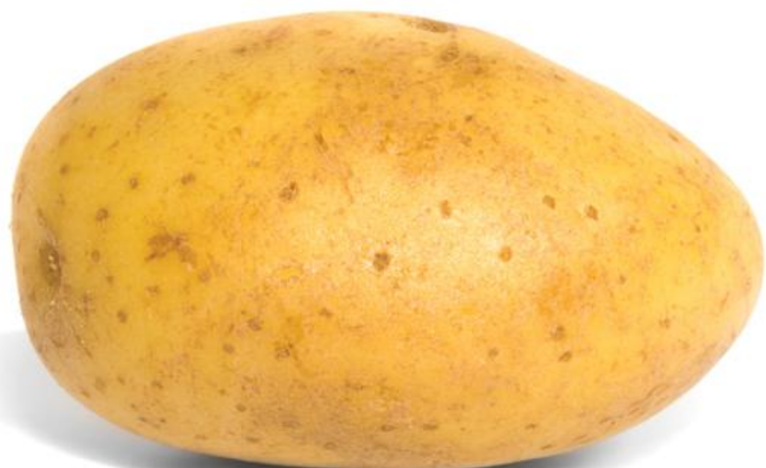
CHAPTER-IV

Assessment of Spatio-temporal Phenology Dynamics of Potato Crop



ASSESSMENT OF SPATIO-TEMPORAL PHENOLOGY DYNAMICS OF POTATO CROP

4.1 Introduction

Potato is a staple food crop in India after cereals and pulses. It plays a major role in agricultural economy of India. The potato growing area has been increasing in recent years due to domestic demand and availability of food processing industries. At present, more than 80% of potato is cultivated in the Indo-Gangetic plains of North India and West Bengal is one of the major potato growing State.

Phenology is the qualitative and quantitative description of a plant's life cycle from seed to seed. Qualitative aspects of phenology include morphological development and the partitioning of the life cycle into distinct stages of development, such as seedling emergence, flowering, and physiological maturity. Quantitative aspects of development include rate of development and the duration of the life cycle. Phenology differs among plant species and varies among cultivars within a species. Environmental effects such as temperature and photoperiod influence phenology. Genotype and environment interactions for phenological development are an important factor in the selection of properly adapted crop cultivars (i.e. crop cultivars differ in their response of phenology to environmental factors, such as photoperiod-sensitive vs. Photoperiod-insensitive genotypes). A good understanding of the phenology of a crop is essential in physiological and agronomic studies of the crop. There are three reasons why phenology is important are:

i) Seasonal dry matter accumulation is a function of the duration of the life cycle of annual crops. In particular, the duration of the period of maximum light interception by the canopy is usually the most important determinant of seasonal dry matter accumulation.

ii) Rates of physiological processes can vary substantially among phases of the life cycle. For instance, (a) dry matter partitioning to the seeds or fruits occurs during the final phase or phases of the life cycle of annual crops. (b) Potential leaf photosynthesis tends to peak when leaves have just fully expanded, declines gradually after full expansion, and declines rapidly before or after physiological maturity has been attained. (c) Leaf photosynthesis may be modulated by the demand of assimilates by the "sinks" (i.e., rate of partitioning can affect leaf photosynthesis).

iii) Most crops are more susceptible to adverse environmental conditions during one or more phases or stages of phenological development. For instance, (a) the impact of adverse conditions on crop yield is particularly large during periods when florets are initiated or when seed number is established. (b) Effects of growth regulators (or herbicides) on crop development and yield are highly depended on the stage of development at which the growth regulator (or herbicide) has been applied.

Monitoring of crop phenology can be categorically assessed by three possible ways, i.e. field-based observations, bioclimatic models, and remote sensing techniques (Schaber and Badeck 2003; Fisher et al., 2007). Field-based observations of crop phenology is scale limited, labour, cost, and time intensive as well as the reliability of some field measurement methods is questionable due to operators bias. The bioclimatic models are exclusively crop species specific and require accurate and exhaustive vegetation and climatic data along with local calibration to extend over larger scale. Remote sensing method is one of the low cost pragmatic approach to monitor crop phenology by virtue of bio-optical response of crop canopy, synoptic and repetitive coverage during the crop growing season. Data footprint from remote sensing platforms can be widely used for monitoring phenological stages. The satellite data could provide continuous information about the entire regions rather than individual species over large temporal span (Soudani et al., 2008). Temporal acquisition of remote sensing data from space platform can be utilized to monitor the anomaly in crop phenology allowing generation of spatial temporal crop phenology map.

Narrow band satellite imaging has capability to discriminate crop species, predicting crop yield, and making inferences about the biochemical properties of plants and their environmental conditions on an almost real-time basis (Schuler, 2002). Extensive research works were conducted using remote sensing techniques to detect the temporal trends of phenology metrics and estimate vegetation phenology analogues over different space and time which was suggested more than 35 years ago by Tucker et al. (1979). Since then, several methods have been proposed and can be classified in different category such as, based on thresholds (White et al., 2002; Wang & Tenhunen, 2004), logistic curves (Badhwar et al., 1984; Zhang et al., 2003), moving averages (Reed et al., 1994; Brown et al., 2002; Schwartz et al., 2002), derivatives (Xin et al., 2002; Viña et al., 2004) and empirical equations (Moulin et al., 1997). Most of the techniques are based on vegetation indices which are frequently used in monitoring crop phenology stages (Karnieli, 2003). The most widely used vegetation index is time series satellite derived normalized difference vegetation index (NDVI) (Tucker et al., 2001; Piao et al., 2006; White et al., 2009). NDVI is calculated as the ratio of normalized difference between NIR and red reflectance's, and quantifies the photosynthetic capabilities of plant canopies; thus, identify the fractional amount of green vegetation present. The NDVI is very sensitive to the changes of chlorophyll content and leaf cellular which has been widely applied for crop growth monitoring. Few decades ago, time series NDVI data was obtained from NOAA-AVHRR satellite though this satellite was not designed for this purpose (Martínez and Gilabert, 2009; Xin et al., 2002). Gallo and Flesch (1989) devised the usage of NOAA/AVHHR data for monitoring the seasonal growth of maize and it was found that the date of maximum NDVI is correspond with the silking stage for 12 crop-reporting districts in the central United States. Reed et al. (1994) studied over a large region of United States to evaluate the phenological characteristics. They analyzed 12 metrics linked to key phenological event which was modified by Hill and Donald (2003) with 10 additional supplementary metrics that can be exclusively used for routinely retrospective assessment of seasonal conditions and changes of vegetation cover. Subsequent to NOAA/AVHRR several researches have been carried out for crop phenology study by analyzing MODIS derived time series vegetation index (VI) data (Wu et al., 2010; Zhang et al., 2003). MODIS 16-days composite data have unique capabilities to provide sufficient spatial and temporal resolution to detect the multi-temporal spectral responses from specific crop types. Several researchers have established the utility of time-series MODIS composite vegetation index (VI) data for discriminating the crop types under different management practices (Sakamoto et al., 2006; Wardlow et al., 2007; Wardlow and Egbert, 2008) and monitoring general crop phenology (Sakamoto et al., 2005; Wardlow et al., 2006). Wardlow et al. (2006) studied with MODIS 250m 16-days composite NDVI to estimate the green up onset date of summer crops (maize, sorghum, and soybean) using the onset date identification method developed by Zhang et al. (2003) across the state of Kansas and also detected the intra-crop date variations due to shifts in the crop calendar in regional scale. Hmimina et al. (2013) investigated the potential use of MODIS 16 day's composite time series NDVI data for monitoring the seasonal dynamics of different types of vegetation cover that are representative of the major terrestrial biomes and showed that inflexion points of a model fitted to a MODIS 16days composite NDVI time series allow accurate estimates of the onset of greenness and the onset of yellowing in deciduous forests. Zhang et al. (2006) approached a new methodology of piecewise logistic model applied to time series MODIS data to determine global vegetation phenology and showed the qualitatively realistic spatial distribution of phenological metrics and developed strong correspondence with climatic variability and with cropping patterns in agricultural areas. Actually, crop phenology study is more complex than natural vegetation cover due to the potential of being used for different degree of planting multiple crops sequentially within a growing season as well as crop phenological metrics. Due to the medium or coarser resolution of MODIS data some researchers have used multi-temporal high resolution satellite data like Landsat-TM (Hansen and Loveland, 2012; Huang et al., 2010; Maxwell and Sylvester, 2012). The applicability of the Landsat TM for crop phenology study depends on the availability of a spatio-temporally adequate supply of Landsat imagery. But in some cases for phenological study of short term crops where require high temporal repitivity especially during critical growth period the temporal frequency of Landsat-TM is not adequate. To resolve the problem few researchers proposed the data fusion techniques to simulating the high spatio-temporal resolution images (Zhang et al., 2013, Huang et al., 2013). But in some cases, data fusion technique is not possible to perform due to several reasons. As a rapid development of remote sensing techniques in recent years a couple of high spatio-temporal satellite like IRS AWiFS has been launched for monitoring the agricultural crop phenology and crop growth study.

Although a wide range of research studies have been conducted on many types of seasonal crop phenology using those satellite data but no significant research has been done especially on potato crop phenology study as well as for Characterizing Spatial Patterns of Potato Agrophenology. The objective of the present study is to investigate the potato crop phenological pattern and to evaluate the spatio-temporal characteristics of potato agro-phenology using MODIS NDVI time-series data.

4.2 Materials And Methods

4.2.1 Data Used

In the present study Terra MODIS NDVI product (MOD13Q1 V005) 16-day time composites with 250m spatial resolution was used to identify the crop phenology. SOI topomaps (1:50,000 scale) and GPS data was used for boundary delineation of potato growing areas and locating the potato field site to validate with satellite based information as well as to segregate the potato growing area from other crops. The details of the data products are in the following table.

Table 4.1: Details of the MODIS NDVI Data of 2012-13 for the Potato Phenological Study

Data Product	Path/Row	Date of Acquisition	Spatial Resolution
MOD13Q1.A2012337.h25v07.005.2012355103248.hdf	h25v06	Nov 29, 2012	250m
MOD13Q1.A2012337.h26v06.005.2012355104057.hdf	h26v06	Nov 29, 2012	250m
MOD13Q1.A2012353.h25v06.005.2013009143232.hdf	h25v06	Dec 15, 2012	250m
MOD13Q1.A2012353.h26v06.005.2013009144921.hdf	h26v06	Dec 15, 2012	250m
MOD13Q1.A2013001.h25v06.005.2013018032657.hdf	h25v06	Jan 01, 2013	250m
MOD13Q1.A2013001.h26v06.005.2013018032845.hdf	h26v06	Jan 01, 2013	250m
MOD13Q1.A2013017.h25v06.005.2013039210159.hdf	h25v06	Jan 17, 2013	250m
MOD13Q1.A2013017.h26v06.005.2013039211429.hdf	h26v06	Jan 17, 2013	250m
MOD13Q1.A2013033.h25v06.005.2013051120031.hdf	h25v06	Feb 02, 2013	250m
MOD13Q1.A2013033.h26v06.005.2013051110741.hdf	h26v06	Feb 02, 2013	250m
MOD13Q1.A2013049.h25v06.005.2013067180606.hdf	h25v06	Feb 18, 2013	250m
MOD13Q1.A2013049.h26v06.005.2013067182036.hdf	h26v06	Feb 18, 2013	250m
MOD13Q1.A2013065.h25v06.005.2013082064224.hdf	h25v06	Mar 06, 2013	250m
MOD13Q1.A2013065.h26v06.005.2013082063828.hdf	h26v06	Mar 06, 2013	250m
MOD13Q1.A2013081.h25v06.005.2013098040514.hdf	h25v06	Mar 22, 2013	250m
MOD13Q1.A2013081.h26v06.005.2013098042505.hdf	h26v06	Mar 22, 2013	250m

Table 4.2: Details of the MODIS NDVI Data of 2013-14 for the Potato Phenological Study

Data Product	Path/Row	Date of Acquisition	Spatial Resolution
MOD13Q1.A2013337.h25v06.005.2013354081900.hdf	h25v06	Dec 03, 2013	250m
MOD13Q1.A2013337.h26v06.005.2013354075801.hdf	h26v06	Dec 03, 2013	250m
MOD13Q1.A2013353.h25v06.005.2014006094150.hdf	h25v06	Dec 19, 2013	250m
MOD13Q1.A2013353.h26v06.005.2014006093824.hdf	h26v06	Dec 19, 2013	250m
MOD13Q1.A2014001.h25v06.005.2014018123023.hdf	h25v06	Jan 01, 2014	250m
MOD13Q1.A2014001.h26v06.005.2014018122859.hdf	h26v06	Jan 01, 2014	250m
MOD13Q1.A2014017.h25v06.005.2014038170520.hdf	h25v06	Jan 17, 2014	250m
MOD13Q1.A2014017.h26v06.005.2014038180653.hdf	h26v06	Jan 17, 2014	250m

MOD13Q1.A2014033.h25v06.005.2014050130334.hdf	h25v06	Feb 02, 2014	250m
MOD13Q1.A2014033.h26v06.005.2014050120546.hdf	h26v06	Feb 02, 2014	250m
MOD13Q1.A2014049.h25v06.005.2014066041829.hdf	h25v06	Feb 18, 2014	250m
MOD13Q1.A2014049.h26v06.005.2014065151830.hdf	h26v06	Feb 18, 2014	250m
MOD13Q1.A2014065.h25v06.005.2014086174317.hdf	h25v06	Mar 06, 2014	250m
MOD13Q1.A2014065.h26v06.005.2014086162533.hdf	h26v06	Mar 06, 2014	250m
MOD13Q1.A2014081.h25v06.005.2014098040514.hdf	h25v06	Mar 22, 2014	250m
MOD13Q1.A2014081.h26v06.005.2014098042505.hdf	h26v06	Mar 22, 2014	250m

4.2.2 Methodology

4.2.2.1 MODIS Data Processing

The 16-day composite terra MODIS NDVI product (MOD13Q1 V005) with 250m spatial resolution with sinusoidal projection and WGS84 datum was obtained from NASA Land Processes Distributed Active Archive Center (http://reverb.echo.nasa.gov), available in public domain. The data products were rescaled and re-projected to UTM system with WGS84 datum by using MODIS Conversion Toolkit (MCTK 2.0). The maximum value composite (MVC) of 16 days NDVI data was used to reduce cloud cover affect while maintaining temporal resolution for precise phenological estimates. The MOD13Q1 NDVI values were constructed using the Constrained View Angle Maximum Value Composite (CV-AMVC) algorithm on a 16-day compositing period (see MOD13 V.05 user guide) (Huete et al., 2002). All the composite NDVI datasets are stacked according to the date for time series analysis.

4.2.2.2 Time Series NDVI Data Interpolation and Reconstruction

The images acquired by optical sensor are subjected to cloud contamination which compels reconstruction of NDVI time series data. Several NDVI reconstructing methods have been developed by various researchers to ensure the integrity before seasonality analysis. Normally the integral approaches to obtain a daily-basis VI time-series can be presented as function-based fitting which results in many cases is too strictly followed that the result may reduce the effectiveness of phenological dynamic phenomenon of vegetation. To avoid this situation linear-interpolation technique is followed to comply with the integrity of NDVI time-series data product and missing observation was given as a valid NDVI value.

In linear-interpolation techniques algorithm treats each pixel as an individual in a time series stacked image, thus the actual value of vegetation indices from any ground substance can be extracted. Linear interpolation algorithm between two images can be presented as follow (Pan et al., 2015):

$$\frac{NDVI - NDVI_a}{DOY - DOY_a} = \frac{NDVI - NDVI_b}{DOY_a - DOY_b} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, NDVI represents the missing day to be interpolated, $NDVI_a$ and $NDVI_b$ represents the valid images between two dates used for interpolation, DOY represents the interpolated Julian day of the year and DOY_a, DOY_b is corresponding two valid image acquisition date. Therefore, the NDVI between $NDVI_b$ and $NDVI_a$ can be treated as a linear relationship and can be rewrite as:

$$NDVI = NDVI_b + (NDVI_a - NDVI_b) * \frac{(DOY - DOY_b)}{(DOY_a - DOY_b)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Hence, NDVI for a given missing day can be calculated by using two valid observations. Undoubtedly, a good result of linear interpolation depends on the evenly distributed more amounts of valid NDVI images.

4.2.2.3 Identification of Cropping Systems

The dynamic changes in crop growth life cycle can be characterized using seasonal variations in the NDVI temporal profile. Notably the NDVI temporal profile of a crop also follows a phenological cycle. From the start of the growing season, the greenness increases progressively, reaches at it maximum during the peak vegetative growth and there after declines during senescence. In terms of temporal profile each crop will have only one peak with varying magnitude, duration and asymmetry which helps to discriminate crops. In an agricultural year, the cropping pattern or the number of crops cultivated in a same field can be identified through investigating the number of local maxima in the annual NDVI profile (Figure 4.2) indicating the cropping intensity.

However, it must be noted that the temporal NDVI data should be smoothened before probing for local maxima. In our study Spirits v.1.1.1 tool (developed by VITO's remote sensing unit behalf of EC-JRC) was used for smoothing the NDVI time-series data. Smoothed NDVI time series was found to be sensitive to subtle peaks which incidentally could represent the weed infestation during fallow period. To avoid the false detection of local maxima, a threshold NDVI value of 0.4 was suggested by several researchers (Sakamoto et al., 2005; Galford et al., 2008). Based upon the local crop calendar, NDVI threshold value and field intelligence collected using hand held GPS, district-wise phenological maps were generated.

4.2.2.4 Identification of Potato Crop Phenology

Different crops can be identified on the basis of their NDVI profile which act as proximal indicator of phenological metrics. For generating potato crop phenology local crop calendar was consulted and approximate dates of critical growth stages were identified. Based upon the local crop calendar satellite data were procured to cover major growth stages of the potato crop. Several field visits synchronized with satellite overpass were carried out field observation were collected which include date of sowing and crop growth stage. The field collected observation points were taken into a GIS vector and a buffer of 250 m radius was drawn to record area averaged NDVI value as a representative NDVI in relation to its growth stage. As there were synchronous sowing over a large area in the study districts, 250 m buffer was considered to be legitimate. In the next stage the NDVI value and the corresponding date after sowing of potato crop was plotted using smoothened time series NDVI data. In most of the cases, during peak of phenology the maximum NDVI value was above 0.4. Thus, a threshold value of 0.4 was set to eliminate the outliers. The local phenology maxima method was then applied to identify the maximum peak value of NDVI and corresponding date of sowing. Lastly, the sowing and harvesting dates were determined by extrapolation from smoothened NDVI time series data based on the local crop calendar and ground based information. Based upon the phenological construction, the average growing period of potato crop was observed to be 95-105 days. The estimated results were compared with the collected field data to make sure that the time series NDVI profile adequately represents the phenological profile of potato crop.

4.2.2.5 Extraction of Areas under Potato Crop

Decision tree classification technique was performed using ENVI image processing software to segregate the potato crop pixels from MODIS NDVI time series data. To determine the threshold value for extracting the potato and other crops district-wise local crop calendar and 269 field survey data points were used. In the study area is mostly triple cropped area where potato is grown after rice last week of November to middle of December and harvested in late February to early March.

4.2.2.6 Phenological Metrics of Potato Crop

Potato phenology is divided into five distinct growth phases. The stages are i) sprout development ii) vegetative growth iii) tuber initiation iv) tuber bulking and v) maturation. Sprouting takes place 7–10 days after showing (DAS) which is considered as start of growing season (SGS). After 20-22DAS vegetative growth stage is started which is called as start of active growing season in terms of phenological metrics. Tuber initiation begins after 28–30 DAS and crop growth reaches at peak in 55–60 DAS which is tuber bulking stage. In 88–95 DAS potato crop reaches at maturity stage that is the stage of end of active growing season and after that crop is harvested marking the end of growing season (EGS).

To analyse the anomaly in the trend in the NDVI time-series data, the daily NDVI data were reconstructed using above mentioned method (equation 2) from available NDVI data which was used as a 'predictor value' on daily basis. The daily NDVI data were smoothened using Spirits v.1.1.1 tool (developed by VITO's remote sensing unit behalf of EC-JRC) which provides basic curve for estimation of potato phenological metrics. To identify the potato phenological metrics smoothed NDVI time series data were calculated using the method described by Reed et al. (1994) and supplementary phenological metrics suggested by Hill and Donald (2003). The onset-of-greenness metrics (time of onset and onset NDVI value) i.e. SGS and the end-of-greenness metrics (end date and end of NDVI value) i.e. EGS, were defined as the period beginning at the point and period ending at the point. The SGS and EGS were calculated by using threshold value based on the distance between the minimum level and the maximum, proposed by White et al. (2009). To determine a threshold value for NDVI, it was assumed that the crop phenological phases and agriculture activities such as crop calendar, time of showing, and time of harvesting should be similar within a small-scale; the NDVI threshold value of SGS/EGS was defines as:

$$NDVI_{thres\ hold} = \frac{NDVI_{min}}{NDVI_{max}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where, $NDVI_{min}$ is the minimum NDVI values of starting and ending point of growing season; $NDVI_{max}$ is the maximum NDVI value of growth peak within a specific range of NDVI time-series. According to the threshold value, pixel wise minimum and maximum NDVI value ware identified and processed for mapping.

The duration of potato crop was calculated by subtracting the time of SGS (onset of greenness) from the time of EGS (end of greenness). Unsmoothed original NDVI time series data were used to identify the values of peak growth and time of maximum NDVI during the growing season. The maximum NDVI values are to be a unique one, so for those metrics no smoothing is needed. After deriving the metrics for the maximum NDVI value, the length of high NDVI period was computed by subtracting the NDVI values of the SGS (onset of greenness)from the NDVI values of EGS (end of greenness). The increasing rate of green-up and rate of senescence were calculated as straight line slopes from SGS (onset) to the maximum peak point and from the maximum peak point to the EGS (end of greenness) respectively. To derive the time-integrated NDVI (T_{NDVI}), the magnitude of the season was calculated using smoothened NDVI curve. The length of low period of NDVI during senescence was computed by subtracting the NDVI values of EGS from the NDVI values of the peak point. Furthermore, the quality of the potato growing season was quantified as a ratio of rate of green up and rate of senescence as supplementary phenological life metrics.

4.2.2.7 Estimation of Fractional Crop Canopy Cover using Improved Pixel Dichotomy Model

Crop fraction is the ratio of crop occupying a unit area in ground pixel, which is important for monitoring crop growth. One of the most important variables in crop growth monitoring is the fraction of available solar radiation intercepted by foliage. The crop phenological growth in respect of productivity can be analysed as product of the solar energy intercepted over a period and the effectiveness with which that energy is converted to biomass. The practical approach for crop fraction estimation is Pixel Dichotomy Model which is based on spectral mixture analysis (SMA) where it is assumed that the ground reflectance from a pixel in satellite image consists of signals received from multiple objects. In the case of potato, photosynthetic vegetation and soil are the main components of a pixel. Based upon the assumption the crop fraction can be estimated from remote sensing reflectance using the following equation:

$$CF = \frac{S - S_{soil}}{S_{veg} - S_{soil}} \quad \ldots\ldots\ldots\ldots (4)$$

Where, CF = crop fraction; S= signal received by the remote sensor; S_{veg} and S_{soil} are the signals of a pure pixel of vegetation and soil respectively.

To minimizing the atmospheric affect and improvement of the ability to estimate the crop fraction, vegetation indices was used by several researchers (Wu et al., 2004; Zhang et al., 2013) as an alternative of ‘S’. The most widely used vegetation index is NDVI which represents the condition of surface vegetation. Ratio Vegetation Index (RVI) is also another widely used vegetation indices to crop fraction estimation which is calculated by dividing red and NIR band or from the NDVI values. RVI can be calculated by using the following equation:

$$RVI = \frac{R_{nir}}{R_{red}} \text{or} \frac{1+NDVI}{1-NDVI} \quad \ldots\ldots\ldots\ldots (5)$$

Where, R_{red} and R_{nir} are reflectance of a pixel for the red and near infrared bands, respectively.

Crop fraction can be estimated by using NDVI and RVI as follows:

$$CF = \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} \quad \ldots\ldots\ldots\ldots (6)$$

$$CF = \frac{RVI - RVI_{soil}}{RVI_{veg} - RVI_{soil}} \quad \ldots\ldots\ldots\ldots (7)$$

Where, $NDVI_{soil}$ and $NDVI_{veg}$ are NDVI for pure pixel, corresponding to bare soil and full vegetation cover respectively and RVI_{soil} and RVI_{veg} are RVI for pure pixel in respect of bare soil and pure full vegetation cover.

In some cases, to estimate the green vegetation fraction of grassland or other small height parsley crop some researchers (Li et al., 2014) showed that crop fraction estimation using NDVI was overestimated due to the saturation of NDVI at high fractional cover of vegetation. Consequently, crop fraction estimation was underestimated using RVI due to less sensitive to low green vegetation fraction than to high green vegetation fraction. It is a most challenging work to identify the pure 'soil' and 'vegetation' pixel from a satellite image which mostly scene specific. Due to the changes of roughness, colour variation, soil type pick up of the pure pixels vary. To avoid this circumstances a combination of those two vegetation indices were made using following formula which produce a notably lower RMSE compared with the previous two results (Li et al., 2014).

$$CF = 0.5 * \frac{NDVI - NDVI_{soil}}{NDVI_{veg} - NDVI_{soil}} + 0.5 * \frac{RVI - RVI_{soil}}{RVI_{veg} - RVI_{soil}} \quad \text{.....................} \quad (8)$$

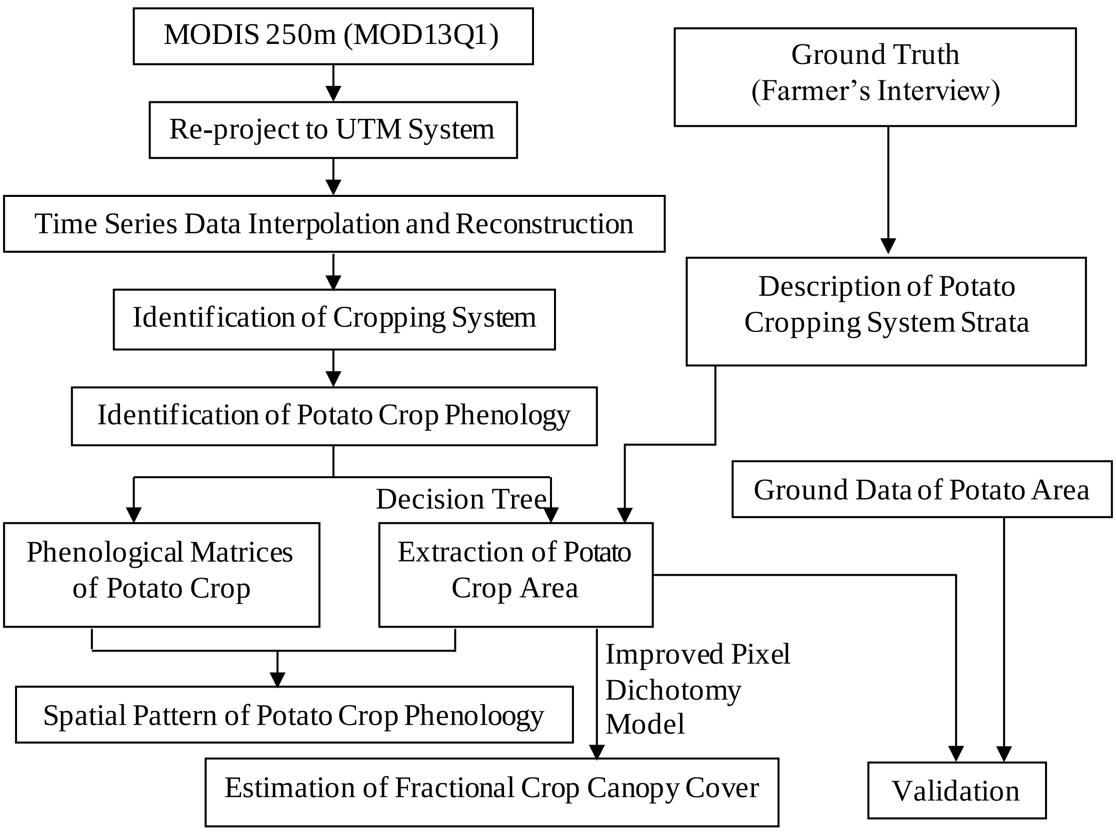


Figure 4.1: Overall Methodology for MODIS NDVI Data Processing

4.2.2.8 Field Validation

As a part of ground validation, field verification was made and GPS point data was collected from the potato fields using "Garmin eTrex Legend Cx" twelve channel GPS receiver. To understand the local crop calendar the GPS points were also collected from other crop area. The potato crop areas of the chosen fields were surveyed during field campaign from January 1st week to February 1st week. To segregate the potato growing area as well as from other crops using the crop phenology those GPS points were utilized. After segregation of potato crop area various statistical analyses was carried out to evaluate the predictability performance of MODIS NDVI data.

4.3 Result and Discussion

4.3.1 Performance of Phenology Detection and Extraction of Potato Crop Phenological Pattern

The curves showed the temporal pattern of the cropping systems (derived from MODIS NDVI data) throughout the years of 2012-13 cropping year (Figure 4.2). The same temporal pattern of the cropping systems was also found in 2013-14 cropping year. The signatures of abnormal pixels were eliminated. In the figure 4.2 triple cropped and double cropped phenological profile were shown in smooth line and break lines respectively. There are three

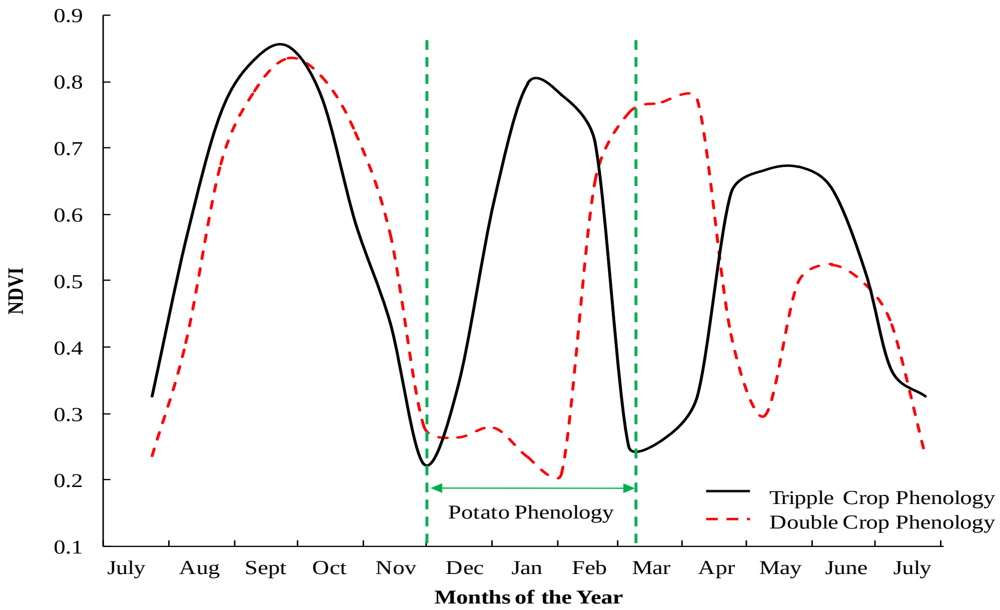


Figure 4.2: Phenological Profiles of Double and Triple Cropped Areas

distinct peaks observed in time series NDVI profile marking the triple cropped areas. However, the magnitude of the NDVI maxima is decreasing from kharif to summer season. The first NDVI maximum in triple cropped pixels is corresponding to kharif rice (aman paddy) which is grown between July to November, the second and third maxima reduce to potato and boro rice respectively in consecutive manner.

In double cropped areas there are two major NDVI maxima and two other secondary maxima. The first maxima matches well with triple cropped areas, but for the second crop there is a lag of about 2 months in comparison to the tripple cropped areas signifying that the crop is not potato but summer rice. The same has been verified in the ground. Between 1st and 2nd maxima there is a small secondary maxima which could be due to grasses naturally grown in the fallow land under moist soil condition. The 2nd secondary maxima is attributed to fodder crop after harvesting of paddy. Potato phenological curve was generated based upon the 269 field observations, the geographic coordinates of which has been overlaid on the NDVI profile and values were extracted and presented as average value over the temporal scale.

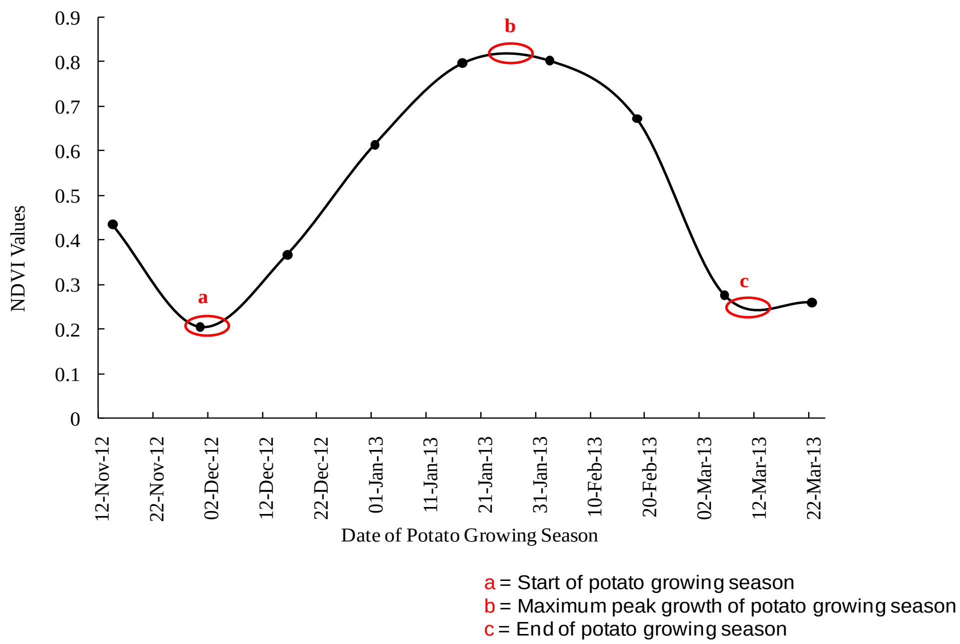


Figure 4.3: Potato Phenological Profile Based on NDVI

The phenological profile of potato crop was extracted from the MODIS time series NDVI data. The average NDVI values were extracted from 269 field observations and potato phenological profile was developed (Figure 4.3). Based upon the Figure 4.3 in general the potato crop is sown during end of November and harvested during 2^{nd} week of March. Same phenological profile was also followed in the cropping year of 2013-14.

4.3.2 Phenological Metrics of Potato

Basic phenological metrics derived include onset of greening, onset of senescence, timing of maximum greenness and length of growing season. Beside few supplementary matrices were also calculated. These helps to provide better sensitivity about the growing phenomenon of potato crops (Islam et al., 2008). The NDVI based phenological profile was further analysed to derive the potato phenological metrics. According to the proposed method of Reed et al. (1994) the basic phenological metrics were calculated and supplementary phenological metrics were calculated using the suggested methods of Hill and Donald (2003) given in table 4.3. The calculated phenological life metrics indicated the start of growing season (SGS), end of growing season (EGS), start of active growing season, end of active growing season, time and rate of maximum indices, rate of green-up, rate of senescence and their integrated metrics. The result showed a significant response (or variability) in their amplitude and quality or pattern of the potato crop season. From the derived phenological metrics additional information of potato crops was also extracted such as the possible date of sowing, possible date of harvesting, estimated ending date of growth, duration of the season etc.

In potato season of 2012-13, the onset of greenness of potato crop started on 05^{th} December 2012 (OnT) with NDVI values of 0.26 (OnV) and the ending date of greenness was 03^{rd} March 2013 (EndT) with NDVI values of 0.34 (EndV) where as the duration from SGS to EGS was 88 days (DurT). The potato phenological profile reached maximum on 02^{nd} February 2013 (MaxT) with NDVI value of 0.80 (MaxV). The range of measureable photosynthetic activity (amplitude) of the season (RanV) was 0.60 which was calculated by the difference of minimum and maximum NDVI values of potato phenological profile. Accordingly, the rate of acceleration of photosynthesis (RIN) and the rate of deceleration of photosynthesis (RDN) for the potato crop in this study area was 0.0101 and 0.0206 respectively. The “quality” of potato crops (PRINDN) can be derived by dividing the rate of increase and the rate of decrease (RIN/RDN) of NDVI of potato growing period, which value was 0.492.

Table 4.3: Description of Potato Phenological Metrics Based on NDVI Values

Abbreviation of Metrics	Metrics	Definition	Result	
			2012-13	2013-14
Basic Metrics *Temporal NDVI Metrics*				
OnT	Time of onset of greenness/Start of Growing Season (SGS)	Beginning of measureable photosynthesis	05th Dec 2012	08th Dec 2013
MaxT	Time of maximum NDVI	Time of maximum measureable photosynthesis	02nd Feb 2013	17th Jan 2014
EndT	Time of end of greenness/End of Growing Season (EGS)	Cessation of measureable photosynthesis	03rd Mar 2013	04th Mar 2013
DurT	Duration of greenness	Duration of photosynthetic activity	88 Days	86 Days
NDVI-value Metrics				
OnV	NDVI Value of onset of greenness	Level of photosynthetic activity at start of growing season (SGS)	0.26	0.27
MaxV	Maximum value of NDVI	Maximum measureable level of photosynthetic activity	0.80	0.81
EndV	NDVI Value of end of greenness	Level of photosynthetic activity at end of growing season (EGS)	0.34	0.32
RanV	Amplitude of season	Range of measureable photosynthetic activity	0.60	0.59
Derived Metrics				
RIN	Rate of greenup	Acceleration of photosynthesis	0.0101	0.0146
RDN	Rate of senescence	Deceleration of photosynthesis	0.0206	0.0127
DurNT	Length of greenness decrease period	Time from maximum greenness to time of end of growing season	29 Days	46 Days
Supplementary Metrics				
PRINDN	''Quality'' of season	Rate of Greenup/rate of senescence	0.492	1.15

HranTO	Start of active growing season	Time of half range value at onset—equals OnV+(RanV/2) when rising	26 DAS	21 DAS
HranVO	NDVI at start of active growing season	Half range value at onset—OnV+(RanV/2)	0.55	0.57
HranTE	End of active growing season	Time of half range value at end—equals EndV+(RanV/2) when falling	78 DAS	76 DAS
HranVE	NDVI at end of active growing season	Half range value at end—EndV+(RanV/2)	0.64	0.61
HDurT	Duration of active growing season	Duration of period from HRanTO to HRanTE	52 Days	55 Days
SMMaxT	Time of maximum smooth NDVI curve	Date of peak of season	28th Jan 2013	21th Jan 2014
SMMaxV	Maximum value of smooth NDVI curve	Value at peak of season	0.82	0.81
SMMinT	Time of minimum smooth NDVI curve	Date of season minimum at the end of growing season	06th Mar 2013	06th Mar 2013
SMMinV	Minimum value of smooth NDVI curve	Value of season minimum at the end of growing season	0.28	0.26

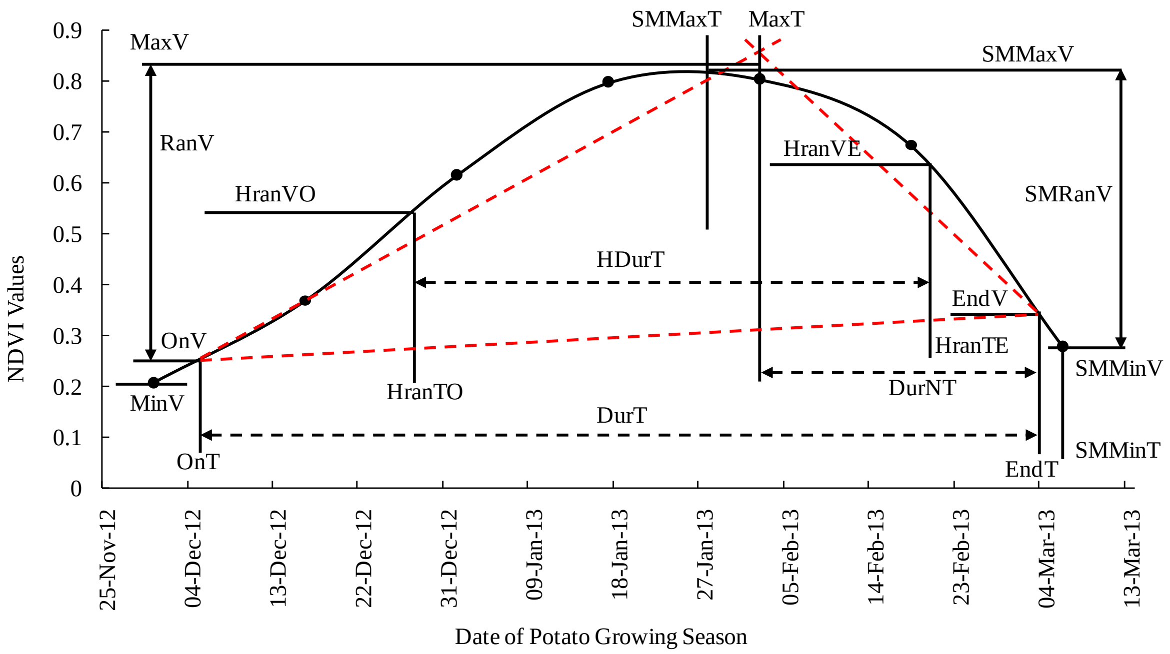


Figure 4.4: Graphical Representation of Potato Phenological Metrics using NDVI

In potato season of 2013-14, the greenness of potato crop started on 08th December 2013 (OnT) with NDVI values of 0.27 (OnV) and the greenness was end with the NDVI values of 0.32 (EndV) on 04th March 2013 (EndT) where as the duration from start of growing season (SGS) to end of growing season (EGS) was 86 Days (DurT). The maximum NDVI value (MaxV) 0.81 was observed on 17th January 2014 (MaxT). The amplitude of the season (RanV) was found 0.59. Consequently, the rate of acceleration of photosynthesis (RIN) and the rate of deceleration of photosynthesis (RDN) for the potato crop was observed 0.0146 and 0.0127 respectively. The PRINDN values was 1.15 which indicated the "quality" of potato crops. The rest of the supplementary phenological metrics are given in table 4.3. The pattern of phenological metrics is presented in figure 4.4.

4.3.3 Spatial Pattern of Potato Crop Phenology

The spatial distribution pattern of potato crop in the study area during 2012–2013 is presented in figure 4.5 and 2013-14 is presented in figure 4.6. Visual appraisal of figure 4.4 shows that the phenological transition profile as function of dates is detected nominally. In regional perspective figure 4.5 and figure 4.6 represents spatio-temporal variability of crop growth due to asynchronous sowing. These figures represent geographically coherent patterns which are in corroboration with local crop calendar. It is apparent from the figure 4.5 greenness of potato crop started at the end of November till beginning of December in the northern part of Paschim Medinipur, south western part of Bankura, south eastern part of Burdwan and central part of Hooghly district. Later on progressive increase in potato area was observed in all the districts whereas in the figure 4.6 it was observed that greenness of potato crop started at the beginning of December and followed the same spatial distribution pattern of 2013-14. In most of areas the phenological maxima is observed during the end of January till the beginning of February and the harvesting date is during last week of February to early of march as is shown in figure 4.5 and figure 4.6. The spatial distribution matches well with field observations. However, some variabilities across different districts are noticeable which could be attributed to availability of optimum soil moisture, harvesting date of kharif crop and logistic supports.

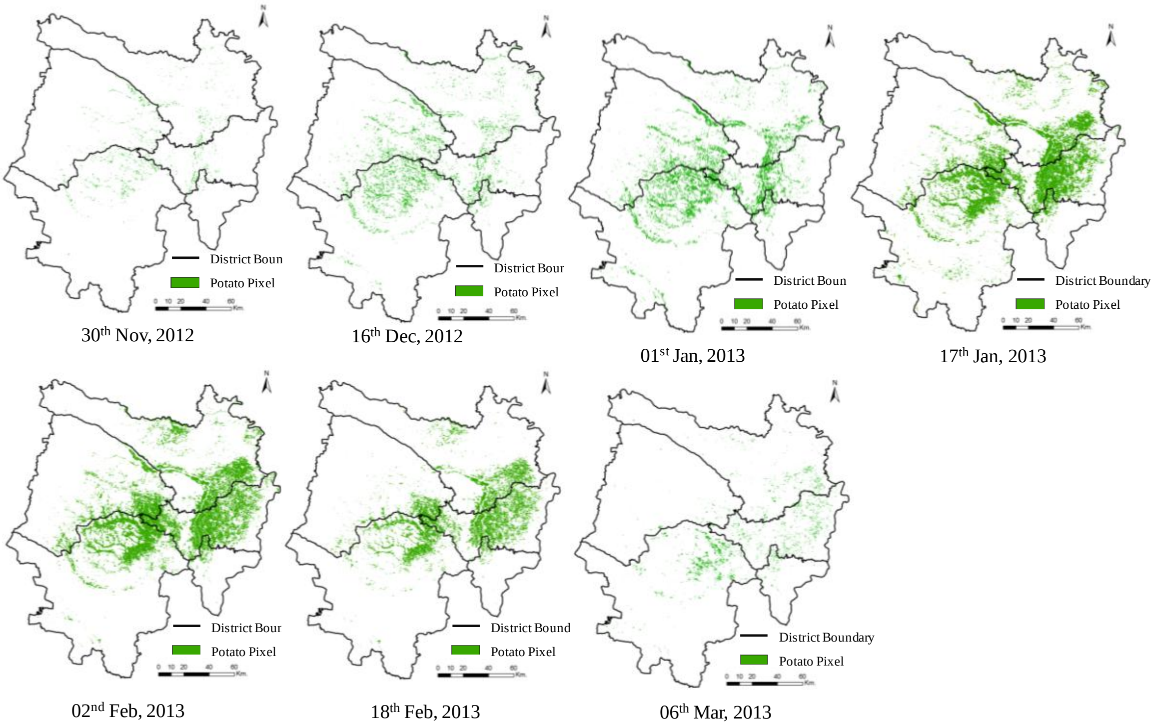


Figure 4.5: Spatial Distribution of Potato Crop of 2012-13 using MODIS 250m NDVI Data

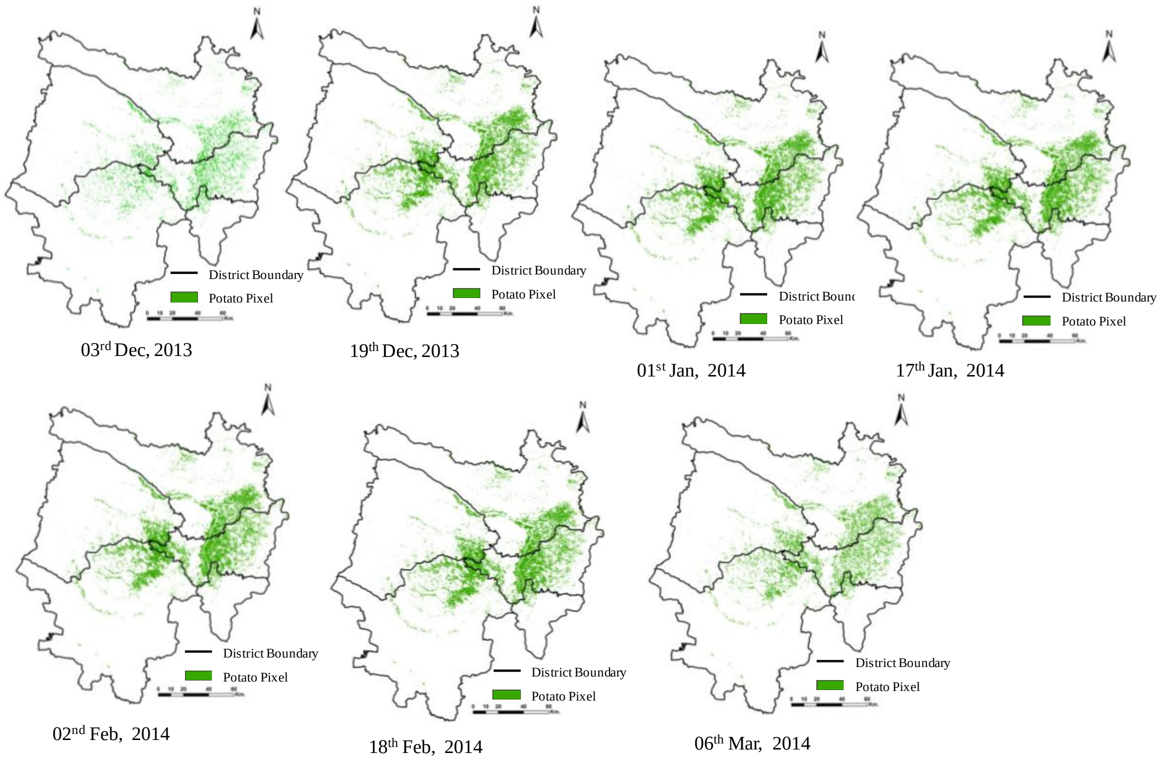


Figure 4.6: Spatial Distribution of Potato Crop of 2013-14 using MODIS 250m NDVI Data

4.3.4 Relationship between NDVI, RVI and Potato Crop Canopy Fraction

Over the past years of 2012-13 and 2013-14, NDVI has been widely used to monitor the biophysical properties of plants such as chlorophyll content, LAI, biomass estimation

(Leprieur et al., 2000). Several researchers pointed out the problems of sensitivity of NDVI to the vegetation canopy (Carlson et al., 1997). NDVI initially increases linearly with increasing of canopy density but the sensitivity decreases at high canopy density. It could be due to NDVI saturation. Many researchers also established a non-linear relationship of NDVI and canopy fraction (Huete et al., 1985, Jiang et al., 2006). Coherently, linear SMA, such as the pixel dichotomy model most probably produces errors for estimating the crop canopy fraction. In figure 4.7 it was seen that Potato Crop Canopy Fraction (PCCF) was overestimated due to the use of NDVI based pixel dichotomy model (red line) and found positive errors. On the other hand, RVI (blue line in figure 4.7) has the under-estimation problem in comparison to NDVI for estimating the crop canopy fraction. To avoid this problem, modelled crop canopy fraction (black line in figure 4.7) was calculated by combining these two indices using the equation 8 which produce less error than that of two indices.

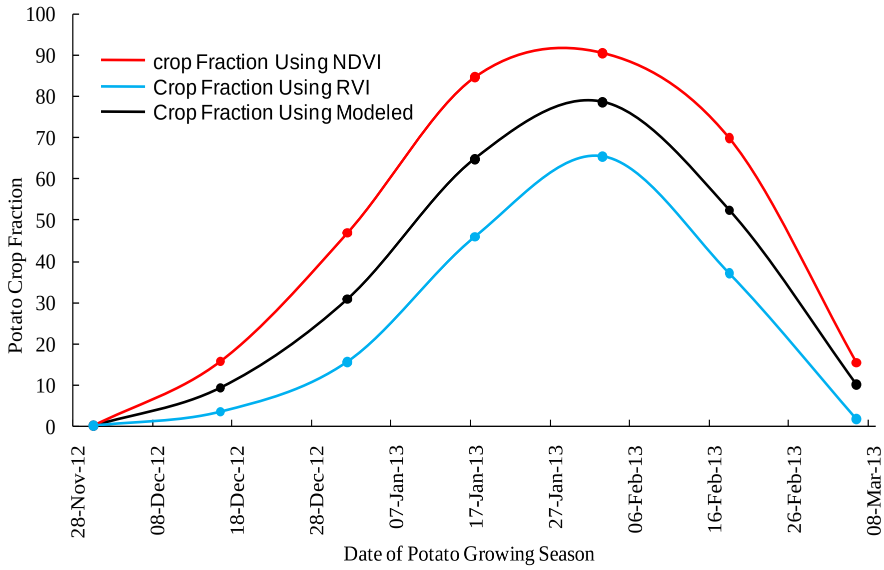


Figure 4.7: Comparison of Potato Crop Canopy Fraction (PCCF) Estimation from NDVI, RVI and Modelled

4.3.5 Spatial Pattern of Potato Crop Canopy Fraction (PCCF)

Spatial distribution of PCCF of 2012-13 is presented in figure 4.8. PCCF tends to follow a well-defined spatio-temporal pattern on the basis of local potato crop calendar. In figure 4.8 greenness of potato canopy initiated at the end of November and continued till the beginning of December with the canopy fraction of more than 29.8% in early shown areas of northern part of Paschim Medinipur, 13.62% in western part of Bankura, 22.17% in eastern part of

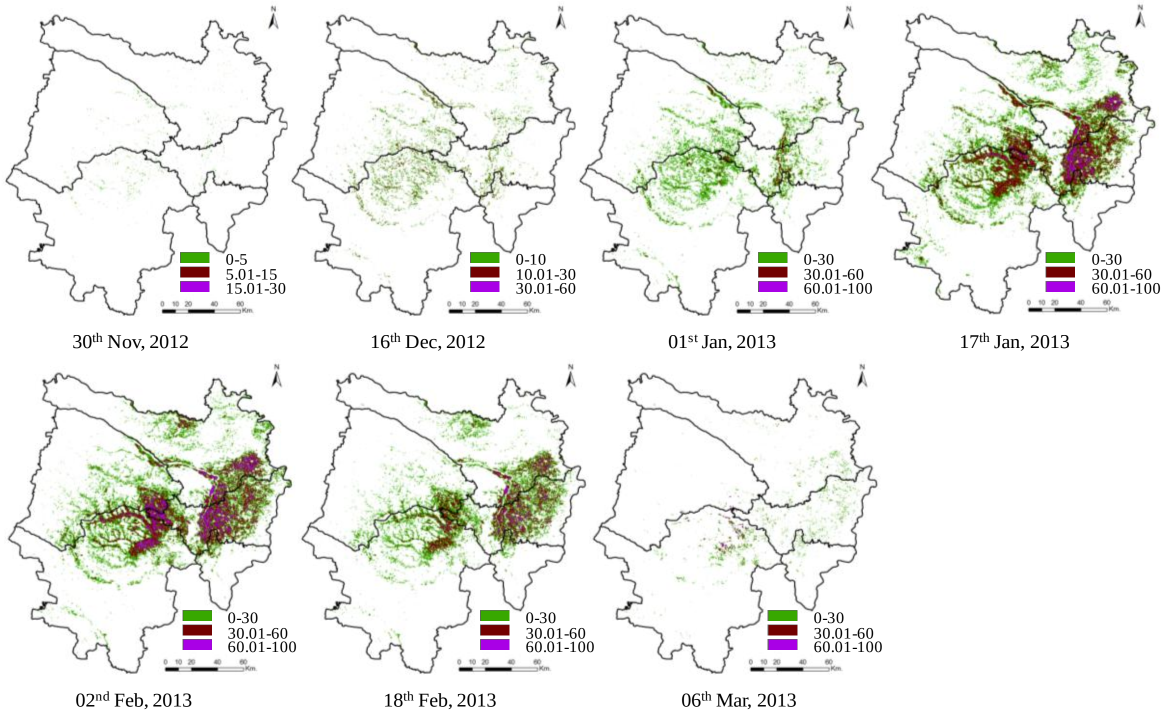


Figure 4.8: Spatial Pattern of Potato Crop Canopy Fraction of 2012-13 using Pixel Dichotomy Model

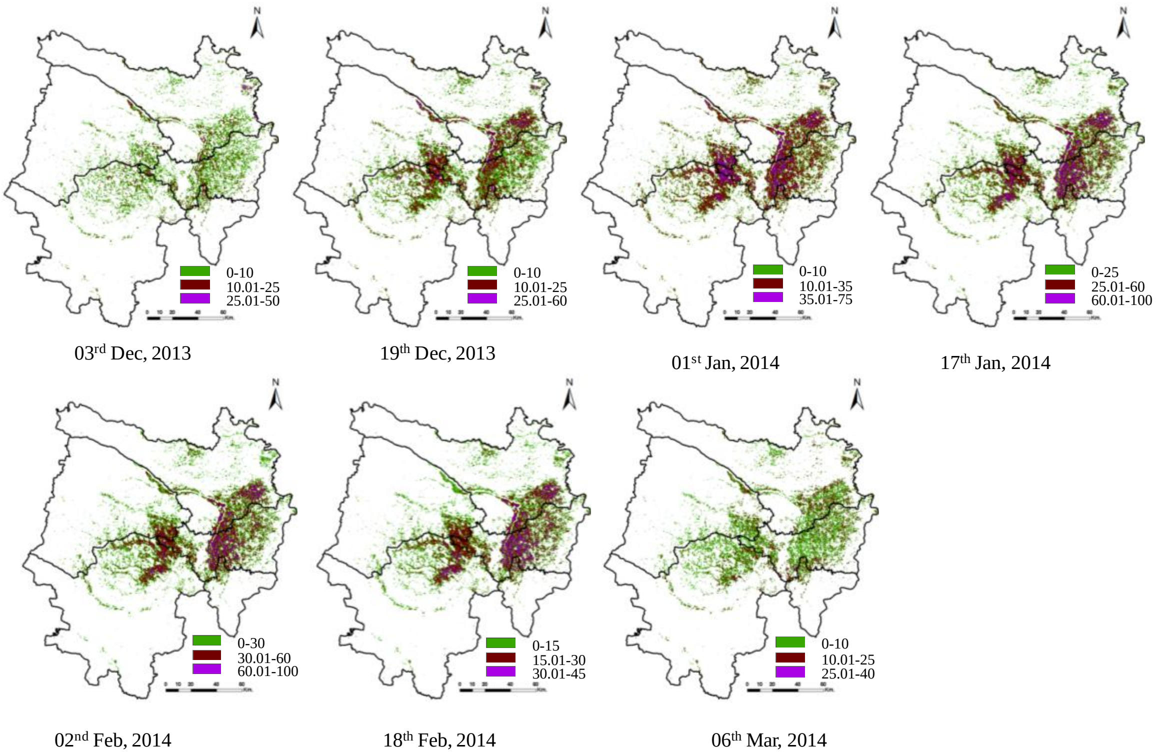


Figure 4.9: Spatial Pattern of Potato Crop Canopy Fraction of 2013-14 using Pixel Dichotomy Model

Burdwan, 19.32% in the northern part of Hooghly and 13.26% in north eastern part of Howrah district whereas for timely and late shown crops the canopy fraction reached upto

57.33% in Paschim Medinipur district on 16th December. During January 1st week canopy fraction reached its highest value (89.39%) in Burdwan district whereas near 17th January canopy fraction reached to 100% in Bankura district. At full vegetative growth stage near 02nd February the crop fraction in Bankura, Burdwan and Hooghly districts was found to be above 95% whereas significantly less values were obtained for Paschim Medinipur (91.80%) and Howrah (84.61%). After maturity, canopy fraction considerably decreased to 81.02%, 7.01%, 85.21%, 94.75%, 72.59% in Paschim Medinipur, Bankura, Burdwan, Hooghly and Howrah district respectively. At the time of harvesting (1st week of March) the PCCF values reduced to 47.20%, 30.68%, 66.52%, 59.13%, and 47.20% for the above mentioned districts respectively.

A well-defined spatio-temporal pattern of PCCF of 2013-14 in figure 4.9 is also presented on the basis of local potato crop calendar. In figure 4.9 the SGS of potato canopy started at the end of November to starting of December with the canopy fraction of more than 5.9% for late shown crop area upto 45.77% in early shown crop area in average of all districts. Canopy fraction reached its highest value of 58.48% in Bankura, 72.63% in Burdwan, 53.71% in Paschim Medinipur, 60.24% in Hooghly and 50.69% in Howrah district on 01st January whereas canopy fraction reached to 100% in Hooghly district around the date of 17th January. Besides the Hooghly district at full vegetative growth stage canopy fraction of 78.28% in Bankura, 98.31% in Burdwan, 88.06% in Paschim Medinipur and 85.60% in Howrah district was seen. After maturity from 02nd February the canopy fraction was gradually decrease to 34.04%, 40.56%, 41.27%, 42.71%, 41.43% in Bankura, Burdwan, Paschim Medinipur, Hooghly, and Howrah district respectively which was observed on 18th February. The PCCF values reduced to 39.52%, 39.51%, 39.50%, 39.53%, and 39.46% for the above mentioned districts at the time of harvesting (1st week of March).

4.3.6 Field Validation

During field validation ground based measured crop area was compared with satellite based predicted potato crop area. In table 4.4 district-wise predicted potato crop area and measured crop area was presented and showed the prediction error (%) which is relatively low. The statistical results and the performance indicators are shown in Table 4.5 for validation. The predicting accuracy was represented by the RMSE which is 37.48 with the coefficient of determination (R^2) value of 0.941 in the cropping year of 2012-13 and 34.68 with the coefficient of determination (R^2) value of 0.944 in the cropping year of 2013-14. The calculated MBE which measured the overall bias error of predicted and measured crop area is 11.85 and 5.25 in the cropping year of 2012-13 and 2013-14 respectively. The Co-efficient of Resudial Mass (CRM) indicates the overall under- or over-estimations. The +ve value indicate the underestimation of overall measurement values and the –ve values indicate the overestimation vice-versa. For perfect estimation, the value would be zero. In the cropping year of 2012-13 CRM value is 0.024 which indicate the underestimation of measured crop area. On the other hand, in the cropping year of 2013-14 the CRM value is -0.010 which indicate the overestimation of measured crop area. But in both years the underestimation and overestimation values is relatively low. Modelling Efficiency (ME) showed the values of 0.91 and 0.92 in respective two consecutive cropping years which indicating good performance. ME value of 1 indicate the perfect match in between the predicted and measured value and the value close to zero indicates the poor performance of the estimation method. The overall results of these comparisons well matched with the measured values.

Table 4.4: Comparison of Modelled Potato Crop Area with Measured Crop Area

Districts	**2012-13**		**2013-14**	
	Predicted Crop Area (Sq. Km.)	Measured Crop Area (Sq. Km.)	Predicted Crop Area (Sq. Km.)	Measured Crop Area (Sq. Km.)
Burdwan	642.96	569.14	672.56	578.22
Bankura	349.61	262.81	391.06	297.25
Paschim Medinipur	509.36	586.07	544.52	613.01
Hooghly	875.22	1001.55	910.89	998.30
Howrah	60.94	77.80	69.88	75.87

Table 4.5: Statistical Validation and Performance Indicator

Cropping Year	**MBE**	**RMSE**	**rRMSE**	**CRM**	**ME**	**R^2**
2012-13	11.85	37.48	0.007	0.024	0.91	0.941
2013-14	5.25	34.68	0.004	-0.010	0.92	0.944

4.4. Conclusion

This study investigates the potato crop phenological pattern and the spatio-temporal characteristics of it using MODIS NDVI time-series data. MODIS derived time series NDVI data was able to accurately calculate the potato phenological metrics with SGS and EGS as well as the date of sowing, possible date of harvesting, estimated ending date of growth, duration of the season etc. Time Series NDVI data was interpolated and reconstructed to fill the data gap between two time composite 16 days NDVI data. Reconstructed NDVI time series data described the crop phenology with high fidelity despite small temporal changes in the potato canopy foliage. In the present method NDVI thresholding method was applied to discriminate the potato crop from other rabi crops based on temporal spectral profile. Based on the local knowledge of cropping pattern, potato crop phenological characteristic was identified from the seasonally aggregated NDVI data and spatial pattern of potato crop was extracted. In addition the NDVI-based pixel dichotomy model has been used for retrieval of potato canopy fraction. To avoid over- / under-estimation of canopy fraction both NDVI and RVI profiles were averaged to provide a legitimate output. However, precise phenological calendars and local cropping systems are necessary for potato crop phenological modelling where two or more crops are grown simultaneously. The large footprint of MODIS will lead to mixed pixel where two different rabi crops may appear and will add uncertainties for selection of endmembers. Further study is required to decompose the mixed pixels.