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Estimation of evapotranspiration and effective rainfall using CROPWAT

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ABSTRACT : Accurate quantification of evapotranspiration is crucial for better management and allocation of water resources. Estimation of effective rainfall are extremely usefull for operation planning and management issues. Cropwat is a computer model, was used to estimate the reference evapotranspiration and effective rainfall for the Nagpur district in Vidarbha region of Maharashtra state. Daily meteorological data including rainfall, maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hours were collected for the period of 2000 to 2009 which were used as input data in Cropwat. Average peak monthly ET_o were estimated as 6.99 and 6.52 mm day^{-1} in the month of May and April, respectively for the average period considered for the study and also for each years, the high values were may be due to high temperature during the summer month. Whereas average minimum ET_o were estimated as 3.06 and 3.22 mm day^{-1} in the month of December and January, respectively due to winter months. The average annual effective rainfall was 803.45 mm with maximum effective rainfall occurs in July (221.05 mm) followed by August (194.76 mm), June (150 mm) and September (137.63 mm) months, respectively.

KEY WORDS : Evapotranspiration, Effective rainfall, Cropwat

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As water becomes increasing scarce and the need becomes more pressing, advance measuring and evaluating techniques of handling water resources are necessary. In terms of agricultural production, approximately 17% of the cropped area of the world is irrigated and contributes more than one third of the total world food production. Around the world, irrigated agriculture uses most of the water withdrawals from the surface and groundwater supplies. Thus, accurate quantification of crop water use (evapotranspiration) is crucial for better management and allocation of water resources.

In general, evapotranspiration(ET_o) can be defined as the transfer of water in the form of water vapor from the soil surface, a body of water, and vegetative and other surfaces to the atmosphere. Evapotranspiration in agro-ecosystems is the sum of two terms; evaporation, in which water evaporats from soil, water surfaces, or from plant leaf surfaces holding water droplets from rain, irrigation, or dew formation and transpiration, in which water entering the plant roots is carried to stems and leaves for building plant tissue via photosynthesis and then passed through the leaves of the plant into the atmosphere.

Monsoon rainfall is one of the major environmental factor influencing agricultural production in India. Rainfall estimates are paramount importance since utilization of rainfall would facilitate assured crop production. A precise estimates of the quantity of rainfall that is usefull over a period of time, could provide a general picture regarding its supplemental role on irrigation.

According to Dastane (1974) effective rainfall is defined as that portion of rainfall which is usefull directly and/or indirectly for crop production at the site where it falls. Consideration of effective rainfall can help in predicting more precisely the water requirement of crops. Effective rainfall is influenced by factors such as quantity and intensity of rainfall, evapotranspiration and percolation losses; crop and irrigation management practices. Estimates of effective rainfall are extremely usefull for operation planning and management issues including determing optimal cropping pattern; determining optimal operational policies for irrigation systems; design of drainage systems and real-time control.

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO, Rome, Italy with the assistance of Institute of Irrigation and Development Studies of Southampton, UK and National Water Research Center, 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 and scheme water supply (Smith, 1991). For estimation of reference evapotranspiration, Cropwat requires either measured ETo data or meteorological data including minimum temperature, maximum temperature, relative humidity, wind speed and sunshine hours. Cropwat model, that calculates evapotranspiration and crop water requirements, allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply condition and yield reduction under various conditions.

CROPWAT model showed that, the annual potential evapotranspiration and effective rainfall in HsuehChia area were 1,444 and 897 mm, respectively (Kuo *et al.*, 2001). The ETo estimated from limited data *i.e.* daily air temperature with annual mean wind speed through CROPWAT have good agreement with estimated ETo from full climatic data set, Raja (2010).

METHODOLOGY

Daily Meteorological data including rainfall, maximum temperature, minimum temperature, relative humidity, wind speed and sunshine hours were collected for the period of 2000-09 from the India Meteorological Department, Nagpur in Maharashtra. Daily rainfall and evaporation data have analyzed for the ten years (2000-09). Fig. A shows the average daily variations in rainfall and evaporation. Average daily rainfall is significantly higher in June to September. As evident, during summer months March to May evaporation increases significantly. Table A shows that minimum and maximum temperature were increased significantly during April and May months. Relative humidity was minimum in the month of March, April and May, whereas it was maximum in rainy season in the month of July, August and September. Sunshine hours were minimum in the month of July and August and the wind speed was maximum in the month of May, June and July.

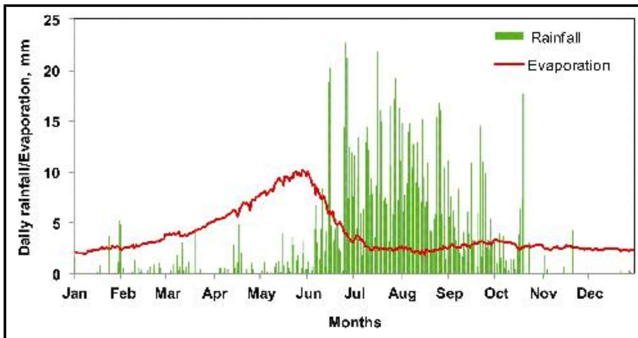

Fig. A : Average daily rainfall and evaporation during 2000-09

CROPWAT:

CROPWAT uses the Penman Monteith method to calculate reference evapotranspiration (ET_o) given by (Allen *et al.*, 1998). The mathematical expression of the same is presented below:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)} \quad (1)$$

where,

ET_o = reference evapotranspiration (mm day^{-1})

Rn = net radiation at the crop surface (MJ m^{-2} day^{-1})

G = soil heat flux density (MJ m^{-2} day^{-1})

T = mean daily air temperature at 2 m height (°C)

Table A : Meteorological data at Nagpur for the period from 2000-09

Month	Min. temp. (ºC)	Max. temp. (ºC)	Relative humidity (%)	Wind speed (km h^{-1})	Sunshine hour
Jan.	13.24	29.77	52.11	4.90	8.32
Feb.	15.99	32.54	42.20	6.87	9.15
Mar.	19.90	36.67	33.91	8.14	9.07
Apr.	24.28	41.17	27.84	10.87	9.47
May	27.72	43.12	32.11	15.38	9.40
Jun.	26.44	37.79	57.52	15.69	5.70
July	24.30	31.75	78.95	13.99	3.63
Aug.	23.68	30.84	81.94	12.73	3.66
Sep.	23.18	32.71	77.48	9.38	6.10
Oct.	19.56	33.77	67.00	5.88	8.48
Nov.	15.97	32.02	60.28	4.46	8.58
Dec.	13.21	30.29	55.69	4.52	8.42

u_2= wind speed at 2 m height (m s^{-1})
es= saturation vapour pressure (kPa)
ea = actual vapour pressure (kPa)
Δ = slope vapour pressure curve (kPa °C^{-1})
γ = psychrometric constant (kPa °C^{-1}).

There are four methods to calculate effective rainfall *viz*. fixed percentage of rainfall, dependable rainfall, Empirical formula, USDA soil conservation service (Dastane, 1974).

Fixed percentage of rainfall:

$$P_{eff} = \text{Fixed percentage x P} \quad (2)$$

where, P_{eff} = effective rainfall, mm and
P= total rainfall, mm.

Dependable rainfall:

Based on an analysis carried out for different arid and sub-humid climates, an empirical formula was developed in Water Service of FAO to estimate dependable rainfall, the combined effect of dependable rainfall (80% probability of exceedance) and estimated losses due to runoff (RO) and deep percolation (DP). This formula used for design purposes where 80% probability of exceedance is required.

$$P_{eff} = 0.6 \times P - 10 \quad \text{for } P_{month} \leq 70 \text{ mm} \quad (3)$$

$$P_{eff} = 0.8 \times P - 24 \quad \text{for } P_{month} > 70 \text{ mm} \quad (4)$$

where, P_{month}= Monthly rainfall, mm and P_{eff}= effective rainfall, mm.

Empirical formula:

Similar expression is used here as dependable rainfall but with the variable parameters, which may be determined from an analysis of local climatic records:

$$P_{eff} = a \times P_{month} - b \quad \text{for } P_{month} \leq z \text{ mm} \quad (5)$$

$$P_{eff} = c \times P_{month} - d \quad \text{for } P_{month} > z \text{ mm} \quad (6)$$

where, values for a, b, c, d and z are correlation co-efficients.

USDA soil conservation service:

Effective rainfall can be calculated using following formulae

$$P_{eff} = P_{month} \times (125 - 0.2 \times P_{month}) / 125 \quad \text{for } P_{month} \leq 250\text{mm} \quad (7)$$

$$P_{eff} = 125 + 0.1 \times P_{month} \quad \text{for } P_{month} > 250\text{mm} \quad (8)$$

■ RESULTS AND DISCUSSION

The experimental findings obtained from the present study have been discussed in following heads:

Reference evapotranspiration:

Estimated monthly reference evapotranspiration for the duration 2000-09 is presented in Table 1 which shows that average peak monthly ET_o was observed to be 6.99 and 6.52mm day^{-1} in the month of May and April, respectively for the average period considered for the study and also in all the years, the high values were may be due to high temperature during the summer month. Whereas average minimum ET_o were 3.06 and 3.22mm day^{-1} in the month of December and January, respectively due to winter months.

Effective rainfall:

Per cent losses of rainfall for the study area was calculated using following four methods and found to be

Fixed percentage of rainfall (80%) = 19.99%
Dependable rainfall = 22.47%
Empirical formula = 32.10%
USDA soil conservation service = 47.62%.

As the estimated losses are 20% of rainfall in study area hence fixed percentage (80%) option was selected to calculate monthly effective rainfall. Table 2 shows that the average

Table 1 : Estimated monthly reference evapotranspiration

Month	Reference evapotranspiration, mm day^{-1}										Average
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	
Jan.	3.25	3.21	3.03	3.23	3.03	3.01	3.45	3.32	3.21	3.43	3.22
Feb.	3.68	4.35	3.94	4.12	4.22	4.34	4.42	4.25	3.99	4.30	4.16
Mar.	5.51	5.21	5.44	5.35	5.54	5.44	5.01	5.41	5.15	5.18	5.32
Apr.	6.71	6.15	6.35	6.50	6.61	6.41	6.63	6.71	6.51	6.59	6.52
May	6.57	7.05	7.18	7.20	6.73	7.08	6.79	7.13	7.25	6.91	6.99
Jun.	5.29	4.77	4.73	5.24	6.09	5.62	5.78	5.91	5.26	4.30	5.30
Jul.	3.47	3.75	3.63	4.64	3.63	4.14	3.28	3.25	3.91	3.60	3.73
Aug.	3.38	3.87	3.83	2.95	3.25	3.45	3.70	3.22	3.60	3.55	3.48
Sep.	2.83	4.02	4.49	4.34	3.12	3.97	3.95	3.99	4.04	3.94	3.87
Oct.	3.65	4.37	3.83	4.17	3.89	4.29	3.83	4.20	4.26	4.20	4.07
Nov.	3.39	3.50	3.50	3.53	3.43	3.58	3.63	3.32	3.49	3.45	3.48
Dec.	2.84	3.13	2.90	3.25	2.90	3.20	3.02	3.14	3.05	3.12	3.06

Table 2 : Estimated monthly effective rainfall

Month	Effective rainfall (mm day^{-1})										
	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
Jan.	0.00	3.40	3.10	0.00	12.20	64.60	0.00	0.00	0.00	0.00	8.33
Feb.	20.70	0.00	16.30	36.10	0.00	2.40	0.00	1.90	0.00	0.00	7.74
Mar.	0.00	16.10	0.20	43.20	0.00	11.40	70.20	6.40	14.30	7.40	16.92
Apr.	0.00	23.00	5.40	8.80	4.20	5.00	3.40	2.80	6.60	0.40	5.96
May	35.50	37.30	19.20	0.00	7.80	8.20	41.00	8.20	12.60	15.90	18.57
Jun.	38.00	157.50	101.40	264.00	220.10	101.90	184.80	86.90	181.10	164.30	150
Jul.	140.40	316.40	165.20	84.10	286.20	231.40	226.00	233.30	290.20	237.30	221.05
Aug.	259.80	139.90	206.60	241.50	245.80	187.50	142.30	218.50	149.60	156.10	194.76
Sep.	189.40	66.20	81.00	109.40	116.60	43.60	248.40	213.40	165.90	142.40	137.63
Oct.	103.40	12.70	147.30	27.00	3.00	0.00	85.10	6.70	2.30	42.20	42.97
Nov.	0.00	0.00	0.00	0.70	3.20	10.70	0.00	11.80	21.70	0.00	4.81
Dec.	0.00	0.00	0.00	0.00	3.80	0.00	0.00	0.00	0.00	0.00	0.38
Total	787.20	772.50	745.70	814.70	902.30	666.70	1001.20	789.90	844.30	766.00	809.05

annual effective rainfall was 803.45 mm with maximum effective rainfall occurred in July (221.05 mm) followed by August (194.76 mm), June (150 mm) and September (137.63 mm) months. Total rainfall and effective rainfall is depicted in Fig. 1.

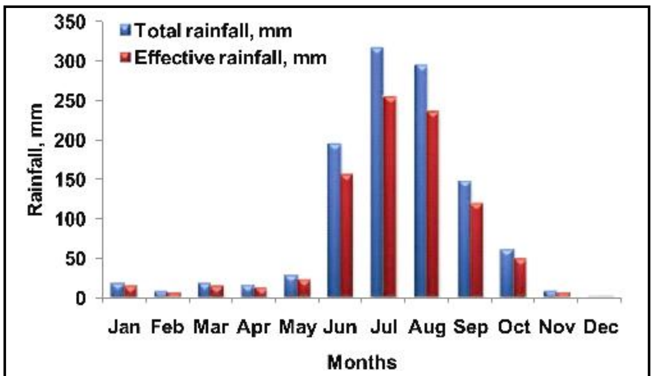

Fig. 1 : Photograph of operation of dhal mill through rotary mode by using bullock power

Conclusions:

From this study it was concluded that reference evapotranspiration can be estimated using Cropwat with the input of climatological data maximum and minimum temperature, humidity, wind speed and sunshine hour. Similarly effective rainfall can also estimated using Cropwat with the input total rainfall of the study area.

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