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Research Article

The Study of NDVI Effect on Yield of Major Crops under Telugu Ganga Project Command in Andhra Pradesh

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ABSTRACT

An assessment is made about effect of NDVI on productivity of different major crops grown in study area under Telugu Ganga Project in Andhra Pradesh during 1997 and 2018. Remote sensing based area of major crops in kharif, rabi in 1997 and 2018 were analyzed. In 1997, total area ranged from 1875 ha (pulses) to 78688 ha (paddy), while groundnut area was 35181 ha, followed by jowar (24707 ha), cotton (17660 ha), sunflower (14601 ha), chillies (13442 ha), sugarcane (8673 ha) and bajra (3199 ha). In 2018, the total area ranged from 1163 ha (bajra) to 180351 ha (paddy), while jowar had an area of 24218 ha, followed by chillies (18420 ha), groundnut (16152 ha), sunflower (16100 ha), cotton (14942 ha), pulses (10032 ha) and sugarcane (4113 ha).

Using Remote sensing and GIS based NDVI, we assessed changes in crop area in kharif and rabi 1997 and 2018.The areas of major crops are classified in to Very good, good, and Average categories based on NDVI values. Effects of NDVI on paddy yield were assessed using regression models of yield through NDVI. There was a positive and significant increase in NDVI in 2018 for unit change in NDVI in 1997 with rate of change and coefficient of determination (R^2) of 0.433. The pooled NDVI ranged from 0.324-0.616 in 1997, while it ranged from 0.475-0.811 in 2018 and paddy yield ranged from 3330-6946 kg/ha in entire TGP. The model gave significant rate of change of NDVI and R^2 of 0.786 for predicting yield in entire TGP command. The findings are useful to planners and researchers for improvement in crop area and better management of resources for attaining higher yields of paddy and other crops under TGP in Andhra Pradesh.

Keywords: *NDVI, Remote Sensing & GIS, Productivity and Command Area*

INTRODUCTION

The Telugu Ganga Irrigation Project is in drought prone areas of Rayalaseema region comprising of Chittoor, Kadapa, Kurnool and uplands of Nellore in Andhra Pradesh and it is designed to irrigate 5.75 Lakh Acres (2.3 Lakh ha).

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We assessed the changes in the area of different crops grown in kharif, rabi and the total area of crops in the entire Telugu Ganga Project (TGP) command in Andhra Pradesh in South India using Remote Sensing (RS) and Geographic Information System (GIS) techniques based on NDVI data. The changes in the crop area (ha) and percentage change in the area have been assessed in kharif and rabi seasons of 1997 and 2018 and also when pooled over the two seasons in the entire TGP command comprising of four districts of Chittoor, Nellore, Kurnool and Kadapa.

The use of remote sensing would necessitate the information on crop land, yield, water application methods, problems associated in the irrigation command and scope of improvement. Based on the opportunities of capturing and analysis of satellite data in temporal scale, Remote sensing technique is used. Hence, it is proposed to carry out an investigation for examining the response of yield to crop water use for different irrigation water scenarios for further improvement using remote sensing. This is done based on efficient integration of available data from Government departments for validating the results. Remote Sensing integrated with Geographical Information System (GIS) would be utilized in developing water resources management applications. The spatial, temporal monitoring of projects during kharif, rabi and summer seasons is necessary to monitor the irrigation potential utilization, and take suitable steps for developing interventions or strategies for improvement. This objective would require spatio-temporal information in a synoptic view for knowing both progressive and problematic pockets under irrigated agricultural lands.

The satellite data would provide scope for synoptic coverage and multi-temporal datasets. Currently, many satellites are providing such datasets in public domain. Many Indian and global satellites are providing medium resolution data at fortnightly/monthly intervals which would provide continuity in data acquisition. The Landsat and Indian Remote Sensing (IRS) Resources at are popular and useful in this category. Satellite data offers many advantages for mapping of irrigated area at temporal and spatial scales studied to estimate the area of kharif crops using Landsat-8 data of satellite images **(**Kumar et al., 2015). However, for making effective use of the remote sensing, the analyst should be aware of limitations and advantages of using satellite data, and choose appropriate strategy from available irrigation mapping options. The methods that are working well in local areas may not be suitable to regional and global applications.

Although remote sensing (RS) cannot provide detailed information to these conventional mapping techniques, it can identify areas where changes are occurring, and detailed information has to be gathered. Different techniques for improving irrigated areas using RS data include use of multi-temporal imagery and ancillary data. These methods are valid across all spatial scales considered in the study. Multi-temporal imagery provides greatest accuracy for delineating the irrigation from other land cover types. While ideal dates would differ depending on both type and location of irrigation system that is studied, it is possible to use high frequency observations at coarse spatial resolutions even in local area investigations. In view of the requirement of detailed information in irrigation projects and scope for using RS, we proposed a detailed investigation on use of satellite datasets like NDVI for efficient assessment of crop yields for efficient irrigation potential utilization by using multi-temporal datasets. Based on regression models, we have assessed the effect of NDVI on crop yield using the details collected on the changes in area of crops, crop condition in Telugu Ganga Project in Andhra Pradesh.

MATERIALS AND METHODS

We have evaluated the performance of Telugu Ganga Project (TGP) area, located in Chittoor, Nellore, Kadapa and Kurnool districts comprising of 33 mandals and irrigation ayacut area of 575000 Ac (2.3Lakh ha) in

Andhra Pradesh. The study area is depicted in Fig 1. The command area along with details of mandals are given in Table 1. Nellore has 8 mandals with highest irrigation ayacut area of 245674 Ac, while Kurnool has 9 mandals with lowest area of 54326 Ac. Chittoor has 5 mandals with area of 98000 Ac, while Kadapa has 11 mandals with area of 177000 Ac. The annual rainfall of TGP command ranged from 675 to 933 mm compared to mean normal rainfall of 1134 mm in the study period. The South-West monsoon (SWM) receives about 525 mm rainfall, which is 70% of annual rainfall. The SWM plays an important role on the productivity of crops. The North-East monsoon (NEM) accounts for the remaining 30% of rainfall.

The three cropping seasons in TGP command are kharif (June–September), rabi (October–December) and summer (January–April). The rice based cropping systems are pre-dominant in kharif season in the TGP, while black gram, green gram, groundnut and chilies are grown under rice fallows in rabi season with the available residual moisture in soil. But sugarcane is grown throughout the year during both seasons. Rice is mostly grown by the traditional method of raising nursery and transplanting in the field by supplying water through flood irrigation.

Table 1: Mandals of different districts and irrigation ayacut area in the TGP Command

District	Irrigation Ayacut (acres)	List of mandals
Chittoor	98000	(i) Thottambedu (ii) B.N.Kandriga (iii) KVB Puram (iv) Varadaiahpalem (v) Satyavedu
Kadapa	177000	(i) Atluru (ii) B.Koduru (iii) Badvelu (iv) B.Matham (v) Duvvuru (vi) Gopavaram (vii) Kalasapadu (viii) Khajipeta (ix) Porumamilla (x) Narasapur (SAKN) (xi) Mydukur
Nellore	245674	(i) Venkatagiri (ii) Balayapalli (iii) Pellakuru (iv) DV Satram (v) Tada (vi) Naidupeta (vii) Chittamuru (viii) Vakadu
Kurnool	54326	(i) Velugodu (ii) Bandi Atmakur (iii) Mahanandi (iv) Nandyal (v) Sirivella (vi) Rudravaram (vii) Allagadda (viii) Chagalamarri (ix) Gospadu
Total	*575000*	*33 mandals*

Remote sensing data

The satellite data provides great scope for efficient coverage and multi-temporal datasets. The Indian and global satellites are providing medium resolution data at 15 or 30 days intervals and there is a continuity for data acquisition. The Landsat and Indian Remote Sensing (IRS) Resources at are useful in this category. In our study, we used Sentinel 2a for carrying out the work in 1997 (starting year) and 2018 (ending year). These two years are considered because TGP has started releasing water from 1997 onwards, while 2018 is the year of our research study. The remote sensing images for these two periods were clear compared to other years.

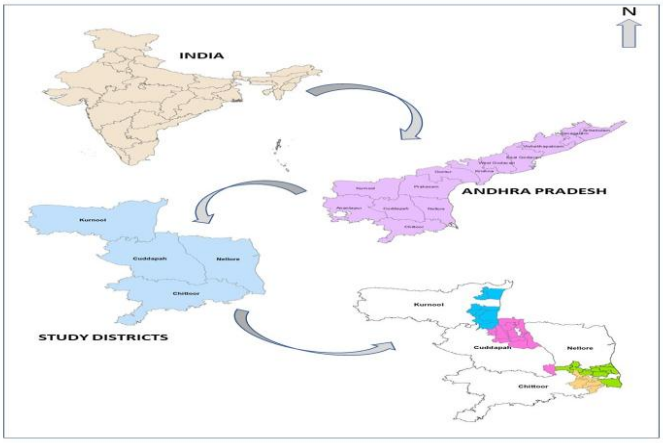


Fig. 1: Study Area of Telugu Ganga Project in Andhra Pradesh

Landsat 4

The Landsat 4 is used to carry out mapping and analysis for 1997. The Landsat 4 was launched from Vandenberg Air Force Base in California, USA on 16th July 1982 on Delta 3920 rocket. Based on an updated design compared to previous three missions, the satellite carried Multi-Spectral Scanner (MSS) and Thematic Mapper (TM) instruments. The sensors fixed onboard in the satellite collected the data upto 1993, and satellite was decommissioned on 15th June 2001. Accordingly, MSS and TM sensors were carried out by Landsat 4.

Multi-Spectral Scanner

The MSS sensor on Landsat 4 was identical to Landsat 1, 2 and 3. It has four spectral bands viz., (i) Band 4 Visible (0.5–0.6 µm); (ii) Band 5 Visible (0.6–0.7 µm); (iii) Band 6 Near-Infrared (0.7–0.8 µm); and (iv) Band 7 Near-Infrared (0.8–1.1 µm). In addition, it has the features of (i) Data: 100 kHz digital; (ii) Six detectors for each reflective band provided six scan lines on each active scan; (iii) Ground Sampling Interval (pixel size): 57 x 79 m; and (iv) Swath width: 185 km (115 miles).

Thematic Mapper

The improved spectral and spatial resolution of Thematic Mapper has allowed the instrument to see the ground in greater detail and included a thermal band. Added the mid-range infrared seven spectral bands, including a thermal band to the data, viz., (i) Band 1 Visible (0.45–0.52 µm) 30 m; (ii) Band 2 Visible (0.52–0.60 µm) 30 m; (iii) Band 3 Visible (0.63–0.69 µm) 30 m; (iv) Band 4 Near-Infrared (0.76–0.90 µm) 30 m; (v) Band 5 Near-Infrared (1.55–1.75 µm) 30 m; (vi) Band 6 Thermal (10.40–12.50 µm) 120 m; (vii) Band 7 Mid-Infrared (IR) (2.08–2.35 µm) 30 m; (viii) Ground Sampling Interval (pixel size): 30 m reflective, 120 m thermal; and (ix) Swath width: 185 km (115 miles).

LISS-III camera

Based on specifications of LISS III camera and characteristics of IRS IC, LISS III sensor and IRS P6, LISS III sensor camera provided multi-spectral data in 4 bands. The spectral revolution for the visible (two bands) and near infrared (one band) would be 30 m with swath of 185 km. The fourth band (short wave infrared band) has a spectral resolution of 30 m with ground swath of 185 km. The receptivity of LISS III was 16 days.

Collection of topo sheets and Ancillary maps

The Survey of India 1:50000 topo sheets were used for identification of various features in the imagery and for geo-referencing of imagery. The irrigation and drainage map was obtained from Department of Irrigation, Government of Andhra Pradesh. It was used to identify various commands in the TGP area.

Crop condition

The crop condition at any given time during its growth cycle is influenced by significant and complex interactions that exist between crop-soil–water and atmosphere parameters. The Normalized Difference Vegetation Index (NDVI) is calculated by using the satellite Remote Sensing data obtained by reflected radiation in the infrared (0.7 µm–1.1 µm) and red (0.6 µm–0.7 µm) bands representing the integrated effect of various factors that would influence the crop condition. We used satellite based NDVI values to assess the condition of crops across entire TGP command. NDVI values are used to efficiently assess the performance of irrigation command areas at disaggregated level. The crop mapping and acreage assessment was made using RS and GIS techniques. The NDVI values derived from satellite data are used for correctly identifying the crop vigor (Ramesh & Dennis, 1995).

Normalized Difference Vegetation Index (NDVI)

The live green plants would absorb solar radiation in the Photo Synthetically Active Radiation (PAR) spectral region, which is used as a source of energy in the photosynthesis process. The leaf cells are evolved to scatter (reflect and transmit) solar radiation in the near infra-red spectral regions which would carry approximately half of the total incoming solar energy. This is because the energy level per photon in that domain (wavelength longer than 700 nano meters) would not be sufficient

to synthesize the organic molecules into a strong absorption and result in overheating the plant and damaging different tissues. Hence, live green plants would appear relatively dark in the PAR and relatively bright in the near infrared. By contrast, the clouds and snow tend to be red (as well as other visible wavelength), and quite dark in the near infrared.

The NDVI could be calculated from these individual measurements as follows:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad \text{(1)}$$

Where RED and NIR would stand for the spectral reflectance measurements acquired in the red and near-infrared regions respectively. These spectral reflectances are themselves ratios of the reflected over the incoming radiation in each of the spectral bands individually. Hence, they would take values between 0.0 and 1.0. By a suitable design, the NDVI itself would vary between -1.0 and +1.0.

The crop mapping and acreage in TGP command were assessed using RS and GIS techniques. These images provided critical information for crop condition assessment. The water body maps were developed for both kharif and rabi 1997 and 2018. The crop condition is determined using NDVI values. They are categorized as very good (> 0.5), good (0.4–0.5) and average crop condition (< 0.4) based on NDVI values.

RESULTS AND DISCUSSION

The Irrigation Performance assessment of TGP command was carried out using Multi Temporal Satellite data for kharif 1997 and 2018. The results are described for the TGP command by assessing the details of Chittoor, Nellore, Kadapa, and Kurnool districts.

Remote sensing based cropping pattern under TGP command

The cropping pattern in TGP command during kharif 1997 and 2018 is derived from the multi-temporal satellite data. Initial observations from field visits and historic information of different cropping patterns indicated that paddy constitutes about 85% of total crop area, while remaining area was for sugarcane, groundnut, millets, jowar, black gram and other crops. The satellite data based crop estimates of TGP command at four canal commands are described. The cropping patterns include crop inventory, changes in crop calendar and crop condition. The remaining crops were insignificant and scattered in small pockets where commercial crops like sugarcane, groundnut and banana are grown. Basically, the study is restricted to paddy crop by considering the details of all parameters.

The RS image of entire TGP command and Land Use Land Cover maps were developed with ERDAS software. The maps were assessed for spatial distribution of crops and land use land cover for kharif and rabi 1997 and 2018 under the TGP command. The RS based area (ha) of crops observed in kharif and rabi of 1997 and 2018, and changes (%) that occurred in the area of crops over years in the entire TGP command are given in Table 2. The physical area of selected crops for 10 years were collected from Directorate of Statistics and Economics, Vijayawada. The detailed findings based on the assessment of satellite based cropping patterns of kharif, rabi and total area (kharif + rabi) are described in this paper.

Change in remote sensing based area of crops in the TGP Command

The RS based area of paddy, groundnut, sugarcane, jowar, cotton, sunflower, bajra, pulses and chillies observed in the TGP Command during kharif and rabi seasons and total area (ha) in 1997 are given in Fig 2 (top), while area of crops in 2018 are given in Fig 2 (middle). The changes in area of crops over years during 1997 to 2018 in the entire TGP

command are depicted in Fig 2 (bottom). In kharif 1997, the area ranged from 'Nil' for jowar and sunflower to 53674 ha for paddy, while it was 17660 ha for cotton, 16055 ha for groundnut, 13442 ha for chillies, 4297 ha for sugarcane, 3199 ha for bajra and 1875 ha for pulses. In rabi 1997, the area ranged from 'Nil' for cotton, bajra, pulses and chillies to 25014 ha for paddy, while it was 24707 ha for jowar, 19126 ha for groundnut, 14601 ha for sunflower and 4376 ha for sugarcane. Thus the total area ranged from 1875 ha for pulses to 78688 ha for paddy, while the area was 35181 ha for groundnut, 24707 ha for jowar, 17660 ha for cotton, 14601 ha for sunflower, 13442 ha for chillies, 8673 ha for sugarcane and 3199 ha for bajra during 1997.

In kharif 2018, the area ranged from 'Nil' for sunflower to 85138 ha for paddy, while it was 14942 ha for cotton, 9201 ha for pulses, 6742 ha for jowar, 4368 ha for groundnut, 3852 ha for chillies, 2834 ha for sugarcane and 1163 ha for bajra. In rabi 2018, the area ranged from 'Nil' for cotton and bajra to 95213 ha for paddy, while jowar had an area of 17476 ha, sunflower had an area of 16100 ha, chillies had an area of 14568 ha, groundnut had an area of 11784 ha, sugarcane had an area of 1279 ha and pulses had an area of 831 ha. The total area ranged from 1163 ha for bajra to 180351 ha for paddy during 2018, while jowar had an area of 24218 ha, followed by chillies with 18420 ha, groundnut with 16152 ha, sunflower with 16100 ha, cotton with 14942 ha, pulses with 10032 ha and sugarcane with 4113 ha over years.

The change (%) in area of crops ranged from -72.8% for groundnut to 390.7% for paddy in kharif, while it ranged from -70.8% for sugarcane to 280.6% for paddy in rabi season. The change in total area of crops of both kharif and rabi ranged from -63.6% for bajra to 435.0% for pulses over years. In kharif, the change in area over years was 390.7% for pulses, followed by 58.6% for paddy, and 'Nil' for jowar and sunflower, while change was negative of -72.8% for groundnut, -71.3% for chillies, -63.6% for bajra, -34.0% for sugarcane and -15.4% for cotton. In rabi, the change in area over years was 280.6% for paddy, followed by 10.3% for sunflower and 'Nil' for cotton, bajra, pulses and chillies, while it was negative of -70.8% for sugarcane, -38.4% for groundnut and -29.3% for jowar. When total area of kharif and rabi was considered, the change in area was 435% for pulses, followed by 129.2% for paddy, 37% for chillies and 10.3% for sunflower, while it was negative of -63.6% for bajra, -54.1% for groundnut, -52.6% for sugarcane, -15.4% for cotton and -2% for jowar.

Table 2: Remote sensing based area (ha) of crops in kharif & rabi in TGP command during 1997 and 2018

Year	Crop	Area (ha)			Change (%)		
		Kharif	Rabi	Total	Kharif	Rabi	Total
1997	Paddy	53674	25014	78688			
	Groundnut	16055	19126	35181			
	Sugarcane	4297	4376	8673			
	Jowar	0	24707	24707			
	Cotton	17660	0	17660			
	Sunflower	0	14601	14601			
	Bajra	3199	0	3199			
	Pulses	1875	0	1875			
	Chillies	13442	0	13442			
	Total	*110202*	*87824*	*198026*			
2018	Paddy	85138	95213	180351	58.6	280.6	129.2
	Groundnut	4368	11784	16152	-72.8	-38.4	-54.1
	Sugarcane	2834	1279	4113	-34	-70.8	-52.6
	Jowar	6742	17476	24218	0	-29.3	-2
	Cotton	14942	0	14942	-15.4	0	-15.4
	Sunflower	0	16100	16100	0	10.3	10.3
	Bajra	1163	0	1163	-63.6	0	-63.6
	Pulses	9201	831	10032	390.7	0	435
	Chillies	3852	14568	18420	-71.3	0	37
	Total	*128240*	*157251*	*285491*	*16.4*	*79.1*	*44.2*

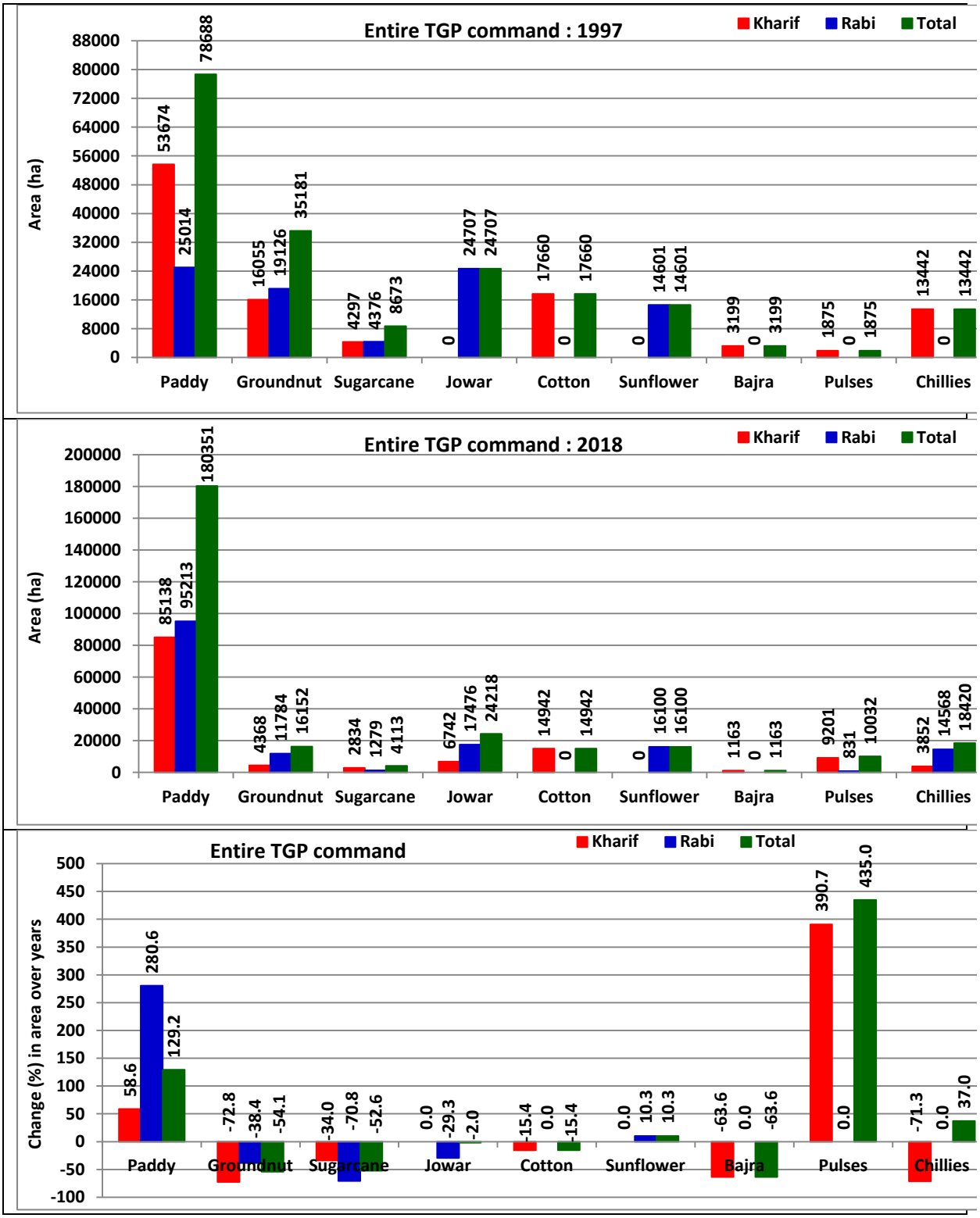


Fig. 2: Remote sensing based area of crops in kharif & rabi in the entire TGP command during 1997 & 2018

Crop condition based on NDVI

The satellite based time composite maximum NDVI observed in rabi 1997 and 2018 was used for assessing the crop condition. The spatial crop condition maps derived from satellite data are given in Fig 3 for kharif and rabi 1997 and 2018.

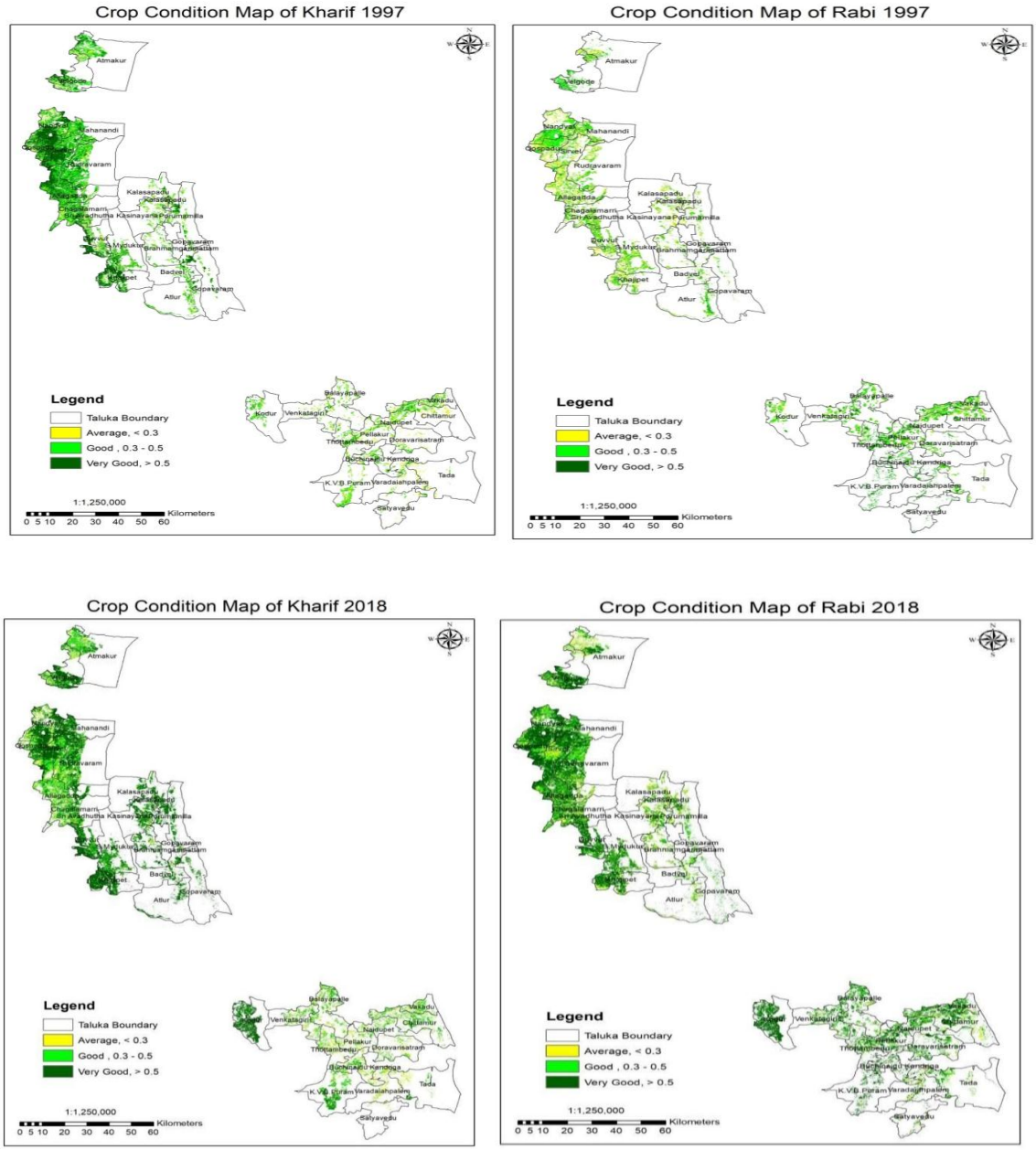


Fig. 3: Satellite based Crop condition (NDVI) map for kharif & rabi of 1997 &2018

It is possible to asses and map the crop condition in quantitative terms. Based on location specific crop condition, the reasons for poor condition are ascertained and interventions are made. With this background, crop condition was monitored in the entire TGP in rabi 1997 and 2018. A etailed qualitative analysis was made to compare the performance of different crops. The spatial variation of crop condition in terms of qualitative conditions of very good, good and average were carried out with good accuracy. About 50.5% of the crop was under very good condition in 2018 compared to 23% in 1997. About 18.25% of crop was in average condition in 2018 compared to 33.5 % in 1997. This was due to a change in the crop calendar, change in management practices and adoptions of new short duration varieties by farmers. The crop condition in terms of NDVI like average, good, very good are given in Table 3, while area (ha) and change in area (%) for kharif and rabi 1997 and 2018 are given in Table 4.

Table 3: District wise crop condition area (ha) based on NDVI in TGP command

Crop condition	Kharif 1997	Rabi 1997	Kharif 2018	Rabi 2018
Chittoor				
a) Average	6018	1327	7241	2097
b) Good	7543	7045	8835	2815
c) Very good	2093	4736	4371	12542
Nellore				
a) Average	11676	9584	13743	8052
b) Good	11576	20046	18082	19248
c) Very good	2459	6523	5383	27948
Kadapa				
a) Average	11376	17348	3883	13257
b) Good	24587	19760	14457	20891
c) Very good	23280	5364	66012	41371
Kurnool				
a) Average	13610	25837	17848	20260
b) Good	56781	34097	43291	37056
c) Very good	57109	6627	64123	77882

A comparison of changes that occurred in area of crops in kharif 1997 and 2018, and rabi 1997 and 2018 is made in Fig .4 (% area) and Fig. 5 (area in ha) using pooled NDVI in entire TGP command. Maximum area of 44% was in 'Good' category, followed by 37% in 'Very Good' category in kharif 1997, while 52% area was under 'Very Good' and 32% area was under 'Good' category in kharif 2018. Maximum area of 51% was in 'Good' category, followed by 34% in 'Average' category in rabi 1997, while maximum area of 56% was in 'Very Good' category, followed by 28% in 'Good' category in rabi 2018.

Table 4: District wise crop condition area (%) based on NDVI in TGP command

Crop condition	Kharif 1997	Rabi 1997	Mean 1997	Kharif 2018	Rabi 2018	Mean 2018
Chittoor						
a) Average	48	10	29	36	12	24
b) Good	39	54	46.5	43	16	29.5
c) Very good	13	36	24.5	21	72	46,5
Nellore						
a) Average	45	55	50	37	10	23.5
b) Good	45	27	36	49	35	42
c) Very good	10	18	14	14	55	34.5
Kadapa						
a) Average	19	41	30	05	17	06
b) Good	42	46	44	17	28	22.5
c) Very good	39	13	26	78	55	66.5
Kurnool						
a) Average	11	39	25	14	15	14.5
b) Good	44	51	47.5	35	27	31
c) Very good	45	10	27.5	51	58	54.5
Entire TGP						
a) Average	30.75	36.25	33.5	23	13.5	18.25
b) Good	42.5	44.5	43.5	36	26.5	31.25
c) Very good	26.75	19.25	23	41	60	50.5

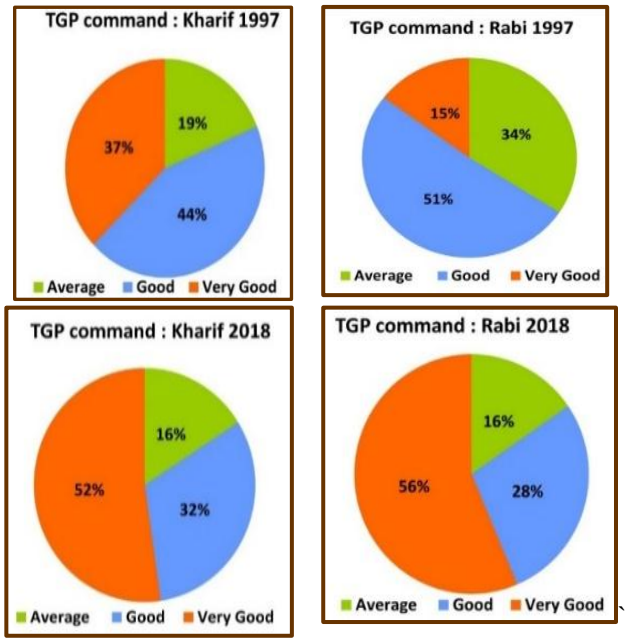


Fig. 4: Crop condition area (ha) based on NDVI in kharif & rabi of 1997 & 2018 in TGP command

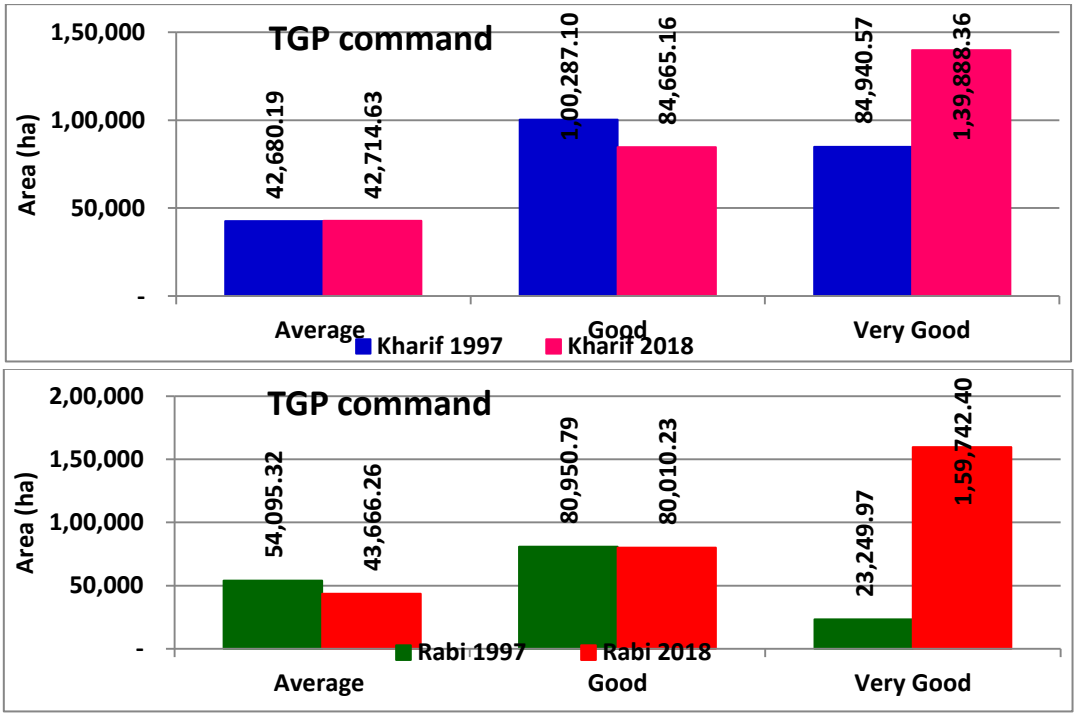


Fig. 5: Crop condition area (ha) based on NDVI in kharif & rabi 1997 & 2018 in TGP Command

The Effect of NDVI on paddy yield in different mandals of TGP command

A comparison of NDVI values of 1997 and 2018 in paddy observed in 33 mandals of entire TGP is made in Fig. 6. The NDVI of paddy observed in 1997 and 2018, and paddy yield during 2018 in 5 mandals of Chittoor, 11 mandals of Kadapa, 9 mandals of Kurnool and 8 mandals of Nellore are given in Table 5 and their descriptive statistics are given in Table 6.

The NDVI observed in paddy were significantly higher in 2018 compared to 1997 as indicated in Fig 15. There was a positive and significant increase in NDVI in 2018 for unit change in NDVI in 1997. The rate of change in NDVI was significant with magnitude of 0.82 and coefficient of determination (R^2) of 0.433 for predicting the changes.

In Chittoor with 5 mandals, NDVI of paddy ranged from 0.480 to 0.642 in 1997, while it ranged from 0.642 to 0.749 in 2018 with mean of 0.492 (CV of 2.3%) and 0.698 (CV of 5.9%) respectively. The paddy yield ranged from 5150 to 6230 kg/ha with mean of 5705 kg/ha (CV of 7.6%) over mandals. In Kadapa with 11 mandals, the NDVI of paddy ranged from 0.530 to 0.578 in 1997, while it ranged from 0.752 to 0.811 in 2018 with mean of 0.557 (CV of 2.7%) and 0.774 (CV of 2.7%) respectively. The paddy yield ranged from 3330 to 3970 kg/ha with mean of 3692 kg/ha (CV of 5.8%) over mandals. In Kurnool with 9 mandals, the NDVI ranged from 0.522 to 0.616 in 1997, while it ranged from 0.554 to 0.650 in 2018 with mean of 0.570 (CV of 6.4%) and 0.597 (CV of 6.2%) respectively. The paddy yield ranged from 5160 to 6312 kg/ha with mean of 5710 kg/ha (CV of 8.0%) over mandals.

In Nellore with 8 mandals, the NDVI ranged from 0.324 to 0.396 in 1997, while it ranged from 0.475 to 0.547 in 2018 with mean of 0.362 (CV of 6.7%) and 0.510 (CV of 4.1%) respectively. The paddy yield ranged from 6530 to 6946 kg/ha with mean of 6760 kg/ha (CV of 2.2%) over mandals. In entire TGP with 33 mandals, the NDVI ranged from 0.324 to 0.616 in 1997, while it ranged from 0.475 to 0.811 in 2018 with mean of 0.504 (CV of 17.6%) and 0.651 (CV of 16.9%) respectively. The paddy yield in TGP command ranged from 3330 to 6946 kg/ha with mean of 5291 kg/ha (CV of 23.8%).

The effect of NDVI on paddy yield in different mandals during 1997 is depicted in Fig. 7 (top) and linear relationship for pooled TGP is described in Fig.7 (bottom). The NDVI had a significant effect on paddy yield with negative rate of change of -9499 kg/ha for unit change in NDVI. The model gave significant R^2 of 0.443 for predicting changes in paddy yield attained in TGP command. During 1997, the rate of change in yield for unit change in NDVI was positive of 24436 kg/ha in Chittoor and 1489 kg/ha in Nellore, while it was negative of -228.8 kg/ha in Kadapa and -2019 kg/ha in Kurnool. The regression models gave R^2 of 0.398 for Chittoor, 0.001 for Kadapa, 0.058 for Nellore and 0.026 for Kurnool. The effect of NDVI on paddy yield attained in different mandals in 2018 is depicted in Fig.8 (top) and linear relationship for pooled TGP is depicted in Fig.8 (bottom). The paddy yield had a significant linear effect with negative rate of change of -10153 kg/ha for unit change in NDVI with significant R^2 of 0.786 for predicting changes in paddy yield. The paddy yield models of different districts through NDVI for 1997 and 2018 are given in Table 7.

Table 5: NDVI values and paddy yield (kg/ha) attained in different districts

Mandal	**Yield**	**NDVI value**									
	Paddy	**Paddy**		**Groundnut**		**Sugarcane**		**Jowar**		**Cotton**	
		1997	**2018**	**1997**	**2018**	**1997**	**2018**	**1997**	**2018**	**1997**	**2018**
Chittoor											
Thottambedu	5938	0.493	0.642	0.595	0.686	0.371	0.547				
B.N.Kandriga	5386	0.485	0.749	0.596	0.867	0.373	0.521				
KVB Puram	5150	0.480	0.698	0.574	0.842	0.365	0.573				
Varadaiahpalem	6230	0.494	0.722	0.584	0.856	0.376	0.524				
Satyavedu	5823	0.509	0.678	0.580	0.856	0.367	0.573				
Nellore											
Venkatagiri	6780	0.324	0.528	0.404	0.513	0.503	0.528				
Balayapalli	6620	0.348	0.516	0.380	0.498	0.433	0.516				
Pellakuru	6530	0.349	0.504	0.317	0.519	0.452	0.504				
DV Satram	6774	0.369	0.475	0.318	0.552	0.402	0.475				
Tada	6946	0.347	0.547	0.282	0.543	0.357	0.547				
Naidu peta	6822	0.375	0.508	0.303	0.499	0.398	0.508				
Chittamuru	6942	0.396	0.507	0.313	0.515	0.412	0.507				
Vakadu	6662	0.387	0.498	0.308	0.489	0.436	0.498				
Kurnool											

Velugodu	6220	0.606	0.629	0.653					0.460	0.544	0.658
B.Atmakur	6180	0.541	0.556	0.614					0.449	0.537	0.616
Mahanandi	6312	0.522	0.590	0.610					0.458	0.532	0.615
Nandyal	5940	0.614	0.636	0.650					0.751	0.547	0.649
Sirivella	5620	0.574	0.621	0.602					0.457	0.536	0.625
Rudravaram	5332	0.526	0.573	0.595					0.451	0.529	0.615
Allagadda	5260	0.578	0.568	0.609					0.452	0.538	0.578
Chagalamarri	5368	0.555	0.554	0.609					0.448	0.529	0.580
Gospadu	5160	0.616	0.650	0.633					0.454	0.543	0.709
Kadapa											
Atluru	3889	0.554	0.759	0.558	0.716			0.563	0.716	0.563	0.760
B.Koduru	3590	0.553	0.761	0.558	0.717			0.503	0.717	0.503	0.809
Badvelu	3730	0.556	0.766	0.555	0.716			0.585	0.716	0.585	0.756
B.Matham	3876	0.542	0.781	0.556	0.714			0.524	0.714	0.524	0.786
Duvvuru	3550	0.578	0.811	0.588	0.729			0.613	0.729	0.613	0.810
Gopavaram	3970	0.552	0.761	0.537	0.707			0.596	0.707	0.596	0.725
Kalasapadu	3890	0.561	0.762	0.563	0.716			0.599	0.716	0.599	0.773
Khajipeta	3450	0.576	0.807	0.607	0.718			0.618	0.718	0.618	0.831
Porumamilla	3330	0.546	0.752	0.562	0.717			0.552	0.717	0.552	0.776
Narasapur	3530	0.530	0.762	0.549	0.710			0.510	0.710	0.510	0.826
Mydukur	3810	0.577	0.795	0.597	0.718			0.593	0.718	0.593	0.771

Table 6: Descriptive statistics of NDVI & paddy yield attained in different districts & TGP command in 1997 & 2018

Statistic	Yield (kg/ha)	NDVI : 1997	NDVI : 2018
Chittoor (5 mandals)			
Minimum	5150	0.480	0.642
Maximum	6230	0.509	0.749
Mean	5705	0.492	0.698
SD	434	0.011	0.041
CV (%)	7.6	2.3	5.9
Kadapa (11 mandals)			
Minimum	3330	0.530	0.752
Maximum	3970	0.578	0.811
Mean	3692	0.557	0.774
SD	212	0.015	0.021
CV (%)	5.8	2.7	2.7
Kurnool (9 mandals)			
Minimum	5160	0.522	0.554
Maximum	6312	0.616	0.650
Mean	5710	0.570	0.597
SD	457	0.037	0.037
CV (%)	8.0	6.4	6.2
Nellore (8 mandals)			
Minimum	6530	0.324	0.475
Maximum	6946	0.396	0.547
Mean	6760	0.362	0.510
SD	148	0.024	0.021
CV (%)	2.2	6.7	4.1
Entire TGP command (33 mandals)			
Minimum	3330	0.324	0.475
Maximum	6946	0.616	0.811
Mean	5291	0.504	0.651
SD	1260	0.088	0.110
CV (%)	23.8	17.6	16.9

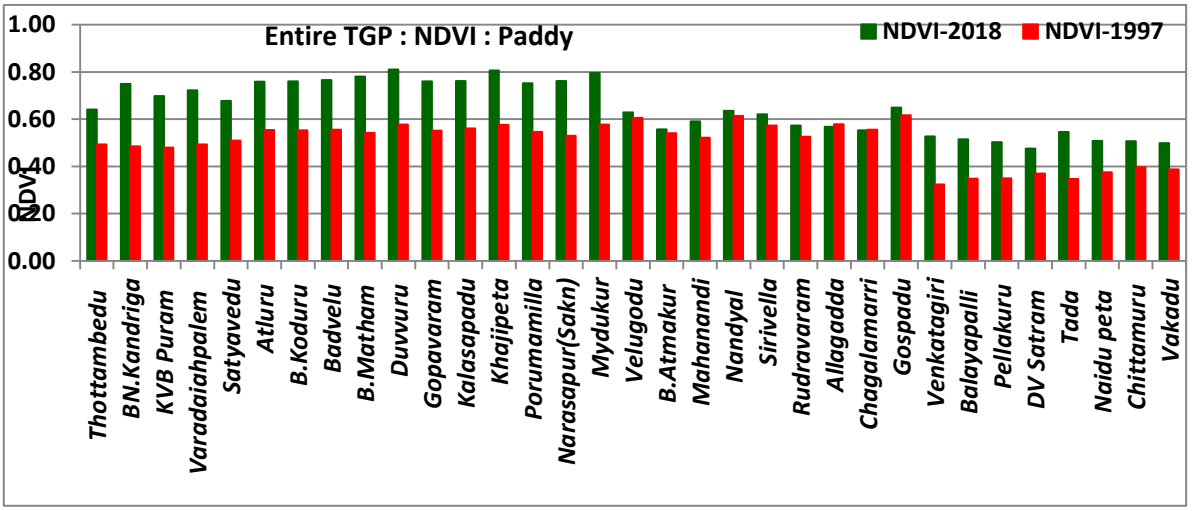


Fig. 6: Comparison of NDVI of 1997 & 2018 in paddy in mandals of TGP command

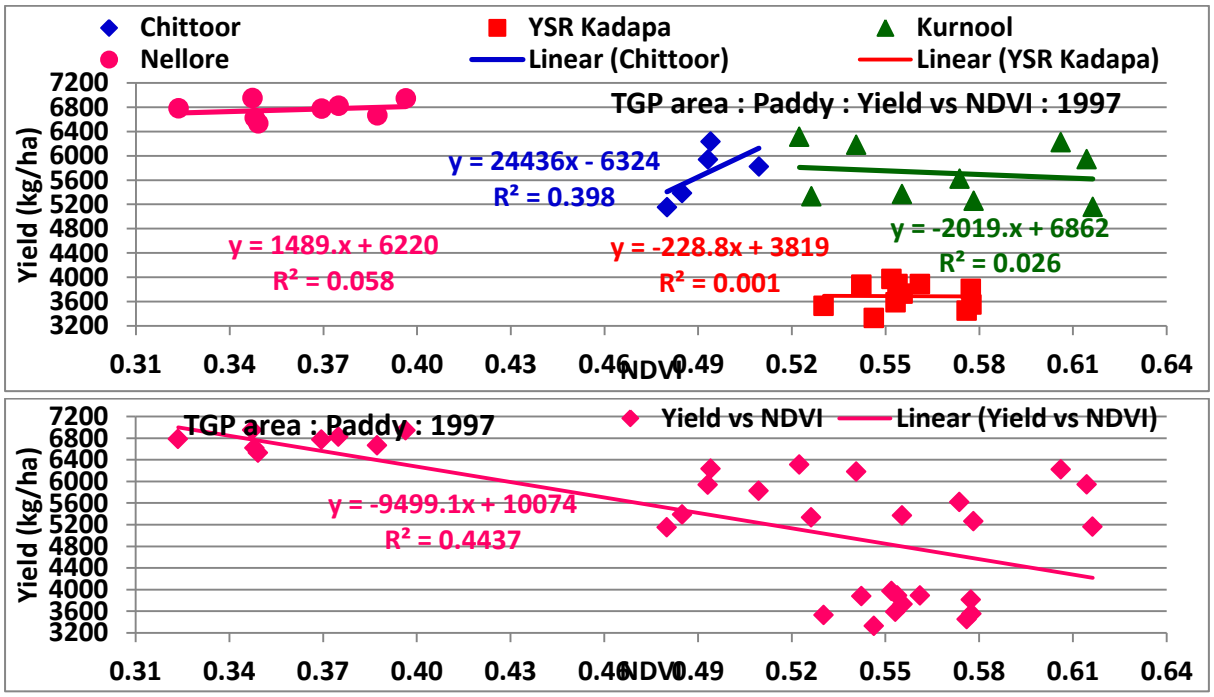
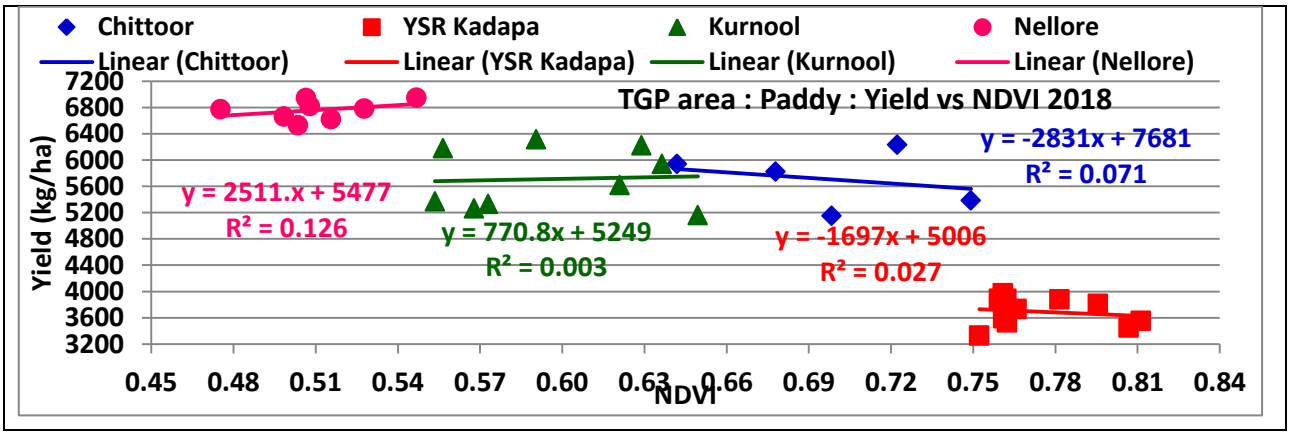


Fig. 7: Effect of NDVI on paddy yield attained in 33 mandals of TGP command in 1997



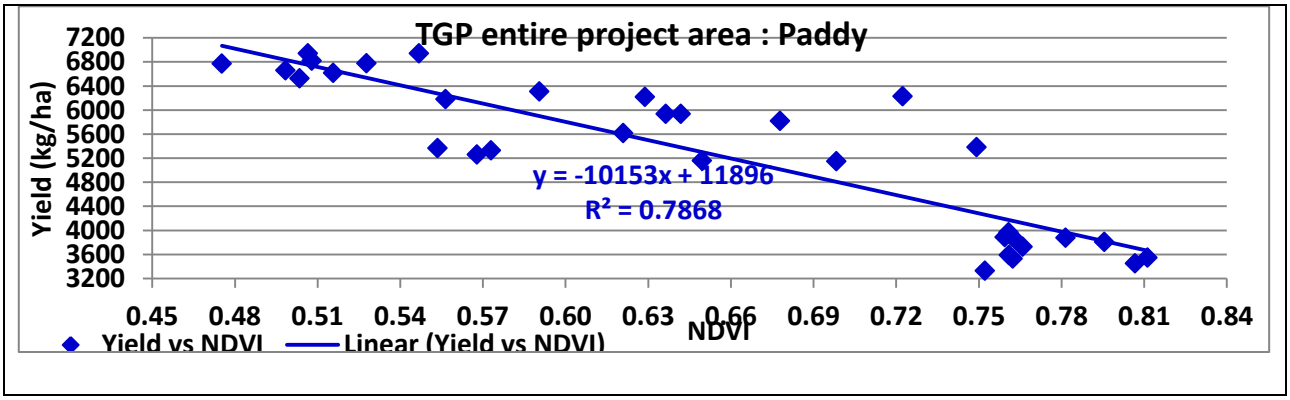


Fig. 8: Effect of NDVI on paddy yield attained in 33 mandals of TGP command in 2018

Table 7: Regression models of paddy yield through NDVI in different districts & TGP command

Year	District	Regression model	R^2
1997	Chittoor	Y = – 6324 + 24436 (NDVI)	0.398
	Nellore	Y = 6220 + 1489 (NDVI)	0.058
	Kurnool	Y = 6862 – 2019 (NDVI)	0.026
	Kadapa	Y = 3819 – 228.8 (NDVI)	0.001
	Entire TGP	Y = 10074 – 9499.1 (NDVI)	0.444
2018	Chittoor	Y = 7681 – 2831 (NDVI)	0.071
	Nellore	Y = 5477 + 2511 (NDVI)	0.126
	Kurnool	Y = 5249 + 770.8 (NDVI)	0.003
	Kadapa	Y = 5006 – 1697 (NDVI)	0.027
	Entire TGP	Y = 11896 – 10153 (NDVI)	0.787

CONCLUSIONS

With the objective of assessing effect of NDVI on crop yield, a study was conducted to assess yields and NDVI of crops in Chittoor, Nellore, Kurnool and Kadapa under TGP in Andhra Pradesh during 1997 and 2018. Assessment of crop condition was made using NDVI based on remote sensing images. We assessed changes in area (ha) and change (%) in area of crops in kharif and rabi and total area in 2018 compared to 1997. Shift in paddy area under early, medium and late sowings in kharif and rabi seasons of 1997 and 2018, total area (ha) and its change (%) were assessed. Area of paddy, groundnut, sugarcane, jowar, cotton, sunflower, bajra, pulses and chillies were analyzed in the study. In 1997, total area ranged from 1875 ha for pulses to 78688 ha for paddy, while area was 35181 ha for groundnut, 24707 ha for jowar, 17660 ha for cotton, 14601 ha for sunflower, 13442 ha for chillies, 8673 ha for sugarcane and 3199 ha for bajra. In 2018, total area ranged from 1163 ha for bajra to 180351 ha for paddy, while jowar had an area of 24218 ha, followed by chillies with 18420 ha, groundnut with 16152 ha, sunflower with 16100 ha, cotton with 14942 ha, pulses with 10032 ha and sugarcane with 4113 ha. The change in total area was 435% for pulses, followed by 129.2% for paddy, 37% for chillies and 10.3% for sunflower, while it was negative of -63.6% for bajra, -54.1% for groundnut, -52.6% for sugarcane, -15.4% for cotton and -2% for jowar.

Using NDVI of TGP command, in kharif 1997, area of 44% was in ‘Good’ and 37% was in ‘Very Good’ category, while in kharif 2018, 52% area was ‘Very Good’ and 32% area was ‘Good’. In rabi 1997, 51% area was ‘Good’ and 34% was ‘Average’, while in rabi 2018, 56% was ‘Very Good’ and 28% was ‘Good’. Using regression model of yield through NDVI, there was a positive and significant increase in NDVI in 2018 with unit

change in NDVI in 1997. The rate of change in NDVI was significant (coefficient of 0.82) and R^2 of 0.433. NDVI had a significant effect on paddy yield with significant R^2 of 0.443. It is observed that NDVI had a positive effect on yield in Chittoor and Nellore, while it was negative in Kadapa and Kurnool. The findings based on our study are useful to planners and researchers for further improvement in the crop area and better management of water and other resources for attaining higher yields of paddy and other crops under Telugu Ganga Project in Andhra Pradesh.

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