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Locally received NOAA based crop yield estimation using vegetation index and atmospheric parameters for Chittoor district

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Abstract

Satellite-based remote sensing is the new wave for monitoring a few earth assets like (water, Vegetation), climate studies and other environmental parameters. The objective of the research is mainly describes elaborately on the estimation of crop yield with the assistance of Cumulative Normalized Difference of Vegetation Index (CNDVI), Cumulative Growing Degree Days (GDD), and monthly average rainfall. Since, agriculture is a cost-effective field where so much of manpower and time are involved. As an application for the technology, remote sensing data is correlated with weather parameters for Chittoor district, Andhra Pradesh. The National Oceanic and Atmospheric Administration (NOAA) Satellite's Advanced Very High-Resolution Radiometer (AVHRR) data have been collected from Local L-band receiving station. Geographically, the yield of Chittoor region is affected by soil type, rainfall and groundwater resources. However, the depicted work is credited only on two fields i.e., Groundnut and Paddy where most of the farmers prefer in each crop cycle throughout the year. A regression-based model is developed to estimate the crop yield (Kg/Ha) with NDVI pixels which are related to crop, temperature, rainfall, and groundwater level as inputs and validated with the ground truth values. To achieve the purpose of a study, Considered latest decade remote sensing data, six decades of yield data (1930-2017) and atmospheric variables like daily/monthly temperature values and rainfall data on an hourly basis have been collected from authorized sources to train the regression network. This model estimates the yield value with ±15 % error rate for both Kharif and Rabi seasons. Even though, a lot of methods were uncovered in this work, it mainly focuses on very large spatial coverage generally, at the country level. In contrast to that, this work is focused on Chittoor district and obtained results with prominent accuracy.

Keywords: Advanced Very High Radiometer (AVHRR), Cumulative Normalized Difference of Vegetation Index (CNDVI), Crop yield, Growing Degree Days (GDD), Normalized Difference of Vegetation Index (NDVI).

INTRODUCTION

Anticipating crop yield a long time before reap is essential (particularly in locale, portrayed by climatic uncertainties). Rice yield forecast is based on a crop growth simulation model using a combination of real-time and historical weather data [1].In ancient method, ground truth collection of data for every point is time taking and costly method to implement in the agriculture field. For that, remote sensing is more suitable to save revenue as well as time. Interestingly, that remote sensing data is also need to be validated at the final stage. This made to derive NDVI and then to predict the crop yield for rice [2-4].The same NDVI also helps to estimate the yield of groundnut [5-6].Technically, vegetation has a higher reflectance in the close infrared (0.7–1.1μm) area of the electromagnetic range than red band (0.4–0.7μm). Vegetation changes take the benefit of this differential reaction in the un-remarkable and close infrared regions of the range. In spite of the fact that the outcomes were empowering, the connections appeared to substantially help to examine the growth of the plant. The standardized contrast vegetation record (NDVI) determined from the obvious and close infrared (NIR) groups of the NOAA AVHRR satellite has been effectively used to screen vegetation changes at local scales [7-9]. A radiative exchange shows the connection between satellite information and yield development [10]. It is found that, correlation r^2=0.82 & r^2=0.86 (for paddy and groundnut crops respectively) between yield and cumulative rainfall over Chittoor region of three decades of time span. .

Geographic information and cloud parameters of the Region of study

Geographically, the Chittoor region is located at 78º30' and 79º 55'E, of the eastern longitudes and 12º37' and 14ºN of northern slopes. The types of soil that exist are red loamy soil (57%), red sandy soil (34%), red dirt, dark loamy, dark earth and dark loamy soil.

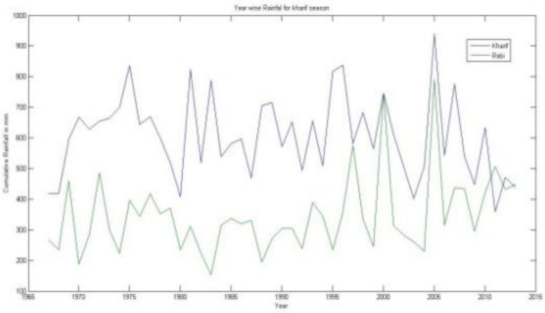


Figure 1: Cumulative Rainfall (mm) Vs Year Four decades from 1964 to 2014.

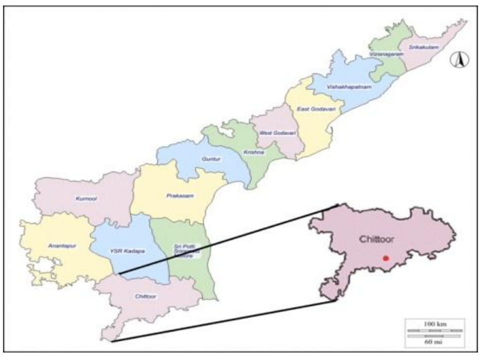


Figure 2: Chittoor District

In this district, the average temperatures extend from 46º C in summer (March-June) and 12-18ºC in winter (November-January).This place gets around 918 mm of precipitation consistently. The temperature in Chittoor is directed by high altitude eastern part. Crop pattern is ever changing due to agro-chemical weather conditions in the district. The entire crop cycle are divided into two seasons, Kharif- June to September (sowing starts in mid of May or early week of June) and Rabi- October to December (sowing starts in last week of September or early week of October). Kharif season depends on South-West (SW) monsoon and Rabi season depends on North-East (NE) monsoon.

MATERIALS AND METHODS

This model involves mainly two types of data. One is remote sensing data and other is atmospheric data. The remote sensing data is collected from the receiving station which has been installed for NOAA 18/19 & METOP-A/B (Meteorological operational satellite – A/B) at Sri Venkateswara University College of Engineering, Tirupathi (13.6272ºN, 79.3964ºE). It is a licensed research by the Department of Space (DoS), India to meet the objectives of Centre of Excellence (CoE) under Technical Education and Quality Improvement Program (TEQIP). From this station, day to day imagery was utilized for observing product condition (with spatial resolution of 1-km). Atmospheric data like temperature, rainfall, humidity etc., are collected from 18 Automatic Weather Stations (AWS) that are installed and maintained by Indian Space Research Organization (ISRO), Indian Meteorological Data (IMD) and Andhra Pradesh State Planning and Development Society (APSDPS) on an hourly basis. Day by day, maximum and minimum temperatures and precipitation are obtained from these stations. Crop wise actual yield data and irrigation data are collected form district planning office and agriculture departments of study region and state and central groundwater Department, AP, INDIA.

Since, the spatial resolution (1.1 Km X 1.1 Km) of NOAA is low the crop classification is error-prone. In order to overcome this problem, Landsat8 (ETM+ sensor) data is utilized for every 16 days which is of very high spatial resolution (30m. X 30 m.) and correlated with these satellites data for every 16 days in a month.

Normalized Difference of Vegetation Index (NDVI)

Vegetation Index is a standout amongst the clearest physical portrayals of resulting yield from crops. Remote sensing is the procedure for measuring the chlorophyll action and vegetation canopy using red and NIR bands from NOAA satellite data. [11], therefore remotely detected information can be utilized to predict crop through NDVI value. The vegetation index can be figured by the distinction of the infrared and red groups as proportion to their sum, thus

$$NDVI = \frac{\rho_{NIR} - \rho_r}{\rho_{NIR} + \rho_r} \quad (1)$$

Where,

NDVI=Normalized Difference Vegetation Index

ρ_{NIR} =Amount of power radiated by Infrared band of the electromagnetic spectrum

ρ_r =Amount of power radiated by red band (visible) of the electromagnetic spectrum

Eq. (1) gives the basic equation for NDVI and its value range between -1 and +1. It relates to full canopy cover. The mathematical equations for Maximum Value Composition of NDVI [12] are shown in eq. (2), (3), (4) and (5) for basic function and Day wise, Fortnight wise approximation respectively.

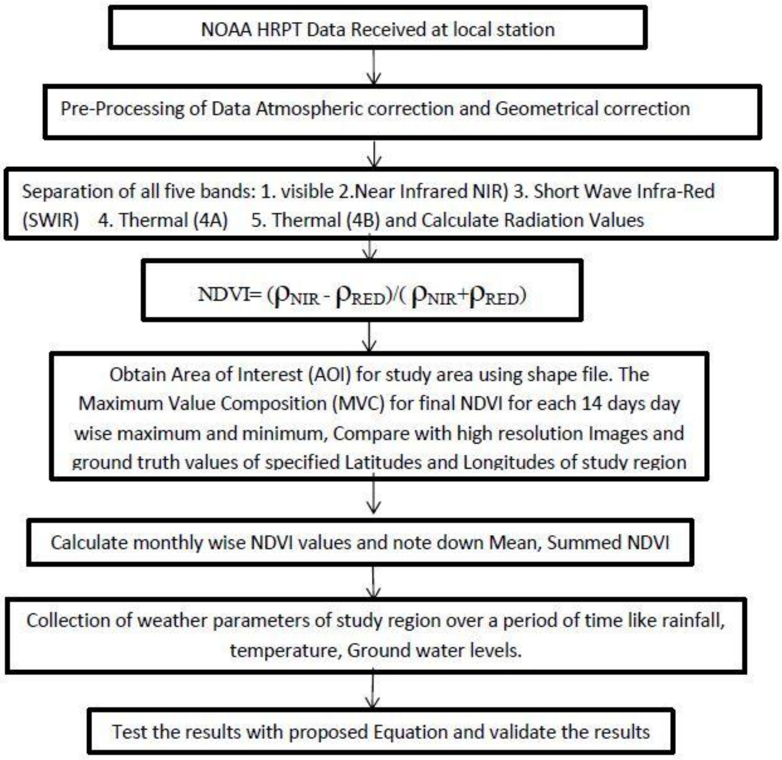


Figure 3: Algorithm for yield estimation using NOAA remotesensing imagery**.**

$$NDVI_1 = Max(NDVI_{Pass1}, NDVI_{Pass2}) \quad (2)$$

$$NDVI_{Fn1} = Avg(NDVI_1, NDVI_2 .. NDVI_{14}) \quad (3)$$

$$NDVI_{Fn2} = Avg(NDVI_{15}, NDVI_{16} ... NDVI_{30}) \quad (4)$$

At the last step of NDVI, Cumulative NDVI (CNDVI) is calculated for that field on season basis.

$$NDVI_S = \text{Summed NDVI for the whole month} \quad (5)$$

NDVI1 is the maximum NDVI of a day among all scenes, NDVIFn1 means first fortnight and fn2 means second fortnight respectively.

NDVIs=Cumulative NDVI for whole month.

Eq. (2), (3) relates to day wise approximation and eq. (5) for whole month.

Impact of Rainfall

By observing crop yield and rainfall of the seasons for last 5 decades, there is 0.66% correlation found between them because of many variations across the southern part of India. So, clearly it says that crop yield cannot be predicted on the rainfall alone. Sincerely, rainfall is one of the main parameters to predict yield in remote sensing field [13]. It drives us for the further research to take inputs from the various directions. The basic notions show that summer precipitation and rainfall

Will affect the crop yield in a serious way. Regression-based models that are involved with weather parameters were widely used in yield estimation. For a better idea, monthly average rainfall is shown in a Table1 from 2014-2017 (Source: APSDPS, Vijayawada).

Role of Temperature/GDD

Temperature is also one of the main factors to drive the crop either towards lively direction or in negative direction. Too much temperature may affect the yield in a large extent. Growing Degree Days (GDD) ($Assuming\ T_{base}$ = 10°C) is the calculation on heat accumulation during the growth period. It helps to decide growth strategy of crop, irrespective of year to year temperature variations. Paddy field is very much sensitive to the temperature variations [14] than groundnut [15]. Equation (7) shows GDD calculation.

$$\text{Growing Degree Days} = \frac{(T_{max}+T_{min})}{2} - T_{base} \quad (7)$$

Where,

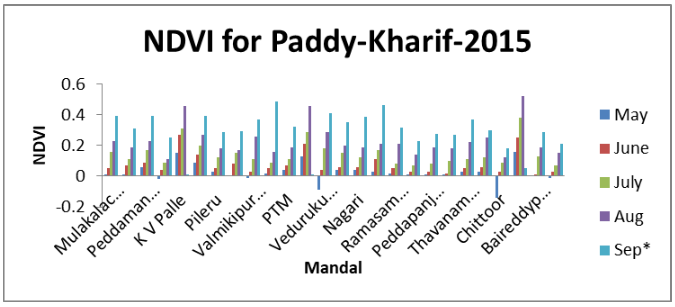
T_{max}, T_{min} are daily maximum and minimum temperatures for that specific region.

Table 2: Monthly ranges of GDD

S. No	Year	Monthly Cumulative GDD (Range Daily basis)
1	2014	570-595 (Highest in July, lowest in September)
2	2015	600-620 (Highest in October, Lowest in July)
3	2016	590-615 (Highest in July, Lowest in November)

RESULTS AND DISCUSSION

The NDVI statistics for paddy and groundnut fields in different mandals under Chittoor region in Kharif and Rabi seasons for the years from 2015-2017(January) are shown in the figure (5).From the analysis, it is clear that during the growing season, NDVI is increasing rapidly and just before the mature state, NDVI decreases as the green content reduces. Early season NDVI, results in wrong prediction because of inconsistency over time. The Summed -NDVI of growing season is liable to be correlated with crop production. For Kharif season, NDVI was taken in the last week of August for early sown areas (midweek of May) and for remaining in the early week of September. For Rabi season, NDVI was taken in the last week of December for early sown areas (midweek of August) and for remaining early week of January of the next year.



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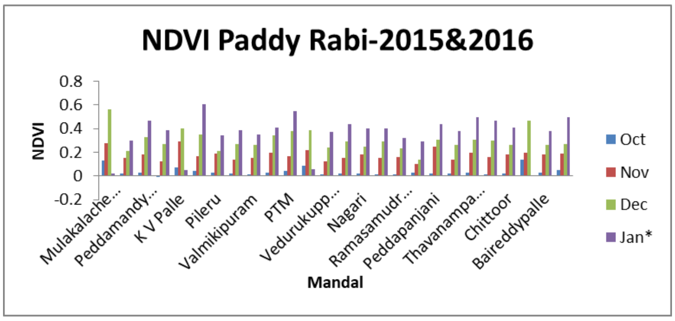

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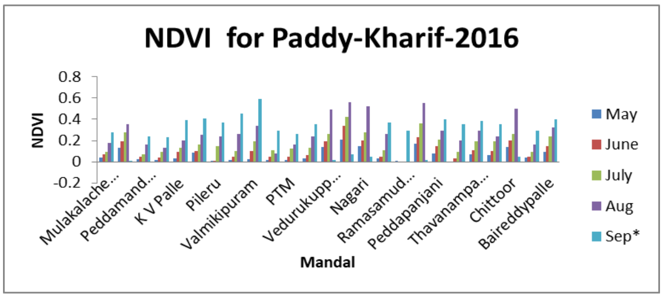

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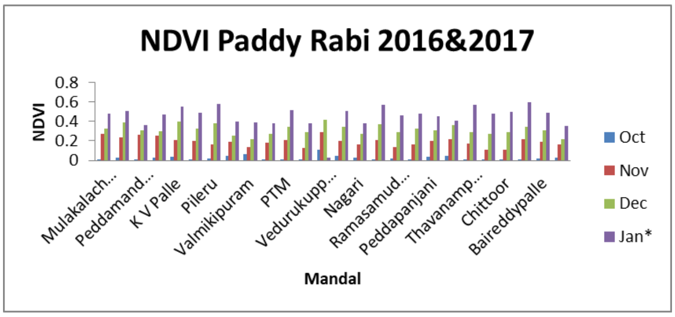

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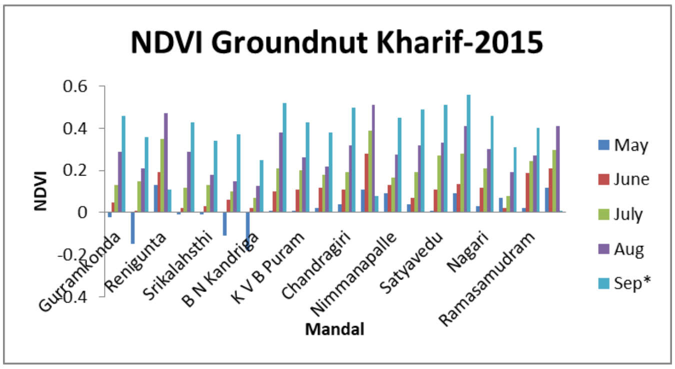

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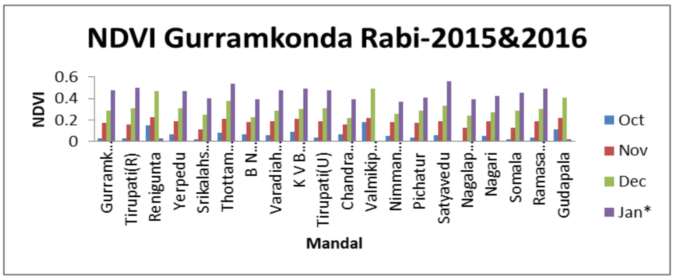

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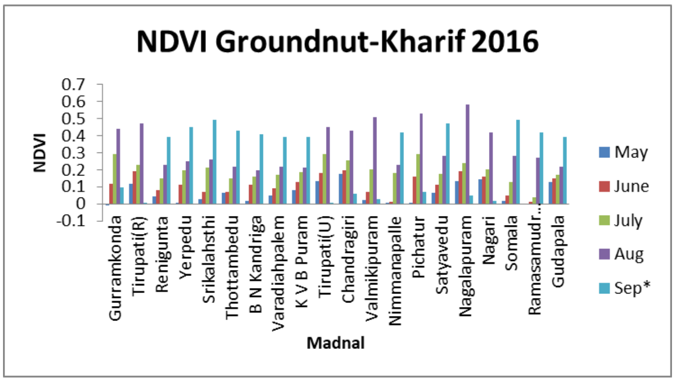

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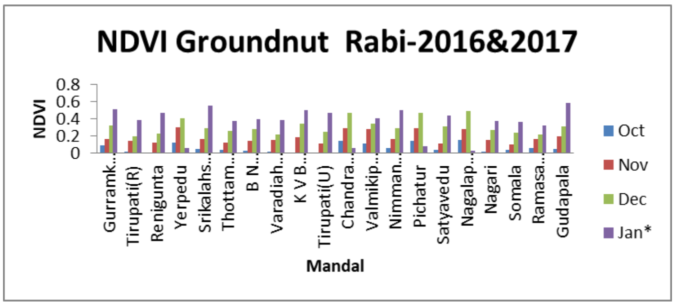


(h)

Figure 4: NDVI Statistics of paddy and groundnut fields for both Kharif and Rabi seasons from 2015-2017

(a): Paddy in Kharif season 2015

(b): Paddy in Rabi season 2015-2016(Jan)

(c): Paddy in Kharif season 2016

(d) Paddy in Rabi season 2016-2017(Jan)

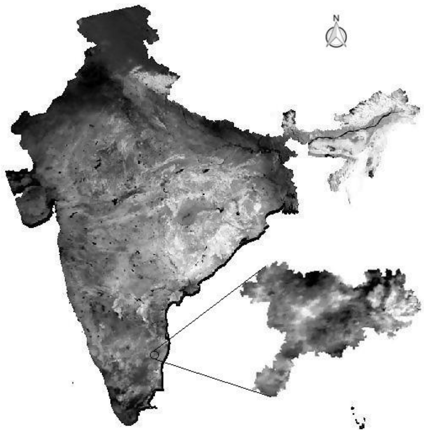
(e): Groundnut in Kharif season 2015

(f): Groundnut in Rabi season 2015- 2016 (Jan)

(g): Groundnut in Kharif season 2016

(h) Groundnut in Rabi season 2016- 2017

Selected mandals are represented in the paper. Among all mandals, 0.56 is the maximum and 0.001 is minimum NDVI (neglecting negative NDVI, which is generally water body).The processed NDVI from NOAA image is shown in figure 6(a), entire India is covered in one pass and AOI of Chittoor district is highlighted for quick reference. In Figure 5(a), a Green dot represents Groundnut sown area and red dot represents paddy sown area. Field data (Latitude, Longitude) was also taken for proper pointing on the imagery and verified. To avoid the unwanted portion of the AOI, crop mask is used in which extreme white pixels denotes (+1) and Extreme black pixels represents (-1).Vegetation is on the grey range of pixels.



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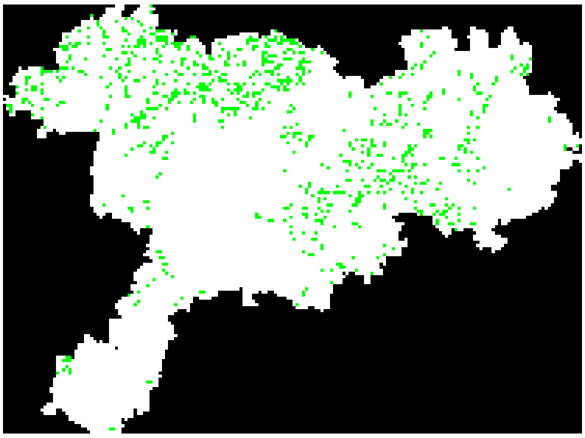

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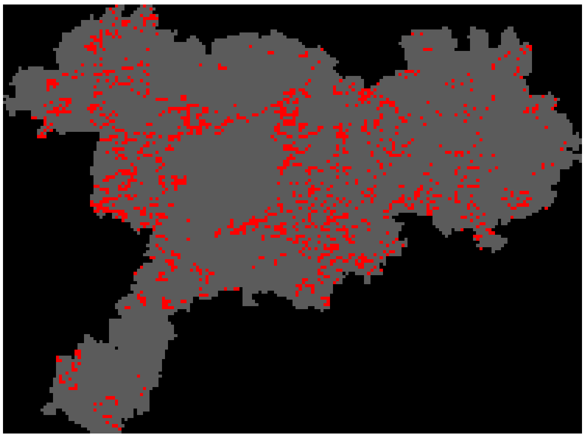


(c)

Figure 5: (a) NDVI Image of NOAA

(b) Locations of Groundnut crops in Chittoor region

(c) Locations of Paddy crops in Chittoor region

REGRESSION MODEL

After so much of literature review, proposed the following model for estimation of crop yield that depends on CNDVI, Rainfall and GDD and some bias error at a regional scale rather than global. The following equation (8) can estimate the yield.

$$Yield_{crop} = \alpha^{Crop}_{Seasonal} * NDVI_{crop} + \beta^{Crop}_{Seasonal} * Rainfall_{Seasonal} + \gamma^{Crop}_{Seasonal} * GDD_{Seasonal} + error(\varepsilon) \quad (8)$$

Where,

$Yield_{crop}$ = Paddy or Groundnut $(\frac{Kg}{Ha})$;

$Rainfall_{Seasonal}$ = Rainfall for Kharif or Rabi seasons in mm

$GDD_{Seasonal}$ = Growing Degree Days for Kharif or Rabi seasons (°C)

$error(\varepsilon)$ = Biasing error.

$\alpha^{Paddy}_{Kharif} = 21.51;\ \beta^{Paddy}_{Kharif} = 2.140;\ \gamma^{Paddy}_{Kharif} = 0.006;$

$\alpha^{Paddy}_{Rabi} = -33.09;\ \beta^{Paddy}_{Rabi} = 0.50;\ \gamma^{Paddy}_{Rabi} = 0.87;$

$\alpha^{Groundnut}_{Kharif} = 18.7;\ \beta^{Groundnut}_{Kharif} = -0.813;$
$\gamma^{Groundnut}_{Kharif} = -0.247;$

$\alpha^{Groundnut}_{Rabi} = 53.80;\ \beta^{Groundnut}_{Rabi} = 0.150;$
$\gamma^{Groundnut}_{Rabi} = -0.86;\ error(\varepsilon) = \pm 3\%$

Cumulative NDVI (CNDVI) is used in this model, for paddy and groundnut fields separately. Rainfall and GDD are on seasonal basis i.e., Kharif and Rabi. As this region is semi-arid region, Rabi season depends on irrigation. As for as paddy is concerned, smoothed CNDVI for 2014-2016 is varied from 119 to 135 during Kharif season and 99 to 130 for Rabi season, respectively. It is because of high Leaf Area Index (LAI) variation [16].GDD is in the range of 1320 to 1910 ºC during 2014 and 2016 respectively. This change is not rapid, since GDD depends on temperature and indirectly on humidity of the atmosphere. During 2015, study region got ample annual rainfall (almost 60% above the normal) that resulted in lavish amount of groundwater which in turn helped to rise the yield. Apart from the meteorological side, geographically area for sowing is also increased 15% from 2014 to 2016 .This model forecasts the yield on a seasonal basis. Generally, in this area, high rainfall occurs during August and September and low rainfall during June and July (only Kharif and Rabi seasons are considered). Actual Yield (paddy) in 2014 is 6522 Kg/Ha (As per the statistics given by District Agriculture Department, Chittoor) and this model estimates 5159 Kg/Ha. In this year total rainfall is just above the normal level and GDD is high in both the seasons (Groundnut: Actual-3199Kg/Ha and predicted-3419 Kg/Ha). It helps to grow the plant but paddy is a rain-fed crop. Due to less rainfall, yield is not increased by a previous year (2013). As coefficients for CNDVI and rainfall are nearer to each other, they are having a prominent role in the yield estimation. In 2015-2016, heavy rainfall occurred almost throughout the year. So, cumulative GDD is also low due to low daily temperatures, which effect the plant growth in a positive way. In addition to this, CNDVI is also large in this year compared to 2014 (119 to 125, 99 to 130 in Kharif and Rabi seasons respectively). Hence the average yield resulted is very high in this decade till now i.e., 9295 Kg/Ha (annually). Rabi season is an irrigated season, where a large amount of groundwater drives the growth. The coefficient of GDD is high for Rabi season compared to Kharif (rainy season). Groundwater data for the study region is also collected from the central board of Groundwater Resource Department. This model forecasts almost realistic values. For 2016, this model gave better performance in the combination of CNDVI, rainfall and GDD data that are more considerable with reference to the previous year data. Table 3, 4 and 5 gives the statistics about the actual and estimated data and compared with existing methods, and also trend based are represented over years.

Groundnut crop is not dependent on rainfall (high yield in sunny season).This model estimates the yield with very less error rate; it is the best model for this region till now. On the remote sensing platform, CNDVI is less for this crop when compared to paddy (as LAI is small) [18].In 2014, CNDVI is 70 and GDD is high since it is a dry season fed crop. In 2014, CNDVI is more in Rabi season than Kharif season resulting a yield of 2605 and 474 kg/Ha respectively. It needs less groundwater level for its growth. In 2015, due to heavy rainfall and permissible range of GDD in the regions, groundnut yield also increased by 57.35%. In 2016, due to soil strength and atmospheric humidity for the crop regions_____ and impact of rainfall is negative for this crop that is stated by the coefficients of model estimation (β).

$$Error\ Rate = \frac{Modelled - Actual}{Actual} X100 \quad (9)$$

Monthly average NDVI for paddy regions is 0.47 and Ground nut region is 0.34. ERDAS Imagine is used to select required range of pixels (As the Forest pixels should not be considered as crop).To completely avoid this problem the coordinates (Lat., Long.) of Forest and Hilly regions are masked from the raster. More greenness from August and December Regions promotes crop yield. Starting from the growing season, NDVI increases and at the mature state, it decreases suddenly.

Using this model, for kharif season, negative error shows, estimated yield is more than the actual. This model is best suitable for Rabi season rather than Kharif season, as it gets less error and better than the existing models.

Table 3: Estimation of crop yield for year 2014-2015 (Kg/ha)

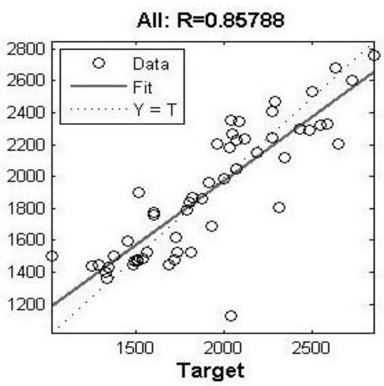
S.No	Crop type	2014-2015									
		Proposed (a)		Actual (b)		Existing (c)		Trend based		Error =(c)-(a)	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
1	Paddy	2521	2638	3342	3180	2257	2110	2140	2126	-24.5	-17
2	Groundnut	628	2791	594	2605	481	2165	474	2084	+5.72	+7.14

Table 4: Estimation of crop yield for year 2015-2016 (Kg/ha)

S.No	Crop type	2015-2016									
		Proposed (a)		Actual (b)		Existing(c)		Trend based		Error %	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
1	Paddy	3800	4787	5020	5625	3418	4300	3216	3937	-24.3	-14.8
2	Groundnut	1247	3968	1148	3697	867	4105	918	2457	+8.62	+7.33

Table 5: Estimation of crop yield for year 2016-2017 (Kg/ha)

S.No	Crop type	2016-2017									
		Proposed (a)		Actual (b)		Existing (c)		Trend based		Error =(c)-(a)	
		Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi	Kharif	Rabi
1	Paddy	3886	4718	5170	5820	3603	4400	3589	4074	-24.8	-18
2	Groundnut	551	3598	500	3041	580	3410	448	2372	+10.2	+6.1



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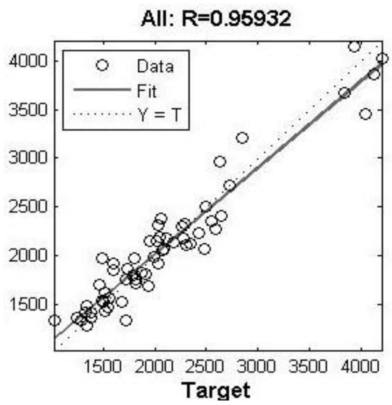

(b)

Figure 6: (a) Correlation of crop yield (paddy) with annual rainfall. (R^2=0.85)

(b) Correlation of crop yield (groundnut) with annual rainfall. (R^2=0.96, Unsmoothed)

CONCLUSION

The combination of CNDVI profile, rainfall and GDD provides relatively good yield estimation especially for groundnut in Rabi season with high correlation. In fact, rainfall in Rabi season is more (692mm). Cumulative NDVI for both the crops in Kharif is more in 2015(425). The Proposed method is compared with existing method that involves rainfall and NDVI as main parameters and trend based prediction which is trained by more than three decades of input parameters. That time series NDVI clearly reflect the changes of plant phenology (germination, vegetative phase, ripening and harvesting).This model gives fair results for Groundnut compared to paddy which is temperature and water-dependent crop. It estimates the yield paddy/groundnut in Kharif and Rabi seasons with an average error rate (%) are -24.5/8.18,-16.6/6.85 respectively. The negative sign in the error rate means there exist a lag in the estimation level and the positive sign indicates lead in the estimation with reference to the actual. Suitable selection of bias value can minimize this error. Summated NDVI based methods result in R^2=0.86 for Kharif Region and R^2=0.82 for Rabi season. As this model is on the district level, site selection also places a major role in deciding the crop estimation. To overcome this limitation, homogenous fields that have similar crop type can be preferred. High-resolution satellite imagery, Landsat 8 data has been incorporated with NOAA for better classification of crop. Soil strength, fertilizer and crop health are not considered for this model. In future, this model can be extended to high-resolution imagery with Leaf Area Index (LAI) and can be used to discriminate crop based on remote sensing imagery. This model doesn't consider pesticide concentration, Co2 levels, and disease on crops.

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