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Assessment of Variability of Rainfall and Canal Water under Telugu Ganga Project Command in Andhra Pradesh

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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

The present study was conducted to make a detailed assessment of the variability and relationships of rainfall (mm) received, canal water (Mcum) supplied and the yield (kg/ha) of major crops viz., paddy, groundnut, sugarcane, sorghum and cotton crops attained under the Telugu Ganga Project (TGP) command area in Andhra Pradesh during 1997 to 2021. The crop productivity would always be influenced by the water resource available to a crop. Accordingly, linear and quadratic regression models of yield were calibrated to predict the yield of crops through canal water supplied in different years. The regression models were assessed based on the significance of coefficient of determination (R^2) and magnitude of prediction error (PE) of the yield over years. The canal water released in different years was found to significantly influence the yield of paddy, groundnut, cotton and sugarcane crops under the TGP command area. The quadratic regression models gave higher and significant values of R^2 compared to the linear regression models calibrated for different crops. The predictability of yield was found to be 0.725 under quadratic model compared to 0.605 under linear model for paddy, while it was 0.458 under quadratic model compared to 0.406 under linear model for groundnut. In case of sugarcane, the predictability of

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yield was found to be 0.488 under quadratic model compared to 0.431 under linear model. The models were found to be useful for prediction of yield of crops through varying levels of canal water released in different years. This will greatly help to efficiently utilize the canal water resources with regard to the quantity and frequency of water to be provided for irrigation of crops. Since the canal water released under TGP command area is highly assured,we recommend that the farmers could efficiently utilize the available canal water by growing less water requiring crops and attain maximum yield and profit by adopting the improved agricultural technologies of different crops grown under the TGP command area.

Keywords: Canal water; rainfall; crop yield; variability; correlation; regression; predictability.

1. INTRODUCTION

India is a developing country for irrigation infrastructure. Many efforts are regularly made for bringing the rainfed area into irrigated agriculture for sustainable food production. Irrigation projects have to be regularly assessed for irrigation potential utilisation. The crop area estimation at mandal level would require a replacement with suitable technology implementation. In Andhra Pradesh, the Telugu Ganga irrigation project is an inter-state project formulated to efficiently irrigate about 5.75 lakh acres under the drought prone areas of Rayalaseema region comprising of Chittoor, Kadapa, Kurnool and uplands of Nellore by utilising 29 TMC of water from the Krishna river flood flows and 30 TMC of water from Pennar river flood flows. The main objective of the Department of water resources in Andhra Pradesh is to create irrigation potential under different drought prone areas, upland areas and maintain all projects for enhancing the productivity of different species per unit of water. In view of the importance of irrigated agriculture prevailing in Andhra Pradesh, the performance evaluation of irrigation systems for crop area, availability of water and its sufficiency would greatly help in developing suitable interventions and enabling water management plans, apart from improving the available water resources [1,2]. A detailed evaluation of performance of irrigation systems was carried out by Jisha and Balamurugan [3] under varying hydro-meteorological conditions. The present study was conducted with the objective of making an assessment of the effects of rainfall and canal water supply on the performance of different crops grown in Chittoor, Nellore, Kurnool and Kadapa districts under the TGP command area.

Correlation analysis could be carried out between variables in order to assess the type of relationship viz., positive or negative relationship, apart from the magnitude of relationship and its significance over a period of time [4]. The regression models could be calibrated for assessing the effects of rainfall and canal water supplied on the yield of crops, apart from making an efficient prediction of yield over years. Maruthi Sankar [5] has screened different regression models for selection of optimal variable subsets for maximizing the yield based on different models. The usefulness of R^2-adequacy and Residual Mean Square Error (RMSE) criteria for identifying an efficient regression model for prediction and optimization of variables for maximizing the yield. In another study, a three-step modeling approach was adopted for a comprehensive analysis of planning the problem involving integrated use of surface and groundwater in irrigation for the Bagmati river basin in Nepal [6]. In a study conducted by Rodriguez et al. [7], the techniques of benchmarking and multivariate data analysis for assessing the variability of irrigation provided to crops in different districts. The multivariate statistical models are useful to identify the constraints in productivity and improve the efficiency of irrigated water for crops.

The crop water requirement of cotton has been studied by Abdelhadi et al. [8] under arid conditions in Sudan. The derivations using Penman-Monteith equation with derived crop coefficients under the Gezira irrigated project. Bhandarkar et al. [9] estimated the crop water requirement of both field and vegetable crops grown under sub-humid conditions in Bhopal in Central India. The study has given scope for identifying the less water requiring crops that could be grown for sustaining the yield and monetary returns under erratic rainfall conditions. In a study by Ganesh et al. [10], the authors have measured the crop water requirement for both long and short duration crops under arid condition in Anantapur in South India. The CROPWAT model for efficiently determining the crop water requirement. Based on the findings, the authors suggested that groundnut based cropping systems are more profitable under low and erratic rainfall conditions in Anantapur. In a study by Thazin [11], the author made an attempt to study the irrigation water requirements of different crops. The CROPWAT 8.0 software for assessing the crop water requirement under Taungdwingyi township. In a study conducted in China, Zhao et al. [12] have assessed in detail about the water requirements of maize crop in the command area of Heihe river basin. The authors suggested useful strategies for maximizing the productivity and water use efficiency of the crop. Bhumika et al. [13] conducted a study at Olpad taluka in Surat about cropping pattern mapping using Remote Sensing and GIS. An attempt was made to map different cropping patterns followed in the location. A multi date Landsat satellite data from USGS was used to generate cropping pattern and assess suitability of crop rotation in *kharif* and *rabi seasons.* Different, crop water requirements were calculated to assess the efficiency of cropping systems.

Attempts have been made by Ahmed [14] for assessing the groundwater and surface water under the Burdekin delta area. The author has assessed the variability of ground and surface water over years and explored strategies for efficient cropping systems that could be grown under the delta area. Azamathulla [15] developed strategies for optimal cropping pattern for a river basin under semi-arid conditions in India. The strategies are useful for growing less water requiring crops and maximizing water use efficiency and crop productivity over years. In a study conducted by Wang et al. [16], the authors made efforts to improve the water use efficiency of crops grown under North China Plains. Based on suitable models of yield and irrigation water provided to the crops at regular intervals, the authors provided strategies for improving the water use efficiency of crops and attaining maximum productivity. Babu et al. [17] studied on improving the water use efficiency of crops grown under Nagarjuna Sagar Project canal command area. The yield, water use efficiency of different short and long duration crops, rainfall received and canal water released in different years. Chavan et al. [18] observed that cropping pattern in Khadambe. It has undergone dramatic changes due to effects of the change and human activities. Cropping pattern is a major factor contributing to yield and food security at local, regional and national scales, and is a critical input variable for many global climate, land surface and crop models. The authors reported on cropping pattern maps for January 2019 at spatial resolution over selected areas of Rahuri. They compared area of selected villages using NDVI and Supervised classification. In NDVI classification, *kharif* crop had highest area, while in Supervised classification, soybean had highest area.

2. MATERIALS AND METHODS

The descriptive statistics of yield attained by major crops, rainfall received and canal water released to the crops in *rabi* season during 25 years of the study period during 1997 to 2021 were determined. An assessment of the changes in the quantity of rainfall received and canal water released for crops during different years has been made and the trends of changes in the rainfall and canal water were determined. Statistical assessment of the relationships between different parameters has been made and the Pearson correlation coefficients between variables were tested based on Student’s t-test [4]. Linear and quadratic regression models of yield through the rainfall received and canal water released for crops were developed for efficient prediction of yield attained in different years.

2.1 Study area of Telugu Ganga Project (TGP)

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.

2.2 Regression Models for Prediction of Yield

Regression models could be calibrated for predicting the yield of a crop through different independent variables [19]. In a simple regression model, only two variables are considered, where one variable would represent the ‘cause’ (denoted as X) and other would represent the ‘effect’ (denoted as Y). A regression model could be assessed based on the coefficient of determination (R^2) which indicates about the predictability of a crop yield through different parameters considered in the study. The coefficient of determination indicates about the variation in the dependent variable explained by the independent variable and could

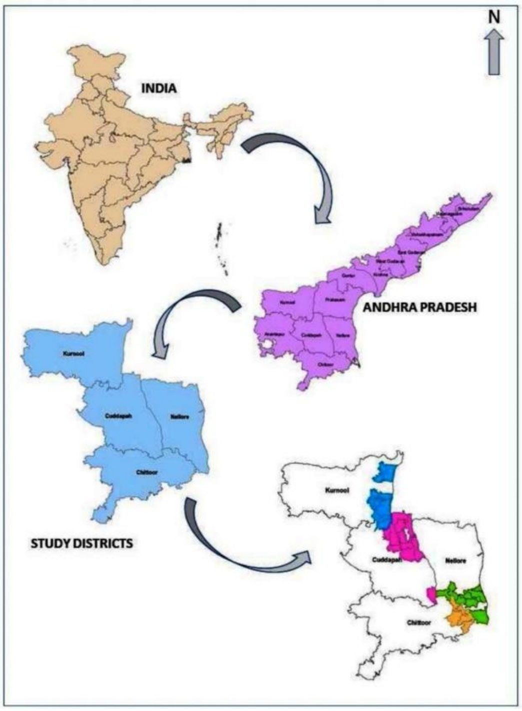

Fig. 1. Study Area of Telugu Ganga Project command

be tested based on Snedecor's F-test. The linear regression model calibrated for predicting the yield (Y) of a crop through canal water (CW) could be given as

$$Y = \alpha + \beta\,(CW) \qquad (1)$$

Here α is intercept and β is the slope of canal water. The slope indicates about the rate of change in yield for an unit change in the canal water supplied in different years. The quadratic regression model for predicting yield as a function of linear and quadratic terms of canal water could be given as

$$Y = \alpha + \beta_1\,(CW) + \beta_2\,(CW)^2 \qquad (2)$$

Here α is intercept; β_1 and β_2 are slopes of linear and quadratic terms of canal water respectively. The linear and quadratic regression models have been assessed based on the estimate of coefficient of determination (R^2) along with prediction error (PE) derived under each model [5]. The models could be used for prediction of yield and also for assessing the contributions of independent variables to yield over years.

3. RESULTS AND DISCUSSION

A detailed assessment of irrigation performance of Telugu Ganga Project (TGP) has been made during *kharif* and *rabi* seasons of 1997 and 2021 in the districts of Chittoor, Nellore, Kurnool and Kadapa with the objective to assess the available surface water resources for irrigation in order to attain maximum productivity of paddy, sugarcane, groundnut, sorghum and cotton crops grown in the region. Observations on different parameters viz., rainfall, canal water flows, area and yield of crops were collected from different sources and analyzed for assessing the impact of the canal irrigation water of the productivity of crops attained under the TGP command area.

3.1 Rainfall Analysis

The quantity of surface water as well as the groundwater would carry maximum effect in deciding about the feasibility of irrigation to be provided to paddy, sugarcane, groundnut and other crops grown under the Telugu Ganga Project command area. Before making any estimation of the quantity of surface water in the study area, the daily rainfall data of 25 years collected for the period from 1997 to 2021 have been analyzed. Chittoor district received annual rainfall in the range of 615 mm to 1999 mm with mean of 1128 mm (Coefficient of variation, CV of 26.1%), while Nellore district received rainfall in the range of 519 mm to 2644 mm with mean of 1092.0 mm (CV of 40.4%) over years. Similarly, Kurnool district received annual rainfall in the range of 504 mm to 1375 mm with mean rainfall of 847.2 mm (CV of 32.3%), while Kadapa district received rainfall in the range of 360 mm to 1348 mm with mean of 715.4 mm (CV of 31.6%) over years. Thus maximum mean rainfall was received in Chittoor, followed by Nellore, Kurnool and Kadapa. However, in terms of the variability of rainfall, Chittoor was found to have lowest variability, followed by Kadapa, Kurnool and Nellore. When the data were pooled over different districts under the entire TGP command area, the annual rainfall was found to be in the range of 582 mm to 1409 mm with mean of 945.7 mm (CV of 21.4%) during 1997 to 2021. The observations of rainfall were used to determine the actual crop water demand (CWD) as well as making an efficient prediction of yield of crops attained in different years. The year-wise canal water flows available for providing irrigation to paddy, sugarcane, groundnut, sorghum and cotton crops duly accounting for the regular seepage losses have been estimated. The daily rainfall observations were collected for each year during 1997 to 2021 from the sources of Automatic Weather Station (AWS) and Directorate of Economics and Statistics (DES) of each of the four districts and are given in Table 1. Rao and Rajput [20] have made a detailed assessment of the variability of rainfall, apart from the effectiveness of rainfall in influencing the productivity of crops under canal command areas.

The changes in annual rainfall received in different districts and the mean rainfall received under the entire TGP command area over years during 1997 to 2021 are described in Fig. 2. The changes in rainfall received in each district were assessed based on the regression analysis of rainfall received in different years. Although there is a significant increase in the rainfall received during 1997 to 2008 as indicated by the positive linear regression coefficient in Chittoor and Nellore districts, it was found to be significantly decreasing from 2009 onwards as indicated by the negative quadratic regression coefficient. In Kurnool district, it is observed that there was a decrease in the rainfall during 1997 to 2009 as indicated by the negative linear regression coefficient, while the rainfall has increased from 2010 onwards as indicated by the positive quadratic regression coefficient over years.

Table 1. Mean annual rainfall (mm) in different districts under the TGP command during 1997 to 2021

Year	Chittoor	Nellore	Kurnool	Kadapa	Pooled
1997	810	720	1275	575	845
1998	825	740	1310	485	840
1999	832	745	1353	360	822
2000	938	880	1009	798	906
2001	1392	1412	550	862	1054
2002	1097	1096	817	504	878
2003	812	799	559	789	740
2004	1015	995	834	528	843
2005	1999	1780	547	844	1293
2006	1077	946	1038	539	900
2007	1297	1363	645	946	1063
2008	1325	1213	781	776	1024
2009	904	888	1018	596	852
2010	1305	2644	656	942	1387
2011	1349	1276	675	715	1004
2012	1140	1005	696	532	843
2013	959	917	903	819	900
2014	973	857	504	433	692
2015	1533	1440	580	664	1054
2016	615	519	736	459	582
2017	1058	652	777	677	791
2018	1056	782	516	725	770
2019	1256	1050	975	945	1056
2020	1175	1125	1050	1025	1094
2021	1458	1455	1375	1348	1409
Minimum	*615*	*519*	*504*	*360*	*582*
Maximum	*1999*	*2644*	*1375*	*1348*	*1409*
Mean	*1128.0*	*1092.0*	*847.2*	*715.4*	*945.7*
CV (%)	*26.1*	*40.4*	*32.3*	*31.6*	*21.4*

In Kadapa also, the rainfall was found to be marginally decreasing up to 2008, but it has increased from 2009 onwards. The regression model for predicting the changes in annual rainfall over different years gave maximum predictability (R^2) of 0.468 for Kurnool district, followed by 0.218 for Kadapa district, 0.100 for Nellore district and 0.092 for Chittoor district. The regression model of pooled data over different districts gave a non-significant and low predictability of 0.030 for predicting the changes in rainfall received in different years during the study period.

3.2 Mean Rainfall, Effective Rainfall and Crop Water Demand

The effective rainfall and irrigation water requirement were derived for each of the four districts based on the CROPWAT 8.0 model. The effective rainfall is one of the important water inputs to the root zone for meeting the evapo-transpiration requirement of any crop grown under any soil. The derivations were made by using CROPWAT 8.0 model by considering the rainfall and other weather parameters on monthly basis. The model was run for paddy and other crops for different periods. The derivations were performed based on the CROPWAT 8.0 model after computerizing the rainfall and crop water demand observed during *kharif* and *rabi* seasons. The mean monthly rainfall and the effective rainfall received in different districts and the entire TGP command area are given in Table 2. From Fig. 3, it could be seen that during the *kharif* season, there was more rainfall than the derived values based on the CROPWAT model when the researcher considered the mean rainfall and other weather parameters on monthly basis. The CROPWAT model was explored for paddy, groundnut and other crops using the data collected from different sources for the four districts and also for the pooled data of the TGP command area.

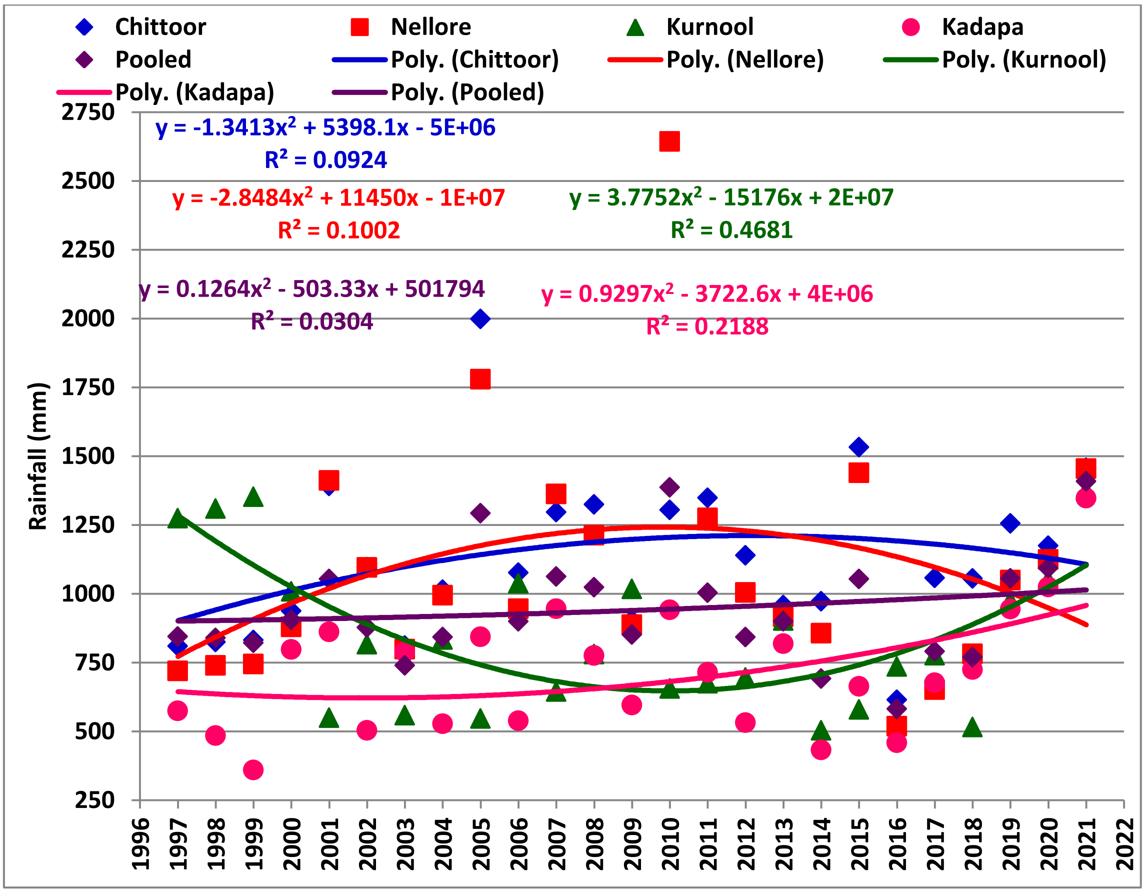

Fig. 2. Changes in annual rainfall in different districts under TGP command during 1997 to 2021

Table 2. Mean monthly rainfall and effective rainfall (mm) of different districts under TGP command during 1997 to 2021

Month	Rainfall (mm)					Effective rainfall (mm)				
	Chittoor	**Nellore**	**Kurnool**	**Kadapa**	**Pooled**	**Chittoor**	**Nellore**	**Kurnool**	**Kadapa**	**Pooled**
Jan	12.7	16.1	1.0	1.4	7.8	12.4	15.7	1.0	1.4	7.6
Feb	9.9	14.9	0.8	3.9	7.4	9.7	14.5	0.8	3.9	7.2
Mar	11.2	17.6	6.1	6.0	10.2	11.0	17.1	6.0	5.9	10.0
Apr	18.6	40.3	33.9	14.4	26.8	18.0	37.7	32.1	14.1	25.5
May	46.5	33.0	43.4	30.3	38.3	43.0	31.3	40.4	28.9	35.9
Jun	66.7	57.0	127.8	63.4	78.7	59.6	51.8	101.7	57.0	67.5
Jul	108.2	85.4	142.7	88.3	106.2	89.5	73.7	110.1	75.8	87.3
Aug	123.6	115.5	172.6	127.9	134.9	99.2	94.2	124.9	101.7	105.0
Sep	110.5	95.4	148.7	104.1	114.7	91.0	80.8	113.3	86.8	93.0
Oct	241.9	252.3	106.4	147.9	187.1	148.3	150.2	88.3	112.9	124.9
Nov	263.8	266.4	25.1	73.5	157.2	151.4	151.6	24.1	64.9	98.0
Dec	120.1	122.5	3.3	14.3	65.0	97.0	94.7	3.3	14.0	52.3
Total	1133.8	1110.4	811.7	675.4	932.8	830.1	813.4	646.0	567.1	714.2
Minimum	*9.9*	*14.9*	*0.8*	*1.4*	*7.4*	*9.7*	*14.5*	*0.8*	*1.4*	*7.2*
Maximum	*263.8*	*266.4*	*172.6*	*147.9*	*187.1*	*151.4*	*151.6*	*124.9*	*112.9*	*124.9*
Mean	*94.5*	*93.0*	*67.7*	*56.3*	*77.9*	*69.2*	*67.8*	*53.8*	*47.3*	*59.5*
CV (%)	*91.4*	*92.9*	*98.4*	*92.3*	*79.8*	*74.4*	*71.8*	*92.4*	*86.3*	*70.6*

The distribution of mean monthly rainfall and annual rainfall over years are depicted in Fig. 3. The mean monthly rainfall under the TGP command ranged from 7.4 mm in February to 187.1 mm in October with mean of 77.9 mm (coefficient of variation of 79.8%) over years. The effective rainfall (mm) ranged from 7.2 mm in February to 124.9 mm in October with mean of 59.5 mm (CV of 70.6%) over years. The effective rainfall had a lesser variability compared to the actual rainfall received in different years. November received the second highest mean monthly rainfall of 157.2 mm, while August received the second highest effective rainfall of 105.0 mm in the study period. It is observed that a good amount of rainfall was received in different months during the period from June to December. Mean annual rainfall of 932.8 mm (CV of 79.8%) was received compared to mean effective rainfall of 714.2 mm (CV of 70.6%) under the entire TGP command area. The analysis indicated that there was a difference of about 218.6 mm between the actual and effective rainfall received during the study period.

The changes in monthly rainfall and effective rainfall received in different districts and the pooled mean rainfall of the four districts received under the entire TGP command area over years during 1997 to 2021 are described in Fig. 3. The changes in monthly rainfall and effective rainfall received in each district over years were assessed based on the regression analysis. The regression model of rainfall gave maximum and significant predictability of 0.722 for Chittoor district, followed by 0.684 for Nellore district, 0.676 for Kurnool district and 0.602 for Kadapa district. The regression model of pooled data of rainfall of all the four districts gave a high and significant predictability of 0.711 for predicting the annual rainfall over years. Kurnool district was found to have maximum rate of change in the annual rainfall, followed by Kadapa, Chittoor and Nellore districts as indicated by the linear regression coefficient of changes in the annual rainfall received over years.

3.3 Crop Water Demand in the TGP Command

The season-wise and total (*kharif* + *rabi*) area (ha) of paddy, groundnut and other crops, the crop water requirement (mm) and the crop water demand (Mcum) during the *kharif* and *rabi* seasons are given in Table 3. During 1997, among different crops, paddy crop was found to have a maximum area of 53674 ha in the *kharif* season which was reduced to 25014 ha during the *rabi* season. Thus paddy crop had a total area of 78688 ha in the two crop growing seasons. The crop water requirement of paddy was found to be 516 mm in *kharif*, while it had a marginally higher water requirement of 544 mm in the *rabi* season making a total water requirement of 1119 mm during the two seasons. On the other hand, the crop water demand of paddy was found to be 277 Mcum in the *kharif* season compared to a lower water requirement

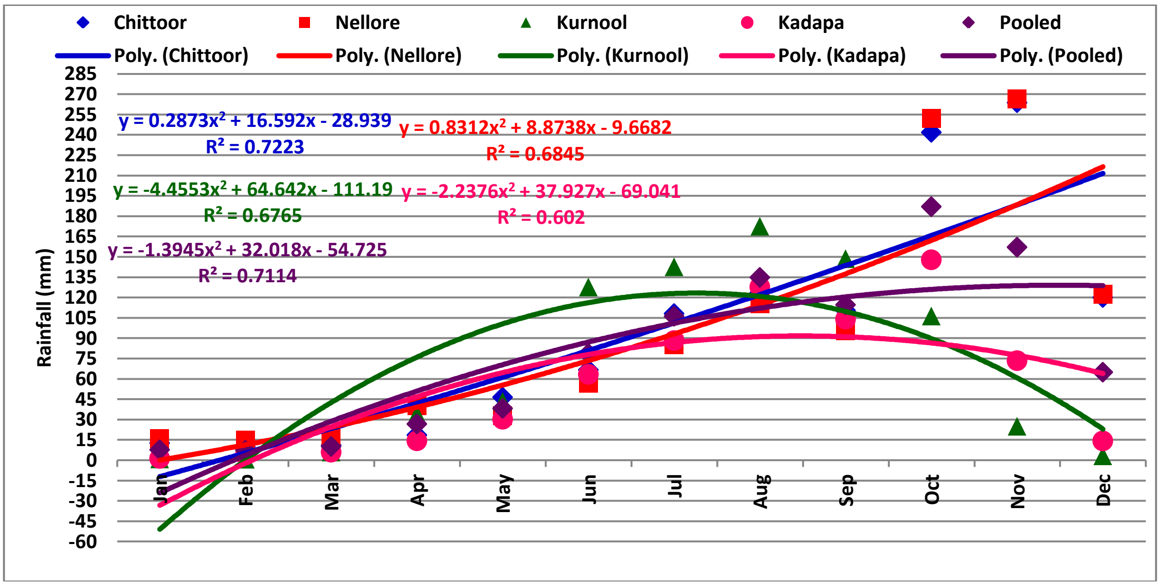

Fig. 3. Mean monthly rainfall and effective rainfall (mm) in the entire TGP command during 1997 to 2021

of 136 Mcum in the *rabi* season. Thus paddy had a total water demand of 413 Mcum when combined over *kharif* and *rabi* seasons. Since the *kharif* area of paddy was found to be higher, the crop water demand of paddy was also higher in the *kharif* season compared to the paddy grown in the *rabi* season.

During 1997, groundnut crop was found to have an area of 16055 ha in the *kharif* season compared to maximum area of 19126 ha in the *rabi* season. Thus groundnut crop had a total area of 35181 ha in the two crop growing seasons. The crop water requirement of groundnut was found to be 341 mm in *kharif*, while it had a marginally higher requirement of 344 mm in the *rabi* season making a total water requirement of 685 mm during the two seasons. On the other hand, the crop water demand of groundnut was found to be 55 Mcum in the *kharif* season compared to a marginally higher water demand of 66 Mcum in the *rabi* season. Thus groundnut had a total water demand of 121 Mcum when combined over *kharif* and *rabi* seasons. Since the *rabi* area of groundnut was found to be higher, the crop water demand was also higher in the *rabi* season compared to the *kharif* season.

During 2021, paddy crop had an area of 85138 ha in the *kharif* season compared to a higher paddy area of 95213 ha in the *rabi* season. Thus paddy crop had a total area of 198026 ha in the two crop growing seasons. The crop water requirement of paddy was found to be 533 mm in *kharif*, while it had a marginally higher requirement of 554 mm in the *rabi* season making a total water requirement of 1087 mm over the two seasons. On the other hand, the crop water demand of paddy was found to be 454 Mcum in the *kharif* season compared to a higher water demand of 527 Mcum in the *rabi* season. Thus paddy had a total water demand of 981 Mcum when combined over *kharif* and *rabi* seasons. Since the *rabi* area of paddy was found to be higher, the crop water demand was also higher in the *rabi* season compared to the *kharif* season.

During 2021, the groundnut crop had an area of 4368 ha in the *kharif* season compared to a maximum area of 11784 ha in the *rabi* season. Thus groundnut crop had a total area of 16152 ha in the two crop growing seasons. The crop water requirement of groundnut was found to be 329 mm in *kharif*, while it had a marginally higher requirement of 349 mm in the *rabi* season making a total water requirement of 678 mm over the two seasons. On the other hand, the crop water demand of groundnut was found to be 14 Mcum in the *kharif* season compared to a higher water demand of 41 Mcum in the *rabi* season. Thus groundnut had a total water demand of 55 Mcum when combined over *kharif* and *rabi* seasons. Since the *rabi* area of groundnut was higher, the crop water demand was also higher in the *rabi* compared to *kharif* season. Our results are in agreement with the findings made by Malekian et al. (2012) while assessing the crop water demand and making an optimal planning of available water resources for attaining maximum crop productivity under an irrigation project command. Pritha et al. (2014) made a comparison of crop water requirements of different crops and suggested suitable crops with lower water requirement using CROPWAT model. In a study conducted by Prasad et al. [21], the authors estimated the crop water requirement of major crops grown under the Nagarajuna Sagar Right Canal command area. They made an optimal irrigation scheduling for different crops for attaining maximum productivity and profitability under semi-arid conditions.

3.4 Canal Water Released in Different Districts under the TGP Command during 1997 to 2021

The district-wise canal water release data from the Telugu Ganga irrigation project during 1997 to 2021 are given in Table 4. The year-wise releases of canal water (Mcum) in the TGP command area during 1997 to 2021 are described in Fig. 4. The different types of losses viz., conveyance loss, seepage loss, infiltration loss etc., occurred during the study period were found to be in the range of 30 to 35%. The actual quantity of canal water reaching the field level was about 65 to 70%. The canal water released during 1997 to 2021 in the four districts under the entire TGP command ranged from 58.5 Mcum (in 2003) to 2201.4 Mcum (in 2008) with mean of 1020.2 Mcum, while the variability as measured by the coefficient of variation was found to be 72.4% over years. In Chittoor, the canal water released in different years ranged from 0 to 155.0 Mcum with mean of 55.0 Mcum (CV of 120.1%), while it ranged from 0 to 710.0 Mcum with mean of 347.4 Mcum (CV of 67.5%) over years in Nellore district. In Kurnool district, the canal water released in different years ranged from 0 to 1160.6 Mcum with mean of 468.7 Mcum (CV of 84.3%), while it ranged from 0 to 568.2 Mcum with mean of 263.2 Mcum

Table 3. Crop water requirement and demand (Mcum) for major crops in the TGP command area

Year	Crop	*Kharif*			*Rabi*			Total	
		Area (ha)	CWR (mm)	CWD (Mcum)	Area (ha)	CWR (mm)	CWD (Mcum)	Area (ha)	CWD (Mcum)
1997	Paddy	53674	516	277	25014	544	136	78688	413
	Groundnut	16055	341	55	19126	344	66	35181	121
	Sugarcane	4297	828	36	4376	848	37	8673	73
	Jowar	0	325	0	24707	365	90	24707	90
	Cotton	17660	444	78	0	496	0	17660	78
	Sunflower	0	310	0	14601	315	46	14601	46
	Bajra	3199	285	9	0	285	0	3199	9
	Pulses	1875	296	6	0	300	0	1875	6
	Chillies	13442	510	69	0	520	0	13442	69
	Total	*110202*	*3855*	*529*	*87824*	*4017*	*375*	*198026*	*904*
2021	Paddy	85138	533	454	95213	554	527	180351	981
	Groundnut	4368	329	14	11784	349	41	16152	55
	Sugarcane	2834	825	23	1279	761	10	4113	33
	Jowar	6742	303	20	17476	335	59	24218	79
	Cotton	14942	448	67	0	498	0	14942	67
	Sunflower	0	305	0	16100	305	49	16100	49
	Bajra	1163	295	3	0	295	0	1163	3
	Pulses	9201	302	28	831	305	3	10032	30
	Chillies	3852	515	20	14568	525	76	18420	96
	Total	*128240*	*3855*	*630*	*157251*	*3927*	*765*	*285491*	*1395*

CWR: Crop water requirement *CWD: Crop water demand*

Table 4. District-wise release of canal water in the TGP command area during 1997 to 2021

Year	Canal water released (Mcum)				
	Chittoor	Nellore	Kurnool	Kadapa	Total TGP
1997	0.0	100.9	0.0	0.0	100.9
1998	3.4	121.7	0.0	0.0	125.1
1999	2.2	79.8	0.0	0.0	82.0
2000	10.2	367.8	0.0	0.0	378.1
2001	2.4	86.4	0.0	0.0	88.8
2002	3.5	126.0	0.0	0.0	129.5
2003	1.6	56.9	0.0	0.0	58.5
2004	3.4	122.4	639.2	256.0	1020.9
2005	2.9	103.3	765.0	263.5	1134.6
2006	9.2	328.9	1083.8	509.7	1931.6
2007	5.0	180.6	694.3	518.6	1398.5
2008	14.6	525.0	1160.6	501.2	2201.4
2009	15.3	549.8	341.8	444.8	1351.7
2010	10.4	372.0	888.1	535.2	1805.7
2011	17.4	626.9	719.3	568.2	1931.9
2012	10.5	375.5	270.6	491.0	1147.5
2013	115.0	710.0	588.0	367.0	1780.0
2014	115.0	614.0	572.0	290.0	1591.0
2015	143.0	337.0	20.0	73.0	573.0
2016	143.0	412.0	438.0	382.0	1375.0
2017	152.0	522.0	234.0	364.0	1272.0
2018	147.0	0.0	550.0	262.0	959.0
2019	145.5	650.0	919.0	254.5	1969.0
2020	*148*	*675*	*925*	*255*	*2003*
2021	*155*	*642*	*910*	*245*	*1952*
Total	*1375.4*	*8685.8*	*11718.6*	*6580.6*	*28360.4*
Minimum	*0.0*	*0.0*	*0.0*	*0.0*	*58.5*
Maximum	*155.0*	*710.0*	*1160.6*	*568.2*	*2201.4*
Mean	*55.0*	*347.4*	*468.7*	*263.2*	*1134.4*
CV (%)	*120.1*	*67.5*	*84.3*	*77.2*	*65.3*

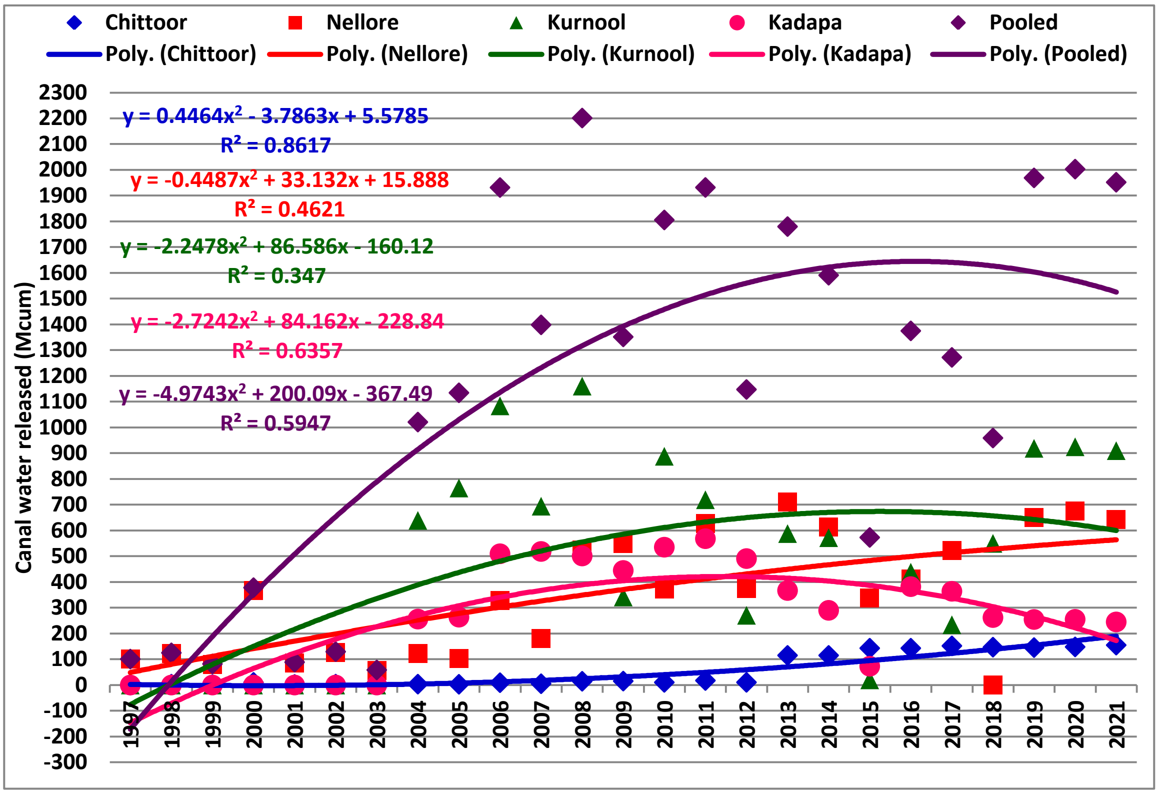

Fig. 4. Canal water released (Mcum) in the TGP command area during 1997 to 2021

(CV of 77.2%) over years in Kadapa district. Thus Kurnool was found to have maximum mean canal water released over years, followed by Nellore, Kadapa and Chittoor. When pooled over districts under the entire TGP command area, the canal water released in different years ranged from 58.5 to 2201.4 Mcum with mean of 1134.4 Mcum (CV of 65.3%) over years. In a study conducted by Mahfuzur et al. [22], the authors have assessed the variability of water resources available in the Ganges basin before developing a suitable mechanism for comparison of three strategies for efficient groundwater and surface water use for different crops.

An assessment of changes in the canal water releases in each district in different years during 1997 to 2021 was made based on the regression analysis. The regression model of canal water released in different years gave maximum and significant predictability of 0.861 for predicting the changes in the canal water releases in Chittoor district, followed by 0.635 in Kadapa district, 0.462 in Nellore district and 0.347 in Kurnool district. The regression model calibrated for the pooled data of canal water releases over all the four districts under the TGP command area during 1997 to 2021 gave predictability of 0.594 for predicting the changes in the release of canal water for growing different crops as depicted in Fig. 3. The rate of change in canal water releases was found to be maximum of 86.58 Mcum/year at Kurnool, followed by 84.16 Mcum/year at Kadapa, 33.13 Mcum/year at Nellore, while it was negative at Chittoor with a rate of change of -3.786 Mcum/year. The pooled canal water releases over the four districts indicated rate of change of 200.0 Mcum/year under the TGP command during 1997 to 2021.

3.5 Crop water demand and canal water released for major crops during 1997 and 2021

A comparison of the details of crop water demand (Mcum) and canal water released (Mcum) for major crops viz., paddy, sugarcane and groundnut during 1997 and 2021 is made in Table 5. Paddy was found to have maximum crop water demand, followed by groundnut and sugarcane. During 1997, the CWD (Mcum) was found to be 754 Mcum for paddy, 109 Mcum for sugarcane and 176 Mcum for groundnut. Compared to this, during 2018, the CWD was higher of 1435 Mcum for paddy, and lower of 56 Mcum for sugarcane and 69 Mcum for groundnut. The annual rainfall (mm) received during 2018 was found to be marginally lower of 770 mm compared to 845 mm in 1997. The canal water released (Mcum) was found to be maximum of 959 Mcum in 2021 compared to minimum of 101 Mcum in 1997. The study has clearly indicated that the total crop water demand of paddy, sugarcane and groundnut crops has significantly increased from 1039 Mcum in 1997 to 1560 Mcum in 2021. A lower water deficit of 601 Mcum was observed during 2018 compared to a higher deficit of 938 Mcum in 1997.

3.6 Assessment of Groundwater Fluctuations in Different Districts under TGP Command

Details were collected from the Central Ground Water Board and utilized for choosing the canals in the concerned districts of the TGP command area for applying both the surface and groundwater resources for growing different crops. The ground water level rise (m) between the pre-monsoon and post-monsoon seasons determined in each year under the entire TGP command area, observations of rainfall received and canal water released during 2010 to 2019 are given in Table 6 and are described in Fig. 5. The analysis indicated that the groundwater level has significantly increased over years with an increase in the canal water supply in different districts under the TGP command area. During 2010, the rise of ground water level was minimum of 3.2 m, while the rainfall received during the year was 845 mm whereas the canal water released was 100.9 Mcum**.** During 2019, the highest rise of ground water level was 5.9 m, while the rainfall received was 790 mm, where as the canal water supplied was maximum of 1969 Mcum for growing different crops. The annual rainfall ranged from 582 to 1054 mm with mean of 811 mm (CV of 15.3%), while the canal water released was in the range of 101 to 1969 Mcum with mean of 1089 Mcum (CV of 59.7%) over years. The pre-monsoon ground water level ranged from 34.6 to 42.5 m with mean of 39.0 m (CV of 6.4%) during 2010 to 2019. Compared to this, the post-monsoon ground water level ranged from 31.4 to 37.0 m with mean of 34.5 m (CV of 5.8%) over years. The rise of ground water level was found to range from 3.2 to 5.9 m with mean of 4.7 m (CV of 17.5%) during the study period.

Table 5. Comparison of crop water demand and canal water release for major crops during 1997 and 2018

Year	Crop	CWD (Mcum)	Canal water released (Mcum)	Remarks
1997	Paddy	754		
	Sugarcane	109		
	Groundnut	176		
	Total	*1039*	*101*	Deficit of 938 Mcum
2021	Paddy	1435		
	Sugarcane	56		
	Groundnut	69		
	Total	*1560*	*959*	Deficit of 601 Mcum

Table 6. Changes in the ground water level, rainfall and canal water supply under the TGP command area during 2010 to 2019

Year	Pre-monsoon (m)	Post-monsoon (m)	Rise of ground water (m)	Rainfall (mm)	Canal water supply (Mcum)
2010	34.6	31.4	3.2	845	101
2011	35.9	32.4	3.5	840	125
2012	37.5	32.8	4.7	843	1148
2013	39.2	34.3	4.9	900	1780
2014	39.9	35.4	4.5	692	1591
2015	39.1	35.5	4.9	1054	573
2016	40.9	36.3	4.6	582	1375
2017	41.8	36.8	5.0	791	1272
2018	42.5	37.0	5.5	770	959
2019	38.9	33.0	5.9	790	1969
Minimum	*34.6*	*31.4*	*3.2*	*582*	*101*
Maximum	*42.5*	*37.0*	*5.9*	*1054*	*1969*
Mean	*39.0*	*34.5*	*4.7*	*811*	*1089*
CV (%)	*6.4*	*5.8*	*17.5*	*15.3*	*59.7*

(Source: Ground water department, Vijayawada, Andhra Pradesh)

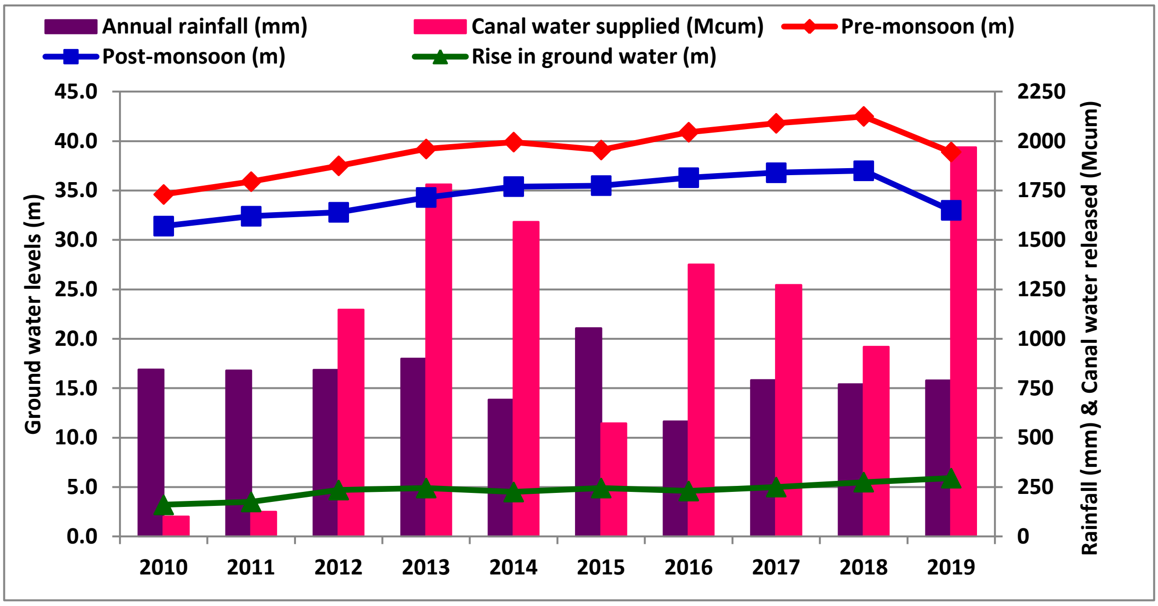

Fig. 5. Pre-monsoon and post-monsoon ground water levels and rise of ground water level (m), rainfall, and canal water supply in the TGP command during 2010 to 2019

Table 7. Descriptive statistics of yield of crops attained under TGP command area during 1997 to 2018

Year	Yield (kg/ha) of different crops				
	Paddy	Groundnut	Sugarcane (q/ha)	Sorghum	Cotton
1997	2798	1230	733	1200	1150
1998	2951	1359	752	1245	1197
1999	2651	1275	745	1210	1145
2000	4150	1785	895	1435	1135
2001	2578	1159	721	891	1098
2002	3497	1512	810	1045	1051
2003	2678	1179	678	852	1010
2004	4964	1875	878	1254	1187
2005	5435	1957	912	1358	1254
2006	5512	2154	925	1458	1352
2007	4589	1854	846	1235	1025
2008	5435	2254	879	1248	1069
2009	5253	2103	845	1150	1048
2010	5378	2268	899	1178	1256
2011	5239	1736	898	1052	1216
2012	4325	1659	783	1078	1278
2013	4239	1896	899	1125	1358
2014	4362	1563	874	1098	1206
2015	3256	1256	843	975	989
2016	5159	1632	712	1210	1256
2017	4963	1876	879	1195	1189
2018	3953	1530	943	1517	1358
2019	*4255*	*1450*	*885*	*1455*	*1275*
2020	*4152*	*1475*	*867*	*1475*	*1315*
2021	*4048*	*1504*	*874*	*1525*	*1328*
Minimum	*2578*	*1159*	*678*	*852*	*989*
Maximum	*5512*	*2268*	*943*	*1525*	*1358*
Mean	*4233*	*1662*	*839*	*1219*	*1190*
CV (%)	*23.1*	*20.1*	*8.9*	*15.4*	*9.6*

Source Chief Planning officer, Vijayawada, Andhra Pradesh
SD: Standard deviation *CV: Coefficient of variation (%)*

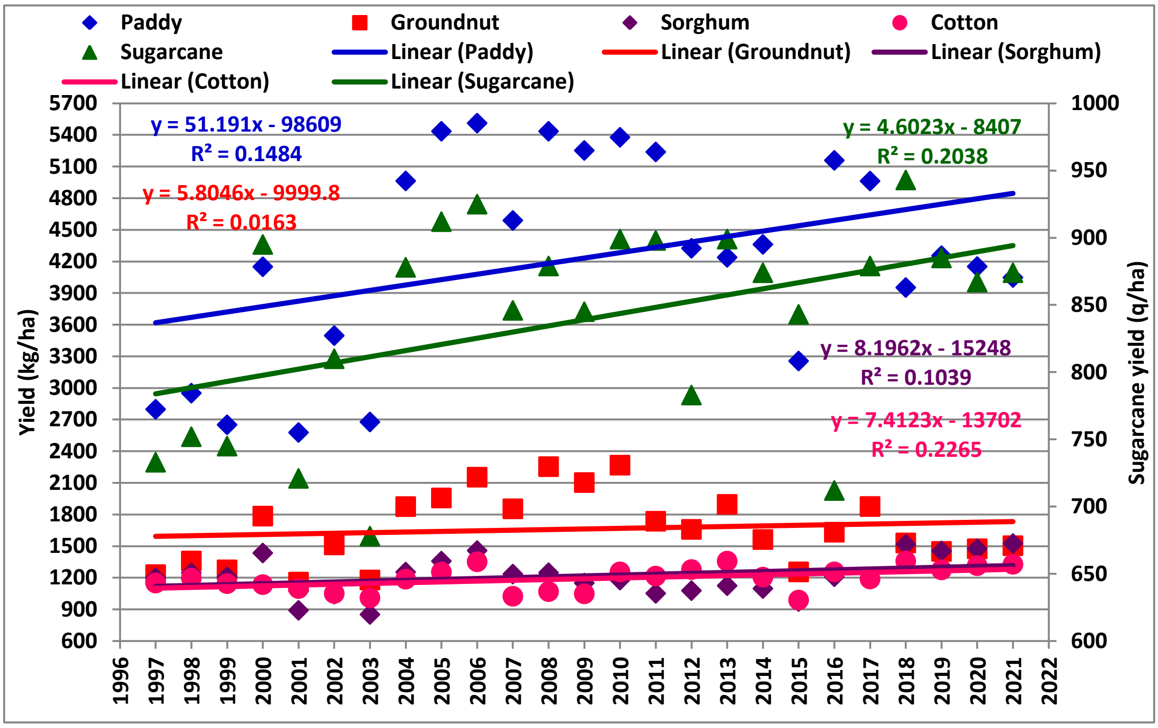

Fig. 6. Trends in the yield of crops attained during 1997 to 2021

3.7 Descriptive Statistics of Yield of Crops Attained in Different Years

The details of yield (kg/ha) of paddy, groundnut, sugarcane, sorghum and cotton crops attained in the TGP command area during 1997 to 2021 are given in Table 7. Among different crops, paddy yield ranged from 2578 to 5512 kg/ha with mean of 4233 kg/ha (CV of 23.1%), while groundnut yield ranged from 1159 to 2268 kg/ha with mean of 1662 kg/ha (CV of 20.1%) over years. The sugarcane yield ranged from 678 to 943 q/ha with mean of 839 q/ha (CV of 8.9%), while sorghum yield ranged from 852 to 1525 kg/ha with mean of 1219 kg/ha (CV of 15.4%) over years. The cotton yield ranged from 989 to 1358 kg/ha with mean of 1190 kg/ha (CV of 9.6%) over years. The variability of yield has clearly indicated that paddy had maximum variability of 23.1%, while sugarcane had minimum variability of 8.9% during the study period. The trends in the yield of crops attained during 1997 to 2021 are depicted in Fig. 6.

3.8 Effect of Canal Water on the Productivity of Crops

The effect of canal water released in different years on the productivity of crops has been assessed based on linear and quadratic regression models of yield through canal water for each crop. The linear and quadratic regression models of yield of paddy, groundnut, sugarcane, sorghum and cotton through canal water released under the TGP command are given in Table 8. The linear regression model gave significant predictability of 0.605** for paddy, followed by 0.431** for sugarcane, 0.406** for groundnut, 0.266** for cotton and non-significant predictability of 0.184 for sorghum over years. Compared to this, the quadratic regression model gave maximum and significant predictability of 0.725** for paddy, followed by 0.488** for sugarcane, 0.458** for groundnut, 0.274** for cotton and non-significant predictability of 0.186 for sorghum. The linear regression model gave prediction error of 627.5 kg/ha for paddy, followed by 263.1 kg/ha for groundnut, 172.7 kg/ha for sorghum, 100.3 kg/ha for cotton and 57.8 q/ha for sugarcane. Compared to this, the quadratic regression model gave prediction error of 535.7 kg/ha for paddy, followed by 257.0 kg/ha for groundnut, 176.4 kg/ha for sorghum, 102.0 kg/ha for cotton and 56.1 q/ha for sugarcane. The canal water released for crops had a significant effect as indicated by the rate of change on the yield of paddy, groundnut, sugarcane and cotton, while it was non-significant for sorghum based on the linear regression model. However, the quadratic regression model indicated about the significance of canal water released on the yield of paddy, groundnut and sugarcane, while it was non-significant for sorghum and cotton. The quadratic coefficients of canal water indicated that there is a great scope for improving the yields of all crops with efficient management of canal water in different districts under the TGP command area. The linear effects of canal water on the yield of crops during 1997 to 2021 are depicted in Fig. 7, while the quadratic effects of canal water on the yield of crops are depicted in Fig. 8. The results described in this paper are in confirmation with the findings made by Mehanuddin et al. [23] who studied about the water requirement of different crops which were significantly influenced by the canal water. The authors have modeled the crop water requirement and made efforts to optimize the crop water requirement of different crops. Similarly, the results described in this paper are in agreement with the findings made by Sachin et al. [24], who developed efficient water production functions for winter wheat by providing drip irrigation. In fact, the researchers have attempted to optimize the crop water requirement for maximizing the wheat yield and monetary returns over years. In another study conducted by Vedula et al. [25], the researchers developed conjunctive use models for assessing the

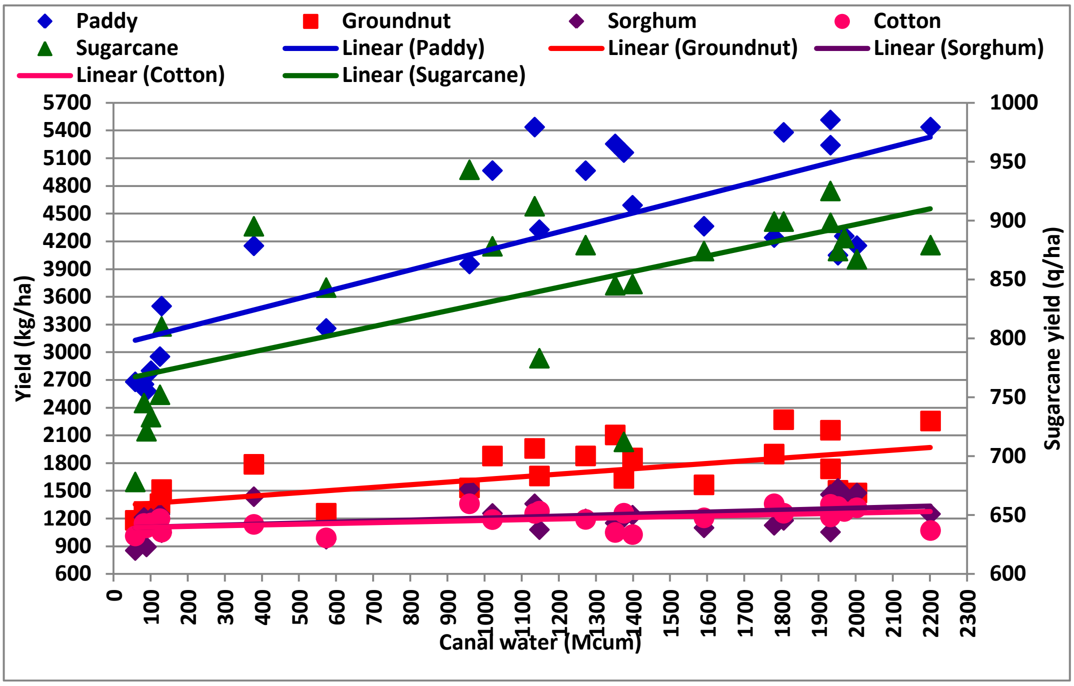

Fig. 7. Linear effect of canal water on the yield of crops attained during 1997 to 2021

Table 8. Prediction of yield of crops through canal water released in different years under the TGP command area

Parameter	Linear regression model	R^2	PE	Quadratic regression model	R^2	PE
Regression model of Yield vs Canal water						
Paddy	Y = 3068.25** + 1.027** (CW)	0.605**	627.5	Y = 2622.0** + 2.751** (CW) - 0.001** $(CW)^2$	0.725**	535.7
Groundnut	Y = 1335.9** + 0.287** (CW)	0.406**	263.1	Y = 1235.4** + 0.676* (CW) + 0.001 $(CW)^2$	0.458**	257.0
Sugarcane	Y = 763.7** + 0.066** (CW)	0.431**	57.8	Y = 740.1** + 0.157** (CW) + 0.001 $(CW)^2$	0.488**	56.1
Sorghum	Y = 1090.1** + 0.086 (CW)	0.184	172.7	Y = 1086.8** + 0.142 (CW) + 0.001 $(CW)^2$	0.186	176.4
Cotton	Y = 1095.6** + 0.108** (CW)	0.266**	100.3	Y = 1085.9** + 0.131 (CW) + 0.001 $(CW)^2$	0.274*	102.0

** and ** indicate significance at $p < 0.05$ and $p < 0.01$ levels respectively*

Y: Yield (kg/ha) CW: Canal water (Mcum) R^2 : Coefficient of determination PE: Prediction error (kg/ha)

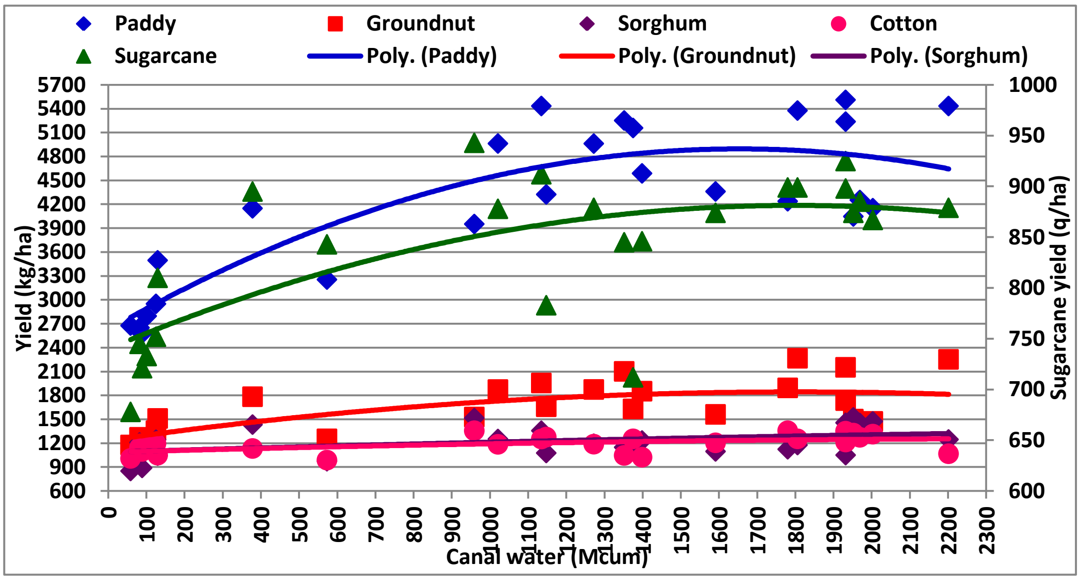

Fig. 8. Quadratic effect of canal water on the yield of crops attained during 1997 to 2021

variability of multi crop irrigation provided in different years. Based on the models, the authors optimized the crop water requirement with the objective to maximize the productivity and monetary returns from different crops.

Thus the study has indicated about significant influence of canal water released in different years on the productivity of paddy, groundnut and other crops during the study period. The rainfall received in different districts over years was found to be erratic with a higher variability in the TGP command area. The predictability of yield could be enhanced by minimizing the variability in the release of canal water. Based on the study, there is also a need to identify efficient crops which have a lower water requirement in order to maximize the water use efficiency, productivity and profitability of crops in the TGP command area.

4. CONCLUSION

Based on a study conducted under the Telugu Ganga Project (TGP) in Andhra Pradesh, a detailed assessment of the variability and relationships between the rainfall (mm) received, canal water (Mcum) supplied and the yield (kg/ha) of five major crops viz., paddy, groundnut, sugarcane, sorghum and cotton attained during 1997 to 2021 has been made in this paper. Linear and quadratic regression models were calibrated to assess the trends in the changes of annual rainfall, canal water released and yield of crops attained in different years. The models of yield were calibrated through the canal water supplied with the objective of assessing the effect of canal water on yield, apart from using the models for efficient prediction of yield attained in different years. The statistical criteria of coefficient of determination (R^2) and prediction error (PE) of the yield were used to assess the efficiency of models for yield prediction. An increase in the release of canal water was found to significantly increase the yield of paddy, groundnut, cotton and sugarcane crops in different districts under the TGP command area. The quadratic regression models gave higher and significant values of R^2 compared to the linear models of different crops. Efficient predictions of yield were found to be possible based on the regression models of yield calibrated through canal water released in different years. The models were found to be useful for prediction of yield of crops through varying levels of canal water released in different years. There is a need for optimization of canal water to be released every year in order to grow less water requiring crops for attaining maximum water use efficiency, crop yield and monetary returns even under drought conditions.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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