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Impact of Telugu Ganga Project on Irrigation Efficiency and Crop Yield in Nellore District, Andhra Pradesh, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A study was conducted to assess the effect of rainfall and canal water on paddy and groundnut yield in Nellore under Telugu Ganga Project (TGP) command in Andhra Pradesh. The evaluation was made using different indicators at the start (1997) and end of the study (2018). The study focused on evaluation of TGP for assessing the crop condition, inventory, calendar, irrigation potential, irrigation scheduling and yield attained in the command. Optimization was done to identify suitable rainfall and canal water levels for maximizing the yield. Paddy area significantly increased by 129.2% (78688 to 180351 ha) due to supply of canal water, while groundnut area decreased by 54.1% (35181 to 16152 ha) over years. Based on NDVI, maximum *kharif* paddy area of 44% was under 'good' category in 1997, while 52% was under 'very good' category in 2018.Maximum *rabi* paddy area of 51% was in 'good' category in 1997, while 56% was under 'very good' category in 2018. In Nellore, mean equity of 60.3% (CV of 55%), uniformity of 69% (CV of 44.5%), irrigation intensity of 72.1% (CV of 62.7%), consumed ratio/efficiency of 50.9% (CV of 53.3%), adequacy of 159% (CV of 24.5%) andyield of 5552 kg/ha (CV of 25.6%) were observed. Among 8 mandals of Nellore, NDVI of paddy ranged from 0.324-0.396 with mean of 0.362 (CV of 6.6%) in 1997, while it ranged from 0.475-0.547 with mean of 0.510 (CV of 4.2%) in 2018. In groundnut, NDVI ranged from 0.282-0.404 with mean of 0.328 (CV of 12.7%) in 1997, while it ranged from 0.489-0.552 with mean of 0.516 (CV of 4.3%) in 2018. Among 33 mandals of TGP command, NDVI of paddy ranged from 0.324-0.616 with mean of 0.503 (CV of 17.6%) in 1997, while it ranged from 0.475-0.811 with mean of 0.650 (CV of 16.9%) in 2018. In groundnut, NDVI ranged from 0.282-0.653 with mean of 0.526 (CV of 22.5%) in 1997, while it ranged from 0.489-0.867 with mean of 0.667 (CV of 15.9%) in 2018.

Keywords: Telugu ganga project; NDVI; canal water; rainfall; performance indicators; correlation; regression.

1. INTRODUCTION

The Telugu Ganga irrigation project is an inter-state project formulated to irrigate 5.75 lakh ac in drought prone areas of Rayalaseema region comprising of Chittoor, Kadapa, Kurnool and uplands of Nellore in Andhra Pradesh by utilising 29 TMC of water from Krishna flood flows, and 30 TMC of water from Pennar river flood flows. With a view to provide drinking water facility to Chennai in Tamil Nadu, the three Krishna basin states of the former combined Andhra Pradesh, Karnataka and Maharashtra have agreed to spare 5 TMC water each from their shares of Krishna river water for meeting the drinking water requirements. In 1977, the project was approved after reaching an agreement between Tamil Nadu, Andhra Pradesh, Maharashtra and Karnataka. Based on the agreement, each state would contribute 5 billion cubic feet ($140×10^6$ m^3) of water annually, for total supply of 15 billion cubic feet ($420×10^6$ m^3). Subsequently, this quantity of water was reduced and revised to 12 billion cubic feet ($340×10^6$ m^3) in 1983 after considering seepage and evaporation losses.

1.1 Study Area

1.1.1 Telugu ganga project jurisdiction

The study area of Telugu Ganga Project (TGP) is shown in Fig. 1. The command area lies between the Northern Latitudes of 14^0 54' and 16^0 18' and Eastern Longitudes of 76^0 58' and 79^0 34'.The TGP main canals covering part of the four districts viz., Chittoor (05 mandals), Nellore (08 mandals), Kurnool (09 mandals), and Kadapa (13 mandals) and total TGP command area covering about 33 mandals.

The annual rainfall of TGP command ranged from 675 to 933 mm compared to normal rainfall of 1134 mm. Every year, the South-West monsoon contributes 70% of the total rainfall, while the remaining three seasons contribute 30% of rainfall. The normal rainfall of South-West monsoon is about 525 mm, which is 70% of the annual rainfall and would play a vital role on the crop production during *kharif* season. (Abdelhadi, A.W *et al*, 2000) .The North-East monsoon would account for the remaining 25 to 30% of annual rainfall.

Ramana (2007) evaluated the canal irrigation systems using remote sensing and GIS for Krishna Western Delta (KWD) with performance indicators of crop condition, crop inventory, crop calendar, yield estimation, irrigation intensity, adequacy and equity distribution of water. Paddy was grown in 90% area, while annual crops were grown in the remaining area (Arunadevi, K. 2017.) NDVI indicated that 52% crop came under good category in 2005 compared to 7% in 1998. Irrigation intensity exceeded 90% in all canal commands, while irrigation efficiency was 42% due to excess water availability. Cultivators are increasingly arranging innovative high technical and scientific estimation to enhance sustainability, effectiveness and plant health. RS may provide framework to systematically consider these issues of smart farming technology to embed high-tech agriculture better. (Bhandarkar, D.M., et al, 2004). The impact is beneficial depending on how data mining, imagery technologies and analysis are applied.

Molden and Gates (1990) developed performance measures for analysis of irrigation water delivery systems in terms of adequacy, efficiency, dependability and equity of the water delivery. These measures could be incorporated in a regular monitoring program which would provide frame work for making assessment of alternatives for system improvement. Bos *et al*. (1994) suggested indicators that are related to the performance of (i) water delivery system, (ii) environment and (iii) irrigated agricultural system. The frame work of indicators includes environment sustainability features to evaluate long-term effects of irrigation on environment like changes in the groundwater table. In order to make an effective performance oriented approach, it is necessary to retrofit new techniques and approaches to existing management practices. Evaluation of efficiency of irrigation water use has under gone major modifications during last 35 years (Bos and Nugteren, 1974).

Bastiaanssen and Bos (1999) assessed the irrigation performance indicators based on remote sensing data. The AET, soil water content and crop growth reflect overall water utilization up to field level. Crop evapotranspiration includes water originating from irrigation supply, water from precipitation, groundwater and water withdrawn from unsaturated zone. Hence, this is a refinement in spatial scale compared to classically collected flow measurements and describes depletion from all water resources.

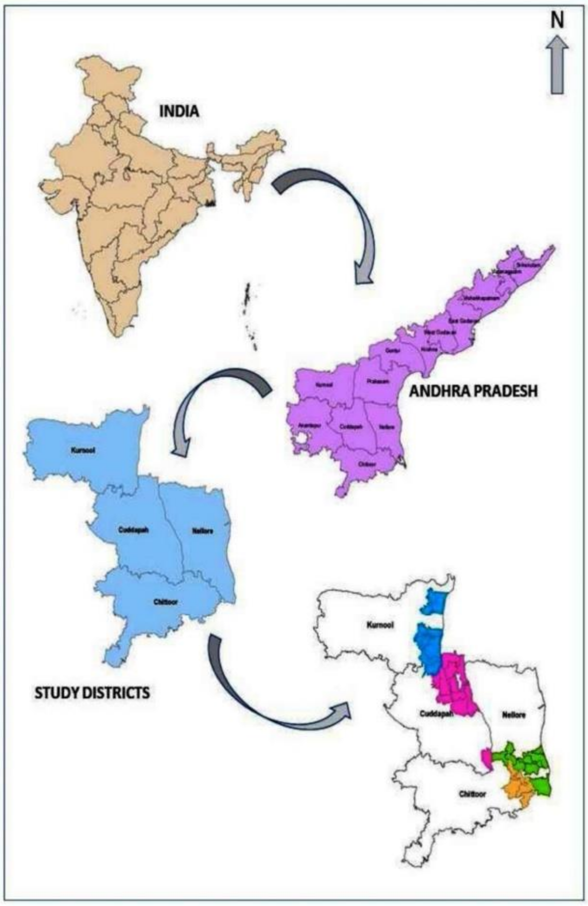


Fig. 1. Study area of Telugu Ganga project

Rodriguez *et al*. (2008) developed a methodology to assess performance indicators of 9 irrigation districts in Andalusia in Spain. The methodology is based on cluster analysis which enabled the districts to be classified into homogeneous groups. Districts were ranked based on an index which aggregates all aspects of the proposed methodology. Cakmak*et et al*. (2009) evaluated irrigation system performance of water user associations in Asartepe irrigation scheme in Turkey. The amount of water delivered to command area, irrigated area and relative water supply were determined, apart from assessing financial, productive and water delivery performances. Gomez and Gomez (1984) described on the computation and testing of correlation between variables. (Karim Ennouri and Abdelaziz Kallel. 2019.) Correlation analysis is carried out to assess the type of relationship viz., positive or negative relationship, apart from the magnitude of relationship and its significance. (Draper, N.R. and Smith, H. 1998)

2. MATERIALS AND METHODS

A study was conducted with the objective to assess the performance of Telugu Ganga project(TGP) in Nellore district and compared with the over-all performance in the entire TGP command comprising of 4 districts of Chittoor, Nellore, Kurnool and Kadapa in Andhra Pradesh during 1997 to 2018. Observations were collected on the rainfall, canal water releases for irrigation, cropping pattern, NDVI, crop area and yield of paddy and groundnut, shifting of crop calendar or sowing of crops. The data were analyzed for assessing the variability, relationships, changes occurred over years and effects of parameters on crop yield, and evaluation was made based on different performance indicators.

The main crop seasons in the TGP command are *kharif* (June–September), *rabi*(October–December) and summer (January–April). The rice-based cropping systems are predominant in the TGP command grown during *kharif*, while groundnut, black gram, green gram, jowar, cotton and chilies are grown in the rice fallows during *rabi* with under residual moisture condition. Sugarcane is grown throughout the year. Rice is mostly grown by the traditional method of growing the nursery and transplanting in the main field with continuous flooding of irrigation water. Nellore has a command area of 98270 ha with 8 mandals in the TGP command viz., Venkatagiri, Balayapalli, Pellakuru, DV Satram, Tada, Naidupeta, Chittamuru and Vakadu. The entire TGP command has 33 mandals with an area of 230000 ha in the project. (Ahmad, T et al, 2016. It was evaluated the impact of TGP command on the performance of crops before (1997) and after (2018) completion of the TGP in Andhra Pradesh.

Paddy is the major crop (around 80% of total crop area), while remaining 20% area is on sugarcane, groundnut, cotton, bajra, jowar, cotton, sunflower and chilies. Since the objective of this study is to map different paddy stages with respect to the lag period in different transplantation stages, one classification approach may not give a desired result. (Ganesh, B.R et al, 2014).

2.1 Normalized Difference Vegetation Index(NDVI)

One of the widely used indices for vegetation monitoring is the Normalized Difference Vegetation Index (NDVI). Spectral reflectance represented by digital number in satellite image is the ratio of energy that is reflected from an object to the energy incident on the object. Spectral reflectance of a crop differs considerably in the near infrared region (λ=700-1300 nm) and in visible red range (λ=550-700 nm) of the electromagnetic spectrum (Kumar *etal*., 2004). Plants have a low reflectance in the blue and red portion of the spectrum because of chlorophyll absorption, with a slightly higher reflectance in the green, so plants appear green to our eyes. (Ramesh, S.H. and Dennis, G.D. 1995.) Near infrared radiant energy is strongly reflected from the plant surface and the amount of this reflectance is determined by the properties of leaf tissues. The live green plants appear relatively dark in PAR and bright in near infrared (David Gates, 1980).

NDVI is calculated from the individual measurements as follows:

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

Where

ρ_{NIR} = reflectance of band at NIR (0.87 µm); ρ_{RED} = reflectance of band at RED (0.66 µm).

2.2 Assess Surface Water Resources for Irrigation Purpose

Estimates of crop water requirement of paddy and groundnut were derived using CROPWAT

8.0 software. CROPWAT is a program that uses modified Penman-Monteith method for determining reference crop evapotranspiration. The parameters required to get the crop water requirement arerainfall,crop,soil and cropping patterns. (Mehanuddin, H., et al, 2018) The data of periodical weather parameters were collected from the Automatic Weather Station (AWS) located in Vijayawada, Andhra Pradesh andused for determining the crop water demand viz., (Mishra, A.K., et al, 2000).

(a) Annual rainfall (mm), maximum and minimum temperature (°C), relative humidity (%), wind speed(km/hr)
and solar radiation (No. of sun shine hours);
(b) Mandal-wise cropping pattern of Nellore district;
(c) Water discharge data (collected from TGP office);
(d) Groundwater table fluctuation data of pre-monsoon and post-monsoon seasons (collected from Ground
Water Department, Vijayawada).

2.3 Assessment of Groundwater Resources using Water Table Fluctuation Method

Water Table Fluctuation (WTF) method is based on the premise that raises in groundwater levels in unconfined aquifers are due to recharge water arriving at the water table (Healy and Cook, 2002). (Usman, M., et al, 2016). Recharge is calculated as

$$R= S_y \, dh/dt \qquad (2)$$

Where

R is recharge, S_y

is specific yield, h is water-table height, and 't' is time. WTF represents spatially averaged recharge. Determining representative values of S_y is difficult to apply this method. Another difficulty lies in ensuring that the fluctuations in water levels are due to recharge and not due to changes in atmospheric pressure, presence of entrapped air or pumping. (Zhou, H and Zhao, W.Z. 2019)

2.3.1 Assessment of water delivery system using performance indicators

Intensity of irrigation: The intensity of irrigation (I) canbe expressed as a percentage value. It is defined as an area of a particular season with respect to the culturable command area.

$$I = [\text{Total area irrigated X 100}]/[\text{Culturable command area}] \qquad (3)$$

Uniformity index: The Uniformity index indicates about how best the water could be distributed among different canal commands within a large irrigation system. (Pushpalatha, R. *et al.,* 2020) It is estimated based on (i) depth of water applied in the individual command; and (ii) depth of water applied in the entire TGP command level (Wolters, W. 1992).

$$\text{Uniformity index} = [(A_x)/(V_x)] / [(A_t)/(V_t)] (4)$$

WhereA_x=Irrigated area in the individual command x; V_x= Volume of water applied to the individual command x; A_t =Irrigated area in the individual command t; V_t= Volume of water applied to the individual command t.

Overall consumed ratio: The overall consumed ratio (efficiency) indicates about the degree to which the crop irrigation requirement is met by the irrigation water(Bos and Nugteren, 1974).The ratio is given as

$$\text{Overall consumed ratio} = (ET_p—P_e)/Vi \quad (5)$$

Where ET_p=Potential evapotranspiration (m^3); P_e=Effective precipitation (m^3);
V_i=Volume of irrigation water applied to the command i (m^3)

Equity: Equity is defined as the actual flow per unit irrigated area. Itis nothing but a measure to assess the temporal variability of the available water within each command. (Salam, H.,et *a*l, 2019)

$$\text{Equity} = Vi/Ai \qquad (6)$$

WhereV_i = Volume of irrigation water (m^3)applied to command i; A_i = Irrigated area of command 'i'.

Adequacy/Relative irrigation supply: The Adequacy/Relative irrigation supply is the ratio of irrigation water supplied to the irrigation water demand including deep percolations (Molden *et al.,* 1998).

$$\text{Adequacy/Relativeirrigation supply} = [\text{Irrigation water supplied}]/ [\text{Irrigation water demand}] =(V_i + R_f)/(ET_p—D_p)(7)$$

Where V_i=water supplied (mm);R_f=Rainfall (mm); ET_p=Potential Evapotranspiration (mm); D_p=Deep percolation losses (mm).

Productivity: The performance indicators listed here relate the output to unit land and water. The indicators provide a basis for comparing the irrigated agricultural performance. If water is a constraint, output per unit of water *would become important.t* Shakthivadivel, R*. et al* 1999). The yield per unit area is given as

Yield per unit area = [Total yield (kg)]/[Total area (ha)] (8)

Yield per unit area = [Total yield (kg)]/[Total water supplied (m^3)] (9)

The yield per unit of water consumed is given as

Yield per unit of water consumed = [Total yield (kg)]/[Total water consumed (ETp)].(10)

In order to assess the crop yield ratio (CYR), it should be related to the intended crop yield. The yield attained could be taken from different pilot areas and crop yield ratios could be determined (Molden *et al.,* 1998). The cropping practices adopted by the farmers under different commands could be considered (Molden and Sakthi Vadivel, 1999).

CYR = [Yield attained in the command]/[Maximum yield attained in research station] (11)

3. RESULTS AND DISCUSSION

The area of paddy and groundnut were collected in the TGP command during *kharif* and *rabi* seasons and derived total area (ha) used for growing crops during 1997 and 2018. The area (ha) of crops observed during *kharif* and *rabi* 1997 and 2018 and the percentage change in area of crops over years in the TGP command are given in Table 1. The Descriptive statistics of NDVI of paddy and groundnut in Nellore and TGP command during 1997 and 2018 are shown in Table 2.

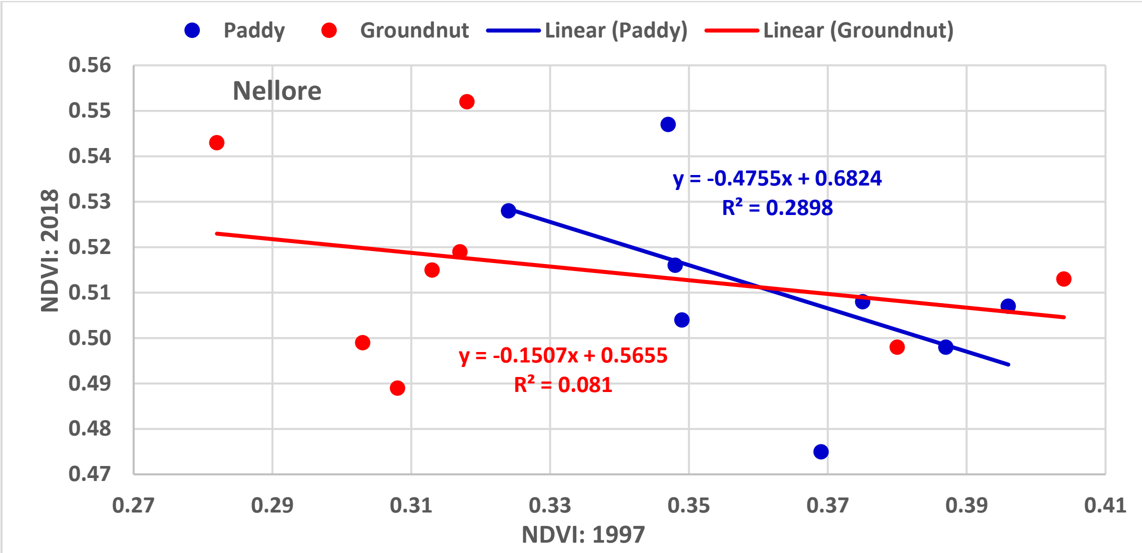
The Changes in NDVI of paddy and groundnut in Nellore and TGP command during 1997 and 2018 is depicted in Fig. 2.

Table 1. Area (ha) ofcrops in *kharif* and *rabi*1997 and 2018 in TGP command

Crops	1997			2018			Change (%)		
	Kharif	***Rabi***	**Total**	***Kharif***	***Rabi***	**Total**	***Kharif***	***Rabi***	**Total**
Paddy	53674	25014	78688	85138	95213	180351	58.62	280.64	129.20
Groundnut	16055	19126	35181	4368	11784	16152	-72.79	-38.39	-54.09
Total	69729	44140	113869	89506	106997	196503	28.36	142.40	72.57

Table 2. Descriptive statistics of NDVI of paddy and groundnut in Nellore and TGP command during 1997 and 2018

Statistic	Paddy		Groundnut	
	1997	**2018**	**1997**	**2018**
Nellore				
Minimum	0.324	0.475	0.282	0.489
Maximum	0.396	0.547	0.404	0.552
Mean	0.362	0.510	0.328	0.516
Standard deviation	0.024	0.021	0.042	0.022
CV (%)	6.6	4.2	12.7	4.3
TGP command				
Minimum	0.324	0.475	0.282	0.489
Maximum	0.616	0.811	0.653	0.867
Mean	0.503	0.650	0.526	0.667
Standard deviation	0.088	0.110	0.118	0.106
CV (%)	17.6	16.9	22.5	15.9



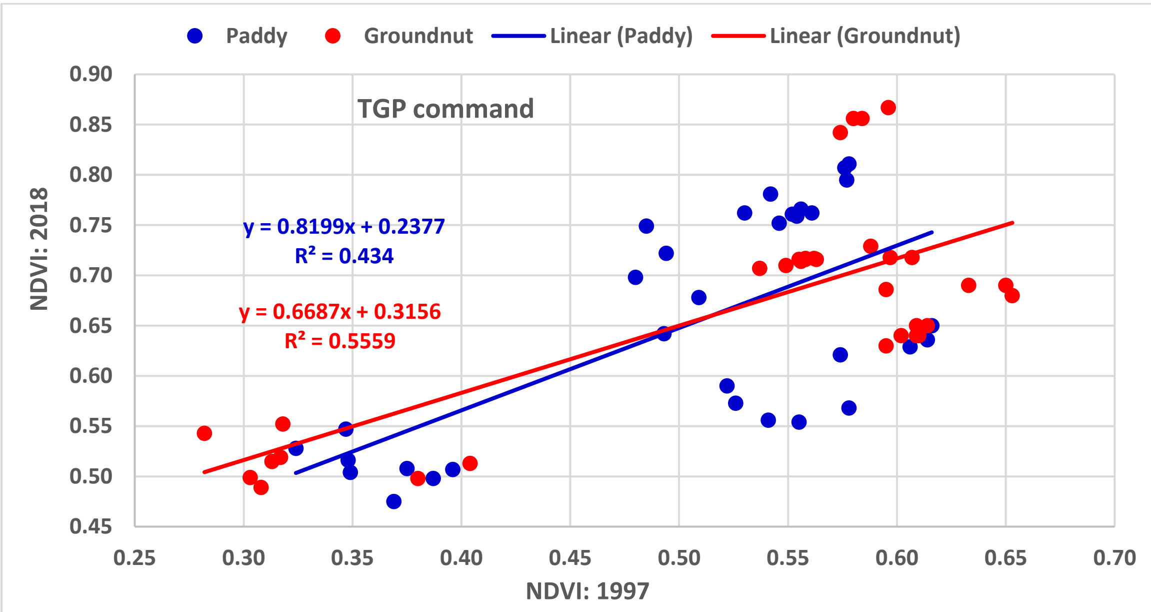


Fig. 2. Changes in NDVI of paddy and groundnut in Nellore and TGP command during 1997 and 2018

Table 3. Crop condition based on NDVI in Nellore and TGP command during 1997 and 2018

Crop condition	*Kharif 1997*		*Rabi 1997*		*Kharif 2018*		*Rabi 2018*	
	Area (ha)	%	Area (ha)	%	Area (ha)	%	Area (ha)	%
Nellore								
Average	11676	45.0	9584	55.0	13743	37.0	8052	10.0
Good	11576	45.0	20046	27.0	18082	49.0	19248	35.0
Very good	2459	10.0	6523	18.0	5383	14.0	27948	55.0
TGP								
Average	42680	30.7	54095	36.3	42714	23.0	43666	13.5
Good	100287	42.5	80951	44.5	84665	36.0	80010	26.5
Very good	84941	26.7	23250	19.3	139888	41.0	159742	60.0

Table 4. Mean monthly and effective rainfall received in Nellore and TGP command during 1997 to 2018

Month	Effective rainfall (mm)		Rainfall (mm)	
	Nellore	Entire TGP	Nellore	Entire TGP
January	15.7	7.6	16.1	7.8
February	14.5	7.2	14.9	7.4
March	17.1	10.0	17.6	10.2
April	37.7	25.5	40.3	26.8
May	31.3	35.9	33.0	38.3
June	51.8	67.5	57.0	78.7
July	73.7	87.3	85.4	106.2
August	94.2	105.0	115.5	134.9
September	80.8	93.0	95.4	114.7
October	150.2	124.9	252.3	187.1
November	151.6	98.0	266.4	157.2
December	94.7	52.3	122.5	65.0
Total	*813.4*	*714.2*	*1110.4*	*932.8*
Minimum	*14.5*	*7.2*	*14.9*	*7.4*
Maximum	*151.6*	*124.9*	*266.4*	*187.1*
Mean	*67.8*	*59.5*	*93.0*	*77.9*
SD	*48.7*	*42.0*	*86.5*	*62.1*
CV (%)	*71.8*	*70.6*	*92.9*	*79.8*

Table 5. The crop water demand of paddy and groundnut in TGP command

Year	Crop	***Kharif***			***Rabi***			Total		
		Area (ha)	CWR (mm)	CWD (Mcum)	Area (ha)	CWR (mm)	CWD (Mcum)	Area (ha)	CWD (Mcum)	Canal water released (Mcum)
1997	Paddy	53674	516	277	25014	544	136	78688	413	101
	Groundnut	16055	341	55	19126	344	66	35181	121	
	Total									
2018	Paddy	85138	533	454	95213	554	527	180351	981	959
	Groundnut	4368	329	14	11784	349	41	16152	55	
	Total									

Table 6. Canal water released in Nellore and TGP command during 1996 to 2019

Year	Canal water release (Mcum)	
	Nellore	Total TGP
1996	78.75	78.75
1997	100.87	100.87
1998	121.69	125.07
1999	79.75	81.97
2000	367.84	378.07
2001	86.35	88.75
2002	126.00	129.50
2003	56.91	58.49
2004	122.35	1020.93
2005	103.29	1134.64
2006	328.94	1931.60
2007	180.57	1398.46
2008	525.03	2201.35
2009	549.82	1351.69
2010	371.98	1805.69
2011	626.90	1931.85
2012	375.46	1147.49
2013	710.00	1780.00
2014	614.00	1591.00
2015	337.00	573.00
2016	412.00	1375.00
2017	522.00	1272.00
2018	0	959.00
2019	650.00	1969.00
Total	*7447.49*	*24484.17*
Minimum	*56.91*	*58.49*
Maximum	*710.00*	*2201.35*
Mean	*323.80*	*1020.17*
SD	*219.92*	*739.08*
CV(%)	*67.9*	*72.4*

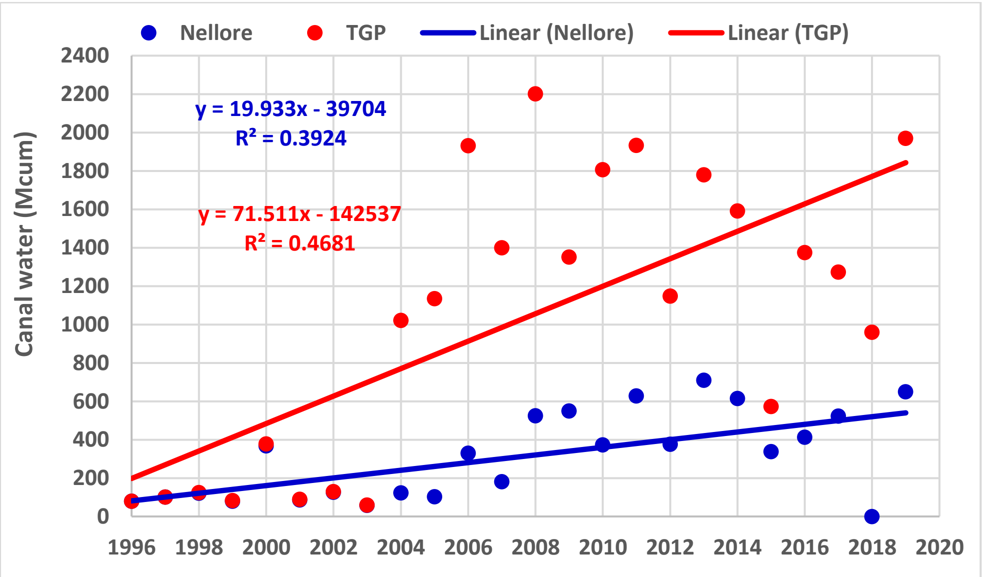


Fig. 3. Changes in canal water released in Nellore and entire TGP command during 1996 to 2019

Table 7. Crop water demand and canal water released during1997and 2018

Year	Crop	CWD(Mcum)	Canal water release(Mcum)	Remarks
1997	Paddy	754		
	Groundnut	176		
	Total	930	101	Deficit of 829Mcum
2018	Paddy	1435		
	Groundnut	69		
	Total	1504	959	Deficit of 545Mcum

3.1 Assessment of Crops Based on NDVI

A comparison of changes occurred in the area of crops and crop condition during *kharif* and *rabi* 1997 and 2018 was made using the pooled data of NDVI under TGP command. It is possible to assess and map the crop condition on a quantitative basis. Based on the location specific crop condition, the reasons for poor condition could be ascertained and interventions could be made. The crop condition was monitored in the TGP during *rabi*1997 and 2018 based on a detailed qualitative analysis. The spatial variation of crop condition in terms of the qualitative condition viz., very good, good and average was made with a high accuracy.

In *kharif* season, maximum area of 44%was under 'good' category, followed by 37% under 'very good' category in 1997, compared to 52% area under 'very good' and 32% area under 'good' categories in 2018. During *rabi* season, maximum area of 51% was under 'good' category, followed by 34% under 'average' category in 1997, while 56%was under 'very good' category, followed by 28% under 'good' category during 2018. The changes occurred due to change in the crop calendar, management practices and adoption of short duration varieties by farmers. The crop condition through NDVI like average, good, very good and area (ha and%) observed in Nellore and TGP command during 1997 and 2018 in *kharif* and *rabi* seasons are given in Table 3.

3.1.1 Assessment of water resources for irrigation in TGP command

The quantity of surface and groundwater would carry maximum importance in terms of deciding about the feasibility for irrigation of any crop grown in the TGP command. Before estimating the quantity of surface water, observations of rainfall received during 1997 to 2018 were collected and analyzed. (Naik, B.R. 2016.)

3.1.2 Effective rainfall and crop water demand

Under CROPWAT model, derivations were made after computerizing the rainfall and crop water demand on seasonal basis (*kharif* and *rabi)*. The estimates of effective rainfall derived for the TGP command are given in Table 4. This information will be used for calculating the performance indicators of paddy grown in the study area.

3.1.3 The crop water demand in the TGP command

The crop-wise and total area (ha), crop water requirement (mm), crop water demand (Mcum) in *kharif* and *rabi* seasons of different crops are given in Table 5. The crop water demand (Mcum) of paddy and groundnut in Nellore and TGP command during *kharif*, *rabi* and total (*kharif+rabi*) for 1997 and 2018were derived using CROPWAT software model.

3.1.4 Assessment of canal water released in Nellore and TGP command

The details of canal water released in Nellore district and the entire TGP command during 1996 to 2019are given in Table 6. The Changes in canal water released in Nellore and entire TGP command during 1996 to 2019 Fig. 3.

3.1.5 Crop water demand and canal water released for crops during 1997 and 2018

The details of CWD (Mcum) and canal water released (Mcum) for paddyand groundnut during 1997 and 2018 are given in Table 7.

3.1.6 Performance indicators of Nellore district

The performance indicators determined for the Nellore district andthe values of equity (%), uniformity (%), irrigation intensity (%), over-all

Table 8. Performance indicators of Nellore during 2013 to 2019

Year	Equity (%)	Uniformity (%)	Irrigation intensity (%)	Over-all consumed ratio/ efficiency (%)	Adequ acy (%)	Yield (kg/ha)	Yield (kg/m^3)	Yield (kg/m^3) of ETo	Crop yield ratio	Irrigation water supplied (m^3)	Water consumed ETp (m^3)	Yield/ water supplied (kg/m^3)	Yield/ water consumed (kg/m^3)
2013	49	76	146.5	43	189	4051	0.06	0.13	0.58	710	305.2	5.7	13.3
2014	83	82	74.3	50	173	4025	0.07	0.13	0.58	614	306.7	6.6	13.1
2015	42	85	81.3	78	220	6711	0.19	0.25	0.96	337	262.9	19.9	25.5
2016	100	82	41.5	65	110	6341	0.15	0.24	0.91	412	267.8	15.4	23.7
2017	78	74	67.1	78	118	6924	0.13	0.17	0.99	522	407.4	13.3	17.0
2018	0	0	0.0	0	144	6760	0.00	0	0.97	0	0	0	0
2019	70	84	93.7	42	159	4051	0.06	0.13	0.83	0	0	0	0
Minimum	*0*	*0*	*0*	*0*	*110*	*4025*	*0*	*0*	*0.58*	*0*	*0*	*0*	*0*
Maximum	*100*	*85*	*146.5*	*78*	*220*	*6924*	*0.19*	*0.25*	*0.99*	*710*	*407.4*	*19.9*	*25.5*
Mean	*60.3*	*69*	*72.1*	*50.9*	*159*	*5552*	*0.09*	*0.15*	*0.83*	*432*	*258.3*	*10.1*	*15.4*
SD	*33.2*	*30.7*	*45.2*	*27.1*	*39*	*1423*	*0.07*	*0.08*	*0.18*	*251*	*136.8*	*7.3*	*9.2*
CV (%)	*55.0*	*44.5*	*62.7*	*53.3*	*24.5*	*25.6*	*69.0*	*55.9*	*21.6*	*58.0*	*53.0*	*72.2*	*59.4*

Table 9. Comparison of performance indicators for TGP during 1997 and 2018

Year	Equity (%)	Uniformity (%)	Irrigation intensity (%)	Overall consumed ratio/efficiency (%)	Adequacy (%)	Crop yield Ratio (%)
1997	55.85	65.75	18.15	22.87	32.1	57
2018	124.25	81.75	79.6	54	84.9	85

consumed ratio/efficiency (%), adequacy (%), yield (kg/ha), yield (kg/m^3), yield (kg/m^3) of ET_o, crop yield ratio and other parameters observed during 2013 to 2019 are given in Table 8. The equity ranged from 0-100% with mean of 60.3% (CV of 55%), while uniformity ranged from 0-85% with mean of 69% (CV of 44.5%). The irrigation intensity ranged from 0-146.5% with mean of 72.1% (CV of 62.7%), while over-all consumed ratio/efficiency ranged from 0-78% with mean of 50.9% (CV of 53.3%) and adequacy ranged from 110-220% with mean of 159% (CV of 24.5%). The yield ranged from 4025-6924 kg/ha with mean of 5552 kg/ha (CV of 25.6%), compared to 0-0.19 kg/m^3 with mean of 0.09 kg/m^3 (CV of 69.0%) and 0-0.25 kg/m^3 of ET_o with mean of 0.15 kg/m^3 (CV of 55.9%), while crop yield ratio ranged from 0.58-0.99 with mean of 0.83 (CV of 21.6%).The analysis indicated that the performance in Nellore was better for (i) irrigation intensity, (ii) uniformity and (iii) equity. The performance in Nellore was poor when efficiency of 50.86%was considered. This implied that 49.14% of irrigation water drained into sea through seepage, evaporative and open drainage. This carried the applied fertilizers with it, apart from causing soil erosion during rainy days. Similarly, adequacy of 189%implied that water was excessively available in the district by about 89%. The water quantity of 412.57Mcum could be better utilised in the upper reaches or more area could be brought under cultivation. (Maruthi Sankar, G.R. 1986).

When different factors pertaining to yield were compared, 5.56 t/ha of yield was attained in Nellore. Similarly, productivity of0.09 kg/cum of water was derived and 0.15 kg/cum of water was consumed, while crop yield ratio of 0.58 was attained. This indicated that there is a large scope for researchers to improve the yield by developing efficient agronomic practices. Only the managerial aspects should be improved in order to meet shortage of canal water, apart from improving the irrigation efficiency. Higher efficiency could be achieved by an appropriate scientific management of irrigation water inflows from time to time. Nellore has an area of 98270 ha. The irrigation water supplied ranged from 0-710 m^3 with mean of 432.5 m^3 (CV of 58.0%), while the water consumed ETp (m^3) ranged from 0-407.4 m^3 with mean of 258.3 m^3 (CV of 53.0%). Paddy yield of 6975 kg/ha was attained at research station, while yield/unit water supplied ranged from 0-19.9 kg/m^3 with mean of 10.1 kg/m^3 (CV of 72.2%). The yield/unit of water consumed ranged from 0-25.5 kg/m^3 with mean of 15.4 kg/m^3 (CV of 59.4%), while crop yield ratio ranged from 0.58-0.99 with mean of 0.83 (CV of 23.7%).

3.1.7 Comparison of performance indicators of TGP during 1997 and 2018

The details of indicators viz., equity (%), uniformity (%), irrigation intensity (%), over-all consumed ratio/efficiency (%), adequacy (%) and crop yield ratio (%) of TGP command observed in 1997 and 2018 are given in Table 9. There was a better performance in 2018 compared to 1997 as indicated by the higher percentage of values. The equity increased from 55.85% to 124.25%, while uniformity increased from 65.75% to 81.75%during 1997 to 2018. The irrigation intensity increased from 18.15% to 79.6%, while the over-all consumed ratio/efficiency increased from 22.87% to 54%over years. The adequacy increased from 32.1% in 1997 to 84.9% in 2018, while the crop yield ratio increased from 57% to 85%over years.

4. SUMMARY AND CONCLUSION

An evaluation of TGP was made using 9 performance indicators at micro and macro level at the start (1997) and end of the study (2018). Optimization was done to identify rainfall and canal water at which maximum yield could be attained. Paddy area significantly increased by 129.2% (78688 to 180351 ha) during 1997 to 2018 due to improvement of canal water supply, while groundnut area decreased by 54.1% (35181 to 16152 ha) over years. Higher efficiency could be achieved by efficient management of irrigation water inflows over years. In Nellore, rainfall had a rate of change of 1.5929 mm/year (R^2 of 0.001) compared to -3.664 mm/year (R^2 of 0.02) in TGP command.

The rate of change of canal water was 19.933 Mcum/year (R^2 of 0.3924) in Nellore compared to 71.511 Mcum/year (R^2 of 0.4681) in TGP command. Mean paddy yield of 4244 kg/ha (CV of 24.6%) and groundnut yield of 1687 kg/ha (CV of 20.7%) were attained. There was a significant correlation of 0.825 for paddy and 0.762 for groundnut with canal water, while yield had no significant correlation with rainfall over years.

The regression model gave maximum rate of change of 78.823 kg/ha/year for paddy ($R^2$of 0.2402) and 16.308 kg/ha/year for groundnut ($R^2$of 0.092).The pre-monsoon level had a mean of 39.0 m (CV of 6.4%), compared to post-monsoon mean of 34.5 m (CV of 5.8%) with rise in the groundwater level of 4.7 m (CV of 17.5%). In 2010, the rise of groundwater level was minimum of 3.2 m at rainfall of 845 mm and canal water release of 100.9 Mcum compared to maximum of 5.9 m at rainfall of 790 mm and canal water release of 1969 Mcum in 2019. The pre-monsoon groundwater level had a rate of change of 0.6709 m (R^2 of 0.6657), while post-monsoon level had a rate of change of 0.4406 m (R^2 of 0.4475) and rise in groundwater level had a rate of change of 0.2382 m (R^2 of 0.7825).

Grouping of rainfall, canal water, paddy and groundnut yields into 3 groups was made using mean and SD to identify optimum rainfall and canal water at which maximum yield could be attained. Maximum mean rainfall and canal water were observed in 3rd group of more than (Mean+SD), while maximum of 13 years each fell in the 2nd group of (Mean-SD) to (Mean+SD) for both crops. Maximum paddy yield of 5440 kg/ha was attained at mean canal water of 1768.3 Mcum and rainfall of 1151 mm, while maximum groundnut yield of 2195 kg/ha was attained at mean canal water of 1822.6 Mcum and rainfall of 1040.7 mm in 3rd group. The results based on the study could be extended to other irrigation commands under similar conditions.

5. LIMITATIONS OF THE STUDY

1.Prohibitive and expensive cost of the software are limiting factors for adoption of this technology everywhere.

2.Field data like water releases, crop area estimates, irrigation potential details pertaining to each irrigation command to the public will not be adequate. Hence, estimation on crop /water indices for all irrigation commands would not be possible.

6. FUTURE WORK

1.A specific training and experience would be required for enabling the operational implementation of such technical procedures and verification from the field.

2. Alternate crops may be planned in the command basis to reduce the water consumption of paddy.

3.Water budgeting should be maintained time to time to overcome the water shortage at crucial periods.Automation has to done in canal irrigation supply irrigation system to improve the water use efficiency.

4.Sowing with seed drills in early sowings without changing the crop colander should be implemented.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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