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Optimizing irrigation for water use efficiency: A study of crop water demand using the CROPWAT 8.0 model in the centre Odisha, India

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Abstract
The unlimited overuse of available resources of water has let it to be very essential to define appropriate planning and management for irrigated agricultural land to ensure water availability and eventually food security. This is possible only after accurate estimation of water requirement of different crops and scheduled application in different farms. One of the major techniques adopted by the scientists and researchers for the above said purpose is modelling. In this research paper CROPWAT 8.0 model, developed by the Land and Water development division of Food and Agricultural Organization (FAO), has been used for determination of crop evapotranspiration and yield responses to water in agro-ecological units (AEUs) of Angul district of Orrisa. The primary objective of this paper is to estimate the water demand of major crops and schedule the irrigation to enhance the water use efficiency. The results indicate that the crop water requirement of rice crop is highest followed by onion crop. The water demand for rice crop is found to be high in the month of January followed by April month. However, the Onion crop requires more water in the month of January followed by the December month.

Keywords: CROPWAT model, crop water requirement, effective rainfall, irrigation demand reference EVAPO-transpiration.

1. Introduction

In the light of growing water demands from different sectors, serious water shortages are developing in many countries particularly in India and water for agriculture is becoming increasingly scarce (IWMI 2010) [6]. Agriculture is the largest (81%) consumer of water in India and hence more efficient use of water in agriculture needs to be the top most priority. Water is an essential input for crop production. Even though the mean annual rainfall in the Orrisa State is 1401.9 mm, available water for crop during the season is becoming increasingly scarce throughout the district. Aridity and drought are primary natural causes of the scarcity. Recently man-made desertification and water shortages have aggravated the drastic situation, while at the same time, population is increasing and there has become increased competition for water among different water user sectors. In addition, the quality of the available water has been degraded, due to high application of fertilizers and chemicals. This has resulted in reduction of the availability of pure water resource. Thus, improved management and planning of the water resources are needed to ensure proper use and distribution of the water among users and also to the agriculture sector. The accurate planning and delivery of the necessary amount of the water in the time and space can conserve water. A scarce water resources and growing competitions for water will reduce its availability for irrigation. Achieving greater efficiency of water use will be a primary challenge for the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops. Prediction of the crop water requirement is of vital importance in water resources management. Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm day^{-1} or mm period^{-1}. One of the major practices adopted by the researchers for water requirement of crops is modelling. For determination of crop evapotranspiration and yield responses to water, CROPWAT 8.0 model is used which was developed by the FAO Land and Water Development Division (FAO 1992) [5]. It includes a simple water balance model that allows the simulation of crop water stress conditions and estimation of yield reductions based on well-established methodologies. Several researchers have used the CROPWAT 8.0 model for analyzing crop water and requirements in different parts of the world (Kar and Verma, 2005; Martyniak *et al*., 2006; Dechmi *et al*., 2003, Vikash *et al*., 2019) [7, 8, 3, 11]. The irrigation schedule recommendations for various crops should be location-specific, considering the soil types and agro-ecological conditions. The scientific crop water requirements are required for efficient irrigation scheduling, water balance, canal design capacities, regional drainage, water resources planning, reservoir operation studies, and to assess the potential for crop production.

2. Materials and Methods

2.1 Study area

Angul district is located in the centre of the state of Orrisa and lies between 20^{0}49´N to 52°00´ N latitude and 85°05´E to 50°00´ E longitude. The altitude is between 564 to 1187 metres. The district has an area of about 150 kilometres. The normal annual rainfall of this area is about 1401.9 mm. It is the one of the hottest district in India where the maximum temperature goes up to 40.2^{0}C during summer.

Table 1: Location and land features for Angul district

District	Latitude	Longitude	Geographical area (000 Ha)	Cultivable area (000 Ha)	Forest area (000 Ha)
Angul	20^{0}49'52.00' N	85^{0}05'50.00" E	638.0	191.0	272.0

2.2 Crop data: The major cultivated crops in study area are Rice, Sesamum, Blackgram, Green, gram, Mango, Groundnut, Redgram, Oil seed, Maize, Capsicum, Tomato, Brinjal, Cowpea, Gram, Citrus, Onion, Okra and Cauliflower. The salient details (i.e. crop coefficient, length of growing stages, yield response factor and crop height etc.) of crops considered for the study are as per the guideline of report of irrigation water requirement, Ministry of Irrigation, Government of India and FAO - Irrigation and Drainage paper, 24 & 56.

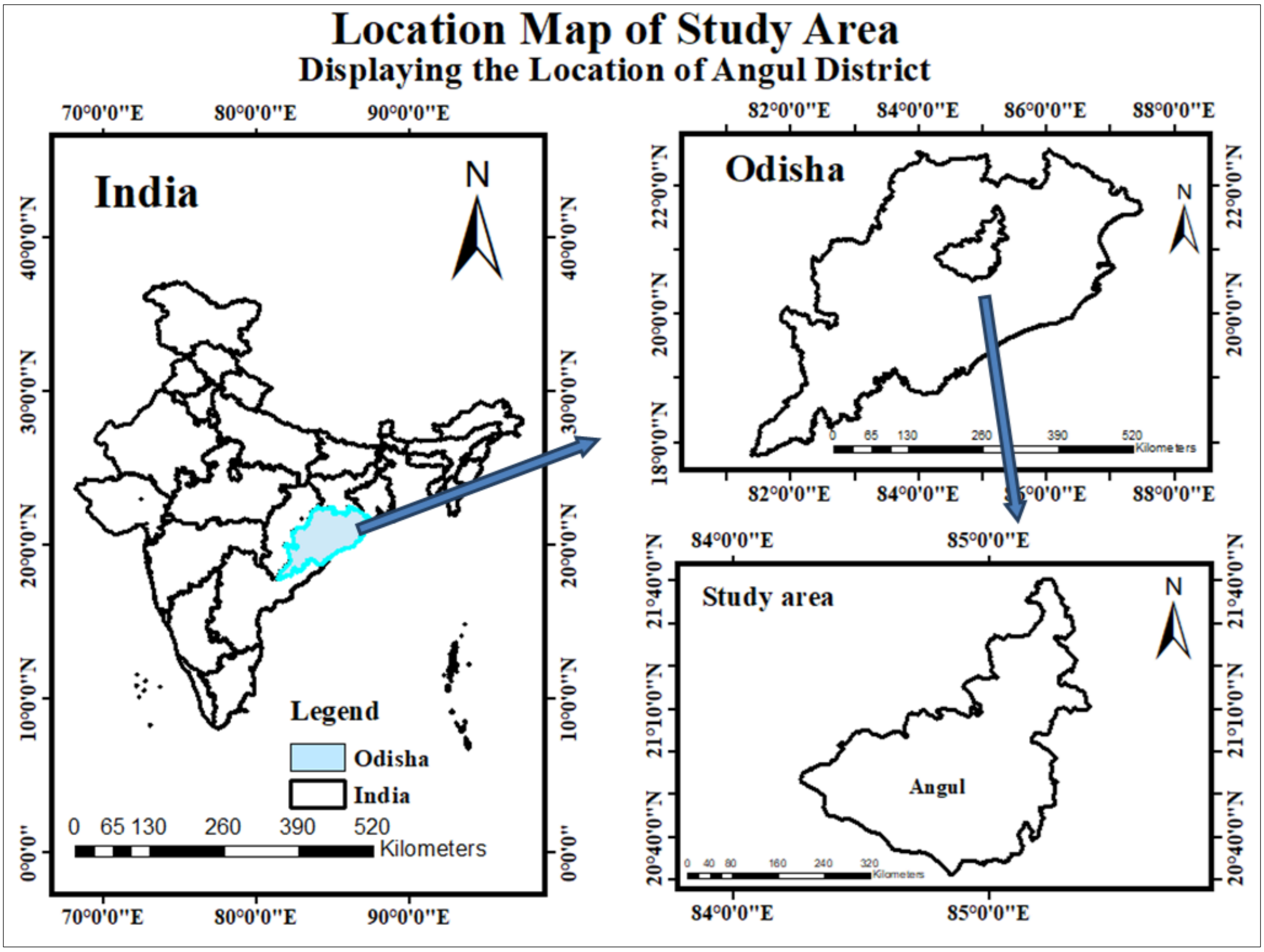

Fig 1: Location Map of Angul District

2.3 Soil data

There are mainly five types of soil available in the study area as: red loam, clay and heavy clay, medium textured red loam, black soil and river valley alluvial. The percentage variation and areal distribution of the different types of the soil texture are presented in Table 2.

Table 2: Spatial variation of different types of soil texture

S. No.	Major Soils	Area ('000 ha)	Percent (%) of total
1.	Red loam	70.496	32.2
2.	Clay & heavy clay soil	62.24	28.4
3.	Medium textured red loam	34.69	15.8
4.	Black Soil	29.10	13.3
5.	River valley alluvial	17.21	7.9
6.	Others (specify)	5.26	2.4

Source: SREP, ATMA, ANGUL, 2007-2008

2.4 Methodology

In this research paper CROPAT 8.0 model has been used for the estimation of crop water requirement and irrigation scheduling of major crops in Angul district of Orissa state in India. The model has been developed by the Land and Water Development Division of FAO, Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, U.K and National Water Research Centre, Egypt. The model carries out calculations for reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rain-fed conditions or deficit irrigation (Adriana and Cuculeanu, 1999) [1].

The sequence of the applied methods in this study, using the model is as follow:

1. Computation of reference evapotranspiration,
2. Estimation of Crop evapotranspiration and
3. Effective rainfall computation.

2.4.1 Reference Evapotranspiration: This parameter is calculated in the model, which uses the FAO Penman-Monteith method (Allen *et al*., 1998) [2]. In this model, most of the equation parameters are directly measured and can be readily calculated from weather data using the Equation 1.

$$ET_0 = \frac{0.408\Delta(R_a - G) + \gamma\frac{900}{T+273}u_2(e_5 - e_3)}{\Delta + \gamma(1 + 0.34u_2)} \qquad \text{Equation (1)}$$

where, ET_o is reference evapo-transpiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}), G is soil heat flux density (MJ m^{-2} day^{-1}), T is air temperature at 2 m height (°C), u_2 is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), e_s - e_a is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa °C^{-1}), Y is psychrometric constant (kPa °C^{-1}).

2.4.2 Crop Evapotranspiration: For calculation of crop evapotranspiration CROPWAT 8.0 model uses crop coefficient approach and crop water requirements of different crops have been estimated by summing up the crop evapotranspiration for all growth stages using the Equation 2.

$$ET_{crop} = K_c \times ET_o \qquad \text{Equation (2)}$$

where, ET_c represents crop evapotranspiration, K_c represents crop coefficient and ET_o represents reference evapotranspiration.

2.4.3 Effective Rainfall: It is the part of rainfall which is stored in the soil profile and helps in the growing of crops. Rainfall of Angul District in Orrisa is given in Table 3. The model applied USDA Soil Conservation Service method to calculate the effective rainfall (Smith, 1991) [9] using Equation 3 and Equation 4.

Table 3: Rainfall pattern for Angul district of Orrisa

District	Average Rainfall (mm)				
	Summer (Jan-March)	Pre-monsoon (Apr-May)	Monsoon (June-Sep)	Post-monsoon (Oct-Dec)	Annual
Angul	64.0	80.1	1147.8	110.0	1401.9

$$P_{eff} = P_{tot} \times (125 - 0.2P_{tot})/125 \text{ for } P_{tot} < 250^{mm} \qquad \text{Equation (3)}$$

$$P_{eff} = 125 + 0.1 \times P_{tot} \text{ for } P_{tot} > 250^{mm} \qquad \text{Equation (4)}$$

Where, P_{eff} represents effective rainfall (mm) and P_{tot} represents total rainfall (mm)

3. Results and Discussion

3.1 Reference Evapotranspiration: The simulated values of reference evapotranspiration (ETo) through CROPWAT 8.0 model using Penman-Monteith equation, for the Angul district along with the meteorological parameters is presented in the Table 4 and monthly distribution of reference evapotranspiration is shown in the Figure 2. From the result, it is revealed that the maximum ET_0 was found in May month (6.66 mm/day), which is mainly due to high temperature and wind velocity, whereas it is minimum in December (2.78 mm/day). The reference evapotranspiration is the function of temperature and is also affected by the relative humidity (RH).

Table 4: Meteorological parameters and reference evapotranspiration

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
Jan	13.8	27.7	67	95	7.9	16.2	2.94
Feb	16.2	30.5	58	112	8.2	18.5	3.82
March	20.3	35.2	47	130	8.5	21	5.16
April	24.8	38.9	49	147	8.2	21.9	6.14
May	26.7	40.2	55	190	7.3	20.9	6.66
Jun	26.5	36.2	69	156	5.2	17.7	5.06
Jul	25.2	31.2	86	147	3.4	14.9	3.55
Aug	25.1	31.1	87	138	4	15.6	3.52
Sept	24.8	31.6	87	112	4.5	15.5	3.46
Oct	22.5	31	82	95	6.3	16.4	3.54
Nov	17.6	28.7	74	95	7.5	16.1	3.19
Dec	13.3	26.8	71	95	7.9	15.6	2.78
Average	21.4	32.4	69	126	6.6	17.5	4.15

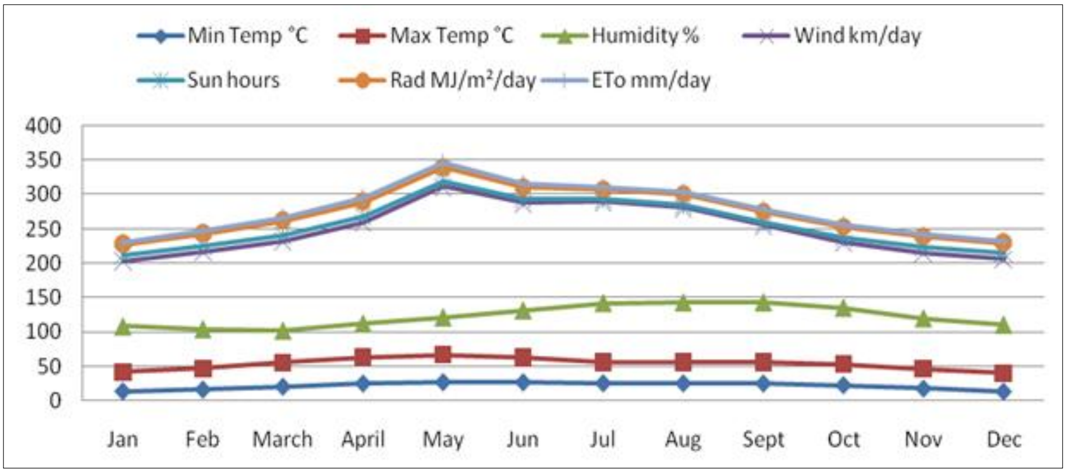

Fig 2: Monthly variations of meteorological parameters and reference evapotranspiration

3.2 Effective Rainfall: The effective rainfall has been calculated for the study area with the help of USDA SCS method which is presented in Table 5 and Figure 3. This will provide help for the estimation of irrigation water requirement of rice crops for the research area. From the analysis, it was found that the effective rainfall was maximum in August month (157.3 mm) followed by July month (149.6 mm), although it was minimum in December (3.0 mm).

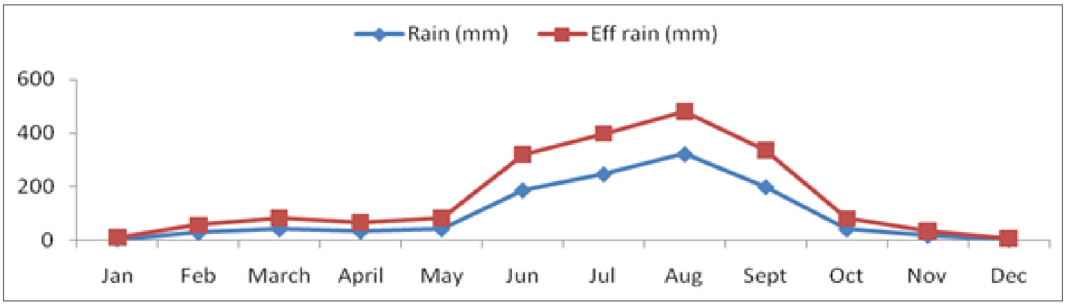

Fig 3: Monthly variation of effective rainfall for Angul district

Table 5: Monthly variation of effective rainfall for Angul district

Month	Jan	Feb	March	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Rain (mm)	5	29	43	34	43	188	248	323	200	42	18	3
Eff rain (mm)	5	27.7	40	32.2	40	131.4	149.6	157.3	136	39.2	17.5	3

3.3 Crop Water Requirement: The difference in the evapotranspiration and evaporation is considered as the water consumed by the crop and termed as crop water requirement. Estimated crop water requirement of major crops for Angul district has been presented in Table 6 and the water demand of crops presented in the Figure 4. The results show that the crop water requirement of rice crop is more in the month of January followed by April month within the study area. This is due to nearly high reference evapotranspiration in the same months. This is also due to the fact that, large quantity of water is needed during the growing and developing period of crops for various physiological functions. The crop water requirement is calculated for Angul district of Orissa State and it has been found to be maximum for Rice crop (844.6mm) followed by Mango (768.6mm), Citrus (464.1mm) ,Onion (388.5mm), Cowpea (326.8mm) and so on, whereas minimum is for Maize crop (3.4 mm). From the result, it is revealed that most of the crops have the average water requirement is in the range of 200mm to 300mm. A crop grown in a sunny and hot climate needs more water per day in comparison to a crop grown in a cool and cloudy climate.

Table 6: Month-wise crop water requirement (mm) of major crops for Angul district

Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rice	252.4	96.4	149.9	178.6	53.5	0	0	0	0	0	0	113.8
Sesamum	0	0	0	24.5	58.4	15.4	0	0	0	0	0	0
Blackgram	0	0	0	27.6	151.2	32.7	0	0	0	0	0	0
Green gram	78.3	1.2	0	0	0	0	0	0	0	10.5	49.9	97.7
Mango	79.8	71.9	110.5	143.8	156.4	19.6	0	0	0	41.9	68.4	76.3
Groundnut	0	0	0	0	0	0	0	0	2.6	32.4	0	0
Redgram	78.3	1.2	0	0	0	0	0	0	0	10.5	49.9	97.7
Oil seed	0	0	0	0	0	0	0	0	7.5	76.3	0	0
Maize	0	0	0	0	0	0	0	0	0	3.4	0	0
Capsicum	23.7	0	0	0	0	0	0	0	0	43.2	89.6	95.6
Tomato	0	0	0	0	0	0	0	0	3	84.9	80.2	12.9
Brinjal	92.8	45.2	0	0	0	0	0	0	0	0	28	70.9
Cowpea	77.3	12.6	0	0	0	0	0	0	0	69.1	80.4	87.4
Gram	61.6	0	0	0	0	0	0	0	0	13.1	61.3	97.9
Citrus	56.8	34.5	71.4	94.2	90.6	0	0	0	0	20.8	40.7	55.1
Onion	93.2	76.7	43.1	0	0	0	0	0	0	20.6	65.6	89.3
Okra	0	0	0	0	0	0	0	0	0	31.1	0	0
Cauliflower	0	0	0	0	0	0	0	0	0	73.6	41.9	0

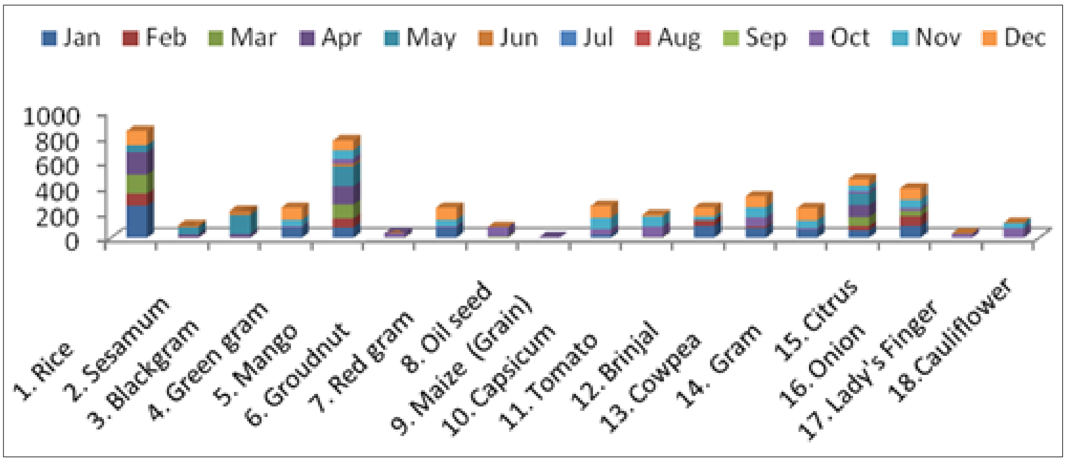

Fig 4: Month-wise crop water requirement of major crops for Angul district

Apart from sunshine and temperature, other climatic factors like wind velocity and humidity also influence the crop water need. Based on the crop water requirement of major crops, irrigation water demand has been calculated for Angul district of Orissa State, which is shown in Figure 5 and Table 7. The water demand for crop will help in water management as well as in the irrigation scheduling in the study area. The areal variation of the net scheme of irrigation required has been shown in Figure 7 and Table 8.

Table 7: Monthly distribution of net Scheme of irrigation required

Month	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
in mm/day	3.5	1.4	1.9	2.5	1.7	0.2	0	0	0	0.3	0.6	2
in mm/month	107.7	38.9	58	76.4	53.4	7.2	0	0	0.3	10.6	16.6	63.4
in l/s/h	0.4	0.16	0.22	0.29	0.2	0.03	0	0	0	0.04	0.06	0.24

Table 8: Monthly and areal variation of net scheme of irrigation required

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigated area (%)	61	58	41	68	68	32	0	0	7	35	29	63
Actual area (000Ha)	165.6	157.5	111.3	184.6	184.6	86.9	0	0.0	19.0	95.0	78.7	171.0
mcm	178.4	61.3	64.6	141.0	98.6	6.3	0	0.0	0.1	10.1	13.1	108.4

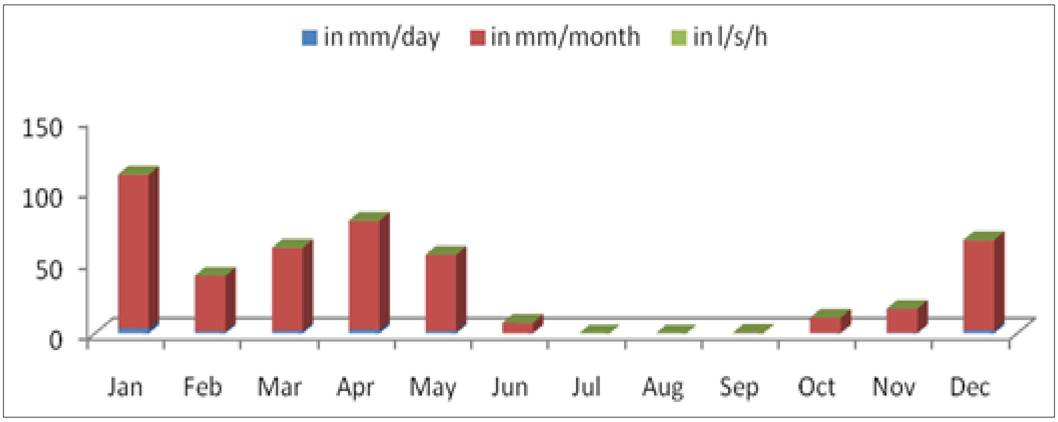

Fig 5: Monthly distribution of net Scheme of irrigation required

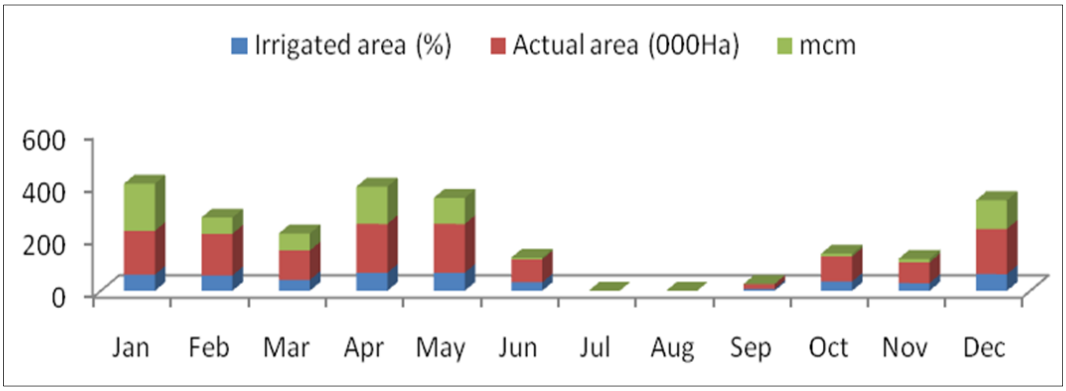

Fig 6: Monthly and areal variation of net scheme of irrigation required

4. Conclusion

This study will help in the calculation of net irrigation water requirement and understanding the behaviour of weather parameter on reference evapotranspiration. The results clearly show that the crop water requirement during the summer period is very high as compared to the other periods. The results of this study may help in planning of efficient water management and ultimately will help in the efficient utilization of available water.

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