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Managing the Irrigation Water Requirements of Command Area of 4(L) Distributory of Pollachi Main Canal under Variable Rainfall Conditions

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Abstract

The 4 (L) distributory of Pollachi main canal, Parambikulam-Aliyar-Palar (PAP) basin has been selected for an in-depth water management study. The project area has been divided into two zones namely, A zone and B zone. Each zone would get water from the canal system once in every two years. From the analysis of rainfall data of the rain gauge stations located in Parambikulam-Aliyar-Palar basin, it was observed that there was a wide temporal and spatial variability in annual rainfall over the years. The lowest annual rainfall recorded was 210.6 mm (over the plain) in 2003 and the highest of 5346.4 mm (in the hills) in 2007. The average annual rainfall for the period 1988-2010 was 1372.1 mm. The irrigation water requirement for the crops grown in the 4 (L) distributory was estimated using AquaCrop3.1 model for the years 2000-2010. The total irrigation water requirement during deficit rainfall year (2002) was 58.4 percent which is higher compared to normal year (2008). During the excess rainfall year (2007), the demand was 5.32 percent lower than the normal year demand. Therefore, the conjunctive use management of surface and groundwater resources in a command area can play a significant role in managing water by distributing the water throughout the season, while also maintaining the long-term sustainability of groundwater resources.

1. Introduction

Rainfall variability widely influences the irrigation water requirement of crops grown in various command areas throughout India. Managing irrigation under scarcity using an integrated approach is a critical issue in irrigation planning. Understanding the vulnerability and resilience of irrigated command areas to climatic extremes viz., drought and excess water situation will be helpful to develop management strategies to mitigate unexpected adverse rainfall conditions. Fiedler (2003) derived station weights of rainfall using Thiessan Polygon and Isohyetal methods and found that more accurate spatial distribution was depicted by the Isohyetel method.

Parambikulam-Aliyar-Palar (PAP) basin is located in the south western part of the Peninsular India and covers the areas in Kerala and Tamil Nadu States. The PAP basin lies (except the Ayacut area) within the coordinates between 10° 10' 00" to 10°57'20" N and 76°43'00" to 77° 12'30" E (Fig 1). The basin area lies within the Coimbatore district only and the Ayacut area is extended beyond Coimbatore and Triuppur districts up to Vellakoil, Erode district. In Tamil Nadu, there is a little scope for the augmentation of water supply to agriculture as the utilization of surface and groundwater resources have already crossed 95 percent and 78 percent of this capacity, respectively (Source: CWC, 2008 & CGWB, 2009). The net irrigated area in the state is around 25 lakh hectares in 1960 to 2010. But the share of irrigation by surface water resources (canals and tanks) reduced from 18.12 lakh ha to 12.19 lakh ha in 2010. But the share of groundwater irrigated areas increased from 6.45 lakh ha in 1960 to 14.18 lakh ha in 2010 (Seasons and Crop report, Tamil Nadu, 2010). The decline in canals and tanks was more or less compensated by the significant increase in the groundwater irrigated areas. There is an urgent need for improving the efficiency of existing irrigation projects, which will ensure its sustainability with the possibility of bringing in additional areas under its command. Estimation of spatial and temporal water availability from rain, surface sources and groundwater sources in the command area and assessment of irrigation water requirements for various crops are prerequisite for crop planning within the command area.

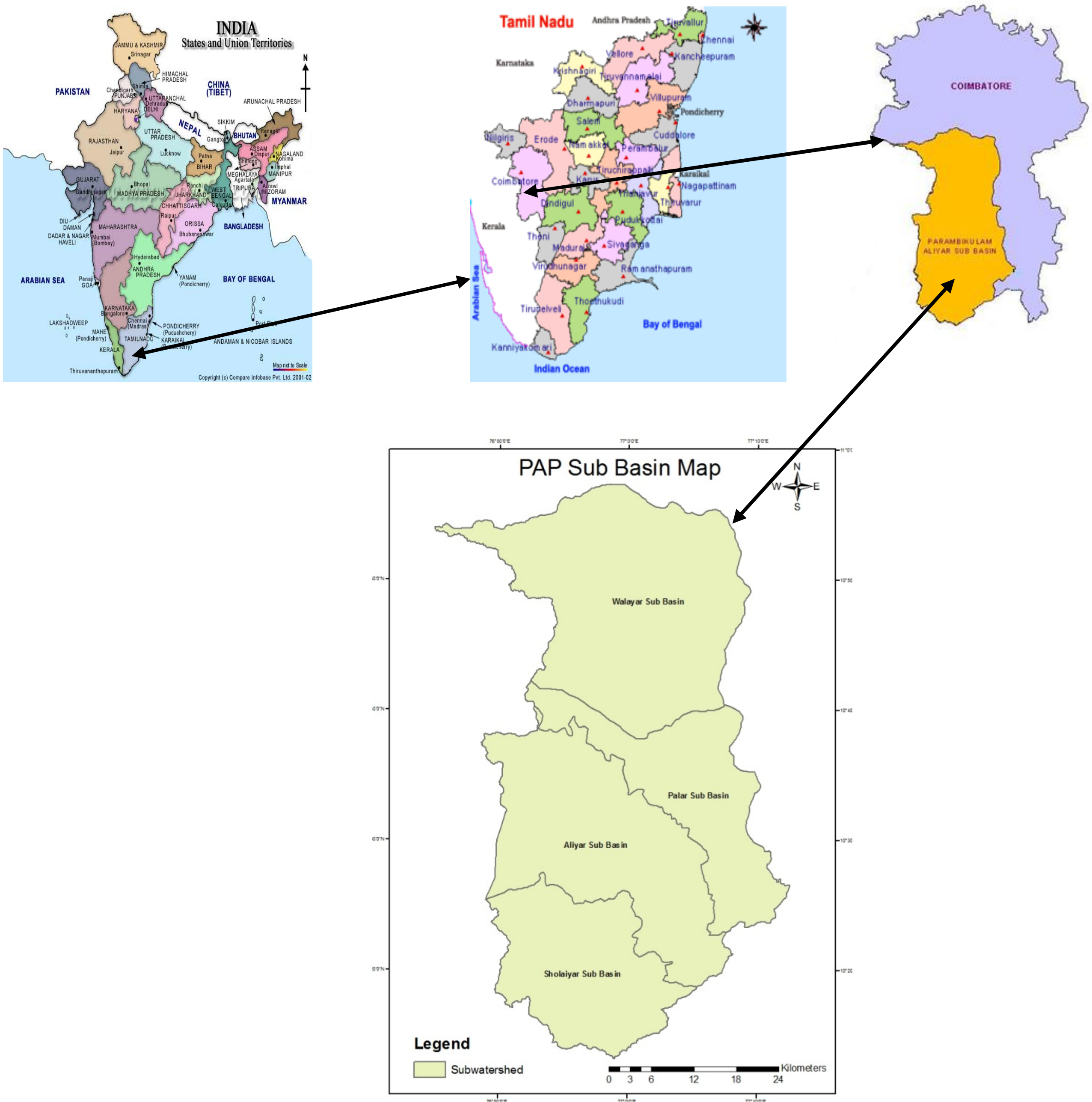

Fig.1. Location map of Parambikulam-Aliyar-Palar (PAP) basin
(Source: CGWB and PWD)

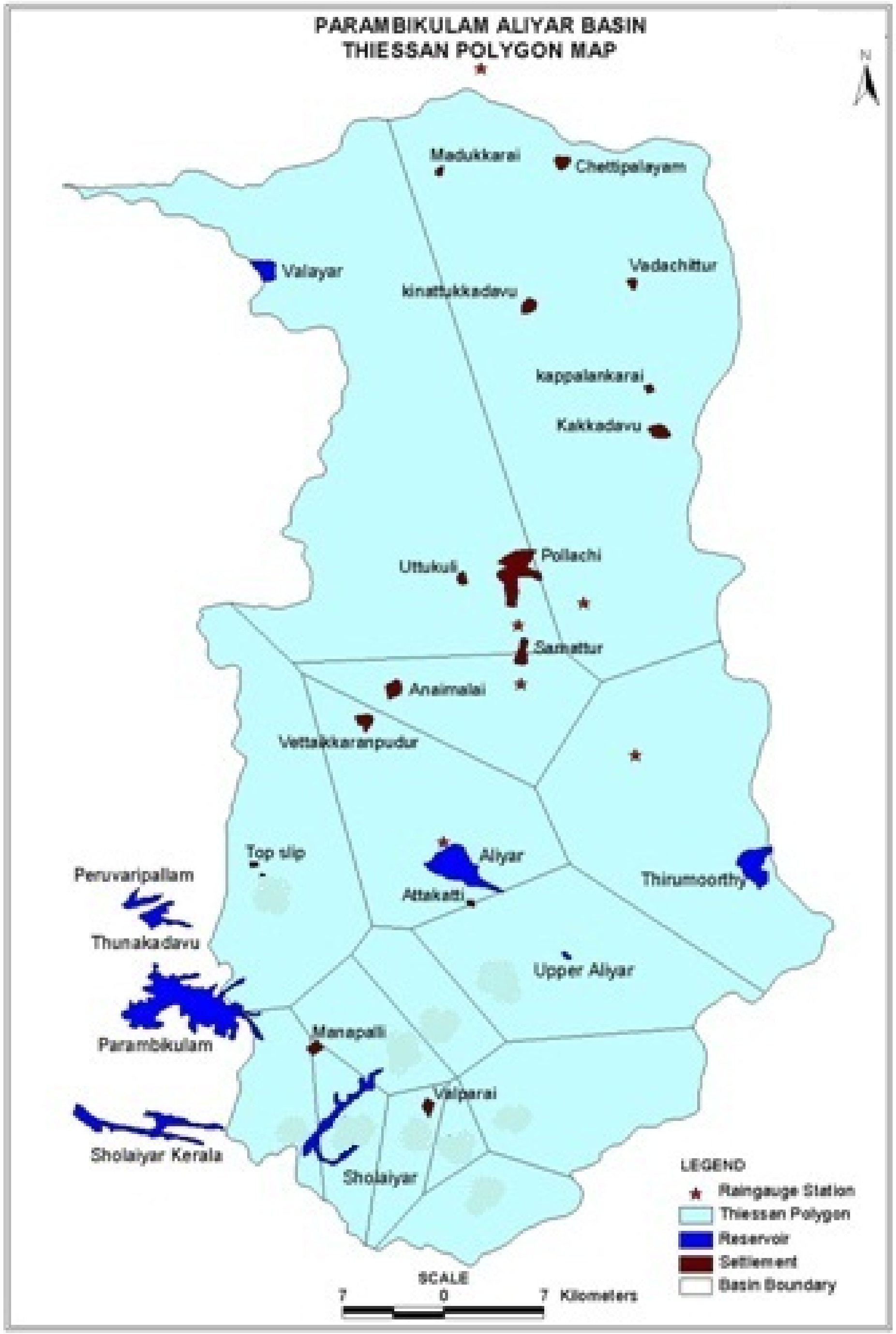

Fig.2. Thiessan polygon map showing the network of rain gauges
in Parambikulam-Aliyar-Palar) basin

2. Methodology

2.1. Study Area

The location of observation wells and rain gauge stations in PAP are as shown in Fig. 2. For micro level study in PAP basin, 4(L) distributory of Pollachi canal coming from Aliyar reservoir was selected for this study. The total length of the Pollachi canal is

48 kms. The total command area under Pollachi canal is 9588.8 ha with 30 distributaries. The canal command is divided into two zones which receive water every alternate year. The distributory is located at an off take point of 5.2 km from the main canal. An attempt has been made to assess the surface, rainwater and groundwater availability of the study area and also to assess the irrigation water requirement (IWR) for the crops grown under different rainfall conditions, with an aim to plan accommodate and adapt for climatic extremes.

2.2. Rainfall Distribution

There are five rain gauge stations viz. Anamalai, Pollachi, Thirumurthy Nagar, Natakalpalyam and Aliyarnagar available in the basin. The average annual rainfall data (1988-2010) were collected and analyzed. Anamalai station recorded the highest average annual rainfall of 1372.1 mm followed by Aliyarnagar (871.3mm), Pollachi (830.3mm), Thirumurthynagar (722.3mm**)** and Natakalpalyam (534.5mm). It has been noted that the stations Anamalai and Pollachi received major portion of their annual rainfall during South West monsoon, while Aliyarnagar, Thirumurthynagar and Natakalpalyam received rainfall during North East monsoon. The rainfall analysis of five rain gauge stations in PAP basin showed a wide variation in the mean annual rainfall over the years (1988-2010) from the lowest of 210.6 mm (2003) to the highest of 5346.4 mm (2007). The mean annual rainfall for the period (1988-2010) was estimated to be 1372.1 mm. The area receives nearly 54.4 percent of annual rainfall during SW monsoon season (Jun-Sept) and 30.6 percent during NE monsoon season (Oct-Dec) and the remaining 15 percent rainfall during winter and summer seasons (Jan-May). Overall, the rainfall distribution pattern is highly stochastic and it can be inferred from the spatial and temporal variability data presented in Figs. 3 and 4.

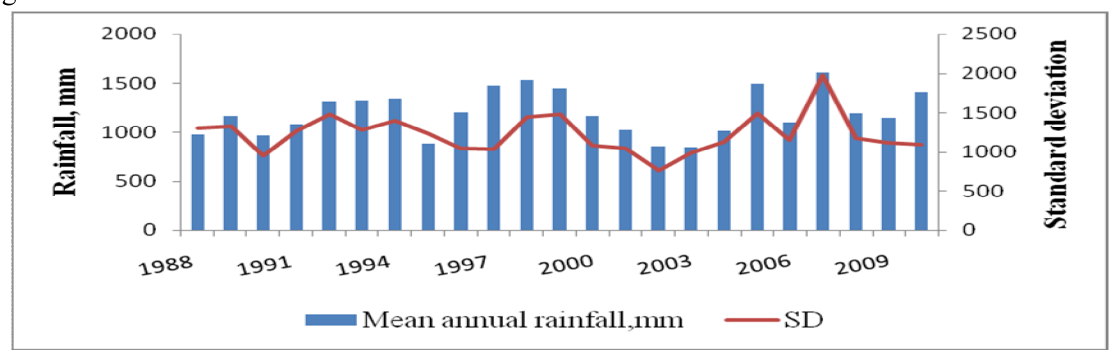

Fig. 3. Annual rainfall and standard deviation of the PAP basin(1988-2010)

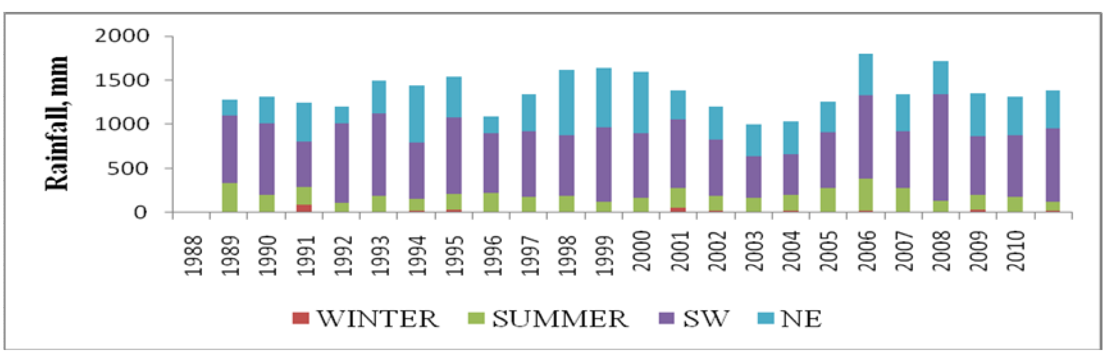

Fig.4. Seasonal average rainfall for winter, summer, SW and NE monsoon in the PAP basin from 1988-2010

The weighted mean rainfall for PAP basin using Thiessan polygon method was 1108.2 mm (Table 1). The Thiessan polygon method of calculating average rainfall over an area is superior to arithmetic mean as weights are assigned to each rain gauge in direct proportion to the area it represents and not to the total basin (Fiedler, F.R. 2003 & R.Suresh, 2005).

The annual and seasonal rainfall at probability levels of 50, 60, 70, 80 and 90 per cent were calculated by Weibull's method (Jayakumar et al.1995) for the study area from 1988-2010. The annual rainfall at 50, 60, 70, 80 and 90 per cent probability levels was found to be 1164.5, 1125.3, 1012.1, 973.6 and 870.3 mm, respectively. The probability of rainfall during winter (Jan-Feb) was almost zero and the highest rainfall occured during SW monsoon followed by NE monsoon (Fig 5).

The mean annual rainfall variability was shown in fig. 6. The results show that the highest mean annual rainfall of 1420 mm and the lowest mean annual rainfall of 580 mm accruing in 2007 and 2002, respectively.

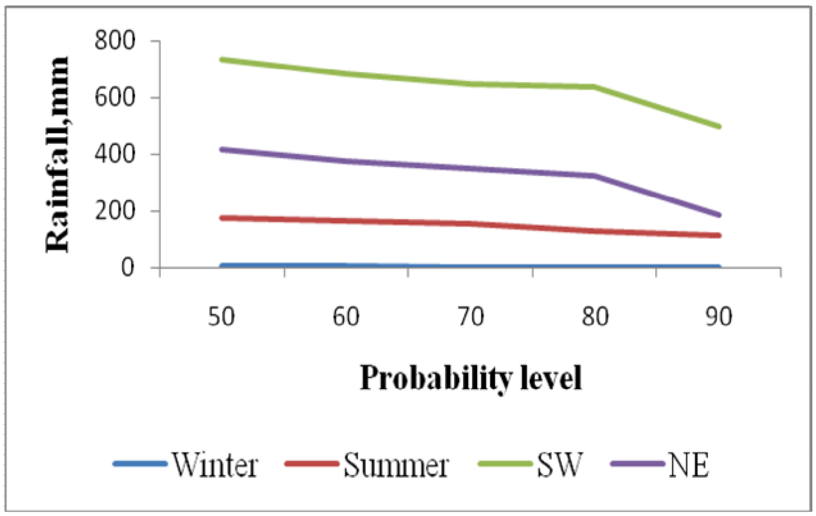

Fig. 5. Seasonal rainfall at different probablility levels

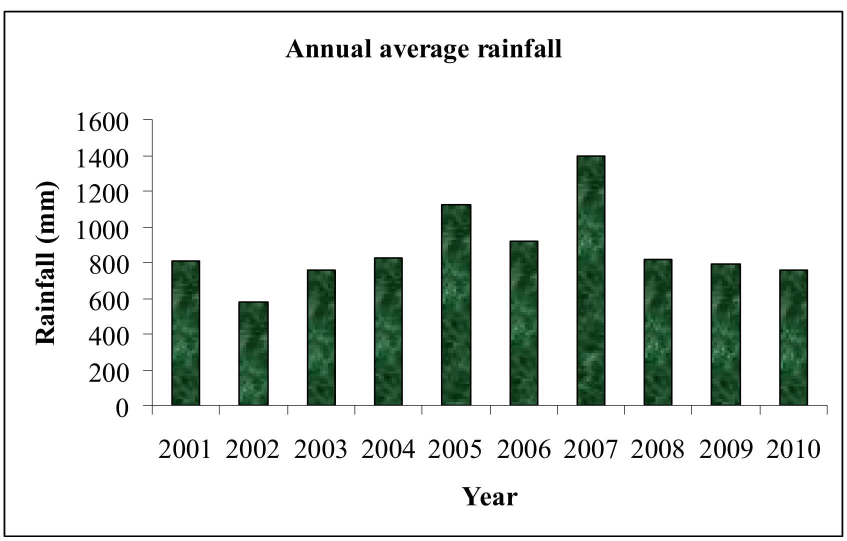

Fig. 6. Annual rainfall variability during 2001-2010

Table 1. Theissan polygon based weighted mean of rainfall distribution

Raingauge station	Aliyar nagar	Pollachi	Thirumurty nagar	Anamalai	Nattakapalayam	Total	Weighted mean rainfall, mm
Area, sq.kms	96.64	362.97	224.51	141.83	338.05	1164.00	
Jan (rainfall, mm)	9.92	6.39	13.11	9.58	5.93		
Area*rainfall sq.kms-mm	958.67	2319.38	2943.33	1358.70	2004.64	9584.71	8.23
Feb(rainfall, mm)	9.52	6.47	7.17	10.90	4.63		
Area*rainfall sq.kms-mm	920.01	2348.42	1609.74	1545.91	1565.17	7989.25	6.86
Mar (rainfall, mm)	26.54	28.57	14.69	58.42	17.28		
Area*rainfall sq.kms-mm	2564.83	10370.05	3298.05	8285.53	5841.50	30359.97	26.08
Apr (rainfall, mm)	73.83	55.37	55.23	121.23	51.52		
Area*rainfall sq.kms-mm	7134.93	20097.65	12399.69	17193.69	17416.34	74242.29	63.78
May (rainfall, mm)	72.71	70.53	50.70	191.81	56.01		
Area*rainfall sq.kms-mm	7026.69	25600.27	11382.66	27203.84	18934.18	90147.64	77.45
Jun (rainfall, mm)	75.60	73.15	34.15	664.71	11.45		
Area*rainfall sq.kms-mm	7305.98	26551.26	7667.02	94273.83	3870.67	139668.75	119.99
Jul (rainfall, mm)	110.90	170.89	46.30	1029.84	8.50		
Area*rainfall sq.kms-mm	10717.38	62027.94	10394.81	146059.12	2873.43	232072.67	199.38
Aug (rainfall, mm)	77.18	81.79	27.68	637.59	15.45		
Area*rainfall sq.kms-mm	7458.68	29687.32	6214.44	90427.48	5222.87	139010.78	119.43
Sep (rainfall, mm)	52.54	37.89	47.65	454.53	48.32		
Area*rainfall sq.kms-mm	5077.47	13752.93	10697.90	64464.63	16334.58	110327.50	94.78
Oct (rainfall, mm)	170.55	150.64	166.71	388.21	144.10		
Area*rainfall sq.kms-mm	16481.95	54677.80	37428.06	55058.66	48713.01	212359.48	182.44
Nov (rainfall, mm)	164.02	135.75	195.51	165.57	147.77		
Area*rainfall sq.kms-mm	15850.89	49273.18	43893.95	23482.30	49953.65	182453.97	156.75
Dec (rainfall, mm)	55.45	39.74	88.26	43.37	41.14		
Area*rainfall sq.kms-mm	5358.69	14424.43	19815.25	6151.04	13907.38	59656.78	51.25
Annual rainfall, mm							**1106.42**

Crop	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Coconut						Perennial crop						
Cotton		GS1	GS2	GS3		GS4	GS5					
G.Nut 1									GS1	GS2	GS3	GS4
G.Nut 2	GS2	GS3	GS4									GS1
Maize 1		GS1	GS2	GS3	GS4							
Maize 2						GS1	GS2	GS3	GS4			
Veg 1		GS1	GS2		GS3	GS4						
Veg 2						GS1	GS2		GS3	GS4		

GS1: Establishment stage GS2: Vegetation stage GS3: Flowering stage

GS4: Yield forming stage GS5: Ripening stage

Fig 7. Crop calendar in the 4 (L) distributory command area

2.3. Cropping Pattern

There are two cropping seasons in the areas which include irrigated crops during NE monsoon season (Season 1) and rainfed crops during SW monsoon season (Season 2). The study area receives 20 percent of annual rainfall between January to May, and the remaining 80 percent rainfall during monsoon season (June-December) with occasional long dry spells.

The soil in the command area is clay loam and is suitable for the cultivation of different types of crops. The crops grown at present are mainly coconut maize, cotton, groundnut and vegetables like tomato, brinjal, to name a few. All of these crops are grown during NE (October to December) and SW (June to September) monsoon seasons. The crop calendar of the study area is presented in Fig 7.

2.4. Canal Water Availability

The total number of canal running days ranged from lowest of 10 days (2003) to the highest of 149 (2007) days. During the years 2000, 2001, 2002, 2003 and 2004, the canal running days were less (10- 23 days only). The reason for less days of canal flow was attributed to low inflows into the reservoir due to deficit in rainfall during these years and also due to repair works in the canal system. However, there was an increasing trend from 2005 onwards with maximum of 149 canal running days in the year 2007. The details of monthly water release into 4(L) distributory from 2000 to 2010 were as shown in Table 2.

Table 2. Month wise details of canal water released into 4(L) distributory from 2000-2010 (ha m)

Year / Month	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Jun	1.53	0.89	0.24				1.57	7.38			
Jul			1.65					2.49			
Aug		0.00				8.59		4.47		5.21	
Sept		0.26			1.56	12.83	8.60	3.24		5.40	
Oct					1.12	12.42	13.06	4.45	8.66	12.62	9.27
Nov					1.96	6.79	7.06	5.38	8.68	3.27	5.92
Dec	0.74			0.76	1.69	0.44	14.07	7.77	11.29	11.21	
Jan	0.38	2.12	2.98	1.03	0.68	1.05	6.36	6.51	10.60	11.72	10.43
Feb	1.57	2.03	0.45	1.34	2.21	1.47				5.57	
Mar	0.68	1.60	4.01		1.09			1.84			
Apr	2.73	1.87	1.41	0.82			7.24				
May	1.67	1.29	0.29								7.54
Total	**9.30**	**10.1**	**11.0**	**4.0**	**10.3**	**43.58**	**57.96**	**43.55**	**39.23**	**54.99**	**33.16**

It is evident from the Table 2 that limited flows prevailed during 2000, 2001, 2002, 2003 and 2004 years. For calculating water available at field level, the seepage losses were calculated using wetted surface area and number of canal flowing days. For estimating the water available at the water courses, a further 10 percent reduction in the available water (as calculated above) was made and the balance was considered available at the field level. The evaporation losses from the free water surface in the water conveyance network were ignored. The details of canal water available at field level are furnished in Table 3, after accounting for all losses.

Table 3. Canal water available at field level (ha m)

Year	Canal water	Seepage losses	Water availability at distributory level	Water course losses 10 per cent	Water available at field level
2000	9.30	1.05	8.25	0.83	7.42
2001	10.1	1.15	8.95	0.90	8.05
2002	11.0	1.33	9.67	0.97	8.7
2003	4.0	0.46	3.54	0.35	3.19
2004	10.3	1.47	8.83	0.88	7.95
2005	43.58	4.21	39.37	3.94	35.43
2006	57.96	10.63	47.33	4.73	42.6
2007	43.55	6.83	36.72	3.70	33.02
2008	39.23	3.76	35.47	3.55	31.92
2009	54.99	6.00	48.99	4.90	44.09
2010	33.16	4.21	28.95	2.90	26.05

2.5. Irrigation Water Requirement

The irrigation water requirement for crop production is the amount of water, in addition to rainfall, that must be applied to meet crop evapotranspiration without significant reduction in yield. Exact amount of water required for different crops in a given set of climatological condition of a region is important for planning irrigation scheme, irrigation scheduling, effective design and management of any irrigation system. Bose and Kselic (1996) developed CRIWAR 2.0, a crop water irrigation requirement simulation model to estimate the crop water requirement of a cropping pattern in any irrigated area. The model is a helpful tool in the management of operational irrigation projects with frequently changing cropping pattern, and it can be used for performance assessment of any irrigation project. The model outputs could be used to identify the water requirements at the delivery structure on an irrigation command area. Considering the above mentioned aspects, an attempt was made to assess the irrigation water requirement for sustainability and maximize the net returns in selected distributory in Pollachi canal system of PAP basin.

The Aqua Crop3.1 model developed by Raes et al. (2011) is different from other existing crop models because of its accuracy, simplicity, and robustness. Aqua Crop has a structure that overarches the soil-plant-atmosphere continuum. It consists of five input components such as climate, crop, soil, field, and irrigation management. The details of crops grown in the command *viz.,* climate, soil data etc are used to assess the net irrigation requirement in the distributory.

The ETo Calculator, an evapotranspiration model developed by FAO was used to compute the reference evapotranspiration values. The model uses Penman-Monteith method to calculate the ETo values. The ETo values thus obtained are uploaded to Aqua Crop model. The effective precipitation is one of the water inputs to the soil root zone. For irrigation purpose the effective rainfall is defined as the part of total precipitation during the crop growing period that is available to meet the evapotranspiration needs of that crop. USDA Soil Conservation Service Method (USDA-SCS Method) is used by the crop model for calculating the effective rainfall.

According to this method the monthly effective rainfall can be calculated according to

$$ER= R\ (125-0.2*R)/125 \text{ for } R_{tot}<250 \text{ mm and} \quad (1)$$

$$ER= 125-0.1\ *R \text{ for } R_{tot}>250 \text{ mm} \quad (2)$$

The net irrigation requirement for crops grown in the distributory is computed by the AquaCrop3.1model. The net irrigation requirement (NIR) of a crop is the amount of water, in addition to rainfall, that must be applied to meet crop evapotranspiration (ETc) without significant reduction in yield. To avoid crop water stress, rainfall and irrigation must be sufficient to meet the crop ET requirement. Various methods are available to estimate the reference crop evapotranspiration (ETo). The crop evapotranspiration is calculated uses the following equation,

$$ET_c = K_c * ET_O \tag{3}$$

where,

ET_C= crop evapotranspiration (mm/day)

K_c= crop coefficient and

ET_O= reference evapotranspiration (mm/day)

The net irrigation requirement of crop can be estimated from the following equation,

$$NIR = ET_C - ER \tag{4}$$

where,

NIR = Net irrigation requirement in a given month, mm/month and

ER = Effective rainfall in a given month, mm/month

The NIR for crops grown in the study area from the year 2000 to 2010 were obtained by running the model for multiple years successively using Aqua Crop 3.1 model.

3. Results and Discussion (Modeling)

3.1. Assessment of irrigation water requirement

Assessment of crop water requirement for various crops is an important factor and basic requisite for crop planning in a command. As summarized before, the major area (199.3 ha) in the selected distributary was used for coconut plantation, which is nearly 80 percent of the total cropped area, whereas crops like cotton, maize, groundnut, tomato, brinjal were also grown in the remaining 20% area. The crop water requirement for years from 2000-2010 were calculated using Aqua Crop3.1 model. From the daily weather data, the monthly ETo values were calculated (2000 – 2010) using ETo Calculator developed by FAO. It can be seen that the monthly average reference evapotranspiration is highest during the month of May (7.36 mm/day) while, ETo value was minimum in the month of December (2.32 mm/day). Effective rainfall is one of the important water input to root zone to meet the evapotranspiration needs of the crop. The USDA soil conservation service (SCS) method was used to calculate the daily effective rainfall is presented in Fig.8.

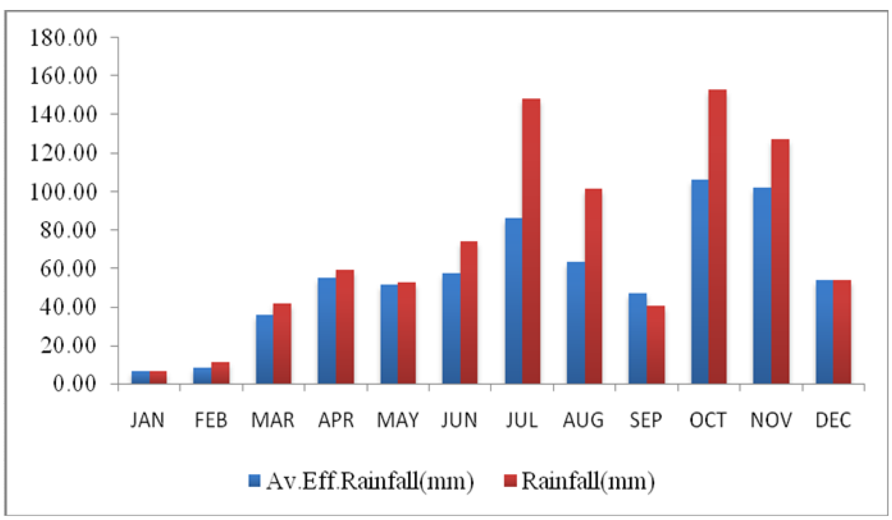

Fig. 8. Average monthly rainfall and effective rainfall predicted by the model for 2000-2010

The average annual effective rainfall (2000-2010) was calculated as 673.3 mm compared against annual mean rainfall of 876.3 mm

3.1.1. Normal

The monthly irrigation water requirements for crops grown in command area for normal rainfall year (2008) followed by excess rainfall year (2007) and deficit rainfall year (2002) are presented in Figs.9, 10 and 11.

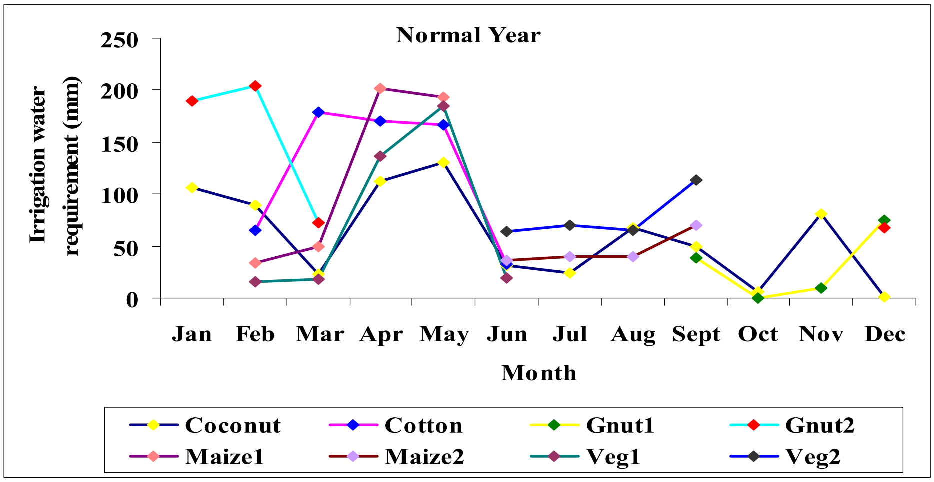

Fig.9. Monthly irrigation water requirement for crops grown in command area for the normal year (2008)

Higher water requirements during the months of April and May were 112.3 and 130.3 mm, respectively due to higher ET_0 values during summer months. The seasonal irrigation water requirement for Groundnut1 (Gnut.1) during (September-December) was less when compared to Groundnut2 (Gnut.2) grown in non-monsoon period. The rainfall received during NE monsoon (Oct- Dec) period was (331.6 mm) was sufficient to meet the water requirement with little supplemental irrigations. The water requirement for Groundnut2 (Gnut.2) was 533.6 mm due to less rainfall (34.3 mm) during January-March. Higher water requirements during vegetative and reproductive stages are beneficial for the crop. The crop water requirement for Maize1 were higher during the months of April (202.0 mm) and May (193.1 mm) (summer period) than February and March. Similarly, the water requirement during Maize2 (Jun-September) was less due to monsoon (258.5 mm) received during the period. Similarly, the irrigation water requirement for Vegetable1 (Veg1) was higher than Vegetable2 (Veg2) grown in monsoon period due to favorable climatic conditions prevailing during crop growth.

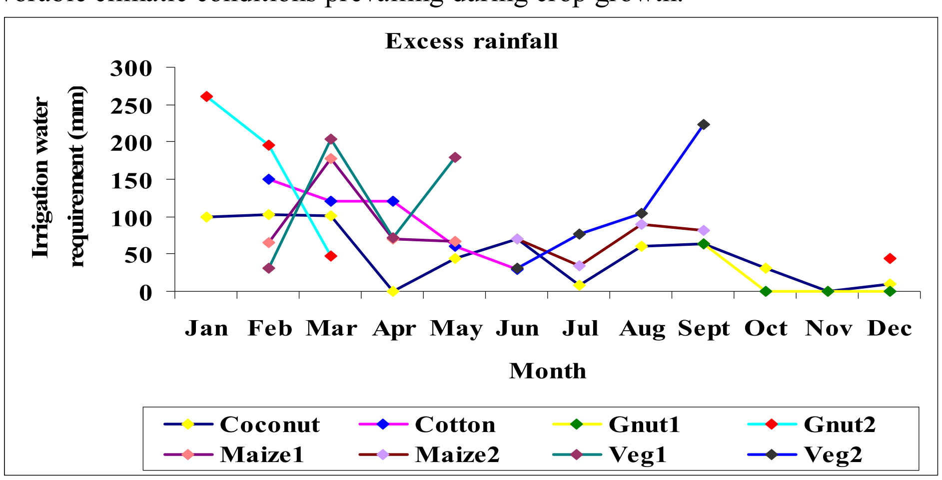

Fig.10. Month wise crop water requirement for crops grown in command area for the excess rainfall year (2007)

3.1.2. Excess Rainfall Situation

The irrigation water requirement for coconut was highest during the months of February and March but less during April and May due to rainfall received during these months. The irrigation water requirement was nil during November and it was just 9.3 mm during the month of December. The monthly water requirements in excess rainfall year (2007) were less when compared to normal rainfall year, 2008. The water requirement for coconut was 18.5 percent less when compared to 2007. The irrigation water requirement for cotton was 225.5 mm only due to rainfall (227.0 mm) received during crop period. The water requirement for Gnut1 was less due to uniform distribution of rainfall during NE monsoon period. The water requirement for Gnut2 in following season (December-March) was higher due to retrieval of monsoon. The reasons for variation in water requirement depends not only on rainfall but also climatic conditions such as temperature, relative humidity etc. Relative humidity will be less in monsoon period than in non-monsoon period resulting in less irrigation water requirement. The water requirements for Maize also follow the same trend. The water required for Vegetable 1 (Veg.1) (February-May) was 11 percent more than Vegetable 2 (Veg.2) grown in following season.

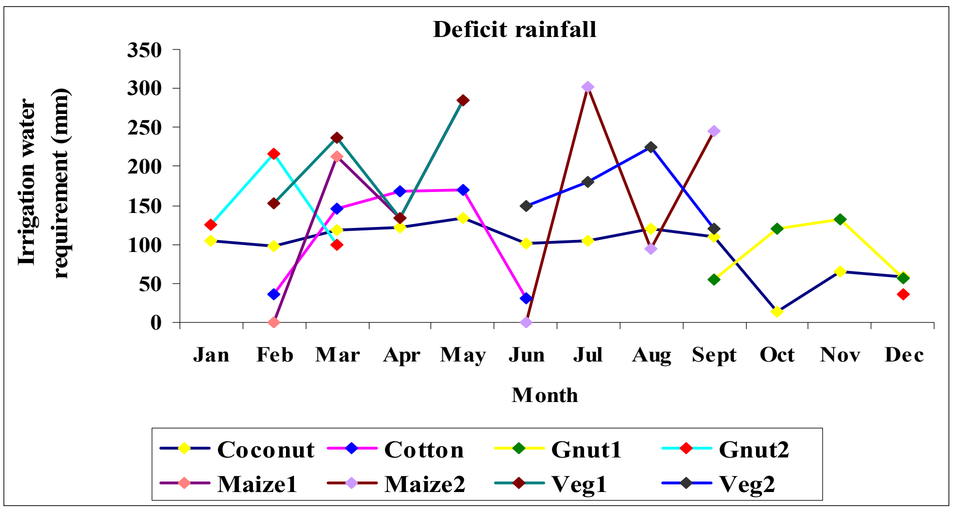

Fig.11. Month wise crop water requirement for crops grown in command area for the deficit rainfall year (2002)

3.1.3. Deficit Rainfall

The irrigation water requirement during the year 2002, (a deficit rainfall year) were higher compared to the years 2007 and 2008 are presented in Fig.10.The water requirement of coconut was 1150.2 mm with highest water requirement of 133.6 mm during the month of May due to higher ETo values. The higher water requirement for Groundnut1 (Gnut.1) crop season (365.3mm) during the year compared to normal (122.6 mm) and excess rainfall years (64.4 mm) reflects the failure of NE monsoon during 2002. Cotton grown in non-monsoon period consumes nearly 50 percent of total water requirement at flowering stage and boll formation stage. Higher irrigation requirements during this period will help in increasing the yields. Also the day temperatures of 25^{o}C and an average 12-13 hours of sunshine are favorable for obtaining optimum yields. An overall increase of 58.4 percent in water requirement was observed for the crops grown during 2002. The variations in irrigation water requirements for deficit, normal and excess years is shown in Fig.12.

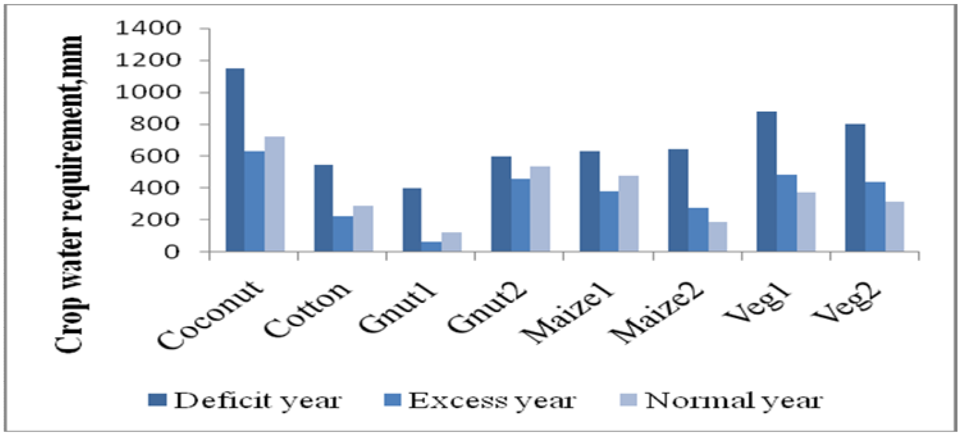

Fig. 12. Variations in irrigation water requirements in deficit, excess and normal years for crops grown in distributor

The average irrigation water requirements of the different crops during the years 2000 -2010, under existing cropping pattern are given in Fig.13.

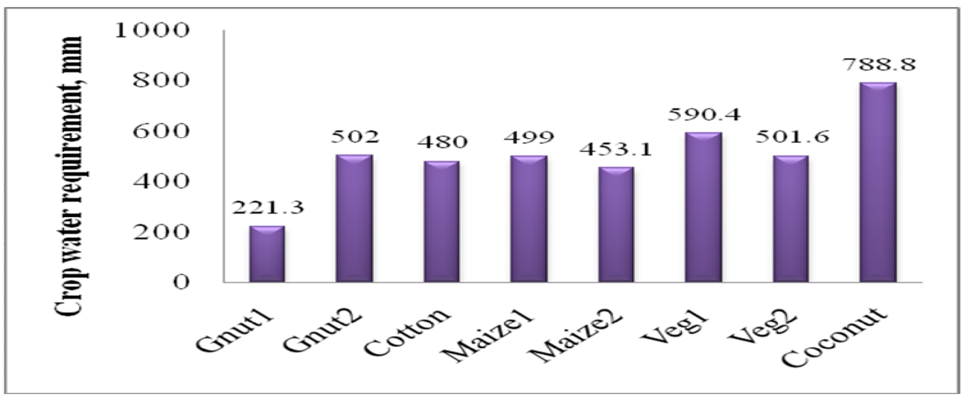

Fig. 13. Average irrigation water requirement for existing crops in the command area

The average irrigation water requirement for crops grown in monsoon period were less when compared to the crops grown during the non monsoon period.The average irrigation water requirement of coconut crop was nearly 788.8 mm with highest water requirement during 2001 and 2002 (1140.6 and 1150.2 mm, respectively) due to deficit rainfall during those years**.** The net irrigation requiremnt of cotton varied from 288.2 mm to 586.0 mm with lowest water requirement during 2008 due to dry soil moisture regime during crop growth period. The varaition in crop water requirement for Gnut1 and Gnut2 (221.3 mm and 502.0 mm) between the seasons is significant. The net irrigation requirement is almost doubled during non monsoon period due to retrival of rainfall during Jan-Mar. In Maize crop, being drought resistant did not show much significant variation in water requirement over the years in both seasons. Similarly, variation in water requirement was observed within seasons and also over years in Vegetable crops.The vegetable crops grown under irrigated conditions during Feb-Jun consumed more water than monsoon period crop (Jun-Sept).

4. Conclusion

The irrigation water requirement for the crops grown in the area was estimated using AquaCrop3.1model for the years 2000-2010. The total irrigation water requirement during deficit rainfall year (2002) was 58.4 percent higher compared to normal year (2008) due to high evapotranspirative demand of the crops.

Total water released from canal during the years 2000 to 2010 varied from 4.0 to 57.96 ha m for the distributory. Subtracting the seepage losses, the water available at distributory varied from 3.54 to 48.99 ha m considering the average conveyance losses of 10 per cent in the water courses, the water available at the field level varied from 3.19 to 35.43 ha m. The data revealed that the amount of water available by surface water supply is low, not sufficient to meet all the crop water requirements. The only means of meeting the crop water requirements is via additional rainfall or by exploiting local groundwater resources. The water course losses estimated varied from 0.35 ha m to 4.9 ha m over the years from 2000 to 2010. The variation was mainly due to the varying canal running days in a year. As per crop water requirements for an average year, the amount of water available in canal system is just $1/10^{th}$ of the total water requirement. Therefore, conjunctive use of water resources through judicious allocation of surface and groundwater resources could be an optimum approach to meet crop water requirements of the command area.

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