Research Article

Jinqiu Zou, Yinlan Huang, Lina Chen, Shi Chen*

Remote Sensing-Based Extraction and Analysis of Temporal and Spatial Variations of Winter Wheat Planting Areas in the Henan Province of China

Abstract: The aim of this study is to assess the winter wheat planting (WWP) area in Henan Province and investigate its temporal and spatial variations by using remote sensing (RS) technology. A spectral angle mapper (SAM) was adopted to identify the WWP area of each district divided by the hierarchical grades of land surface drought index during 2001-2015. The results obtained show the expediency of monitoring the WWP areas at the regional scale via drought regionalization, which provides a goodness-of-fit R^2 =0.933, a mean relative error MRE=49,118 ha, and an overall accuracy up to 90.24%. The major WWP areas in Henan Province were located in Zhoukou, Zhumadian, Shangqiu, Nanyang, and Xinxiang prefecture-level cities. Two representative sites are mountainous districts, with rich water resources or high urbanization rate, which have a low probability of WWP. Both sites exhibited a strongly manifested evolution of WWP areas, which could be attributed to extremely cold weather conditions, crop alternation, the popularization of new varieties, and fast expansion of built-up areas. The results of this study are instrumental in the analysis of crop planting variation characteristics, which should be taken into account in the further decision-making process related to the crop planting strategies.

1 Introduction

Henan province of China is a large-scale producer of winter wheat, whose crop yield is closely correlated to the planting area and applied planting strategies. In view of global climate change, especially, the effect of global warming on the safety of agricultural production, real-time accurate monitoring of winter wheat planting (WWP) area data becomes a "must-have" feature of state-of-the-art agricultural management, which stimulates the relevant government departments in China to master the monitoring techniques [1]. In this respect, remote sensing (RS) technology possesses a series of advantages, such as a wide coverage, short data updating cycle, strong objectivity, and low cost, which makes it a lucrative tool for the accurate, rapid, and convenient extraction of the WWP area data [2, 3].

Thus, a comprehensive analysis of phenological (i.e., related to periodic plant life cycle events influenced by seasonal and interannual variations in climate) characteristics can be considerably enhanced by RS-based monitoring.

Since the pioneer application of RS technology to the estimation of wheat area and total yield by the US researchers in 1974 [4], international scholars have reported numerous achievements in this domain and implemented several innovative RS-treatment procedures, which can be briefly outlined as follows:
1) Visual interpretation and automated computerised identification. According to the phenological characteristics of winter wheat growth and development, RS images are appropriately selected, and the multi-dimensional green map is constructed. Then, the winter wheat data are hierarchically and automatically

*Corresponding author: Shi Chen, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China; Bureau of Land Resources Lishui, Lishui, 323000, China, E-mail: shic11@126.com
Jinqiu Zou, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China
Yinlan Huang, Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing, 100081, China; Bureau of Land Resources Lishui, Lishui, 323000, China
Lina Chen, School of Information Technology, Shangqiu Normal University; Shangqiu, 476000, China

extracted via the pattern recognition, which is then corrected through the artificial visual interpretation [5, 6] with either supervised or unsupervised classification options [7, 8].

2) Options of pixel-based extraction (for areas with a wide planting range of winter wheat but a simple planting structure) and sub-pixel one (for areas with a complex terrain, scattered fields, and diverse crops). Here spectral unmixing is used, which is a quantitative analysis procedure used to recognize constituent ground cover materials (or endmembers) and obtain their mixing proportions (or abundances) from a mixed pixel [9]. The extraction accuracy of planting area depends on the selection of appropriate endmembers in the pixel unmixing [10, 11].

3) Plot-based extraction. The complexity of mixed pixel and the differences between the spectra of different objects on the ground can be reduced with the use of plot data, thus improving the extraction accuracy and operating stability to a certain degree [12].

4) Extraction of planting area is based on the RS monitoring model. According to the variation rules of the vegetation index in different key phases of the winter wheat growth, the spectral thresholds for distinguishing different objects are adjusted, the RS-based monitoring model of winter wheat is established, and moreover, in order to enhance the extraction accuracy, some auxiliary data are introduced, and effective classification rules are constructed using a decision-making tree [13, 14].

5) Extraction is based on textual features: the winter wheat spectral, phonological, and textural features are taken into account for further enhancement of winter wheat identification precision [15].

Conclusively, the above achievements and procedures have expanded the application range of RS technology in the monitoring of WWP area.

MODIS has advantages such as short revisit period, wide coverage and characterization of phenology [16]. It has become an important data source for monitoring WWP area [17]. It can give full play to the temporal and spectral characteristics of winter wheat. The method of monitoring WWP area using MODIS data is mainly to master the variation of phenological curve in winter wheat growth period. According to the variation of winter wheat growth phenology curve and the difference of other crops, the WWP area is extracted [18,19] using the shape characteristics of winter wheat growth curve.

In recent years, due to the effects of both natural factors (such as crop alternation, the adjustment of planting structure, and farmland occupation) and human factors, WWP in Henan underwent substantial changes. The data were gathered using Moderate Resolution Imaging Spectroradiometer (MODIS) instruments located aboard the Terra and Aqua satellites. The aim of this study is to monitor WWP area in Henan and assess the planting probability, reflecting variations in the planting structure. The present study is anticipated to be instrumental in getting a deeper insight into the driving forces of winter wheat spatial and temporal variations, whose account should promote further agricultural sustainable development and food security.

2 Research Area

Henan province of China is located in the middle and lower reaches of the Yellow River (110°21′E-116°39′E, 31°23′N-36°22′N). Regarding terrain, it is high in the east but low in the west, while regarding climate, it is in a transition between temperate and subtropical monsoon climates. Henan is characterized by a moderate climate, four distinct seasons, abundant sunshine and ample rainfall, with an average temperature of 12℃-16℃, an average sunshine duration of 1740-2310 h. Average annual precipitation in Henan ranges from 500 to 900 mm but steadily decreases from south to north. An overwhelming majority of lands possesses deep soil layers, nutrient-rich and fertile soils, abundant heat, light and water resources. All of these favorable conditions have laid solid foundations for agricultural development in Henan. According to *Henan Economy and Social Development Statistical Bulletin in 2015*, the grain planting area in Henan amounted to 10286150 hm^2, with a share of winter wheat being 53.14% or 5465660 hm^2, which strongly suggests that the winter wheat crop is an integral component of Henan's agricultural production (Figure 1).

3 Data source and processing

3.1 Data source

Global MOD13Q1 data are provided by National Aeronautics and Space Administration (NASA) every 16 days at a 250-meter spatial resolution as a gridded level-3 product in the Sinusoidal projection. MODIS medium-resolution imaging data show a series of advantages mainly including a wide field of view, large revisiting period and free sharing, and are lucrative for the large-area RS monitoring of WWP. In this study, MODIS 13Q1 data were downloaded from the official website of NASA with temporal and spatial
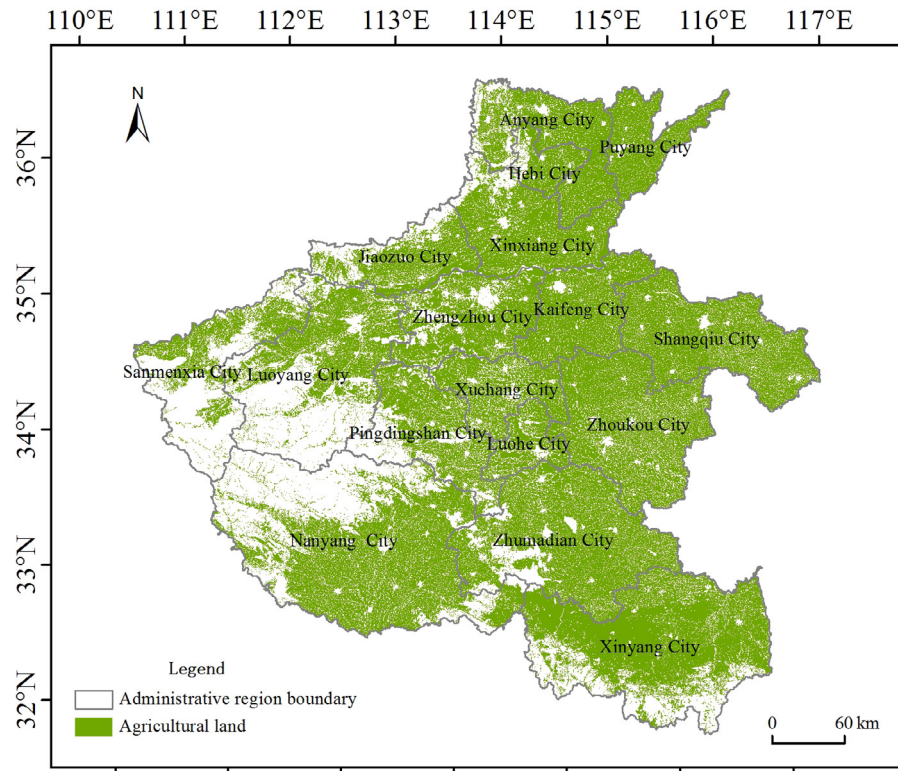
Figure 1. Overview of farmlands in Henan

resolutions of 16 days and 250m×250m, respectively. The time dimension of the data was from 2000 to 2015. Then, using MODIS Reproduction Tools (MRT) software, data preprocessing, including image merging, data format conversion, projection transformation, and maximum value composite (MVC) was performed. In particular, the images were spatially merged and resampled, with a format conversion from HDF to Tiff; meanwhile, SIN map was projected and transformed to Albers Equal Area Conic/ WGS84 projection; then, through Henan administrative boundary trimming, the normalized difference vegetation index (NDVI) datasets for various districts of Henan at different times were acquired. Synthetic images for the time periods from the first decade of October of each year to the last one of May of the following year, which corresponded to the winter wheat phenological growth periods in Henan, were finally selected for identification.

Meteorological data including daily precipitation and temperature data, which have been collected by many stations in Henan and surrounding districts during the period from 1969 to 2013 and underwent a preliminary preprocessing and quality control, were obtained from the China Meteorological scientific data sharing service network [20]. Land use data (in the format of GlobeLand30 soil type) were interpreted from RS data collected by Landsat TM (Thematic Mapper),

ETM+ (Enhanced Thematic Mapper Plus), and HJ-1 in 2010 [21, 22]. Noteworthy is the data masking frequently applied to the data fields, in order to protect data that are classified as commercially sensitive, while the data must remain usable for undertaking valid test cycles. In this case, the data masking was applied only to the farmland data in Henan, which exhibited slight variations and were difficult in the dynamic acquisition. Alternatively, the farmland data were obtained from Henan Statistical Yearbook and provided by the Statistical Bureau of Henan province, whereas the WWP area data in Henan were organized based on the corresponding time relationships between statistical yearbook data and those of various administrative districts [23].

3.2 Zoning of WWP in Henan

Precipitation is the main driving factor of winter wheat growth. The WWP characteristics in various districts differ by their responses to precipitation and spatial patterns [24]. Accumulated temperature directly affects winter wheat growth rate and the growth period duration, and therefore, the actively accumulated temperature (≥10℃) is commonly used in agriculture for revealing its effects on the growth of winter wheat [25].

For accurate interpretation of winter wheat growth in Henan and enhanced extraction accuracy of the planting area, this study accounts for the effect of precipitation and accumulated temperature in Henan on the WWP by using the annual precipitation and accumulated temperature (≥10℃) as the independent variables and calculating the drought indices of various meteorological stations in Henan and the surrounding districts [26]. $k=0.16\Sigma \geq 10℃/r$ was used to calculate drought indices in meteorological stations. The grade distribution of drought index was classified by natural breaks (Jenks) method after kriging spatial interpolation among different meteorological stations. Then, zoning was created according to the different drought indices value contour line (Figure 2). The geological environment in Henan, as well as the differences in phenological calendar and planting rules and distribution, the WWP area in Henan was conventionally subdivided into three districts, namely, Southern, Central, and Northern ones. In particular, the Southern District included Xinyang, Zhumadian and Nanyang, the Central one included Shangqiu, Kaifeng, Zhoukou, Luohe, Xuchang, Pingdingshan, Luoyang and Sanmenxia, while the Northern District included Zhengzhou, Jiaozuo, Xinxiang, Hebi, Anyang, and Puyang. Noteworthy is that, according to the official administrative division of the Hehan province, the seventeen prefecture-level divisions and one directly administered county-level city of Henan are subdivided into 158 county-level divisions (51 districts, 21 county-level cities, and 86 counties). Therefore, term "district" in this study also covers county-level cities and counties, besides the conventional administrative districts.

3.3 Data processing

At different stages of winter wheat growth, the data collected by RS satellites are strongly affected by clouds, atmospheric aerosols, sensor performances, and deviations in data transmission, producing interference in the RS-based identification of winter wheat crops. Therefore, it is necessary to perform smoothing and filtering on NDVI time series data so as to reflect the winter wheat growth characteristics and phenological variation rules. This study adopted a harmonic analysis of time series (HANTS) to perform on time-series RS images for a reliable reflection of the periodic variation rules of the plantation.

According to the planting situation and MODIS data characteristics of winter wheat in the study area, the parameter of the min and max threshold is set to 3 000 and 10 000 respectively. The length of period is set to 23.
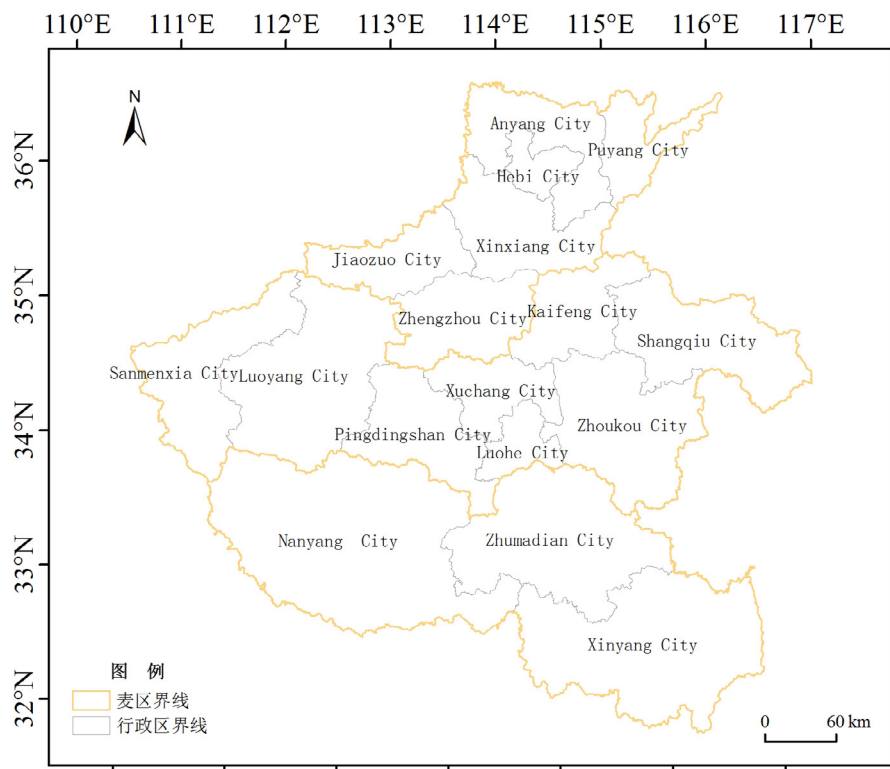

Figure 2. Zoning of WWP area in Henan

The number of frequencies is set to 2. The curve matching threshold is set to 1000. The number of remaining points is set to 8 and the scaling factor of the amplitude is set to 1.

As shown in Figure 3, the NDVI time-series spectra show specific variation rules in winter wheat phenological phase and is characterized by obvious high temporal spectral resolution. Therefore, the spectral angle mapper (SAM) identification method was adopted for RS-based monitoring of WWP area, in which the endmember curves reflecting winter wheat NDVI variation and the pixel curves were used for calculating their spectral angles. A smaller spectral angle reflects a similarity between the spectra of estimated pixels and endmembers, thus reflecting a higher classification probability and precision. The spectral angle was mainly determined based on the individual experience and winter wheat phenological growth rules. The phenological growth curve between crops was fully analyzed. Winter wheat time-series spectra show unique variation characteristics and are immune to those of other crops. The characteristics of winter wheat during the growth period was mastered. Therefore, misclassification in winter wheat identification can be reduced, as well as the number of pixel segments [27]. It can be observed that the winter wheat identification endmembers vary by districts and mainly decrease with latitude. Accordingly, this study adopted different interpretation methods for various districts.

Using the Endmember Collection tool in ENVI5.1 software, the WWP areas from 2001 to 2015 were identified via the SAM identification method. According to winter wheat phenological growth rules in the Northern, Central, and Southern districts, the identification spectra for each district were determined for each year. Next, the optimal identification thresholds for each district each year were adjusted based on the winter wheat statistical data for Henan's various city level cities. Finally, after the identification precision was satisfied, the decision-tree-based classification rules in farming areas were established, and the grid map of WWP in the research area was plotted based on the classification results.

4 Temporal and Spatial Evolutions of WWP Area in Henan

4.1 Interpretation precision of WWP area in Henan

The accuracy of RS monitoring of WWP area in different districts of Henan was verified by the comparative analysis of the RS-interpreted data on WWP area in various counties and cities with the statistical data for 2002 to 2015 [23]. The statistical area of WWP in 210 cities and counties was used as a validation sample. The statistical area of cities and counties in each district is verified by the area extracted by remote sensing monitoring. According to such statistical parameters as the goodness-of-fit (R^2), root-mean-square error (RMSE), and the mean relative
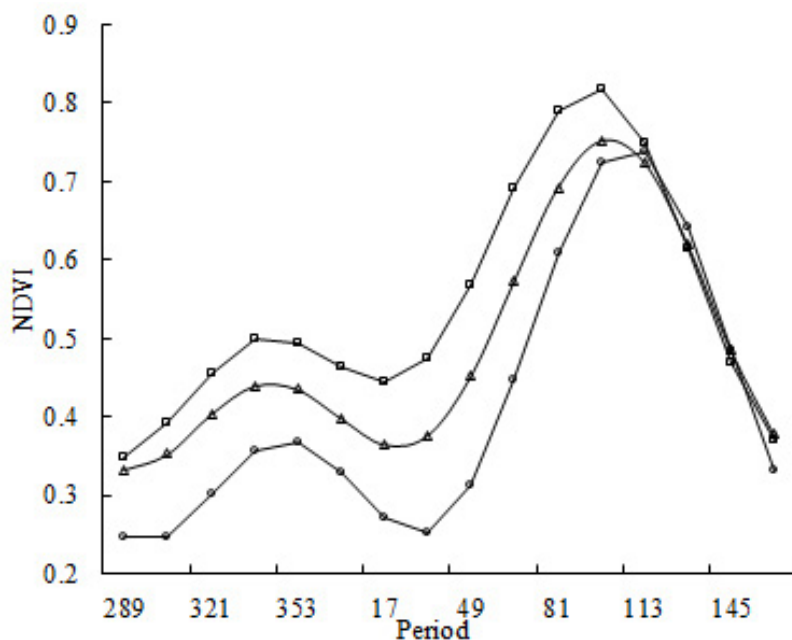

Figure 3. NDVI time-series spectra of winter wheat in Southern (□), Central (△), and Nothwern (O) districts

**Table 1.** Accuracy analysis of the RS monitoring of WWP area

District	R^2	RMSE (hm²)	MRE (%)	Accuracy (%)	Mean Error (hm²)
Southern District	0.959	49943	2.99	97.01	-14.77
Central District	0.929	49187	13.82	86.18	-8.58
Northern District	0.788	49107	3.99	96.01	0.68
Total region	0.933	49118	9.76	90.24	-5.97

Table 2. Calculation methods of WWP probability and the related classification rules used for each period

Period	2001-2005	2006-2010	2011-2015	2001-2015
Planting probability calculation formula	$x/5*100\%$			$y/15*100\%$
Probability-based classification rules	WWPP <20%(Level 1)；20 ≤WWPP< 40% (Level 2)；40≤WWPP <60% (Level 3)；60 ≤WWPP< 80% (Level 4)；WWPP ≥80% (Level 5)			

Note: *x* and *y* denote the values in a grid accumulated during 5- and 15-year periods, respectively

error (MRE) [28]. The RS interpretation and statistical data are compared in Table 1, which shows that the goodness-of-fit (R^2) values of Southern, Central, and Northern districts are 0.959, 0.929 and 0.788, respectively. Noteworthy is that the RMSE fails to reveal obvious differences among three districts and varies from 49000 to 50000 hm². Regarding MRE and accuracy, the best values are observed for the Southern and Northern districts. The results obtained for the total region also indicate a close fit of RS-interpreted and statistical data, according to R^2=0.933 and accuracy of 90.24%. This implies that after the region subdivision into different planting districts, the interpretation of winter wheat in Henan using SAM is feasible and the identification of WWP area based on the MODIS data shows a high-precision.
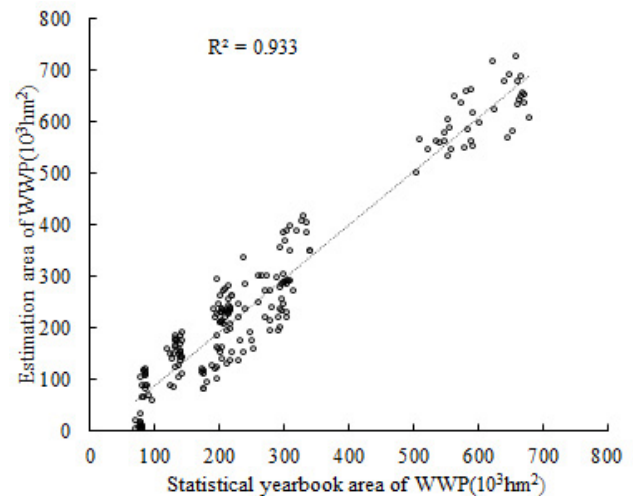
Figure 4. RS estimation area verification scatter plot

4.2 Temporal and spatial variation characteristics of WWP probability in Henan

Due to the joint effect of agricultural regional economy and policies, and soil texture changes, the crop alternation has become a common phenomenon. Based on RS monitoring results of the WWP area in Henan over the last 15 years, this study used the variation of spatial planting probability in different periods for the unbiased analysis of temporal and spatial variation characteristics of the main planting area in Henan.

In this study, the total analyzed range (2001-2015) was subdivided into three periods: 2001-2005, 2006-2010, 2011-2015, respectively, and then, the WWP probabilities (Winter Wheat Planting Probability, WWPP) for three different periods and the total one (denoted as the fourth period) were calculated using the ArcGIS grid. The specific calculation procedure is described below. In the RS results, the values of the grids that were interpreted as winter wheat were set as 1, while those of the other grids were set as 0; then, the interpretation results for different periods were added, and the spatial distributions of WWP probability for different periods were classified and plotted according to the classification rule of planting probability as listed in Table 2.

Figure 5a shows the spatial distributions of WWP probability and the statistics of planting probability in different districts of Henan for the period from 2001 to 2005. Here Zhumadian, Shangqiu, Zhoukou, Nanyang, and Xinxiang show the highest probabilities of WWP. In particular, as shown in Fig. 5 (right), the winter wheat areas with the planting probability over 60% occupied 47.35% of the total WWP area and approximately covered 497280 hm² in Zhumadian, 8.83% and 64170 hm² in
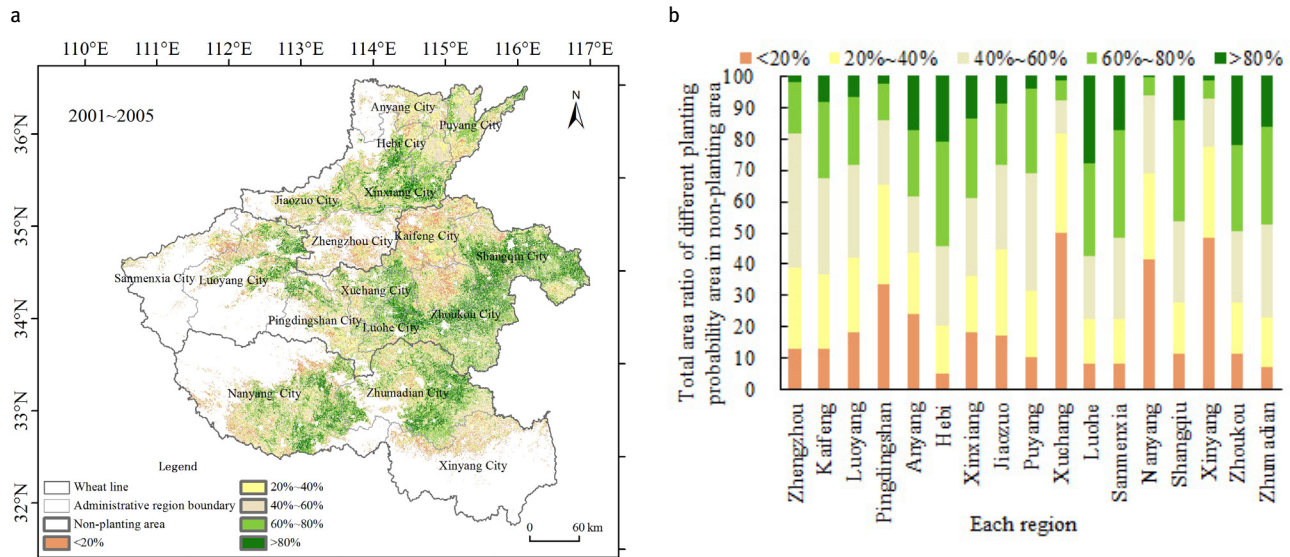
Figure 5 a. Regional spatial pattern of WWP probability and statistical variation from 2001 to 2005 in Henan. **b.** Ratios of the planting areas with different planting probabilities to the total planting area from 2001 to 2005 in Henan.
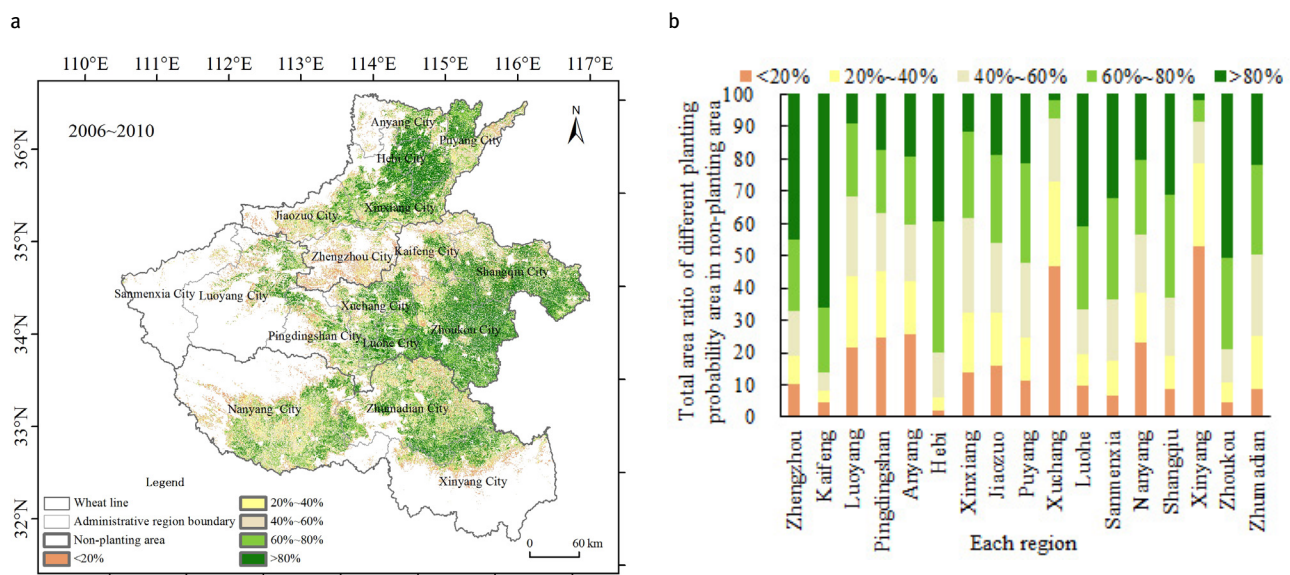

Figure 6a. Regional spatial pattern of WWP probability and statistical variation from 2006 to 2010 in Henan. **b.** Ratios of the planting areas with different planting probabilities to the total planting area from 2006 to 2010 in Henan.

Shangqiu, 57.34% and 447600 hm² in Zhoukou, 51.69% and 375660 hm2 in Nanyang, respectively.

Figure 6a shows the spatial distribution of WWP probability and the statistics of planting probability in different districts of Henan for the period from 2006 to 2010. In general, the planting probability of winter wheat for this period is obviously higher than that of the period from 2001 to 2005. Zhoukou, Anyang, Xinyang and Hebi show the highest probabilities of WWP. As shown in Fig. 6b, as compared with the results for the period from 2001 to 2005, the winter wheat area in Zhoukou, Anyang, Xinyang,

and Hebi with the planting probability over 60% increased by 285380 hm², 179360 hm², 146110 hm2 and 73020 hm², respectively. In terms of the ratio of the overall wheat area with the planting probability over 60% to the overall wheat winter planting area, Hebi, Anyang, Zhoukou, and Xinyang exhibited a significant increase within the period from 2006 to 2010; as compared with the results for the period from 2001 to 2005, the ratios in these four cities increased by 53.73%, 49.09%, 37.51% and 29.60%, respectively.

Figure 7a shows the spatial distribution of WWP probability and the statistics of planting probability in
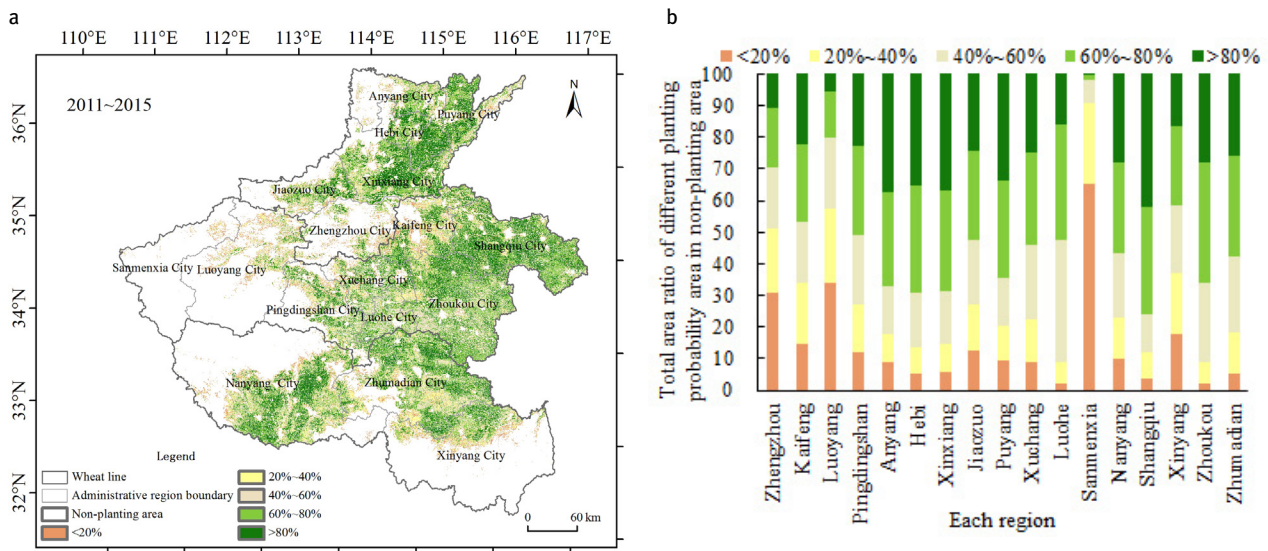
Figure 7a. Regional spatial pattern of WWP probability and statistical variation from 2011 to 2015 in Henan. **b.** Ratios of the planting areas with different planting probabilities to the total planting area from 2011 to 2015 in Henan.

different districts of Henan for the period from 2011 to 2015. In general, the planting probability of winter wheat for this period shows no obvious difference from that for the period from 2001 to 2005, except for some districts. As compared with the results for the period from 2006 to 2010, the winter wheat area in Nanyang and Shangqiu with the planting probability over 60% increased by 139570 hm² and 121960 hm2, respectively; by contrast, the winter wheat area in Zhoukou and Luoyang with the planting probability over 60% decreased by 107010 hm² and 72780 hm², respectively.

Figure 8a shows the spatial distribution of WWP probability and the statistics of planting probability in different districts of Henan over the last 15 years. Zhoukou, Zhumadian, Shangqiu, Nanyang, and Xinyang show the highest probabilities of WWP, with the winter wheat area with the planting probability over 60% up to 732380 hm², 679330 hm², 603880 hm², 542040 hm² and 403220 hm², respectively. Accordingly, Zhoukou, Zhumadian, Shangqiu, Nanyang and Xinyang were five core planting areas in Henan over the last 15 years. Noteworthy is
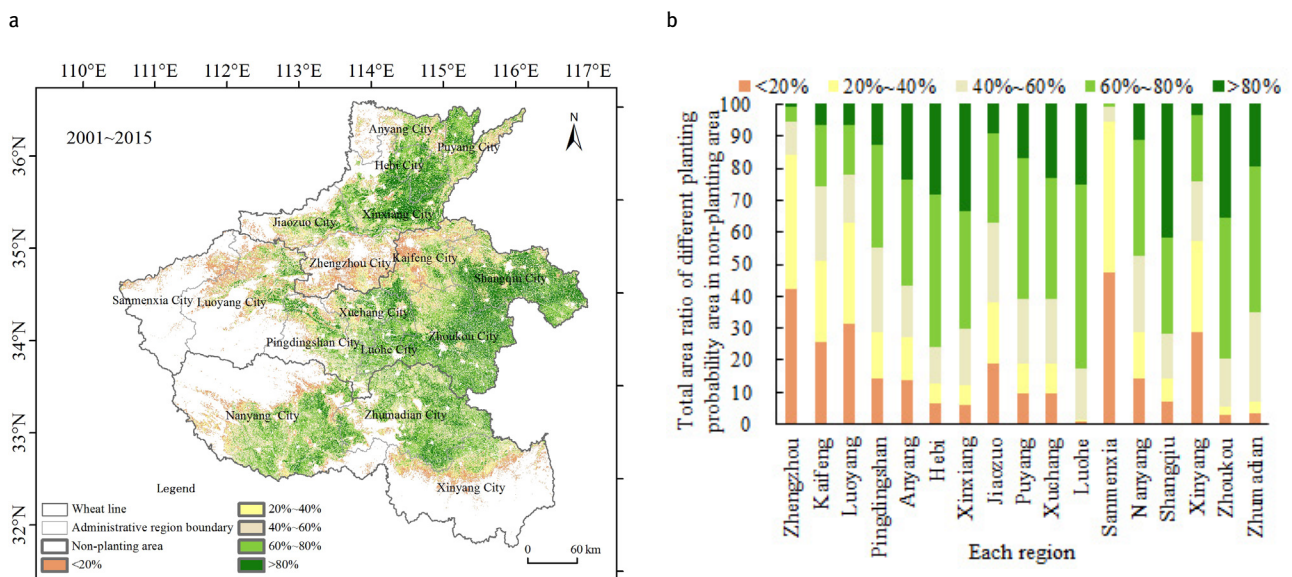

Figure 8a. Regional spatial pattern of WWP probability and statistical variation from 2001 to 2015 in Henan. **b.** Ratios of the planting areas with different planting probabilities to the total planting area from 2001 to 2015 in Henan.

that the ratio of the winter wheat area with the planting probability over 60% to the total planting area of Luohe is the highest and reaches 82.65%, followed by the ratios of Zhoukou, Hebi and Shangqiu, with the values of 79.24%, 75.85% and 71.63%, respectively, while the ratio of Xinyang is the lowest (70.16%).

4.3 Reasons for temporal and spatial variations of WWP area in some typical districts

Next, in-depth investigation of the WWP temporal and spatial evolutions in Shagnqiu and Nanyang was carried out.

Over the last 15 years, the WWP area in Shangqiu increased in a fluctuant way, with a correlation coefficient $R^2 = 0.270$, which shows two low points (troughs) in 2005 and 2010, respectively. Since temperature fluctuated significantly from December 2004 to February 2005, this district has experienced extremely cold weather conditions [29], the growth of winter wheat was deteriorated, thereby reducing the planting area [29]. In 2010, the winter wheat crop in Shangqiu had sustained cold-air and heavy snowfalls at the tillering stage and, thus, was strongly affected.

Regarding spatial variation, WWP area in Shangqiu shows significant variations in the most of the northwest, northern, central, and the surrounding districts of the city. The variations in the former two districts were induced by abundant water resources, which have provided favorable

conditions for crop alternation. As for the variation observed around the city, the primary reason was the rapid development and expansion of the urban construction.

The WWP area in Nanyang also increased in a fluctuant way from 2001 to 2015, with a correlation coefficient $R^2 = 0.333$. In particular, the planting area has exhibited the sharpest increase during the period from 2004 to 2006, demonstrating the area increment and WWP ratio of 183,640 hm^2 and 34.54%, respectively. An additional survey of this issue via questionnaires, interviews, and consultations with experts has revealed that some new varieties were popularized over a large area from 2004 to 2006, which can thus account for the significant increase of planting area in this period. In terms of the spatial planting pattern variation, most of the mountainous areas in the northwest and the surrounding areas of the city show most significant variations, which may be induced by the complex climate conditions and dramatic variations of some important meteorological factors including temperature and precipitation.

5 Conclusions

The approach used in this study can be summarized as follows. Based on the time-series data of winter wheat growth collected by MODIS 13Q1, the drought index was calculated from the precipitation and temperature data and used as the basis for subdivision of the WWP area in Henan into three districts. Then, the WWP areas of different districts of Henan over the last 15 years were
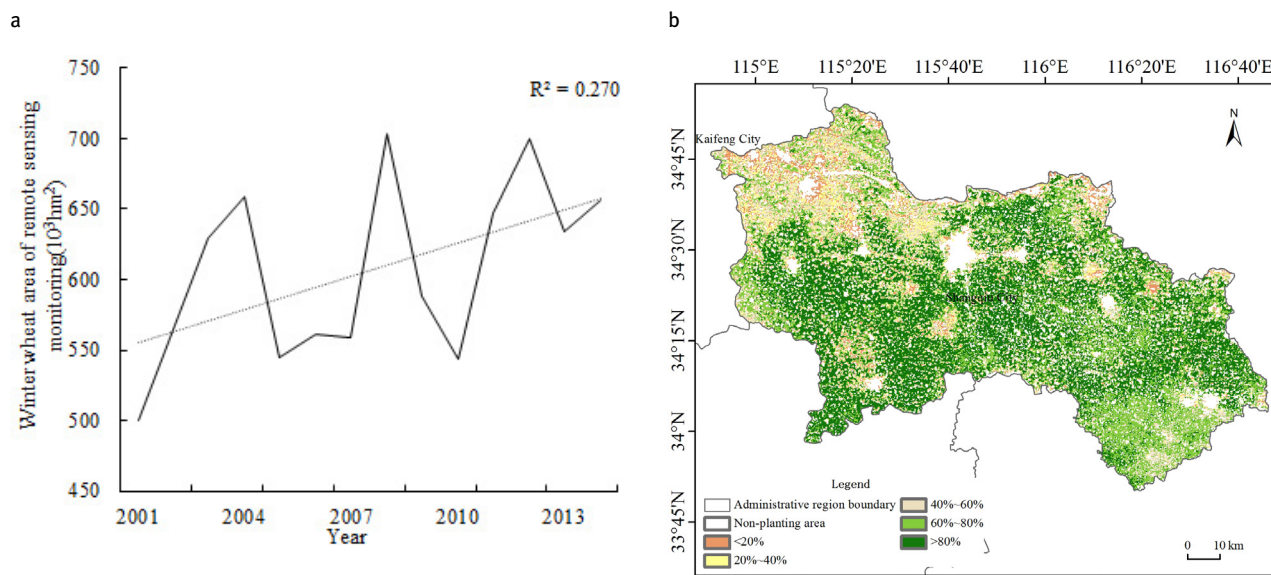

Figure 9a. The spatial-temporal RS-based evolution graph of WWP area in Shangqiu. **b.** The spatial pattern of WWP probability and statistical variation from 2001 to 2015 in Shangqiu.
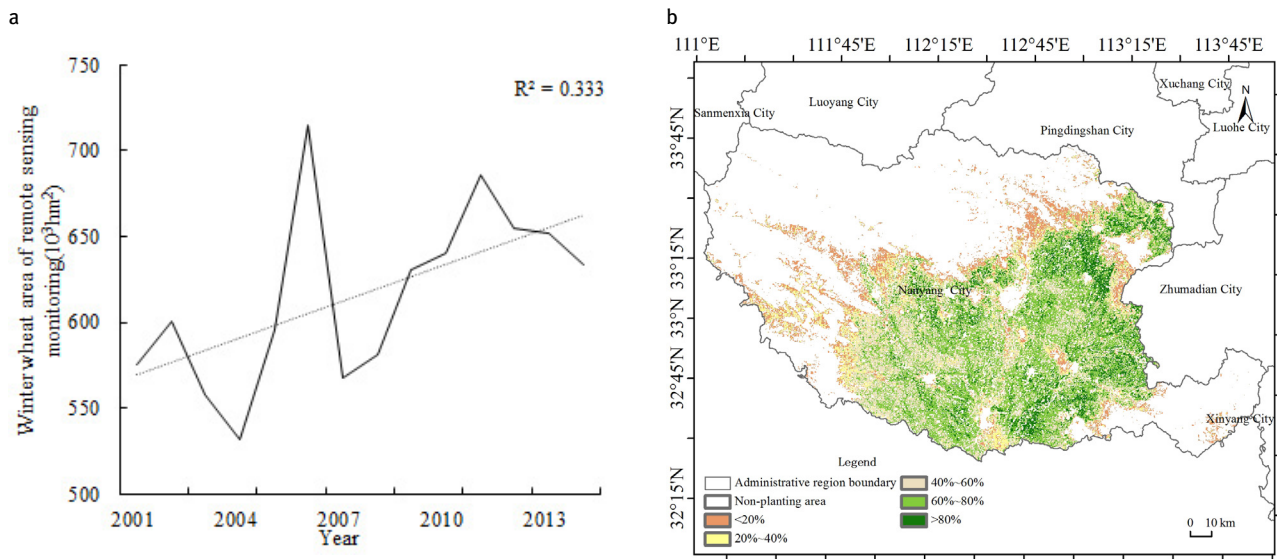
a

b

Figure 10a. The spatial-temporal RS-based evolution graph of WWP area in Nanyang. **b.** The spatial pattern of WWP probability and statistical variation from 2001 to 2015 in Nanyang.

identified using the SAM method, and the spatial and temporal variation characteristics of WWP probability in Henan were obtained based on the interpretation of the RS results for different time sections. Finally, the annual planting area variations and spatial variation patterns in two particular districts (Shangqiu and Nanyang) were analyzed in more detail, and possible reasons for these variations were discussed. The results obtained make it possible to draw the following conclusions.

1) The proposed SAM identification of different WWP districts classified by the calculated drought index was feasible in RS monitoring of WWP area in Henan. The interpreted planting areas of different cities were verified by the data recorded in Statistical Yearbook during the same period. According to the comparison results, the extraction of WWP area in Henan shows a high precision. The proposed method is applicable to the identification of large-scale WWP areas.

2) As is shown by the temporal and spatial distributions of WWP probability for different periods from 2001 to 2015, the WWP area in Henan increased in a fluctuant way over the last 15 years. The most significant increase was observed in Nanyang, Zhumadian, Zhoukou, and Shangqiu. The above areas and Xinxiang are shown to be the core WWP areas over the last 15 years in Henan.

3) The temporal and spatial evolutions of two case study WWP areas in Shangqiu and Nanyang are attributed to extreme low-temperature conditions, crop alternation, the popularization of new varieties, as well as the expansion of urban construction. The related analysis can provide the scientific substantiation for the

agricultural and economic development planning in Henan.

4) Wang et al used Landsat to extract the WWP area in Henan Province via the Google Earth Engine (GEE) platform. The accuracy reached 97% [30]. Compared with the results of their winter wheat planting area in 2015, the results we extracted were quite similar.

The SAM identification method is shown to be efficient in eliminating segments in the interpretation of crops and reducing the probability of misclassification in the identification of winter wheat crop. In order to enhance the RS interpretation precision, the optimal time-series spectra should be acquired based on the processing of annual data. The WWP area in Henan was subdivided based on the estimated drought index, with the phenological differences of winter wheat growth under different climatic environments were considered. The identifications of WWP areas in different districts show a high precision. However, There are some limitations to this approach, include: 1) The SAM identification threshold is dynamic and susceptible to human experience. 2) We need to reuse the zoning of the drought index in other study areas. 3) Although land use data are used to mask the study area, the spatial resolution of MODIS is coarse, which leads to a certain error in the extraction results. 4) Henan is located in the north-to-south climate transition zone and exhibits complex climate conditions, which provide significant interferences to the RS imaging quality and strongly deteriorate the winter wheat crop identification accuracy in the interpretation of MODIS time-series spectral data.

This issue cannot yet be fully resolved using the current technology and requires further research efforts and technological breakthrough solutions.

Conflict of interest: Authors state no conflict of interest

References

[1] Justice CO, Becker RI. Report from the workshop on developing a strategy for global agricultural monitoring in the framework of Group on Earth Observations (GEO). Rome: UN/FAO; 2007. p. 1-67.

[2] Zhang JH, Feng LL, Yao FM. Improved maize cultivated area estimation over a large scale combining MODIS-EVI time series data and crop phonological information. ISPRS J. Photogramm. Remote Sens. 2014;94(94):102-13.

[3] Wang X, Li XB, Xin LB. Impact of the shrinking winter wheat sown area on agricultural water consumption in the Hebei Plain. J GEOGR SCI. 2014; 24(2):313-30.

[4] Chen SS, Liu QH, Chen LF, Li J, Liu Q. Review of research advances in remote sensing monitoring of grain crop area. Trans. Chin. Soc. Agric. Eng. 2005; 21(6):166-71.

[5] Wang NB, Jia P, Zhou YC. A study on extracting winter wheat area automatically from TM imagery using pattern recognition technology. Remot Sens Technol Appl. 1993;8(4):28-33.

[6] Feng MC, Yang WD, Zhang DY, Cao LL, Wang HF, Wang Q. Monitoring planting area and growth situation of irrigation-land and dry-landwinter wheat based on TM and MODIS data. Trans. Chin. Soc. Agric. Eng. 2009;25(3):103-9.

[7] Qi L, Liu LY, Zhao CJ, Wang JH, Wang JH. Selection of optimum periods for extracting winter wheat based on multi-temporal remote sensing images. Remot Sens Technol Appl. 2008;23(2):154-60.

[8] Li ZJ, Li WG, Shen S. A classification of what yield by remote-monitoring based on optimization ISODATA. Remot Sens Inf. 2008;8:30-2.

[9] Li LL, Pan YZ, Zhang JS, Song GB, Hou D. Method of winter wheat planting area estimation based on support vector machine and post-classification changed vector analysis. Trans. Chin. Soc. Agric. Eng. 2010; 26(9):210-17.

[10] Zhao L, Zhang JS, Hu TG, Chen LQ, Li L. The application of the dynamic end member linear spectral unmixing model to winter wheat area estimation. Remot Sens Land Resour. 2011;26(1):66-72.

[11] Wang LX, Xu SN, Li Q, Xue HX, Wu JS. Extraction of winter wheat planted area in Jiangsu province using decision tree and mixed-pixel methods. Trans. Chin. Soc. Agric. Eng. 2016;32(5):182-7.

[12] Li L, Zhang JS, Zhu WQ, Hu TG, Hou D. Winter wheat area estimation with MODIS-NDVI time series based on parcel. Spectrosc Spect Anal. 2011; 31(5):1379-83.

[13] Huang Q, Li DD, Chen ZX, Liu J, Wang LM. Monitoring of planting area and growth condition of winter wheat in China based on MODIS data. T Chin Soc Agric Mach 2012;43 (7):163-7.

[14] Wang X. Li X.B., Tan M.H., Xin LJ. Remote sensing monitoring of changes in winter wheat area in North China Plain from 2001 to 2011. Trans. Chin. Soc. Agric. Eng. 2015;31(8):190-9.

[15] Zhu XF, Jia B, Pan YZ, Gu XH, Han LJ, Zhang YQ. Effects of various feature information on the accuracy of winter wheat planting area measurement. Trans. Chin. Soc. Agric. Eng. 2007;23(9):122- 9.

[16] Ren JQ, Chen ZX, Zhou QB, Tang HJ. Regional yield estimation for winter wheat with MODIS-NDVI data in Shandong, China. Int J Appl Earth Obs. 2008;10(4):403-13.

[17] Xu WB, Zhang GP, Fan JL, Qian YL. Remote sensing monitoring of winter wheat areas using MODIS data. Trans. Chin. Soc. Agric. Eng. 2007;23(12):144-9.

[18] Pan YZ, Li L, Zhang JS, Liang SL, Zhu XF, Damien SM. Winter wheat area estimation from MODIS-EVI time series data using the Crop Proportion Phenology Index. Remote Sens. Environ. 2012;119(3):232-42.

[19] Sun HS, Xu AG, Lin H, Zhang LP, Mei Y. Winter wheat mapping using temporal signatures of MODIS vegetation index data. Int J Remote Sens, 2012;33(16):5026-42.

[20] Chen S, Gao C, Xu B, Jin YX, Li JY, Ma HL, et al. Quantitative inversion of soil salinity and analysis of its spatial pattern in agricultural area in Shihezi of Xinjiang. Geogr Res. 2014;33(11):2135-44.

[21] Chen J, Chen J, Liao AP, Cao X, Chen LJ, Chen XL, et al. Concepts and key techniques for 30mGlobal land cover mapping. Acta Geod Cartogr Sin. 2014; 43(6):551-557.

[22] Chen J, Chen J, Liao AP, Cao X, Chen LJ, Chen XL, et al. Global land cover mapping at 30m resolution: A POK-based operational approach. ISPRS J. Photogramm. Remote Sens. 2015;103(6): 7-27.

[23] Henan Statistical Yearbook of the Henan Province Statistical Bureau. Henan: China Statistics Press, 2001- 2015.

[24] Dang TH, Gao CQ. Study on key water factors affecting wheat yield in Weibei dry highland. Res Soil Water Conserv. 2003;10(1):9-11,36.

[25] Wang XX, Feng XF, Zhang FR, Zhang YS. Analysis on effective accumulated temperature variation characteristic of growth for Jixiaomai in Chaoyang area in 50 Years. Chin Agric Bull. 2014;30(2):280-85.

[26] Chen S, Xu B, Jin YX, Huang YL, Zhang WB, Guo J, et al. Remote sensing monitoring and spatial-temporal characteristics analysis of soil salinization in agricultural area of northern Xinjiang. Sci. Geogr. Sin. 2015;35(12):1607-15.

[27] Wu WJ. A red tide detecting method based on spectral signatural and spectral angle mapping technology. Remot Sens Inf. 2009;8:50-54.

[28] Jin Y X, Yang X C, Qiu J J, Li JY, Gao T, Wu Q, et al. Remote sensing-based biomass estimation and its spatio-temporal variations in temperate grassland, Northern China. Remote Sens. 2014;6: 1496-513.

[29] Li MS, Wang DL, Zhang Q. Cause analysis of frost damage to winter wheat in Huang-Huai-Hai plain during 2004-2005. J Nat Disaster. 2005;14(4):51-55..

[30] Wang JZ, Tian HF, Wu MQ, Wang L, Wang CY. Rapid mapping of winter wheat in Henan Province. Geo-Inf Sci. 2017;19(6):846-53.