International Journal of Biological, Life and Agricultural Sciences
ISSN: 2415-6612
Vol:12, No:6, 2018

Analyzing the Impact of Spatio-Temporal Climate Variations on the Rice Crop Calendar in Pakistan

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***Abstract*—**The present study investigates the space-time impact of climate change on the rice crop calendar in tropical Gujranwala, Pakistan. The climate change impact was quantified through the climatic variables, whereas the existing calendar of the rice crop was compared with the phonological stages of the crop, depicted through the time series of the Normalized Difference Vegetation Index (NDVI) derived from Landsat data for the decade 2005-2015. Local maxima were applied on the time series of NDVI to compute the rice phonological stages. Panel models with fixed and cross-section fixed effects were used to establish the relation between the climatic parameters and the time-series of NDVI across villages and across rice growing periods. Results show that the climatic parameters have significant impact on the rice crop calendar. Moreover, the fixed effect model is a significant improvement over cross-sectional fixed effect models (R-squared equal to 0.673 vs. 0.0338). We conclude that high inter-annual variability of climatic variables cause high variability of NDVI, and thus, a shift in the rice crop calendar. Moreover, inter-annual (temporal) variability of the rice crop calendar is high compared to the inter-village (spatial) variability. We suggest the local rice farmers to adapt this change in the rice crop calendar.

Keywords—Landsat NDVI, panel models, temperature, rainfall

I. Introduction

PATTERNS of temperature and rainfall have been shifted since the mid 21st century [1], [2]. For instance, air temperature is incremented globally by 0.76°C from the year 1850 to the year 2005 and it is predicted that this will further increase in the range of 1.4°C to 5.8°C from 1990 to 2100 [3]. Climate change occurs due to various factors, including the release of greenhouse gases, deforestation, urbanization and industrialization. All economic sectors suffer from the global climate change. Particularly agriculture has been declared highly endangered, as crop phenology largely depends on the climatic processes [4], [5]. Climate variability and its impacts on agriculture have not been intensely investigated in developed countries, as in developed countries for last three decades.

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Among other climatic processes, temperature and rainfall greatly affect crop yields and cause their space-time variability [6]. Intense daily temperatures beyond the certain threshold influence the crop yields [7]. Consequently, an increase in temperature due to the global climate change may decrease the crop yields and motivate the weed and pest production. Depending on the crop and region, changes in the intensity of temperature and rainfall overall have a negative impact on crop yields [8], [9]. For instance, in 2003, an increase in summer temperature reduced overall food production in Europe [10]. It is established that change in rain patterns has affected crop calendars. Consequently, early or late plantings have influenced the crop yields [11]. Crop calendars are therefore required to be consistently upgraded, particularly in the present scenario of climate change.

Due to the wider spatial and temporal coverage, remote sensing (RS) has been widely applied to derive crop calendars timely and effectively [12]. Methods to do so are often based on simulating the pixel-based change in crop patterns [5]. These methods however ignore the influence of climate change, which is a primary cause of change in crop calendars. Some studies used the NDVI as a proxy for biophysical conditions, to quantify the impact of climate change on crop growing conditions over the temporal coverage of available RS data [13]-[15]. The resulting shifts in the NDVI time series represent shifts in crop growing seasons, and, thus in crop calendars. However, modelling direct relationships among the climatic parameters (e.g. temperature, rainfall, evapotranspiration, relative humidity and wind) and the crop growing seasons depicted by crop calendars is still missing. Moreover, modelling these relationships for heterogeneous regions over large areas is challenging.

Relationships among climatic parameters and crop growing seasons can be modeled through linear regression [16], [17], multivariate regression [18] and correlation coefficients [19]. These methods only examine the global relationships among distinct meteorological parameters and crop seasons depicted by crop calendars [12]. Spatial and temporal analysis of climatic impact on crop calendars however requires applying local models. To this end, techniques for panel data analysis are used to model the relationship between multiple strata of cross sections and temporal changes [20], [15]. Their wider application on regional scales however requires the climatic parameters to be derived from remote sensing.

The influence of climate change on crop colanders varies from crop to crop [9]. Rice is the second most important food crop after wheat in Pakistan. It requires specific climatic conditions for the crop phonology [21]. The main objective of the study is to investigate the spatio-temporal (i.e. inter-village and inter-annual) variations in the rice growing conditions in Pakistan from the years 2005 to 2015, and how these variations caused a shift in the rice crop calendar. To do so, RS-derived NDVI and climate data were obtained for the decade 2005-2015. Fixed effect panel models with time fixed (inter-annual) and cross section fixed (inter-village) were used to quantify the spatio-temporal impact of climate change on the crop calendar of rice crop in the study area.

Gujranwala, the 5th largest district of the Punjab province, is selected as study area (see Fig. 1). It is one of the dominant growers of rice in Pakistan, growing about 90% of the Punjab rice (SUPARCO, 2016). It is situated at 32.1544° north and 74.1842° east. This study includes 17 villages of the district Gujranwala, including Alipur (A), Dera Shah Jamil (DJ), Pandoke (P), Nokhar (N), Philoki (PL), DhagaPur (D), Fakheerwali (F), Mata Virkan (M), Shameer (SM), Sapray (S), SangoWali (SW), Babar (B), Bhuda Rajda (BR), Kot Hizri (KH), Kotli Sayan (KS), Kingriali (K), and Kotli Ghulam Muhammad (KG).

II. Study Area

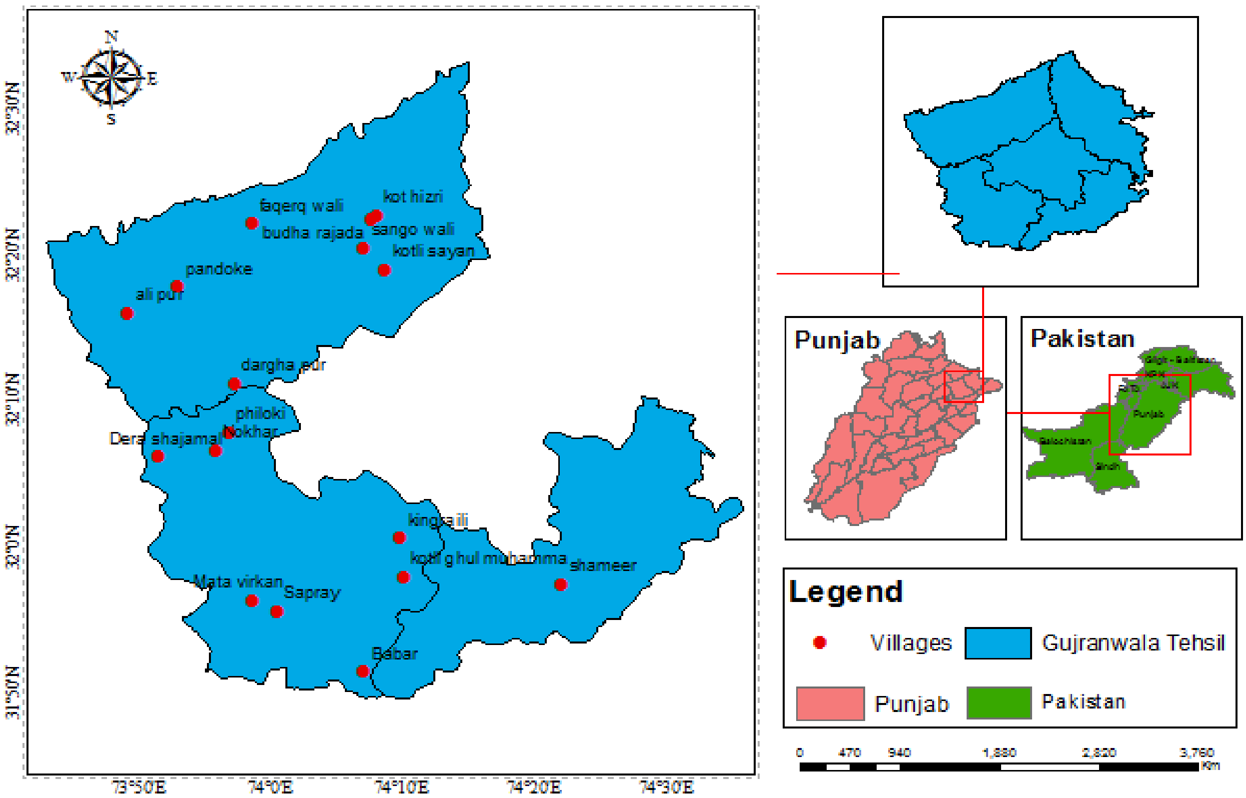

Fig. 1 The study area showing the boundaries of all 17 villages of the district Gujranwala

III. Materials and Methods

A. Data

Crop statistical data were obtained from the Pakistan Agriculture Department (PAD) for the decade 2005-2015. For the same period, data on meteorological parameters, i.e., rainfall and temperature were acquired from Pakistan Meteorological Department [22].

Covering the crop growing period of rice (i.e. from April to December), Landsat's sensor TM, ETM+ and OLI (Operational Land Imager) images were obtained from obtained from United States Geological Survey (USGS) [23]. The RS data have a spatial resolution of 30 m and cover the 2005-2015 decade. Data on the rice crop calendar were acquired from Space and Upper Atmosphere Research Commission, Pakistan [24]. Data on district and town level administrative boundaries of Gujranwala were downloaded from DIVA-GIS [25].

B. Methods

The modeling process is comprised of two distinct steps: (i) data pre-processing, (ii) global and local spatial regression to model spatial (inter-village) and temporal (inter-annual) influence of climate change on rice crop colanders and yields, and (iii) spatial prediction and validation of crop yields.

1. Data Pre-Processing

Crop statistical data obtained from PAD were not geo-referenced. To overcome this, Google Earth was used to assign coordinates according to rice locations in the study area. Landsat data often have problems related to cloud cover. Landsat 7 ETM+ was launched in 1999 after TM. The ETM image however has drawback that 22% of the image pixels are absent due to permanent failure of the Scan Line Corrector (SLC) on May, 2003. This SLC gap gradually decreases toward the center of the images [26]. The SLC gap lines were removed from the images by using the focal statistical tool [27], and the processed images were then stacked and clipped according to the extent of Gujranwala.

2. Spatial Modeling of Spatio-Temporal Impact of Climate Change on Rice Crop Calendars and Yields

To include rice growing periods since the year 1980 and proximity of rice fields into the analysis, the NDVI images were obtained from the Landsat data as, NDVI = (NIR – RED) / (NIR + RED), where NIR and RED are the values recorded in near infrared and red bands, respectively. NDVI has been widely used to estimate the vegetation strength [28], [29].

Peaks of all rice growing periods were marked through local maxima points that were recognized from time-series of the NDVI profiles since the year 1980. The local maxima are a point where NDVI value is higher than any other NDVI values in the time series [30], [31], [26]. In doing so, we assume that (I) rice sowing dates approach before 60 days of heading dates, (II) heading dates show peaks of NDVI, and (III) harvesting dates approach after 30 days of heading dates [31].

Conditioning plots (a.k.a. coplots) were used to show the spatial (inter-village) and temporal (inter-annual) impact of change in climatic parameters over NDVI since the year 1980 [32]. Coplots generate scatter plots between a variable of interest and year. In this study they took village's attributes as conditioning variables. Moreover, mean plots were used to check the impact of temperature and rainfall on the variation of NDVI across villages as well as across crop growing periods. Climatic parameters are often correlated. Multiple correlated (a.k.a. multicollinearity) coefficients often cause problems in estimating regression parameters [33]. To analyze the multicollinearity among the explanatory variables, the Variance Inflation Factor (VIF) was used as:

$$VIF = \frac{1}{1-R^2} \quad (1)$$

where R^2 is the regression coefficient to check the collinearity between explanatory variables. A VIF value less than 5 (VIF<5, provided R^2 is minimized) means no multicollinearity between explanatory variables [34].

To model the relationships between NDVI and climatic parameters, i.e. temperature and rainfall, Ordinary Least Square (OLS) and Fixed Effect (FE) panel models were applied. OLS assumes that patterns in data are globally constant and therefore parameter estimates are similar for the entire study area, i.e. stationary relationships between NDVI and climatic variables, as:

$$NDVI = \beta_\circ + \beta_1 T + \beta_2 P + \varepsilon \quad (2)$$

where NDVI is dependent variable, β0 is intercept, β_1 is global parameter coefficient for the temperature T and β_2 is global parameter coefficient for rainfall P and ε is residual error. The relationship between NDVI and climatic variables (temperature and rainfall) however may be non-stationary, i.e. there exist local relationships for heterogeneous regions over larger areas [35]. To include this non-stationary effect, panel models were used to analyze the impact of climatic variables on NDVI, depicting the rice crops in space (17 villages in the study area) and in time (growing seasons of rice crops from year 2006 to year 2015), i.e. in multi-dimensions of time and cross sections.

Here we used fixed effect panel models with time fixed (FE inter-annual) and cross section fixed effect (FE inter-village), as:

$$NDVI_{it} = \beta_1 T_{it} + \beta_2 P_{it} + \alpha_i + \gamma_t + \epsilon_{it} \quad (3)$$

where NDVI is dependent variable, introduced a as a proxy variable for rice, i are 17 villages in the study area, t are the crop growing seasons of rice during the period 2006-2015, γ_t is intercept for t, β_1 and β_2 are coefficients of temperature T_{it} and rainfall P_{it}, respectively, α_i is unknown intercept for each entity (i, t), ϵ_{it} is residual error. The equation for time-fixed effect model can take the form:

$$NDVI_{it} = \beta_1 T_{it} + \beta_2 P_{it} + \alpha_i + \epsilon_{it} \quad (4)$$

where NDVI is dependent variable of growing season of rice, i are villages in the study area, t are the crop growing seasons of rice during the period 2006-2015, β_1 and β_2 are coefficients of temperature T_{it} and rainfall P_{it}, respectively, α_i is intercept vary over villages, ϵ_{it} is residual error. The cross section fixed model can be represented as:

$$NDVI_{it} = \beta_1 T_{it} + \beta_2 P_{it} + \gamma_t + \epsilon_{it} \quad (5)$$

where NDVI is dependent variable of growing season of rice, i are villages in the study area, t are the crop growing seasons of rice during the period 2006-2015, $\gamma_t$is intercept vary across time (2005-2015), $\beta_1 T_{it}$ and $\beta_2 P_{it}$ are coefficients of temperature and rainfall respectively, ϵ_{it} is residual error.

To compare the global OLS and local panel models, we used R -squared and P-value statistics**.** Moran's I was used to analyze spatial autocorrelation in the models' residuals.

R software environment was used to produce conditioning and mean plots. Moreover, R package *plm* [36] was used to run panel models with fixed effect and cross sectional models.

IV. Results

Fig. 2 shows peaks of all rice growing periods that are marked through local maxima points recognized from the time-series of NDVI profiles since the year 2005. Conditioning plots (a.k.a. coplots) (see Fig. 3) show the spatial (i.e. inter-village) and temporal (i.e. inter-annual crop growing seasons of the rice crop) of NDVI since the year 2005.

Impact of spatial variability of temperature and rainfall on the spatial variation of NDVI is shown through mean plots in Fig. 4.

This shows some stress in NDVI cycles over the K, KG, KS and KH villages (see Fig. 4 (c)) due to low rainfall in these areas (see Fig. 4 (b)); however, no variation in NDVI is seen due to spatial variation in temperature (see Fig. 4 (a)) for the decade 2005-2015. Impact of the spatial variability of temperature and rainfall on the temporal variation of NDVI is shown through the mean plots presented in Fig. 5. This clearly shows that temporal (inter-annual) variability of temperature (see Fig. 5 (a)) cause the temporal variability of NDVI over the crop growing seasons of rice (see Fig. 5 (c)) for the years 2005-2015, whereas no significant temporal variation in rainfall (see Fig. 5 (b)) is observed during the same period.

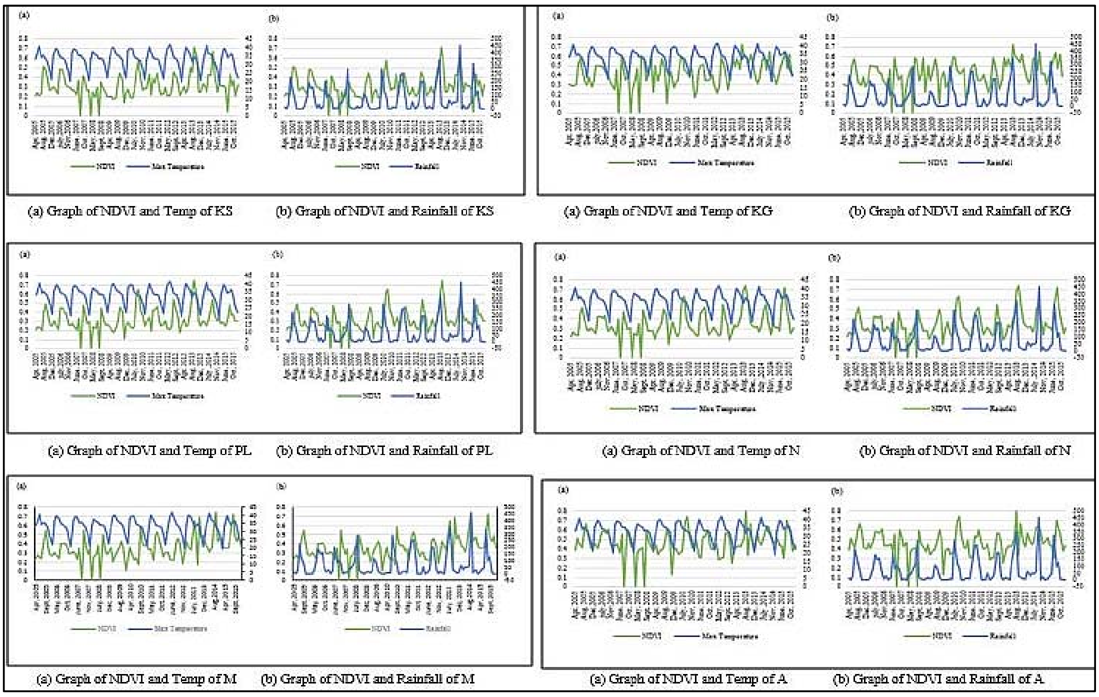

Fig. 2 Peaks of all rice growing periods that are marked through local maxima points recognized from time-series of the NDVI profiles since 2005

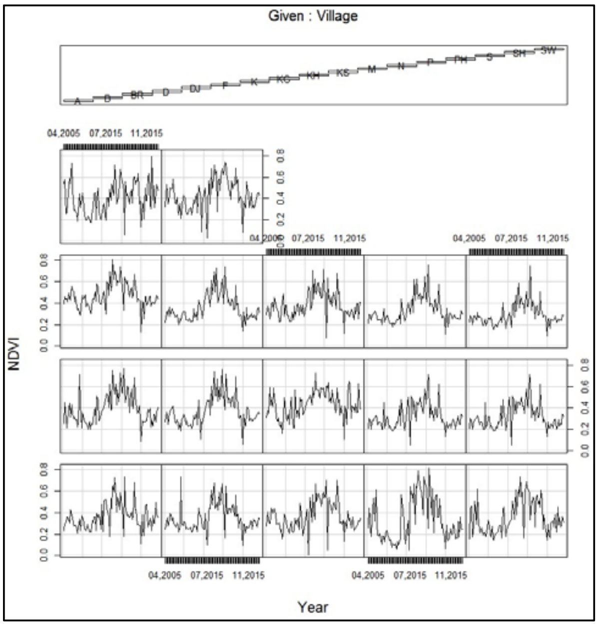

Fig. 3 The conditioning plots (a.k.a. coplots) show the spatial (inter-village) and temporal i.e. inter-annual crop growing seasons of the rice crop) variation of NDVI since 1980

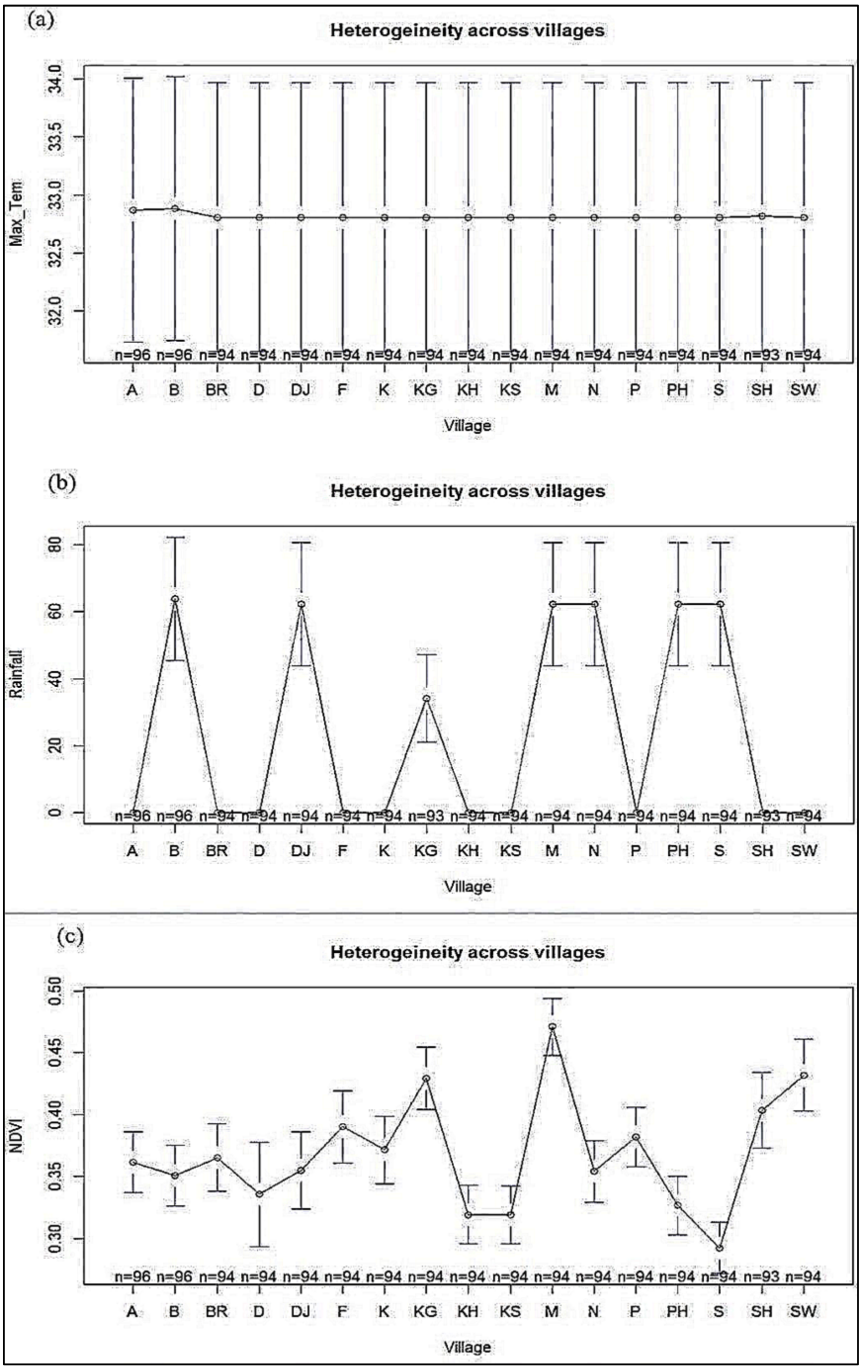

Fig. 4 The mean plots showing spatial (inter-village) variability of (a) Maximum Temperature, (b) Rainfall, and (c) NDVI for 17 villages in the district Gujranwala

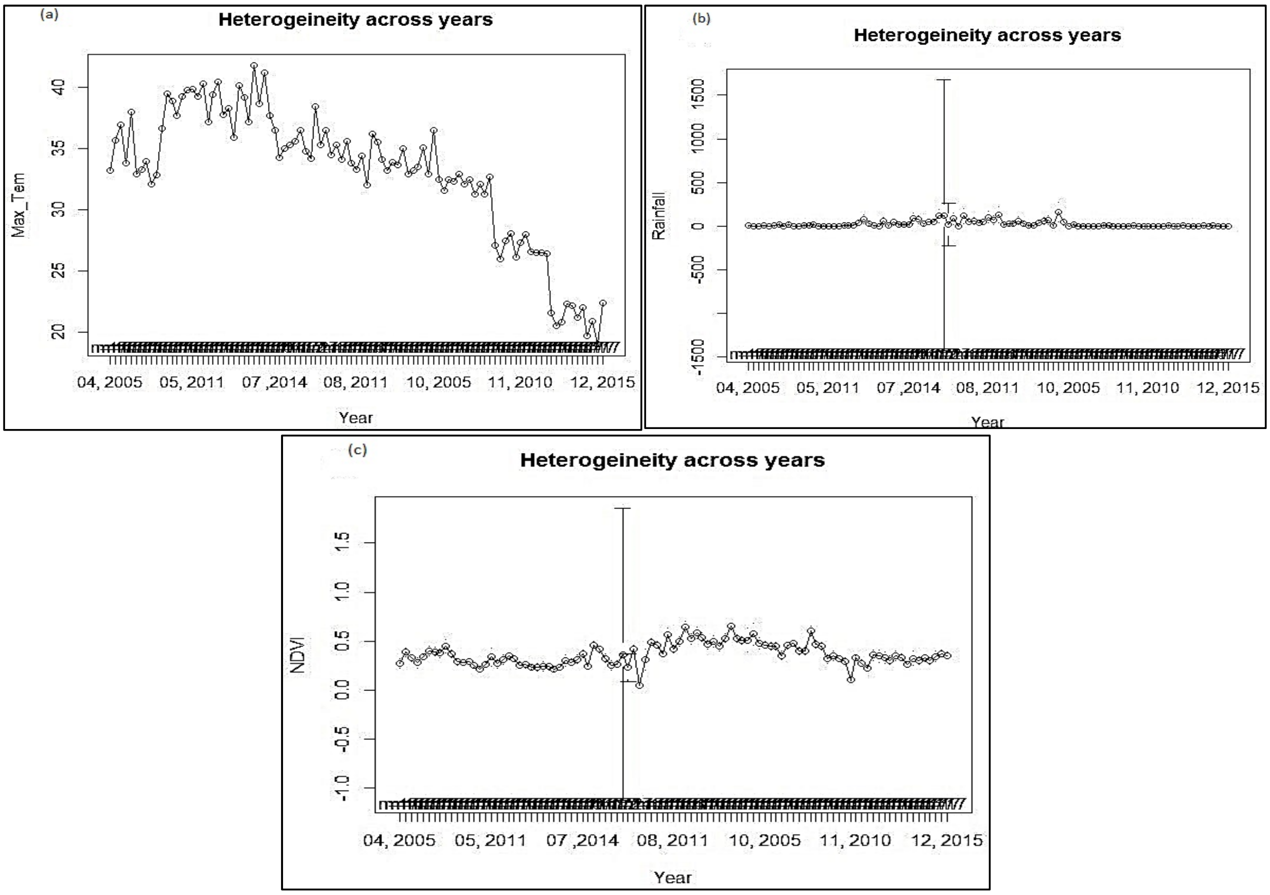

Fig. 5 The mean plots showing temporal (inter-annual) variability of (a) Maximum Temperature, (b) Rainfall, and (c) NDVI for 17 villages in the district Gujranwala

TABLE I
PARAMETER ESTIMATES FROM ORDINARY LEAST SQUARE (OLS), FIXED EFFECT PANEL MODEL WITH TIME FIXED (FE INTER-ANNUAL) AND CROSS SECTION FIXED (FE INTER-VILLAGE) EFFECTS OF THE RICE CROP IN VILLAGES OF DISTRICT GUJRANWALA

Models	Variables	VIF#	Est.†	SE‡	T-value	Pr(>|t|)
OLS Global	Temperature	1.06	1.96e-03	5.56e-04	3.52	0.00044***
	Rainfall	1.31	2.36e-04	5.66e-05	4.17	3.2e-05***
FE Inter-Village	Temperature	-	1.70e-03	8.11e-01	0.62	0.54
	Rainfall	-	3.42e-04	4.47e-05	1.42	0.16
FE Inter-Annual	Temperature	-	5.03e-01	5.31e-04	3.21	0.0014**
	Rainfall	-	6.35e-05	6.12e-05	5.60	2.5e-08***

#Variance Inflation Factor, †Estimated coefficient, ‡Standard Error.

Table I shows parameter estimates from Ordinary Least Square (OLS), fixed effect panel model with time fixed (FE Inter-Annual) and cross section fixed (FE Inter-village) effects of the rice crop in the villages of district Gujranwala. VIF values less than 5 shows temperature and rainfall do not have multicollinearity effect. Both temperature and rainfall are significant (p = 0.001 to p< 0.00001) external covariates of NDVI for the global OLS model and the fixed effect panel model with time fixed (FE inter-annual). These variables are however less significant (p = 0.1 to p< 0.5) for the cross section fixed (FE inter-village) model. This is further observed as residuals of OLS models showed little or no spatial autocorrelation (Moran's I = 0.12), suggesting that the OLS coefficients do not suffer from local dependence.

Comparisons of the models are shown in Table II. The ANOVA F-test suggests that panel models gave a significant improvement (p = 0.001) over the OLS model for the NDVI observations. Compared with the cross section fixed (FE inter-village) model, the residual sum of squares (RSS) of the fixed effect panel model with time fixed (FE inter-annual) is lower (26.9 vs. 9.1). This indicates that FE inter-annual is the best fit to the data. This is further indicated from the explanatory power of the FE inter-annual model (R_a^2 equal to 0.624) is increased, compared to the OLS model (R_a^2 equal to 0.0239) and FE inter-village model (R_a^2 equal to 0.0334).

TABLE II
COMPARISONS STATISTS FOR ORDINARY LEAST SQUARE (OLS), FIXED EFFECT PANEL MODEL WITH TIME FIXED (FE INTER-ANNUAL) AND CROSS SECTION FIXED (FE INTER-VILLAGE) EFFECTS OF THE RICE CROP IN VILLAGES OF DISTRICT GUJRANWALA

Model	RSS†	R_a^2‡	R^2§	DF¶	F-Statistics#	P-value††
OLS Global	------	0.023	0.0239	1597	19.5	4.21e-09
FE Inter-village	26.9	0.034	0.0334	1581	27.694	1.51e-12
FE Inter-annual	9.1	0.673	0.624	1485	31.1655	<2e-16

†Residual Sum of Squares, ‡Adjusted R^2, §R-squared, ¶Degree of Freedom

V. DISCUSSIONS

The present research investigates the impact of climatic variations on the rice crop calendar in the tropical areas of Pakistan using RS-derived NDVI data. High spatial and temporal resolution of RS data help analyze the effects of spatio-temporal climate change (i.e. inter village and inter annual) on the rice crop calendars over large areas.

Impact of climate change on crop yields has been intensively investigated both in tropical region [37] and temperate regions [38], but effect of climate change on shifting crop calendars has rarely been focused [39]. Climate change affects both planting [40] and sowing dates of the rice crop [39]. Here, we explicitly focused on investigating any relationship between climate change and the rice crop calendar in larger areas of tropical Southeast Asia.

Regression is used to investigate the influence of climatic parameters, e.g. temperature, rainfall, evapotranspiration, relative humidity, and wind on crop output [39]. These studies however target relatively small and well-defined areas. Moreover, they did not consider the time factor which is highly important to the change analysis of crop calendars. These studies included only meteorological parameters that are often not sufficient for investigating the effects of climate change on rice crop calendars over large areas. To overcome this, here we applied RS data that proved to be highly useful for spatio-temporal change detection of the crop calendar. Moreover, being cost-effective and timely, RS data can be used for efficient and effective mapping of climate change effects on agriculture.

This study applies panel regression for establishing a relationship between climate change and the rice crop calendar in space and time. Alternatively, probabilistic techniques (e.g. kriging-based) are used in the literature to predict the sowing dates of tomatoes according to the upcoming climate changes [3]. Thus, it was concluded that increment in air temperature is the major influential factor of the tomato sowing and harvesting dates, and consequently, the cultivated time will change in year 2050 due to climate change. This however did not predict the exact amount of shift in the sowing dates.

Satellite-derived Crop Calendar for Agricultural Simulations (SACRA) is a method for the estimation of global high-resolution crop calendars from the satellite derived NDVIs [5]. However this method is not able to assess the impact of climate change on the crop calendars. Here, we explicitly quantified the climate change impact, but like SACRA, we produced the rice crop calendar using past data, which may be inapplicable to future simulations. Further researches may include more data on climatic parameters such as humidity, sun shine hours along with temperature, and precipitation and soil data.

VI. CONCLUSIONS

Climate variation is the accumulation of activities occurring due to natural and anthropogenic activities. Pakistan is also included in the list of countries affected by long-term climate change. This research examined the shifting of the rice crop calendar (i.e., sowing, heading and harvesting dates) through local maxima method and quantifying the spatio-temporal impact of climate change on crop calendar using fixed effect panel models with time fixed (FE inter-annual) and cross section fixed effect (FE inter-village). This is to analyze whether spatial or temporal or both variations in temperature and rainfall cause shifting in the rice crop calendar.

Regression is used to quantify the impact of climate change (depicted by change in climatic parameters over time) on the time series of NDVI covering the rice growing season (depicting the phonological stages of rice). Results show that the change in climatic parameters have significant impact over the phonological stages of rice and, thus, on the rice crop calendar in Pakistan. The FE time model proved more significant ($R_a^2 =$ 0.67) to model the relationship between spatio-temporal change in the rice crop calendar with climatic parameters, compared to the fixed effect cross section ($R_a^2 =$ 0.03). The research concludes that variation of the rice crop calendar in the study area is high inter-annually (year) than inter-village. It is therefore required that farmers in Gujranwala adapt change in the rice crop calendar to obtain maximum increase in the rice yields, which is vital to secure food locally as well as to meet the global rice requirements.

REFERENCES

[1] IPCC, 2007. IPCC Fourth Assessment Report: Climate Change 2007 (AR4). IPCC, Geneva, Switzerland.

[2] Ramirez-Villegas, J., A. Jarvis and P. Laderach, 2011. Empirical approaches for assessing impacts of climate change on agriculture: The EcoCrop model and a case study with grain sorghum. *Agricultural and Forest Meteorology*, 12:67-78

[3] Abou-Shleel, S. M. and M. A. El-Shirbeny, 2014. GIS Assessment of Climate Change Impacts on Tomato Crop in Egypt. *Global Journal of Environmental Research*, *8*(2): 26-34.

[4] Brown, M., K. Beurs and M. Marshall, 2012. Global phenological response to climate change in crop areas using satellite remote sensing of vegetation, humidity and temperature over 26 years. *Remote Sensing of Environment. 126*: 174–183.

[5] Kotsuki, S. and K. Tanaka, 2015. SACRA – a method for the estimation of global high-resolution crop calendars from a satellite-sensed NDVI. *Hydrology and Earth System Sciences, 19(11)*: 4441–4461.

[6] Lauxa, P., G. Jackel, R. M. Tingem and H. Kunstmanna, 2010. Impact of climate change on agricultural productivity under rainfed conditions in Cameroon — A method to improve attainable crop yields by planting

date adaptations. *Agricultural and Forest Meteorolog, 150*: 1258–1271.

[7] Rowhani, P. B., D. Lobellb and M. Linderma, 2011. Climate variability and crop production in Tanzania. *Agricultural and Forest Meteorology. 151*: 449–460.

[8] Thornton, P. K., P. G. Jones, P. J. Ericksen and A. J. Challinor, 2011. Agriculture and food systems in sub-Saharan Africa in a 4˚C+ world. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences,* 369: 117–136.

[9] Waha, K., C. Muller, A. Bondeau, J. Dietrich, P. Kurukulasuriya, J. Heinke and H. Lotze-Campen, 2013. Adaptation to climate change through the choice of cropping system and sowing date in sub-Saharan Africa. *Global Environmental Change, 23*:130–143.

[10] Battisti, D. S. and R. L. Naylor, 2009. Historical warnings of future food insecurity with unprecedented seasonal heat. *Science, 323(5911)*:240–244.

[11] Rosenzweig, C. and D. Hillel, 1998. Climate Change and the Global Harvest: Potential Impacts of the Greenhouse Effect on Agriculture. Oxford University Press.

[12] Wang, H., H. Lin, D. K. Munroe, X. Zhang and P. Liu, 2016. Reconstructing Rice Phenology Curves with Frequency-Based Analysis And Multi-Temporal NDVI In Double-Cropping Area In Jiangsu, China. *Front. Earth Sci, 10*(2): 292–302.

[13] Wang, H., J. Chen, Z. Wu and H. Lin, 2012. Rice heading date retrieval based on multitemporal MODIS data and polynomial fitting. International Journal of Remote Sensing, 33(6): 905–1916.

[14] Propastin, P. A. and M. Kappas, 2008. Reducing Uncertainty in Modeling the NDVI-Precipitation Relationship: A Comparative Study. *GIScience & Remote Sensing, 45*(1): 47–67.

[15] Vijayan, L. and F. Talhi. 2015. Significance of Meteorological Parameters in the Implementation of Agriculture Engineering Practices in and Around Tabuk Region, KSA. *International Journal of Applied Science and Technology, 3*(5): 53-65.

[16] Camberlin, P., N. Martiny, N. Philippon and Y. Richard, 2007. Determinants of the interannual relationships between remote sensed photosynthetic activity and rainfall in tropical Africa. *Remote Sensing of Environmen, 106(2)*: 199-216.

[17] Foody, G. M., 2003. Geographical weighting as a further refinement to regression modelling: an example focused on the NDVI–rainfall relationship. *Remote sensing of Environment*, *88*(3): 283-293.

[18] Gurung, R. B., F. J. Breidt, A. Dutin and S. M. Ogle, 2009. Predicting enhanced vegetation index (EVI) curves for ecosystem modeling applications. *Remote Sensing of Environment*, *113(10):* 2186-2193.

[19] Fabricante, I., Oesterheld, M., and Paruelo, J. M., 2009. Annual and seasonal variation of NDVI explained by current and previous precipitation across Northern Patagonia. *Journal of Arid Environments*, *73(8)*: 745-753

[20] Seto, K. C. and R. K. Kaufmann, 2003. Modeling the drivers of urban land use change in the Pearl River Delta, China: integrating remote sensing with socioeconomic data. *Land Economics*, 79(1): 106-121.

[21] Wassmann, R., S. V. K. Jagadish, K. Sumfleth, H. Pathak, G. Howell, A. Ismail, R. Serraj, E. Redona, R. K. Singh and S. Heuer, 2009. Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation. *Advances in Agronomy, 102,* pp.91-133.

[22] PMD, 2016. Climate and Astronomical Data, Punjab Meteorological Department (PMD), URL:http://www.pmd.gov.pk/, accessed on June, 2016.

[23] USGS, 2016. Landsat collection. Technical Report. United States Geological Survey (USGS).

[24] SUPARCO, 2016. Crop Calendar. Data, Pakistan Space and Upper Atmosphere Research Commission (SUPARCO), URL:http://suparco.gov.pk, accessed on June, 2016.

[25] DIVA-GIS, URL http://www.diva-gis.org/gdata Accessed on 21 June 2017.

[26] Chen, C., C. Chen and N. T. Son, 2012. Detecting Rice Crop Phenology from Time-Series MODIS Data. *The 33rd Asian Conference on Remote Sensing.*

[27] Pratt, W. K., 2007. Digital Image Processing. John Wiley & Sons, New York.

[28] Usman, U., S. A. Yelwa, S. Gulumbe and A. Danbaba, 2013. Modelling Relationship between NDVI and Climatic Variables Using Geographically Weighted Regression. *Journal of Mathematical Sciences and Application, 1*(2): 24-28.

[29] Lopresti, M. F., C. M. Bella and A. J. Degioanni, 2015. Relationship between MODIS-NDVI data and wheat yield: A case study in Northern Buenos Aires province, Argentina. *Information Processing in Agriculture, 2*(2): 73–84.

[30] Sakamoto, T., N. V. Nguyen, H. Ohno, N. Ishitsuka and M. Yokozawa, 2006. Spatio–temporal distribution of rice phenology and cropping systems in the Mekong Delta with special reference to the seasonal water flow of the Mekong and Bassac rivers. *Remote Sensing of Environment. 100*: 1-16.

[31] Sakamoto, T., M. Yokozawa, H. Toritani, M. Shibayama, N. Ishitsuka and H. Ohno, 2005. A crop phenology detection method using time-series MODIS data. *Remote Sensing of Environment, 96*: 366 – 374.

[32] Jacoby, W. G., 1998. Statistical Graphics for Visualizing Multivariate Data (Vol. 120).

[33] Wheeler, D. C. and C. A. Cadler, 2007. An assessment of coefficient accuracy in linear regression models with spatially varying coefficients. *J. Geogr. Syst*, 9: 145-166.

[34] Yan, X., 2009. Linear Regression Analysis: Theory and Computing. World Scientific.

[35] Li, S., Y. Xie, D. G. Brown, Y. Bai, J. Hua and K. Judd, 2013. Spatial variability of the adaptation of grassland vegetation to climatic change in Inner Mongolia of China. *Applied Geography, 43*: 1-13.

[36] Croissant, Y. and G. Millo, 2008. Panel data econometrics in R: The plm package. *Journal of Statistical Software*, *27*(2), 1-43.

[37] Tao, F., M. Yokozawa, Y. Xu, Y. Hayashi and Z. Zhang, 2006. Climate changes and trends in phenology and yields of field crops in China, 1981–2000. *Agricultural and Forest Meteorology, 138(1)*: 82-92.

[38] De Beurs, K. M. and G. M. Henebry, 2005. A statistical framework for the analysis of long image time series. *International Journal of Remote Sensing*, *26*(8): 1551-1573.

[39] Yegbemey, R. N., H. Kabir, O. H. Awoye, J. A Yabi and A. A. Paraïso, 2014. Managing the agricultural calendar as coping mechanism to climate variability: A case study of maize farming in northern Benin, West Africa. *Climate Risk Management*, *3*:13-23.

[40] Sacks, J. W., D. Deryng, A. Foley and N. Ramankutty, 2010. Crop planting dates: an analysis of global patterns. *Global Ecology and Biogeography, 19*:607–620.