World Academy of Science, Engineering and Technology
International Journal of Agricultural and Biosystems Engineering
Vol:5, No:11, 2011

Precipitation Change and its Implication in the Change of Winter Wheat drought and Production in North China Region from 2000 to 2010

Y. Huang, Q. J. Tian, L. T. Du, J. Liu, S. S. Li

***Abstract*—**Understanding how precipitation inter-annually changes and its implication in agricultural drought and production change in winter wheat (Triticum aestivum L.) growth season is critical for crop production in China. MODIS Temperature-Vegetation Dryness Index (TVDI) and daily mean precipitation time series for the main growth season(Feb. to May) of winter wheat from 2000 to 2010 were used to analyze the distribution of trends of precipitation, agricultural drought and winter wheat yield change respectively, and relationships between them in North China region(Huang-huai-hai region, HHH region), China. The results indicated that the trend of precipitation in HHH region past 11 years was increasing, which had induced generally corresponding decreasing trend of agricultural drought and increasing trend of wheat yield, while the trend of drought was spatially diverse. The study could provide a basis for agricultural drought research during winter wheat season in HHH region under the ground of climate change.

***Keywords*—**drought, MODIS, precipitation change, TVDI, winter wheat production

I. INTRODUCTION

WATER supply situation is the main limiting factor to crop production in North China region (Huang-huai-hai region, HHH region) for the small quantity, large inter-annual and seasonal variation of precipitation, especially in winter wheat growth period [1]. Serious water supply deficit would lead to agricultural drought and might induce wheat yield reduction. So learning the trend of drought and crop yield and the way they respond to climate change is very meaningful for guiding cropland irrigation scientifically so as to prevent and reduce disaster and insurance of food security. The relationships between drought, precipitation and crop production are very complicated. Nevertheless, drought itself is one of the most severe manifestations of climate change [2], and robust relationships can be established between surface climate and crop productivity in regional scale [3].

Remote sensing, which can provide much greater spatial and temporal coverage of drought conditions than from site measurements of soil moisture and precipitation, has gained an increasing attention for drought monitoring in recent years. Among various remote sensed drought indices, Temperature-Vegetation Dryness Index(TVDI), based on an empirical parameterization of the relationship between surface temperature (Ts) and vegetation index (NDVI) in monitoring soil moisture and drought regionally and only needs satellite-derived information, has been used widely [4], [5] and validated to be a superior indicator to monitor the agricultural drought in HHH region [6], [7].

In this paper, the remote sensing-based drought indices TVDI, interpolated meteorological site data and statistic datasets will be used to study the trends of precipitation and its implication on drought and wheat production. The result should provide references for winter wheat production under the background of the agricultural drought influenced by climate change.

II. STUDY AREA

North China region (Huang-Huai-Hai region, HHH region) locates between 112°E and 122°E, 32°N and 41°N, and lies in the warm-temperate zone, with continental monsoon climate. The annual mean temperature, days of frost-free period and precipitation of HHH region are 10~15℃, 182~198d and 500~600 mm respectively. There’ s large inter-annual and seasonal variation of precipitation here with a most difference of 4 to 6 times between the rainy years and dry years. And summer precipitation accounts for over 60% of total annual precipitation, while the winter part is less than 5%. The average attitude of HHH region is below 50 m, with alluvial plain as the main landform type and alluvial soil as the main soil type, as well as the main cultivated soil type. Administrative division of HHH region includes all of Shandong Province and Tianjin City, Most parts of Hebei, Henan Province and Beijing City and parts of Jiangsu and Anhui Province in north of Huai River. This region is one of the top five major grain bases in China (winter wheat and summer maize rotation) with the average grain crop plant area over 2.2×107hm-2. And the main spring crop type of this region is winter wheat (Sowing in early Oct. and returning green in middle Feb. next year). This region is also China’s drought-prone areas with a frequency up to 95% historically [8] due to the obvious contradiction between limit of rainfall supply and crop’s demand for water during winter wheat growth period [9]. Therefore, it’s very meaningful to understand the trends of precipitation in winter wheat growth season and its implication in agricultural drought and wheat production this region.

Y. Huang(e-mail: yhuang.work@gmail.com), Q. J. Tian(e-mail: tianqj@nju.edu.cn), L. T. Du(e-mail: dult80@qq.com), J. Liu(e-mail: 8886355@163.com), S. S. Li(e-mail: lissnju@gmail.com) are with the International Institute for Earth System Science, Nanjing University, Nanjing, 210093, China

Supported by the National Program on Key Basic Research Project of China (No. 2010CB951503), Graduate Student Innovation Project of Jiangsu Province, China(No. CXLX11_0023).

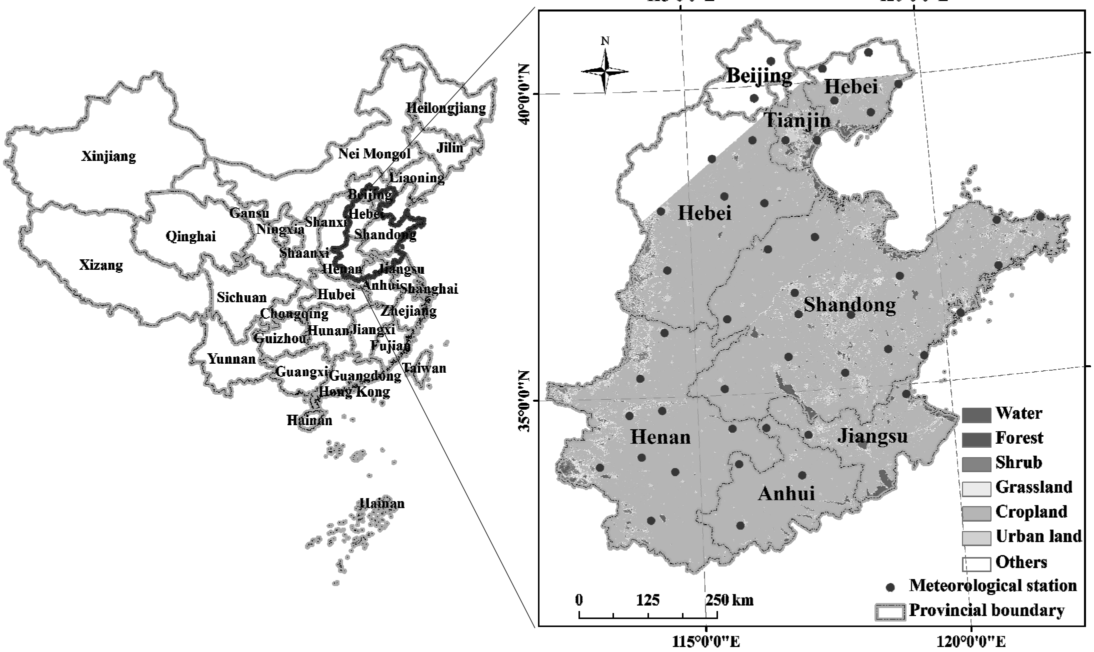


Fig. 1 Location and land cover type (2009) of HHH region and spatial distribution of meteorological station

III. Data and Method

A. Remote Sensed Data and Drought Index

The Moderate Resolution Imaging Spectroradiometer (MODIS, boarding on NASA satellites of Terra) data used in this study are the 8-day composite (the best quality daily reflectance data of the 8-day period) 500-meter surface reflectance data (MOD09A1, h27v05, middle Feb. to late May, from 2000 to 2010, totally 142 scenes), 8-day composite 1000-meter land surface temperature data (MOD11A2, h27v05, middle Feb. to late May, from 2000 to 2010, totally 141 scenes) and annual 1000-meter land cover type data (MCD12Q1, from 2001 to 2009, totally 9 scenes) obtained from NASA Goddard Earth Sciences Data and Information Services Center (GESDISC). The absent MOD09A1 image (Julian day: 2007065) was substituted by the corresponding one in 2006, absent MOD11A2 images (Julian day: 2000049 and 2000057) were substituted by the corresponding one in 2001 and the MCD12Q1 images of 2001 and 2009 were used to substitute the ones in 2000 and 2010 respectively. The original datasets were transformed by the MODIS Reprojection Tool (MRT) and all resized into 1000-meter spatial resolution by Bilinear interpolation method. UMD land cover type dataset, which is a revised edition from International Geosphere-Biosphere Program (IGBP) land cover type dataset by Maryland University [10], extracted from MCD12Q1 was used to obtain the cropland type to mask the reflectance and land surface temperature data.

The vegetation drought index Temperature-Vegetation Dryness Index (TVDI) was calculated to indicate the status of agricultural drought during the main winter wheat growth period. TVDI is a simplification [11] of vegetation index-land surface temperature feature space (Ts-NDVI space) [12], [13]. And it was calculated according to (1).

$$TVDI = \frac{Ts - Ts_{\min}}{Ts_{\max} - Ts_{\min}} \quad (1)$$

Where Ts is land surface temperature at a given pixel, $Ts_{\min} = a_1 + b_1 NDVI$ is the minimum surface temperature for a given NDVI corresponding to the 'wet edge' (maximum evapotranspiration and unlimited water access) in the Ts-NDVI space, $Ts_{\max} = a_2 + b_2 NDVI$ is the maximum surface temperature for a given NDVI corresponding to the 'dry edge' (limitation of water availability) in the Ts-NDVI space. a_1, b_1, a_2 and b_2 are the intercepts and slopes of the wet edge and dry edge respectively, as well as the fitting coefficient of $Ts_{\min}$, $Ts_{\max}$ and $NDVI$. $NDVI = (NIR - Red)/(NIR + Red)$, Where, NIR and Red are the reflectance for MODIS bands 2 (841~876 nm), and 1 (620~670 nm), respectively. $Ts_{\min}$ and $Ts_{\max}$ were determined by establishing Ts-NDVI space with NDVI interval of 0.01 in ENVI/IDL software environment, then TVDI values were calculated. Larger values of TVDI indicate less soil moisture and heavier vegetation dryness, whereas lower ones

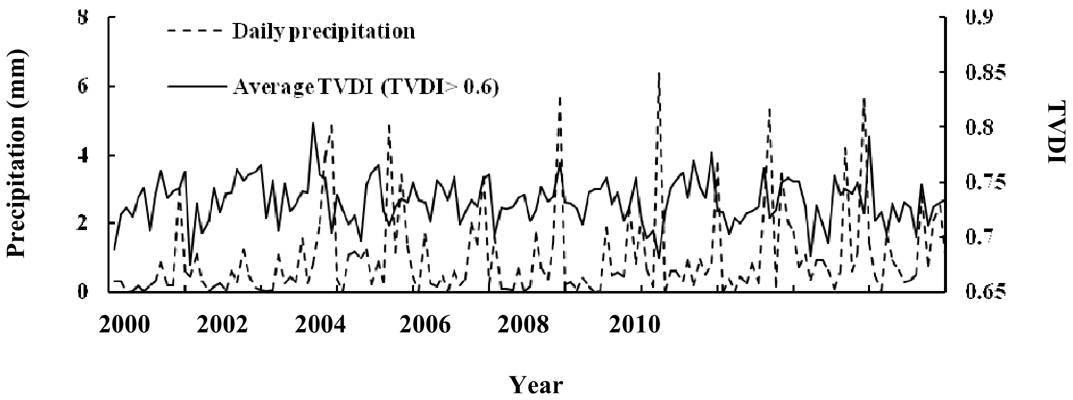


Fig. 2 Time series of 8- day average daily precipitation and TVDI between middle Feb. and late May from 2000 to 2010 in HHH region

indicated more soil moisture and lower dryness. The 8-day TVDI composites were sequentially stacked to generate an 11-year (2000~2010, totally 143 scenes) time series.

B. Precipitation and Statistic Data

Daily mean precipitation (middle Feb. to late May, from 2000 to 2010) and annual precipitation anomaly of 46 meteorological stations in HHH region were used to analyze the rainfall change in the past 11 years, which were obtained from China Meteorological Data Service System. Daily precipitation was interpolated into 1000-meter resolution raster datasets using the Thin Plate Spine (TPS) method [14] (ANUSPLINE Version 4.3). USGS GTOPO30 global DEM dataset (30-arc-second, obtained from USGS EROS Center) was used in the processing of interpolation, which was resampled into 1000 meter resolution later. The average values of 8-day precipitation composites were calculated according to the period of TVDI values and also sequentially stacked to generate an 11-year (2000~2010, totally 143 scenes) time series. The datasets of annual agricultural drought affected area and disaster area and crop planting area of the 7 provinces HHH region involves in from 2000 to 2009 were obtained from the national and provincial statistical yearbook, as well as the winter wheat yield datasets of the cities in HHH region.

C. Data Analysis Method

The linear trend line was used to simulate the trends and inter-annual variation of the remote sensed indices and the climate elements, the trend line slope (*Slope*) were expressed as (2) [15].

$$Slope = \frac{n*\sum_{i=1}^{n} i*Xi - \sum_{i=1}^{n} i \sum_{i=1}^{n} Xi}{n*\sum_{i=1}^{n} i^2 - (\sum_{i=1}^{n} i)^2} \quad (2)$$

Where i and n are serial number and count of the years respectively, Xi is the variable studied. A positive value of slope indicates increasing trend, and vice versa, indicating a decreasing trend [16].

And the correlations between the indices and the meteorological elements were calculated through SPSS Statistic (Version 17.0).

IV. Result and Analysis

A. Trends of Precipitation

Fig. 3 (a) and (b) provide the trends of annual precipitation anomaly and the average precipitation between Feb. to May from 2000 to 2010. In addition to 2001, 2002 and 2006, annual precipitation anomaly values of other years are greater than 0, and there is a relatively significant increasing trend of mean precipitation between Feb. to May from 2000 to 2010. And Fig. 4 (a) shows the spatial distribution of the trend of precipitation. There's an increasing trend of precipitation in almost all the HHH region with the proportion 99.78% (slope>0), and relatively severe increasing (slope>0.1, proportion is 9.53%) ocuured in south of Henan, southwest of Anhui and northeast of Jiangsu Province, relatively gentle increasing (0<slope<0.05, proportion is 24.72%) happened in Northern HHH region, middle of Shandong and a northern part of Henan Province, and the others is moderately increasing (0.05<slope<0.1, proportion is 65.53%).

B. Trends of Drought Indices

Fig. 3 (e) shows the generally trend of the average value where TVDI is greater than 0.6, which indicates the agricultural drought has happened [7], is decreasing with a very small negative slope value, while the significant decreasing trends of annual proportion of agricultural drought affected area and disaster area in crop planting area from the statistic datasets were shown as Fig. 3 (c) and (d), which shows negative correlation with the general trend of precipitation anomaly (r^2 is 0.24, 0.07 and 0.21, respectively) and precipitation (r^2 is 0.03, 0.35 and 0.26, respectively) shown in Fig. 3 (a) and (b). Fig. 4 (b) provide the spatial distribution of trends of TVDI. There's a gentle decreasing trend of TVDI with the proportion 49.73% (-0.05<slope<0), moderately decreasing trend with the proportion 7.02%

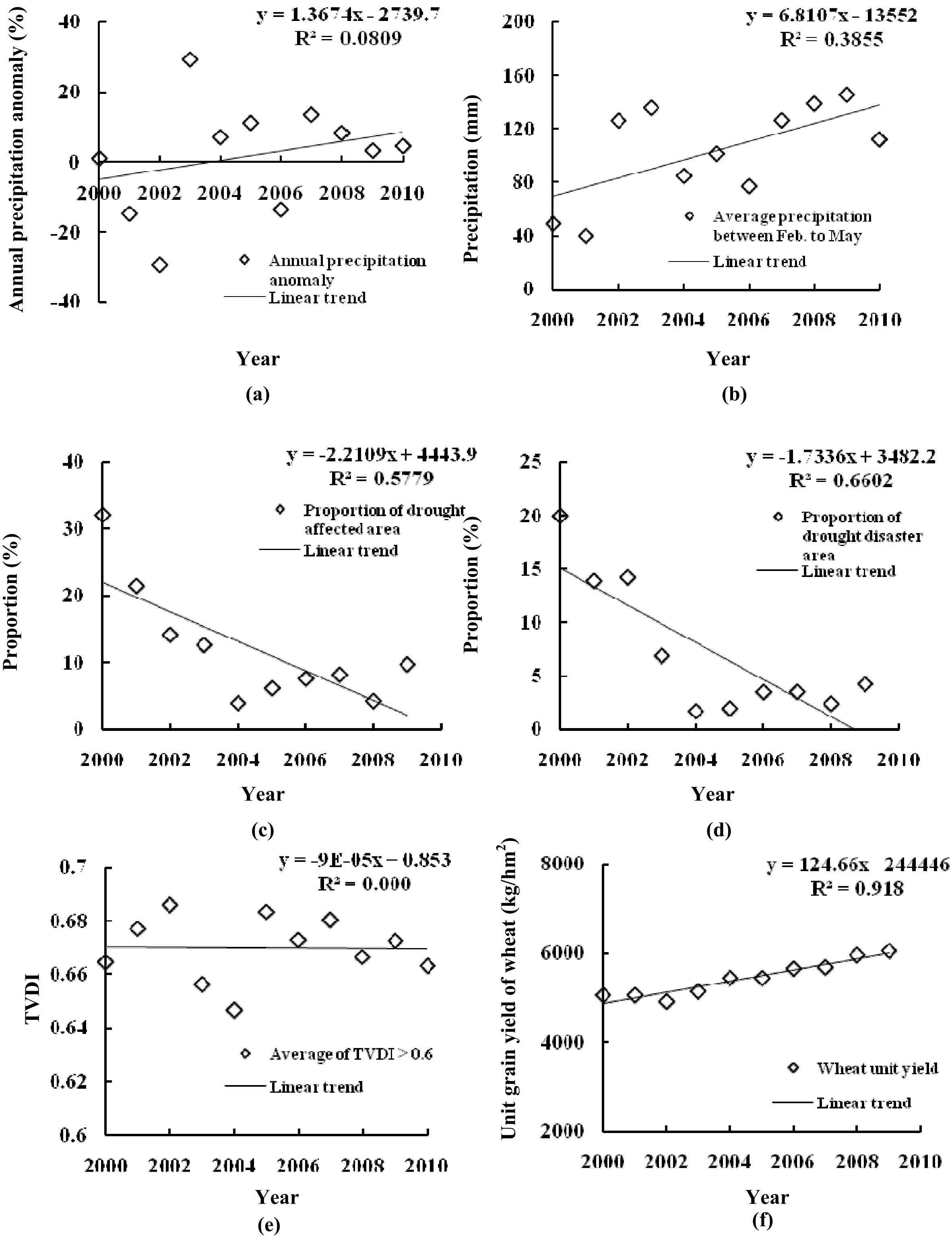
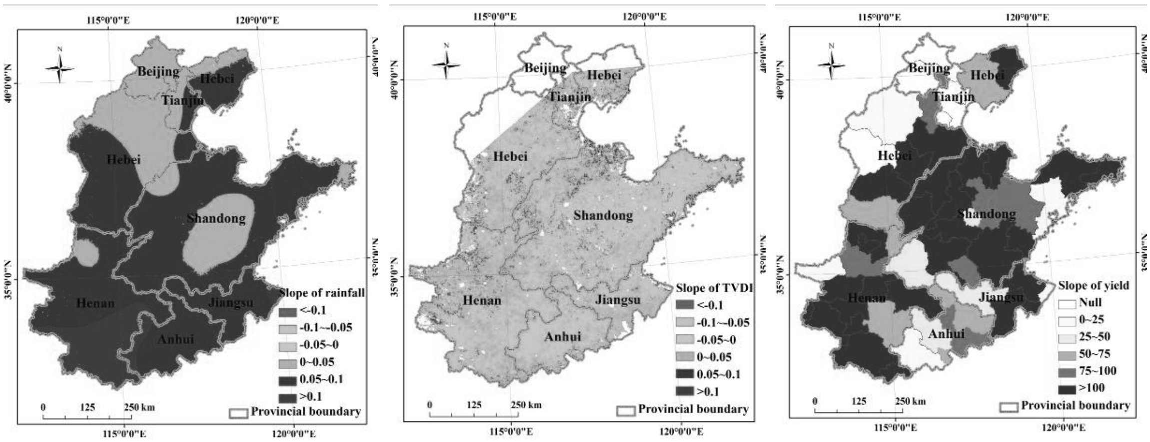


Fig. 3 Annual precipitation anomaly (a) and average precipitation between Feb. to May (b) from 2000 to 2010, annual proportion of agricultural drought affected area (c) and disaster area (d) in crop planting area from 2000 to 2009, average TVDI between Feb. to May from 2000 to 2010 (e) and annual unit grain yield of winter wheat from 2000 to 2009 (f) in HHH region



(a) **(b)** **(c)**

Fig. 4 Spatial distributions of trend of precipitation (a), TVDI (b) from 2000 to 2010 and winter wheat unit grain yield from 2001 to 2009 (c) in HHH region

(-0.1<slope<-0.05), relatively heavier decreasing trend with proportion 0.74% (slope<-0.1), gentle increasing trend with proportion 35.93 (0<slope<0.05), moderately increasing trend with the proportion 5.97% (0.05<slope<0.1) and relatively heavier increasing trend with proportion 0.62%(slope>0.1). About 57.49% region of HHH has a decreasing trend of TVDI, which indicated a trend of mitigation of agricultural drought. However, in most parts of northern Henan, northern Jiangsu, western Shandong and parts of Hebei and Tianjin, there is increasing trend of agricultural drought. As is shown in Fig. 4 (a) and (b), we can see there isn't a similar spatial pattern of the trend of precipitation and agricultural drought, which may because precipitation is not the only limiting factor related to agricultural drought in a short term, and hysteresis may exist in the relationship between precipitation and drought.

C. Trends of Winter Wheat Yield

As in shown in Fig. 3 (f), there is an increasing trend of annual unit grain yield of winter wheat from 2000 to 2009 in HHH region, which indicated a positive correlation with the annual precipitation anomaly (r^2=0.10) and precipitation (r^2=0.25) and a negative correlation with TVDI (r^2=0.002), annual proportion of agricultural drought affected area (r^2=0.41)and disaster area (r^2=0.56) in crop planting area. Fig. 4 (c) provides the regional diversity of the trend of winter wheat unit grain yield. In addition to the part where data is unavailable, there is an increasing trend in the whole HHH region, which may result from the increasing trend of precipitation and decreasing trend of agricultural drought.

V. Conclusion and Discussion

In this study, we constructed 8-day composed MODIS Temperature-Vegetation Dryness Index (TVDI) and daily mean precipitation time series for the main growth season (middle Feb. to late May) of winter wheat from 2000 to 2010 to analyze the distribution of trends of precipitation, agricultural drought and wheat yield change respectively in North China region (Huang-huai-hai region, HHH region). The results indicated that the trend of precipitation in HHH region past 11 years was increasing, correspondingly the trend of agricultural drought was generally decreasing but spatially diverse at regional scale, and the trend of wheat yield was increasing. The study could provide a reference for the further researches on climate change, drought disaster and crop production, and a much longer term, which would provide a more significant relationship between the elements and more meaningful trends and regular, will be used in the future study.

Acknowledgment

The authors would like to thank the reviewers for providing constructive comments.

References

[1] X. Zhao and J. Liu. "Analysis of drought during the period of winter wheat growth in Huang-huai-hai Plain," *Scientia Geographica Sinica*, vol. 19, no.2, pp. 181-185, 1999.
[2] S. Piao, P. Ciais, Y. Huang, Z. Shen, S. Peng, J. Li, et al. "The impacts of climate change on water resourses and agriculture in China," *Nature*, vol. 467, no.2, pp. 43-51, 2010.
[3] F. Tao, M. Yokozawa, J. Liu and Z. Zhang. "Climate–crop yield relationships at provincial scales in China and the impacts of recent climate trends," *Climate Research*, vol.38, pp. 83-94, 2008.
[4] N. Pater, R. Anapashsha, S. Kumar, S. Saha, and V. Dadhwal. "Assessing potential of MODIS derived temperature/vegetation condition index (TVDI) to infer soil moisture status," *International Journal of Remote Sensing*, vol. 30, pp. 23-39, 2009.
[5] S. Qi, C. Wang and Z. Niu. "Evaluating soil moisture status in China using the Temperature / Vegetation Dryness Index(TVDI)," *Journal of Remote sensing*, vol. 7 no. 5, pp. 420-427, 2003.
[6] J. Chen, C. Wang, H. Jiang, L. Mao and Z. Yu. "Estimating soil moisture using Temperature–Vegetation Dryness Index (TVDI) in the Huang-huai-hai(HHH) plain," *International Journal of Remote Sensing,* vol. 32, no. 4, pp. 1165-1177, 2011.
[7] C. Wang, L. Mao, Y. He, L. Han, J. Chen and Z. Yu. "Application of temperature-vegetation dryness index(TVDI) in estimation of soil moisture in the HHH plain," *Chinese Journal of Soil Science*, vol.40, no. 5, pp. 998-1005, 2009.
[8] L. Wang, J. Liu, H. Deng, L. Zhang and D. Li. "Practice of regional drought in spection by remote sensing system in Huang-huai-hai region," *Journal of Agricultural Science and Technology*, vol. 9, no. 4, pp. 73-78, 2007.
[9] S. Wang and X. Lou. "Impacts of climate change on the water deficit status and growth of winter wheat in North China," *Quarterly Journal of Applied Meteorology*, vol. 7, no. 3, pp. 308 - 315, 1996.

[10] M. Friedl, D. Sulla-Menashe, B. Tan, A. Schneider, N. Ramankutty, A. Sibley and X. Huang. "MODIS Collection 5 global land cover: Algorithm refinements and characterization of new datasets," *Remote Sensing of Environment,* vol. 114, no. 1, pp. 168-182, 2010.
[11] Sandholt, K. Rasmussen, J. Andsersen. "A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status," *Remote Sensing of Environment*, vol. 79, no. 2-3, pp. 213-224, 2002.
[12] R. Nemani, L. Pierce, S. Running and S. Goward. "Developing satellite-derived estimates of surface moisture status," *Journal of Applied Meteorology*, vol. 32, no. 3, pp. 548-557, 1993.
[13] R. Gillies and T. Carlson. "Thermal remote sensing of surface soil water content with partial vegetation cover for incorporation into climate models.," *Journal of Applied Meteorology*, vol. 34, no. 4, pp. 745-756, 1995.
[14] M. Hutchinson, "Anuspline version 4.3 user guide," http://fennerschool.anu.edu.au/publications/software/anusplin.php.
[15] M. Ma, L. Dong, and X Wang. "Study on the dynamically monitoring and simulating the vegetation cover in northwest China in the past 21 years," *Journal of Glaciology and Geocryology*, vol. 25, no. 2, pp. 232-236, 2003.
[16] M. Ma, J. Wang, and X. Wang. "Advance in the inter-annual variability of vegetation and its relation to climate based on remote sensing," Journal of Remote Sensing, vol. 10, no. 3, pp. 421-431, 2006.

Y. Huang, female, was born in P.R. China in 1985, Ph.D. Candidate in International Institute for Earth System Science, Nanjing University, P.R. China, with expected date of completion 2013. MS awarded by Nanjing Agricultural University, P.R. China in 2010. The author's major field of study is remote sensing of resource and environment.

Q. J. Tian, male, was born in P.R. China in 1965, Ph.D. Professor in International Institute for Earth System Science, Nanjing University, P.R. China, major in remote sensing.

L. T. Du, male, was born in P.R. China in 1980, Ph.D. Candidate in International Institute for Earth System Science, Nanjing University, P.R. China, with expected date of completion 2013. MS awarded by China University of Geosciences, P.R. China in 2005. The author's major field of study is remote sensing of resource and environment.

J. Liu, female, was born in P.R. China in 1982, Ph.D. Candidate in International Institute for Earth System Science, Nanjing University, P.R. China, with expected date of completion 2012. MS awarded by Taiyuan University of Technology, P.R. China in 2007. The author's major field of study is remote sensing of resource and environment.

S. S. Li, female, was born in P.R. China in 1985, Ph.D. Candidate in International Institute for Earth System Science, Nanjing University, P.R. China, with expected date of completion 2012. MS awarded by Nanjing University, P.R. China in 2009. The author's major field of study is remote sensing of resource and environment.