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K Kishan Neelambika
College of Agricultural
Engineering, Sangareddy,
PJTAU, Telangana, India

N Hari
College of Agricultural
Engineering, Sangareddy,
PJTAU, Telangana, India

M Srinivasulu
College of Agricultural
Engineering, Sangareddy,
PJTAU, Telangana, India

Assessment of surface and groundwater quality and availability in the Appapuram channel command area

K Kishan Neelambika, N Hari and M Srinivasulu

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Abstract

The present study aims to Assessment of Surface and Groundwater Quality and Availability in the Appapuram Channel Command Area of the Krishna Western Delta (KWD). The command area, covering approximately 10,000 ha, In the KWD irrigation system, canal water is supplied continuously until about ten days prior to harvest, meeting the water needs for land preparation, field saturation, crop establishment, and subsequent growth stages. The analysis revealed that groundwater in branches 3 to 7 is of acceptable quality ($EC \approx 1.07 \text{ dS m}^{-1}$) and can be safely used for irrigation in conjunction with canal water. In contrast, groundwater in branches 1, 2, 8, and 9 is saline ($EC > 4.0 \text{ dS m}^{-1}$), limiting its suitability for irrigation due to the risk of soil salinization. Accordingly, optimization modelling was applied only to branches with fresh groundwater, while surface water alone was considered in saline-affected areas.

Keywords: Surface water quality, groundwater quality, water availability

Introduction

India's rapidly growing population poses a serious challenge to national food security under conditions of limited and increasingly stressed water resources. The population, which has already crossed one billion, is projected to reach about 1.33 billion by 2025. Food grain production has increased significantly from around 50 million tonnes in the 1950s to nearly 235.88 million tonnes in 2010-11; however, future demand continues to rise. At the global level, nearly 60% more food will be required by 2050 to feed an estimated population of 9.5 billion (FAO, 2013; United Nations, 2012), placing immense pressure on freshwater resources. Agriculture remains the largest consumer of water, and the sustainability of water resources has become a critical issue due to rising demand from agricultural, industrial, and domestic sectors. Rapid urbanization, groundwater contamination, climate change impacts, improved living standards (Mariolakos, 2007) ^[6], and changing dietary patterns have further reduced both the quantity and availability of water for agriculture. India's groundwater resources are estimated at 433 billion cubic metres (BCM), of which about 399 BCM is available for development. Nearly 92% of groundwater withdrawals are used for irrigation, yet groundwater development is highly uneven across regions, ranging from about 98% in the North Western Plains to less than 45% in the Eastern and Central Plains. This spatial imbalance makes groundwater management a complex and region-specific challenge. Although rainfed agriculture contributes significantly to food production, future increases must largely come from irrigated agriculture due to its higher productivity. The average yield of irrigated land is about 2.2 t/ha compared to only 0.5 t/ha under rainfed conditions (National Water Policy, 2002). With the population expected to stabilize at around 1,600 million by 2050, food grain demand is projected to reach about 450 million tonnes. Considering climatic variability and the need for buffer stocks, planning for a minimum production of around 500 million tonnes of food grains by 2050 is essential. Achieving this target requires improving water productivity, enhancing irrigation efficiency, ensuring sustainable groundwater use, and adopting appropriate technologies to obtain more crops per drop of water.

In Andhra Pradesh, agriculture consumes more than 95% of the harnessed water resources, with irrigation systems largely dependent on interstate rivers such as the Krishna and Godavari. Increasing upstream water use by neighboring states has created uncertainty in the timing and

Corresponding Author:
K Kishan Neelambika
College of Agricultural
Engineering, Sangareddy,
PJTAU, Telangana, India

quantity of water availability. While head-end farmers generally receive adequate supplies and grow water-intensive crops like rice, tail-end farmers often suffer from severe water shortages. This inequitable distribution of water highlights the urgent need to integrate and evaluate efficient water management technologies at the field scale to improve water use efficiency, ensure equitable water availability, and sustain agricultural productivity.

Materials and Methods

The assessment of surface water quality and quantity, the study area details, climate, cropping pattern, rainfall and effective rainfall are described in the following sections

Description of study area

The command area of Appapuram channel, which branches from Commamuru branch canal (Krishna Western main canal) near Sangam Jagarlamudi lock is selected as the study area. It lies in Krishna Western Delta in Guntur district of Andhra Pradesh and is located at 16° 01' N to 16° 04' N latitude and 80° 25' to 80° 34' E longitudes (Fig.1). Field visits were made to study the actual cropping pattern existing in the command. Interaction meetings and interviews with the farmers, WUA members were conducted to collect the information to the nearest possibility to the ground truth. It spreader over 10000 ha and is on an average 6 m above the mean sea level.

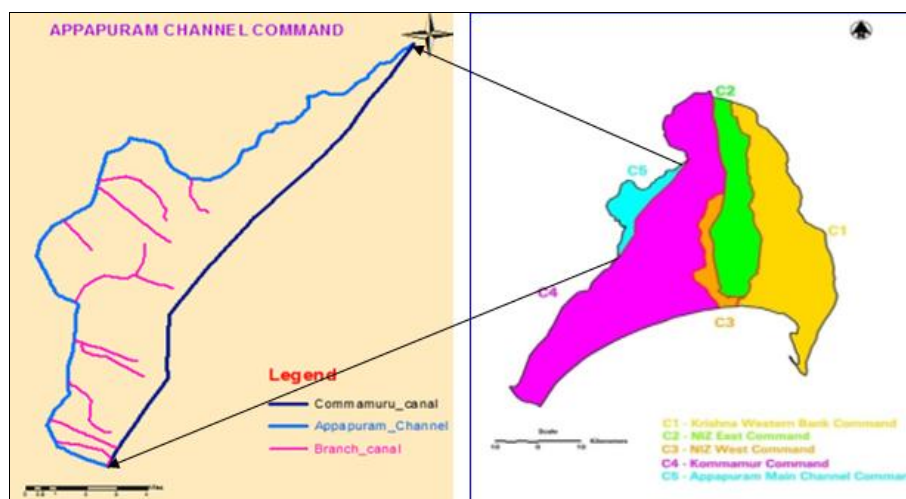


Fig 1: Location map of Appapuram Channel Command

Climate

The Appapuram Channel command area experiences a sub-humid climate with heavy rainfall during the late *kharif* season, mainly in August and September. The southwest monsoon generally begins in mid-June and continues until mid-October, contributing about 90% of the annual rainfall, while cyclonic rainfall occurs once in about five years during October-November. The summer season from April to mid-June is characterized by very high temperatures. Daily climatic data for the period 2000-2015 were collected from the Regional

Agricultural Research Station, Acharya N.G. Ranga Agricultural University, Lam Farm, Guntur. The mean maximum temperature reaches about 40.8 °C in May, while mean minimum temperatures range from 17.16 to 27.62 °C. Maximum monthly rainfall occurs in August (200.1 mm) and September (176.4 mm). Evaporation is highest in May (153.76 mm/day) and lowest in December (3.0 mm/day). Wind speed is highest in June (9 km h⁻¹) and lowest in November (4 km h⁻¹), while maximum sunshine hours are recorded in April (8.1 h) and minimum in July (4.2 h).

Table 1: Monthly mean meteorological data of study area (2000- 2015)

S. No.	Month	Min. temp. (°C)	Max. Temp. (°C)	Humidity (%)	Wind speed (km/d)	Sunshine (h/day)	Solar Radiation (MJ/m ² /d)	ET ₀ (mm/d)	Monthly ET ₀ (mm)
1	January	17.2	30.5	90	5	6.5	15.7	2.89	89.59
2	February	17.5	31.8	88	5	7.7	18.9	3.42	95.76
3	March	22	35.5	86	7	7.3	19.9	4.04	125.24
4	April	25.2	37.7	81	8	8.1	21.9	4.77	143.10
5	May	27.6	40.8	72	9	7.7	21.4	4.96	153.76
6	June	26.7	37.5	71	9	5.5	17.9	4.13	123.90
7	July	25.2	34.5	78	8	4.2	15.9	3.59	111.29
8	August	24.2	33.3	83	7	4.3	16.0	3.5	108.50
9	September	24.1	33.4	82	5	4.8	16.3	3.49	104.70
10	October	23	32.5	87	4	5.1	15.5	3.19	98.89
11	November	23	35.3	96	4	6.5	16.0	3.42	102.60
12	December	19.9	34.1	98	4	5.8	14.3	3	93.01
Total									1350.33

*Penman- Montith equation was used in ET₀ calculations with the values for Angstrom's Coefficients a = 0.25 and b = 0.5

Soils

The Appapuram Canal command area comprises four major soil types, namely black cotton soils, sandy clay loams, red loamy

soils, and sandy soils, including patches of problematic saline and alkali soils. Sandy soils occur mainly along the coastal fringe, while black cotton soils are the most extensive and are

distributed across all mandals of the command area. Sandy clay loam soils are predominantly found along rivers and stream courses. The soil reaction varies from slightly acidic to moderately alkaline, with pH values ranging from 6.40 to 8.21. Electrical conductivity ranges between 1.0 and 3.0 dS m⁻¹, and exchangeable sodium percentage (ESP) varies from 10.0 to 15.8%. The soils are generally low to medium in available nitrogen, medium to high in available phosphorus, and high in available potassium. The study area is largely characterized by deep black clay soils with a two-layered profile, having an average effective soil depth of about 180 cm, of which the surface layer constitutes approximately 40-50 cm.

Crops grown and cropping pattern

A variety of crops such as rice, cotton, maize, chilli, black gram, green gram, and sugarcane are traditionally cultivated in the Appapuram Canal command area. However, during the past three years, the dominant cropping pattern has shifted, with farmers primarily growing paddy during the *kharif* season and maize and black gram during the *rabi* season. The predominance

of black soils in the command area makes the region suitable for the cultivation of a wide range of crops. At present, rice, maize, cotton, chilli, black gram, and green gram are the major crops grown in both *kharif* and *rabi* seasons.

The daily rainfall data were collected from Regional Agricultural Research Station, Acharya N.G.Ranga Agricultural University, and Guntur from the year 2000-2015 for analyzing the rainfall in the study area. The annual average rainfall of the study area has been monthly worked out to be 986.7mm and almost all area lies under sub humid climatic zone. The CROPWAT model was run to calculate the effective rainfall which is an important parameter for calculating crop irrigation requirement and is presented in Table 3. The USDA Soil Conservation Service formula was opted to find out the effective rainfall as given below.

$$P_{\text{eff}} = (P * (125 - 0.2 * 3 * P)) / 125 \text{ for } P \leq 250/3 \text{ mm}$$

$$P_{\text{eff}} = 125/3 + 0.1 * P \text{ for } P > 250/3 \text{ mm}$$

Month wise average rainfall and effective rainfall in mm are given table 3.

Table 2: Monthly rainfall and Effective rainfall of study area

S. No.	Month	Rain fall (mm)	Effective Rainfall (mm)
1	January	7.4	7.3
2	February	21.6	20.9
3	March	28.5	27.2
4	April	16.5	16.1
5	May	53.8	49.2
6	June	107.0	88.7
7	July	164.5	121.2
8	August	200.1	136
9	September	176.4	126
10	October	128.7	102.2
11	November	59.7	54
12	December	22.5	21.7
	Total	986.7	770.5

The canal water release data for 10 years (2005-2015) were collected from Water Resources Department at Bapatla and analyzed for further investigation. The daily discharges of the Appapuram channels for ten years. The monthly averages were calculated for all the years (2005-2015) and are presented in Table 4. It could be observed from the table that almost in all the years, the canal is running dry during May and June months.

Monthly averages canal discharge of Appapuram channel command (cusecs)

The average wetted perimeter is 10.04 m and total wetted

surface area of Appapuram channel distributary is 568150.6 m². Seepage in the distributary was calculated taking into consideration the number of days' canal is flowing and seepage factor as 3.6 ham/day/10⁶sqm of wetted area for lined canals (GEC, 2007) and are furnished in Table 4.3. This approximately accounts for around 20% of the released water. The losses account for the breaches of the sides and bottom and poor maintenance of the canal system throughout the length.

Table 3: Estimation of Seepage losses in Appapuram channel distributary

S. No.	Year	Canal flow (days)	Wetted surface area, (m ²)	Seepage losses (ha m)
1	2005	226	568150.6	462.25
2	2006	188	568150.6	384.52
3	2007	238	568150.6	486.79
4	2008	227	568150.6	464.29
5	2009	245	568150.6	501.11
6	2010	234	568150.6	478.61
7	2011	251	568150.6	513.38
8	2012	197	568150.6	402.93
9	2013	150	568150.6	306.80
10	2014	264	568150.6	539.97
11	2015	162	568150.6	331.35

The monthly canal flows were converted to volumetric units (ha m) and the monthly seepage volumes were deducted to arrive

the monthly surface water resources availability (canal water) ready for allocation to various crops and are presented in.

Table 4: Available surface water resources (canal water) in the study area

S. No	Month	Discharge (cusec)	Discharge (m ³ /sec)	Volume of water in (ha m)	Seepage losses from main canal (ha m)	Volume of water for allocation (ha m)
1	January	151.66	4.29	429.20	85.84	343.36
2	February	149.87	4.24	424.14	84.83	339.31
3	March	138.54	3.92	392.07	78.41	313.65
4	April	52.77	1.49	149.35	29.87	119.48
5	May	2.99	0.08	8.45	1.69	6.76
6	June	0.00	0.00	0.00	0.00	0.00
7	July	35.94	1.02	101.71	20.34	81.36
8	August	190.96	5.40	540.43	108.09	432.34
9	September	228.69	6.47	647.20	129.44	517.76
10	October	227.57	6.44	644.03	128.81	515.22
11	November	180.70	5.11	511.37	102.27	409.10
12	December	125.78	3.56	355.95	71.19	284.76

Water quality

The water used for irrigation in the Appapuram channel command area is the fresh water that comes from Prakasam barrage. The water samples were obtained from 10 different locations in Appapuram Channel Command for water quality analysis. The EC and pH of canal water are given in Table. 6 covering all the branches of Appapuram Channel. As per the CGWD board report, Guntur as a preliminary basis, 10 locations in the entire command in 10 villages covering all the 9 branches were identified. The samples were collected in the month of December 2015. The quality parameters were found out for identifying the branches of the command where the conjunctive use of surface and ground water resources could be applied. Hence only one time the samples were collected. Use of saline water for the crops of the command was not considered for the present study. Hence the quality parameter is not included in formulating constraints.

Table 5: Quality Parameter of canal water of Appapuram channel

S. No	Location	EC(dSm ⁻¹)	pH
1.	Sangam Jagarlamudi (Head rich)	0.735	7.2
2.	Chebrolu	0.733	7.3
3	Mutluru	0.732	7.4
4	Vatticherukuru	0.735	7.2
5	Lingaya Palem	0.735	7.2
6	Golla Palem	0.734	7.2
7	B.Palem	0.732	7.4
8	Valluru	0.733	7.3
9	Kondapadu	0.734	7.3
10	Appapuram (Tail end)	0.735	7.3

As per the above table, it is evident that the quality of canal water is good for irrigation as well as for domestic purpose because EC and pH are well within the permissible limits

Assessment of availability of ground water 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. It is the most widely used method for estimating recharge.

Recharge is calculated as

$$R = S_y \, dh/dt$$

Where

R recharge, S_y the specific yield, h is water-table height, and 't'

is time (Healy and Cook, 2002). Water Table Fluctuations represent spatially averaged recharge. Determining representative values of S_y is a major difficulty in applying this method. Another difficulty lies in ensuring that the fluctuations in water levels are due to recharge and are not the result of changes in atmospheric pressure, the presence of entrapped air or other phenomena such as pumping.

For the efficient utilization of ground water, the quality plays a major role in terms of selection of crop variety for sustainable agriculture. Hence the grounder water samples were collected at 5 locations viz head, middle lower reaches specifying all this locations were analyzed. The average the EC and pH of groundwater are given in Table 6.

Table 6: Quality Parameter of Groundwater

S. No.	Location	EC (dSm ⁻¹)	pH
1	Sekuru	4.860	7.92
2.	Mutluru	5.190	8.7
3	Kakumanu	1.070	7.09
4	Nadendla	7.470	7.92
5	Pedanandipadu	1.150	8.67

The canal network (main canal, distributaries, sluice outlets, pipe points etc.) were found on unlined sections. To minimize the seepage losses and water-logging, canal lining is very much required in the command area. The water saved by minimizing conveyance losses can be utilized for additional irrigation. Although water logging is found at tail ends, it is not regarded as a severe problem in the command area.

Results and Discussion

The study aims to assess the quantity and quality of available surface water resources and to estimate the quantity and quality of groundwater resources in the command area. It also seeks to determine the irrigation water requirements of existing crops as well as other high-value crops. Further, the study focuses on optimizing the conjunctive use of surface and groundwater resources through the application of an appropriate optimization model to improve water use efficiency and ensure sustainable water management. The quality of surface water and as well as ground water is also of more importance in terms of deciding its feasibility for irrigation of different crops in the study area. The samples from all the nine branches and from the ground water observation wells were collected and analyzed in the laboratory

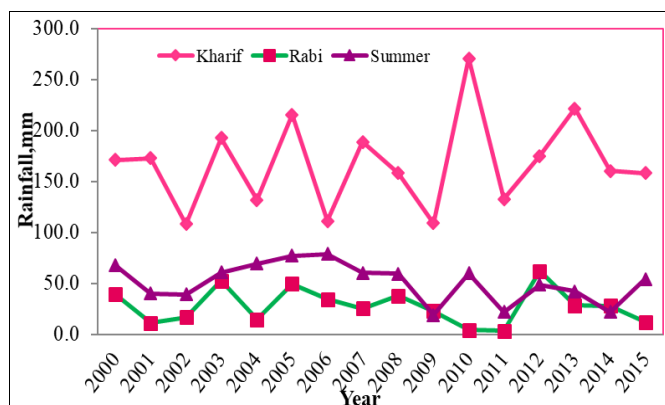


Fig 2: Seasonal rainfall in Appapuram channel command

From the above figure, it could be observed that the during the Kharif, there is more rainfall than the other two seasons. This information was utilized in the estimation of irrigation water requirements of different crops finally in formulating the constraints also.

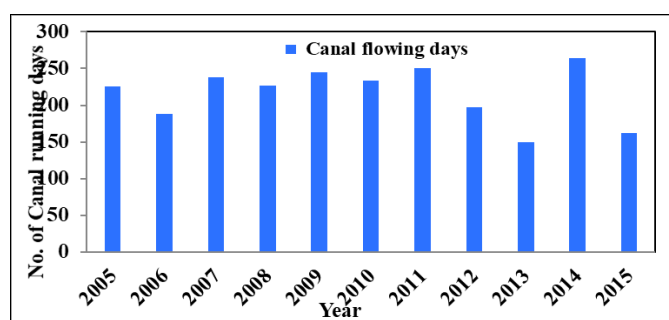


Fig 3: Year wise canal flowing days of Appapuram channel

The monthly canal flows were converted to volumetric units (ha m) and the monthly seepage volumes were deducted to arrive the monthly surface water resources availability (canal water) ready for allocation to various crops and are presented

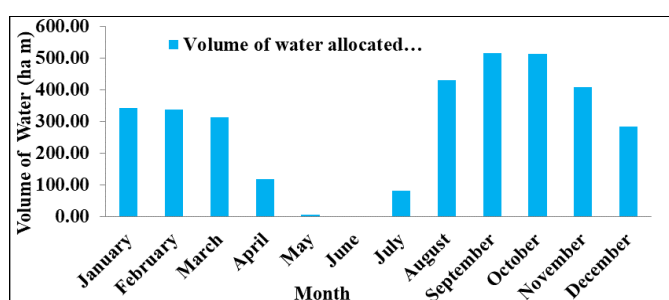


Fig 4: Month wise availability of surface water for allocation to different crops

Assessment of quantity of ground water in the study area

The information published in the reports of The Central Ground Water Department Board were utilized for choosing the canal branches for applying the conjunctive use model for both surface and ground water resources. Accordingly, where there is more ground water salinity is found, the model is run only for surface water utilization and crop area allocation to maximize the profit. The water table fluctuation method is used for finding out the availability of ground water in the study area without affecting the deeper aquifer zones for the sustainable usage. The quantity arrived at for one season is distributed equally for 12 months as supplement for irrigating the crops. The ground water quantity

available for allocation is presented in Table.

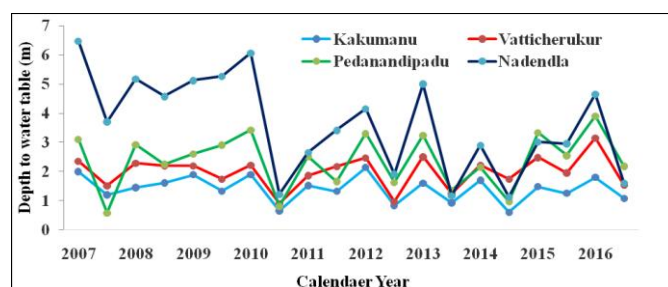


Fig 5: Season wise ground water table fluctuations in different mandals of Appapuram channel

Groundwater quality data obtained from the Central Ground Water Board were used to assess groundwater salinity in different canal branches of the study area, Analysis of the data indicated that mandals covered under branches 3 to 7, namely Kakumanu and Peddanadipadu, exhibited no salinity hazard, with electrical conductivity values around 1.07 dS m^{-1} . Groundwater in these branches is therefore suitable for irrigation and can be safely used in conjunction with canal water.

In contrast, groundwater samples from branches 1 and 2 (Vatticherukuru Mandal) and branches 8 and 9 (Nadendla Mandal) showed high salinity levels, with EC values exceeding 4.0 dS m^{-1} . In these areas, the use of groundwater for irrigation is likely to increase soil salinity unless adequate leaching provisions are made. Moreover, shortfalls in canal flows and untimely release of surface water limit the feasibility of conjunctive use of surface and groundwater resources in these branches. Consequently, optimization modelling was applied only to branches 3, 4, 5, 6, and 7, where both surface and groundwater resources of acceptable quality are available, while only surface water was considered for irrigation planning in the remaining branches.

Although previous studies have demonstrated the feasibility of conjunctive use of saline and fresh water under conditions of groundwater salinity, the present study is confined to areas with fresh surface water and low-salinity groundwater. The use of saline groundwater requires careful management of the root zone through adequate leaching and soil amendments, which was beyond the scope of the present work. Such investigations may be taken up in future studies, particularly under scenarios of severe canal water shortages.

Conclusion

The analysis revealed that groundwater in branches 3 to 7 is of acceptable quality ($\text{EC} \approx 1.07 \text{ dS m}^{-1}$) and can be safely used for irrigation in conjunction with canal water. In contrast, groundwater in branches 1, 2, 8, and 9 is saline ($\text{EC} > 4.0 \text{ dS m}^{-1}$), limiting its suitability for irrigation due to the risk of soil salinization. Accordingly, optimization modelling was applied only to branches with fresh groundwater, while surface water alone was considered in saline-affected areas. Future studies should focus on the safe conjunctive use of saline and fresh water under conditions of severe canal water shortages. To improve the quality of waters in the study area measures to be taken are in alluvium areas the fresh water repositories are to be protected from over pumping. Optimum utilization of surface and ground water may be considered locally after micro level surveys considering quality constraint. Environmental protection measures are to be followed in aqua culture practices and during oil & gas exploration. In the limited groundwater potential area,

modern irrigation methods like drip and sprinkler irrigation should be adopted. Artificial recharge measures should be adopted in the urban areas, in the deltaic area and areas with considerable exploitation of groundwater for improving the ground water situation.

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