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Mapping of Evapotranspiration Zones in India Using GIS

M.V.S.S. Giridhar[1] and B. Satyanarayana
Centre for Water Resources, Institute of Science and Technology
JNTU, Kukatpally, Hyderabad, INDIA
E-mail: [1]mvssgiri@yahoo.com

G.K. Viswanadh
Department of Civil Engineering, J.N.T.U. College of Engineering
JNT University, Hyderabad, INDIA
E-mail: gorti_gkv@yahoo.co.in

ABSTRACT: Several studies showed that the Penman method is superior, when the required data are available and reliable to all other commonly used methods for estimating ET_0 under varying locations and climatic conditions. More physically based FAO-56 Penman–Monteith (PM) combination method yields consistently more accurate ET_0 estimates across a wide range of climates. Methodologies on crop water requirements were reviewed at international level to advice on the revision and update of procedures for estimating ET_0 and the panel of experts recommended the adoption of the FAO-56 Penman - Monteith combination method as standard. Hence for the present study, the same method was chosen as the standard method for the calculation of reference evapotranspiration. Monthly normal climatic parameters like maximum temperature, minimum temperature, minimum relative humidity, maximum relative humidity, wind speed and sunshine duration was colleted for 167 locations in all over India. Reference evapotranspiration was calculated for all locations in the India using FAO-56 Penman Monteith method. Climatic zones were prepared using Arc. GIS 9.1 software. Reference evapotranspiration zones were demarcated through out the India based on daily ET_0 values. These ET_0 zones will be useful to calculate daily crop water requirement in that particular area. Further, it will be useful for accurate estimation of surface runoff. Maximum daily reference evapotranspiration was varying from 4.71 mm to 11.17 mm at Bhaunagar and Indore respectively. Minimum daily reference evapotranspiration varies from 0.61 mm to 2.47 mm at Srinagar and Darjeeling respectively. Maximum reference evapotranspiration was observed in the month of May and minimum reference evapotranspiration was observed in the month of January.

INTRODUCTION

Evapotranspiration (*ET*) represents the major consumptive use of irrigation water and rainfall on agricultural land. Transpiration (*T*) is the portion of *ET* that flows through the plant system, it is the main component of *ET* that impacts the *ET* yield relationship. Nevertheless, the evaporation (*E*) component within and outside the crop growing season can be a significant component of the total *ET*. Given the increased competition for water, it is important to search for new ways to conserve water and/or to use it more efficiently. Land surface evapotranspiration *ET* transfers large volumes of water from soil evaporation and vegetation transpiration to the atmosphere. Quantifying the consumption of water over large areas and within irrigated projects is important for water rights management, water resources planning, hydrologic water balances, and water regulation. Spatial estimates of *ET* are essential components of general circulation and hydrologic models Wigmosta *et al.*, 1994; Betts *et al.*, 1997 and *ET* is used to infer soil moisture, a valuable input to weather and flood forecast models. Traditionally, *ET* from agricultural fields has been estimated by multiplying a weather-based reference *ET* by a crop coefficient Kc determined according to the crop type and growth stage. These *ET* maps i.e., images provide the means to quantify *ET* on a field by field basis in terms of both the rate and spatial distribution. The *ET* images show a progression of *ET* during the year or growing season as well as its spatial distribution. These applications have been made to estimate water budgets for hydrologic modeling; monitor compliance with water rights; support water resources planning; estimated aquifer depletion; support groundwater model calibration and operation; estimated water use by irrigated agriculture, estimated historical water use for water rights transfers and evaluate relative performance of an irrigation canal company by comparing

[1]Conference speaker

ET_0 with diversions. (Monteith 1965), (Shih *et al.*, 1981), (Amatya *et al.*, 1995), (Ahmed 1999), (Sudeer Reddy 2001), (George *et al.*, 2002), (Giridhar *et al.*, 2004) and (Lakshman *et al.*, 2006) found that the FAO-56 Penman-Monteith method is the more reliable method to calculate the ET_0 for all climatic conditions. The objective of the present study is to develop reference evapotranspiration (ET_0) maps for India on monthly basis.

STUDY AREA

India covering an area of 3.28 million sq kms, it is the seventh largest country in the world. The mainland of India extends between 8° 4′ N and 37° 6′ North Latitude and 68° 7′ and 97° 25′ East Longitudes. The Tropic of Cancer 23° 30′ N divides India almost into two halves. The land frontier of the country is 15, 200 km and the total length of the coastline is over 7,500 kms. India can be divided mainly into four climatic zones namely Alpine, Subtropical, Tropical and Arid. Alpine Zone: This climate zone can be experienced in the high altitudes of Himalayas. In this region there are high climatic fluctuations due to steep altitude variations. Different types of climatic zones can be seen in this region. If on the foothills occur subtropical climate there is Alpine Tundra Zone to greet you on the higher altitudes. Sub Tropical: This zone is prevalent in most of the northern part of India. It can be called as the typical Indian climate. Summers are hot and wet while in winter temperature may drop down to freezing point in higher ranges. Rainfall is common in summer season whereas winters are cold and dry. Tropical: It can be divided into two sub types viz, Tropical Wet Monsoon and Tropical Dry. The characteristics of Tropical Wet Monsoon include average temperature, which normally does not fall below 18°C, accompanied by average to high rainfall. In Tropical Dry type rainfall is not so common. Arid: High temperature and low rainfall are marked features of this climatic zone. It is prevalent in western part of the country and includes large part of Rajasthan. The temperature in this zone may shoot up to as high as 50°C in summer.

ESTIMATION OF REFERENCE EVAPOTRANSPIRATION (ET_0)

Reference Evapotranspiration refers to loss of water from the land and water surfaces of catchment due to the combined processes of evaporation and transpiration. In this model, Reference Evapotranspiration is considered to take place from Interception storage, Upper zone storage, Lower zone storage, Streams and lakes surface, and Ground water storage. Daily ET_0 was estimated from FAO-56 Penman-Monteith method using the software. The FAO56-PM equation as given by FAO irrigation and Drainage Paper No. 56 in (Allen *et al.*, 1998) has been used as given in equation (1). The software developed by (Viswanadh *et al.*, 2004) is used to calculate reference evapotranspiration for the present study. The ET_0 thus calculated is taken as input to propose evapotranspiration ranges for all over India on monthly basis,

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_d)}{\Delta + \gamma(1 + 0.34u_2)} \quad \ldots (1)$$

ET_0 = reference evapotranspiration (mm d^{-1}); Δ = slope of vapour pressure curve (kPa °C^{-1}); R_n = mean daily net radiation (MJ $m^{-2}.d^{-1}$); G = soil heat flux (MJ $m^{-2}.d^{-1}$); γ = psychometric constant (0.0671 kPa °C^{-1}); T = mean daily air temperature at 2 m height [(T_{max}+ T_{min})/2, °C]; U_2 = wind speed at 2 m height (m. s^{-1}); e_s = saturation vapour pressure (kPa). ET_0 (H) = ET_0 estimated by the Hargreaves equation (mm day^{-1}), R_a = extraterrestrial radiation (mm day^{-1}), T_{max} = daily maximum temperature (°C), T_{min} = daily minimum temperature (°C) and e_d = vapour pressure at due point temp.

PREPARATION OF ET MAPS USING GIS

Meteorological database such as normal maximum temperature, minimum temperature, sunshine hours, relative humidity, wind speed and rainfall has been generated for all 167 locations in India on monthly basis. Mean monthly reference evapotranspiration (mm/day) has been calculated using FAO-56 Penman Monteith method for all meteorological stations. 167 meteorological stations in India were listed in Table 1. The latitude and longitude values for the above stations were collected and the geo-reference points for the same were registered and rectified in GIS 9.1 software. Mean monthly meteorological data and reference evapotranspiration values have been exported to GIS environment to build the topology. Reference evapotranspiration maps were then prepared for all over India on monthly basis. These ET_0 values estimated from FAO-56 Penman-Monteith method were further classified into 5 ranges. The variation of normal Reference Evapotranspiration with time within the climatic zones available in India i.e. Alpine, Subtropical, Tropical and Arid has been analyzed.

Table 1: Meteorological Stations in India

1	Ahmadabad	50	Darjeeling	99	Kozhikode	148	Salem
2	Agra	51	Dehra-dun	100	Krishnanagar	149	Sambalpur
3	Ahmadnagar	52	Dhanbad	101	Kurnool	150	Sangli
4	Amer	53	Dhubri	102	Leh	151	Satna
5	Akola	54	Dibrugarh	103	Lucknow	152	Seoni
6	Alibag	55	Dibrugarh	104	Ludhiana	153	Shillong
7	Alighar	56	Dohad	105	Lumding	154	Shimla
8	Allahabad	57	Dumka	106	Machilipatnam	155	Sholapur
9	Allahabad	58	Dwarka	107	Madikeri	156	Sibsagar
10	Ambala	59	Fatehpur	108	Madras	157	Silchar
11	Amini-divi	60	Fort-cochin	109	Madurai	158	Srinagar
12	Amraoti	61	Gadag	110	Mahabaleshwar	159	Surat
13	Amritsar	62	Ganganagar	111	Mainpuri	160	Tezpur
14	Angul	63	Gauhati	112	Malda	161	Tiruchchirapalli
15	Asansol	64	Gaya	113	Malegaon	162	Trivandrum
16	Aurangabad	65	Goa-panjim	114	Mangalore	163	Umaria
17	Bahraich	66	Gonda	115	Masulipatam	164	Varanasi
18	Balasore	67	Gopalpur	116	Midnapore	165	Vellore
19	Balehonur	68	Gorakhpur	117	Minicoy	166	Veraval
20	Bangalore	69	Gulbarga	118	Mormugao	167	Vishakhapatnam
21	Bareilly	70	Guna	119	Motihari		
22	Barmer	71	Gwalior	120	Mount-abu		
23	Baroda	72	Hanamkonda	121	Mukteshwar-		
24	Belgaum	73	Hassan	122	Mussoorie		
25	Bellary	74	Honavar	123	Mysore		
26	Berhampore	75	Hazaribagh	124	Nagappattinam		
27	Bhaunagar	76	Hoshangabad	125	Nellore		
28	Bhopal	77	Hyderabad	126	New-delhi		
29	Bhubaneswar	78	Indore	127	Nimach		
30	Bhuj	79	Jabalpur	128	Nizamabad		
31	Bidar	80	Jagdalpur	129	Nowgong		
32	Bijapur	81	Jaipur	130	Pachmarhi		
33	Bikaner	82	Jaipur-sanganer	131	Pamban		
34	Bombay	83	Jalgaon	132	Patna		
35	Burdwan	84	Jalpaiguri	133	Pendra-road		
36	Calcutta	85	Jammu	134	Phalodi		
37	Calcutta	86	Jamnagar	135	Poona		
38	Chaibasa	87	Jamshedpur	136	Port-blair		
39	Chandbali	88	Jhalawar	137	Puri		
40	Chandrapur	89	Jhansi	138	Purnea		
41	Cherrapunji	90	Jodhpur	139	Raichur		
42	Chitradurga	91	Kakinada	140	Raipur		
43	Coimbatore	92	Kalimpong	141	Rajkot		
44	Coonoor	93	Kalingapatam	142	Ranchi		
45	Cuddalore	94	Kanker	143	Rentachintala		
46	Cuddapah	95	Kanpur	144	Roorkee		
47	Cuttack	96	Khandwa	145	Sabaur		
48	Caltonganj	97	Kodaikanal	146	Sagar		
49	Carbhanga	98	Kota	147	Sagar-island		

RESULTS AND DISCUSSION

Normal monthly meteorological variables such as maximum temperature, minimum temperature, sunshine hours, relative humidity and wind speed were converted to average monthly variables for India as shown in Table 2. Mean monthly reference evapotranspiration (mm/day) has been calculated using FAO-56 Penman-Monteith method. From the calculated normal monthly reference evapotranspiration (ET_0), average ET_0 was calculated. Table 3 contains Average ET, Minimum ET and Maximum ET in mm per day along with the corresponding place of occurrence. Total Five ET_0 ranges were framed and shown in Table 4. Monthly ET_0 ranges were developed in GIS environment and shown in Figures from 1 to 12 based on monthly normal reference evapotranspiration values.

The variation of normal Reference Evapotranspiration with time within the climatic zones has been analyzed and presented in Table 5. Variation of ET ranges with in the climatic zones during a year has been graphically presented in Figure 13.

Table 2: Average Monthly Meteorological Parameters in India

Month	*Avg Max. Temp (°C)*	*Avg. Min. Temp (°C)*	*Avg. RH (%)*	*Avg. Wind Speed (Km/day)*	*Avg. Sun Shine in (hrs)*	*Avg. Rainfall in (mm)*
January	25.39	12.35	61.40	111.79	7.92	14.76
February	27.72	14.30	55.02	123.77	8.40	15.62
March	31.87	18.12	48.02	143.70	8.71	23.18
April	35.07	22.12	47.08	167.00	8.80	45.21
May	35.07	22.12	47.08	167.00	8.80	45.21
June	34.35	24.96	65.36	222.68	6.44	198.17
July	30.93	23.99	79.20	215.26	4.50	328.54
August	30.32	23.62	81.06	188.74	4.67	287.57
September	30.78	22.98	78.02	148.91	5.96	195.63
October	30.80	20.33	68.08	108.49	7.54	95.34
November	28.40	15.85	63.11	100.06	7.99	42.28
December	25.94	12.80	63.40	103.59	7.92	19.92

Table 3: Monthly Reference Evapotranspiration (mm/day)

Month	*Avg. ET (mm/day)*	*Min. ET (mm/day)*	*Place*	*Max. ET (mm/day)*	*Place*
January	2.82	0.61	SRINAGAR	4.71	BHAUNAGAR
February	3.56	0.94	LEH	6.28	BHAUNAGAR
March	4.69	1.58	SRINAGAR	7.81	BHAUNAGAR
April	5.69	2.47	DARJEELING	9.14	INDORE
May	6.34	2.47	DARJEELING	11.17	INDORE
June	5.44	2.16	DARJEELING	9.82	PHALODI
July	4.07	1.92	DARJEELING	8.37	TIRUCHCHIRAPALLI
August	3.82	2.05	MUSSOORIE	7.76	TIRUCHCHIRAPALLI
September	3.93	1.98	DARJEELING	6.52	TIRUCHCHIRAPALLI
October	3.84	2.2	SRINAGAR	6.04	JAIPUR
November	3.18	1.28	SRINAGAR	5.31	BHAUNAGAR
December	2.70	0.69	SRINAGAR	4.72	GOA-PANJIM

Table 4: Monthly Minimum, Maximum and Average ET_0

Sl. No.	*RET range*	*ET_0 (mm/day)*
1.	I	0–2
2.	II	2–4
3.	III	4–6
4.	IV	6–8

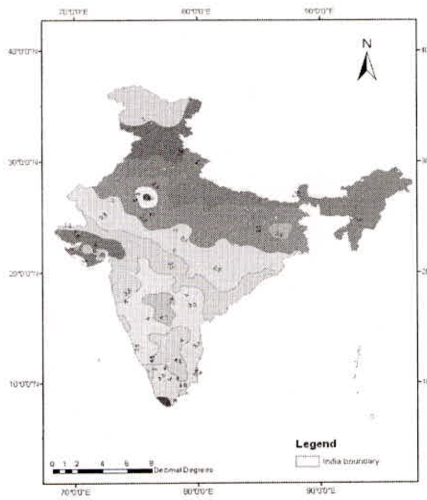

Fig. 1: Reference evapotranspiration map for the month of January

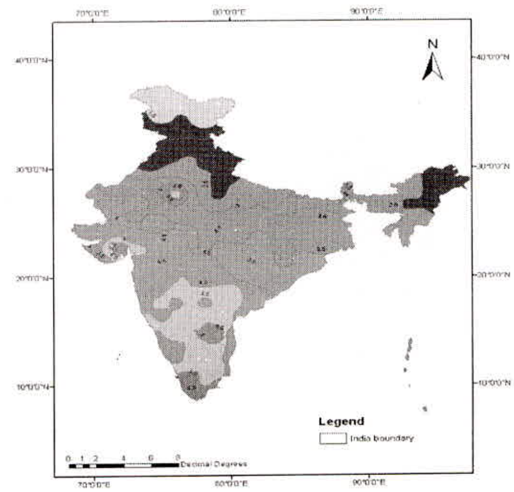

Fig. 2: Reference evapotranspiration map for the month of February

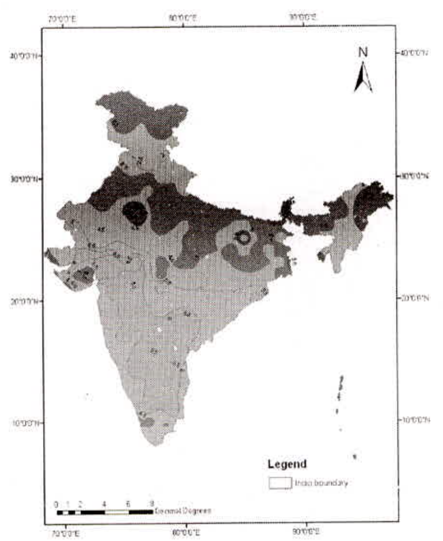

Fig. 3: Reference evapotranspiration map for the month of March

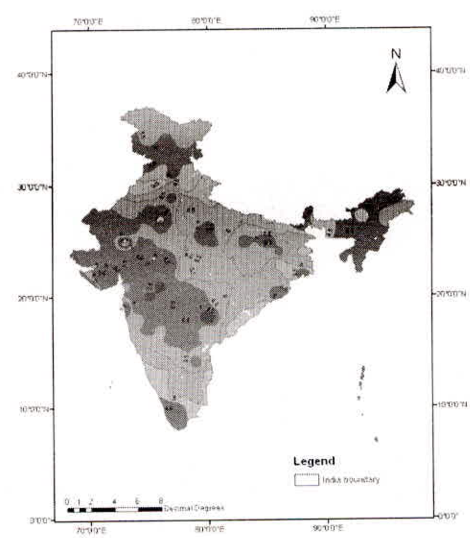

Fig. 4: Reference evapotranspiration map for the month of April

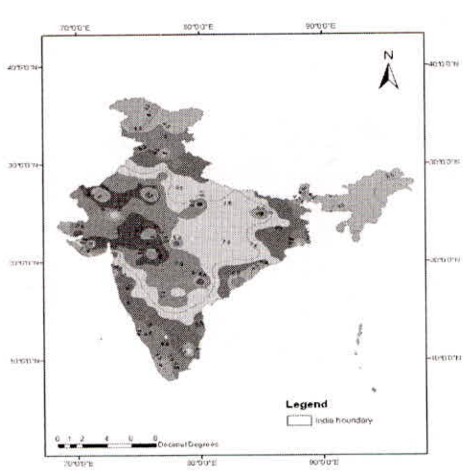

Fig. 5: Reference evapotranspiration map for the month of May

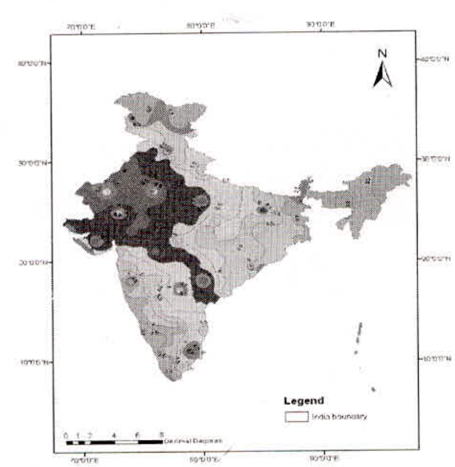

Fig. 6: Reference evapotranspiration map for the month of June

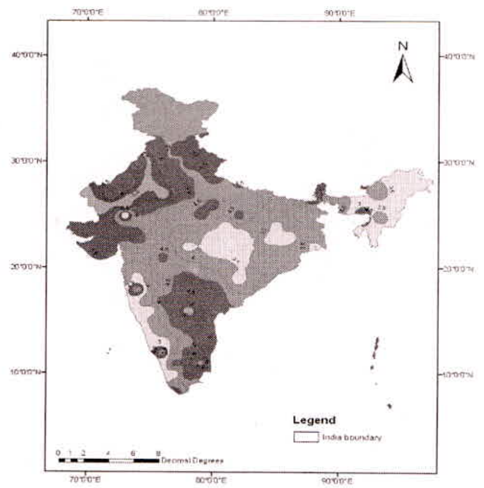

Fig. 7: Reference evapotranspiration map for the month of July

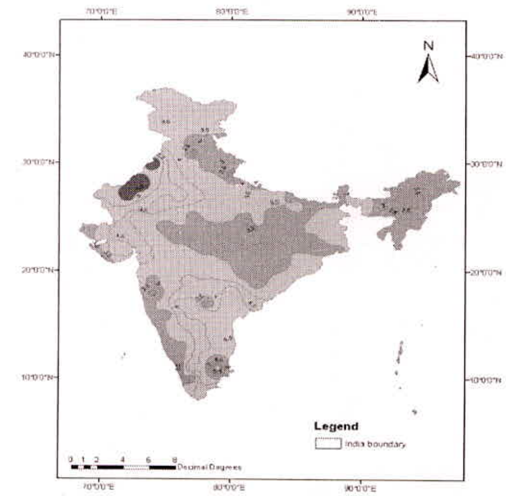

Fig. 8: Reference evapotranspiration map for the month of August

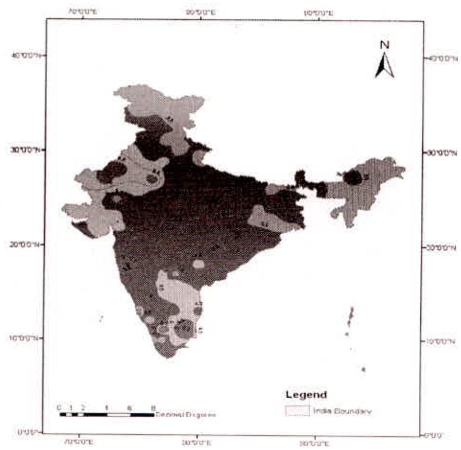

Fig. 9: Reference evapotranspiration map for the month of September

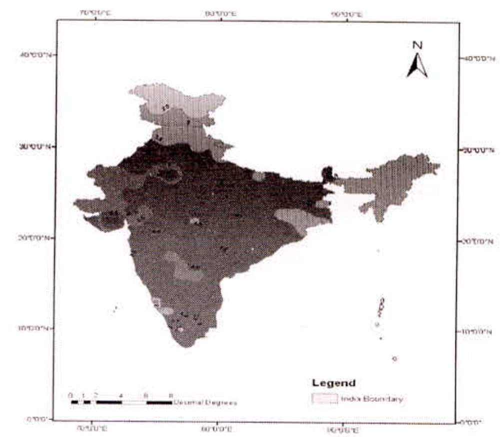

Fig. 10: Reference evapotranspiration map for the month of October

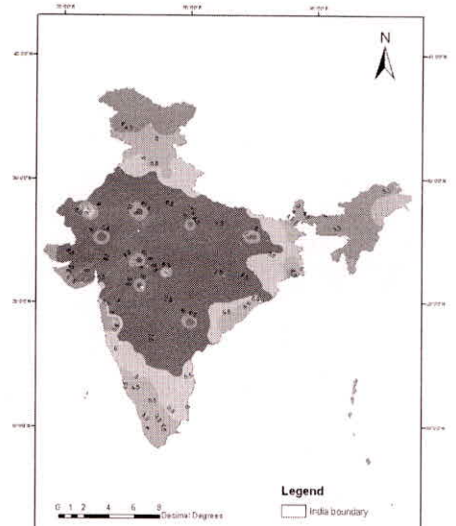

Fig. 11: Reference evapotranspiration map for the month of November

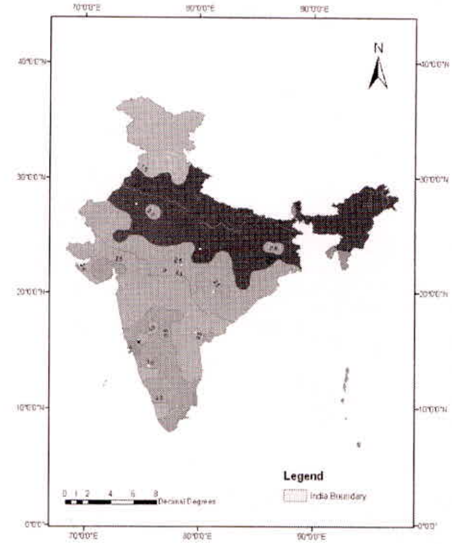

Fig. 12: Reference evapotranspiration map for the month of December

Table 5: Evapotranspiration Zones Based on Climatic Conditions in India

Sl. No.	*Month* / *Climatic Zone*	*J*	*F*	*M*	*A*	*M*	*J*	*J*	*A*	*S*	*O*	*N*	*D*
1.	Alpine	I	II	II	II	III	III	II	II	II	II	I	I
2.	Sub Tropical	I	II	II	III	IV	III	II	II	II	II	II	I
3.	Tropical	II	III	III	IV	IV	IV	III	II	II	II	II	II
4.	Arid	II	III	III	IV	V	V	IV	III	III	III	II	II

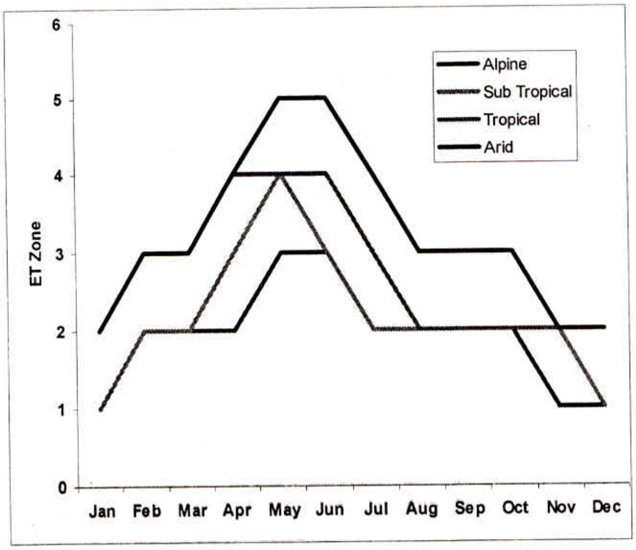

Fig. 13: Variation of ET ranges with in the climatic zones during a year

In the Alpine climatic zone, Reference Evapotranspiration varied from range I to III from January to December. Range II persisted for seven months namely February to April and June to October in this climatic zone. ET_0 values were found to occur in Range I in months of January, November and December, and Range III in the months of May and June coinciding with the summer months.

In the Sub Tropical climatic zone, ET_0 varied from range I to IV from January to December. Range II dominated for seven months namely February and March and June to November in this climatic zone. ET_0 values were found to occur in Range I in months of January and December, Range III in the months of April and June, and Range IV in the month of May coinciding with peak summer.

In the Tropical climatic zone, ET_0 varied from range II to IV from January to December. In this climatic zone also, range II continued for six months namely January, August to December. ET_0 values were found to occur in Range III in months of February, March and June, whereas summer months of April to June experienced ET_0 values in the range IV.

In the arid climatic zone, ET_0 varied from range II to V from January to December. In this climatic zone, range III occupied Five months namely February, March and August to October. ET_0 values were found to occur in Range II in months of January, November and December, Range III in the months of February, March and August to October. ET_0 values of the months April and July fell in the Range IV where as the ET_0 values of peak summer months fell in the Range V.

CONCLUSIONS

Prepared maps shall be useful in the areas of agriculture, ecological and water resources management. The calculated maximum daily reference evapotranspiration was found to vary from 4.71 mm to 11.17 mm at Bhaunagar and Indore respectively. The calculated minimum daily reference evapotranspiration varied from 0.61 mm to 2.47 mm at Srinagar and Darjeeling respectively. Maximum reference evapotranspiration has been observed to occur in the month of May and minimum reference evapotranspiration in the month of January. In the Alpine climatic zone, Reference Evapotranspiration varied from range I to III from January to December. In the Sub Tropical climatic zone, ET_0 varied from range I to IV from January to December. In the Tropical climatic zone, ET_0 varied from range II to IV from January to December. In the arid climatic zone, ET_0 varied from range II to V from January to December.

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