corresponding increased conversion from DCR to SCR; and a negligible change in the conversion of SCR to DCR. During this deadline, the replanting index declined from 124% to 115 %. The increased planting of SCR was more prominent in urban centers like Hefei and Chuzhou.

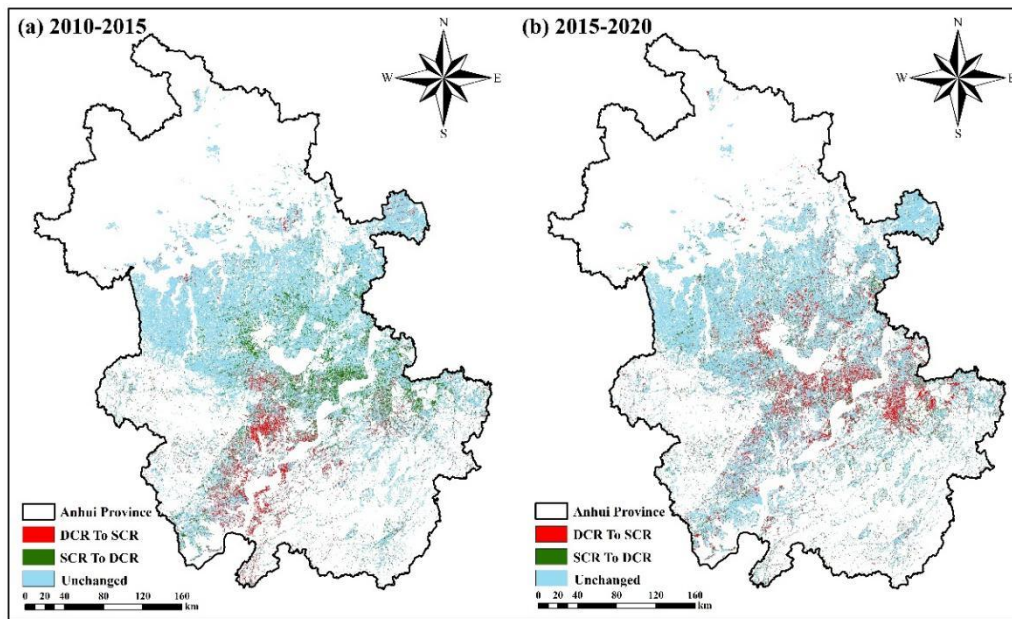


Fig. 3 Changes in rice ripening in Anhui Province

4. Conclusion

China aims to address the "Three Rural Issues" as part of its socialist modernization objectives. However, urbanization has led to a shortage of arable land for non-agricultural uses. Furthermore, the migration of rural laborers to cities has caused a shift from DCR to SCR crops in southern China, thereby hindering China's agriculture modernization plans. Therefore, it is crucial to conduct research on the spatial distribution pattern of rice production in China to determine grain production areas and expand planting regions.

This study used Landsat and Sentinel image data to analyze the spatial and temporal variations of the rice variety structure and SCR and DCR structure in Anhui Province from 2010 to 2020. Combined with the rice cultivation data in Anhui Province, an analysis of the changes in the rice cultivation structure in the study area was conducted, and the following conclusions were drawn:

(1) In Anhui, the land used for growing rice decreased overall between 2010 and 2020. However, more land was used to grow SCR, notably by changing land that was previously used to grow DCR.

(2) Rice production mainly takes place in eight cities. The way rice is grown changed from having DCR to having SCR mostly in the south. As of 2020, Lu'an is the only city still producing a lot of DCR.

(3) The changes in the planting structure of SCR and DCR were influenced by multiple factors, such as urbanization development, policy proposals, economic conditions, and water sources.

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