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STANDARDISATION OF CROP WATER REQUIREMENT OF NAGPUR REGION BY MODIFIED PENMAN METHOD

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Preface

This book contains new technique for the evaluation of crop water requirement for Nagpur region based upon Modified Penman method.

To plan a new irrigation project at any place, it is necessary to give more attention towards the crop water requirement in the concerned region, which needs climatological data such as rainfall, relative humidity, wind speed, sunshine hours etc. of previous 15 to 20 years These data are required to collect from nearby meteorological stations i.e. may be 150 to 200 km away from the irrigation project. As the location of the project command in most of the irrigation project are normally distant from climatological stations. Therefore the crop water requirement calculated will not give any realistic value. Thus if of two meteorological stations around the command are considered and crop water requirement is evaluated individually. As the command lies in between, then the intermediate value give true representation.

To achieve this, it is decided to establish the pattern of crop water requirement lines in between the stations within Nagpur region. These lines will help to find more precise and realistic value of crop water requirement at a particular location. This is termed as iso crop water requirement lines.

If such is requirement lines are available for all crops then it can be used as a ready reckoner. This will give an idea about the crop water requirement at plant level. This establishment of isoline for estimation of crop water requirement of wheat is presented in this book

***Chapter 1:** It contains the introduction wherever it gives the details of the estimation of crop water requirement by various method and creation.*

***Chapter 2:** It contain the literature of from research article by renowned researcher and academician. The review was classified based upon various method on for requirement of region and each method was status comfily and their results have seen compared*

***Chapter 3:** It deals with the estimation of evapotranspiration of Nagpur region which consist of four district Nagpur, Wardha, Chandrapur, Gondia. It is calculated using Modified Penman method. It also emphasize on study of various method of Eto & its contain of different method with modified penman method.*

***Chapter 4**: It contains the calculation of crop coefficient of various crop in the region. It also suggests a mathematic equation to estimate the crop coefficients of various crop at different stages.*

Chapter 5: *This deals with estimation of fortnightly crop evapotranspiration in Nagpur region*

Chapter 6: *It contain the estimate of average rainfall all which requires region fortnightly rainfall of all rain gauge stations in the district. This is estimated by using Theison polygon method.*

Chapter 7*: It deals with calculation of effective rainfall which contribute the overall growth of crop. Generally effective rainfall is calculated on the basis of average rainfall by using USDA method. This suggests mathematical equations to find out the effective rainfall.*

Chapter 8: *It contains the estimation of net irrigation requirement which depend upon the crop evapotranspiration and effective rainfall. This is the actual water to supply for growth of crop.*

Chapter 9: *It deals with new concept to develop the isolines for crop water requirement based upon Modified Penman Method*

Acknowledgment

Writing a book is a journey that requires support and assistance of many individuals along the way. I am deeply grateful to everyone who has contributed to the creation of this book

I wanted to state from the bottom of my heart that, throughout the journey of writing the book I have received great support and assistance from my co-author Dr Balram Timande Associate Professor, Department of. Electronics and telecommunication of GNIET, Nagpur. He provides valuable guidance in development of isolines for crop water requirement. he has given his input while preparing the mathematical equations' while carrying out the research work in connection with crop water requirement. I am delighted to introduce him as a coauthor due to his tireless support and advise in writing this book

The most required strength, support, inspiration and motivation was given by my mother, Mrs. Kusum Hajare through her dedicated, workaholic and always happy attitude on the family front undoubtedly boosted my moral to accomplish this work. I do not have any hesitation in accepting the fact that, my sons, Shreyas & Shardul had to bear with me a lot; they had to cut-short many of their desires and wishes. It is because of their love and patience, and the work could be completed. It is equally because of the affection and blessings of my parents, who inculcated the importance of consistent hard work towards a constructive goal, this work could be accomplished.

I offer my sincere thanks to all those who have directly and indirectly supported, helped, and encouraged me to accomplish my research work.

[Dr. Hemant V. Hajare]

Dedicated to

My

Father (Late Vithalrao Hajare), Mother (Late Kusum Hajare)

and

My Sons (Shreyas & Shardul)

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Notations

C_{h},	=	coefficient for relative humidity;
C_{s},	=	coefficient for percentage of possible sunshine;
C_{e},	=	coefficient for elevation, respectively;
CNM	=	Christiansen Method;
E	=	Adjustment factor for day and night wind veloulejes and different Humidity levels;
ea-ed	=	vapor pressure detint expressed in m bar;
ERe	=	effective rainfall;
ET_{o}	=	reference crop evapotranspiration;
EtcI	=	evapotranspiration of crop in m/day;
E_{v}	=	is the computed pan evaporation equivalent to Class A pan Evaporation;
F.A.O	=	food and agriculture organization;
f(u)	=	wind fornetion or effect of wind on ET_{0} expressed in terms of Equivalent Evaporation mm/day;
HGM	=	Hargreaves Method;
I	=	is the annual indicator of the air temperature that is calculated with the equation;
I_{J}	=	corresponding monthly indicators of heat, Exponent α is the empirical coefficient estimated from t;
Kc	=	crop coefficient
K_{ev}	=	dimensionless empirically developed constant, the value of which is given by Christiansen as 0.473;
L_{d}	=	is the ratio of the mean duration of the days of each month to the 12-hour day [$\mu / 360$],

MPM	=	modified penman method;
N	=	daylight hours, a function of latitude and the day of year;
P	=	Daily percentage of total annual daytime hours;
NIR	=	net irrigation requirement;
Ra	=	extraterrestrial radiation;
RDM	=	Radiation method;
Rm	=	average rainfall;
Rn	=	Net radiation in equivalent in mm/day;
T	=	temperature in degree Celsius;
TD	=	difference of maximum and minimum temperature;
THM	=	Thornthwaite Method;
W	=	weighing factor for altitude and temperature effecton Radiation;

Chapter 1

Introduction

1.1 Definition and Description

India is basically an agricultural country and all its resources depends on the agricultural out put. Water is the most critical input for the crops. Water is applied to the plants by nature through rain. The total average Rainfall in India is 120 cm. However total rainfall globally is 98 cm. The details of the average rainfall of all the States of India is given in Table1.1

However, the total rainfall in a particular area is be either insufficient or there is no rainfall in a particular period of year. Generally it occurs for the crops growing in rabbi season, hot weather season. As this study is carried for Nagpur region, therefore the details about the scarcity of water for growing of crops are given in Table1.3. In order to get maximum yield, it is essential to supply the optimum quantity of water and maintain correct timing of water. This is possible only through the system irrigation by collecting water during the periods of excess rainfall and to release it to the crop as and when it is needed.

To meet the requirement of water for proper growth of crop, the water is supplied from storage tank though canals or it is lifted up in well irrigation. Therefore Irrigation is very important in our country.

Therefore, estimation of an optimal crop water requirement is an integral aspect of the design and management of an irrigation system. The output of crop is maximum when water is applied optimally and any deficient or excess amount of water usually reduces the output. It is therefore primary importance to use it judiciously for each hectare to increase agricultural production. Due to introduction of Hybrid and high yielding varieties of different crops and day-to-day advance agricultural technology, water management has acquired special significance.

Earlier the crop water requirement was based on the results of trials conducted by Agricultural Institutions. Intervals and depths of irrigation fixed in the trials were arbitrary. But due to innovations in irrigated agriculture, a new concept of consumptive use of water based on meteorological data is introduced to know the exact amount of water required by different crop.

This makes an accurate estimation of crop evapotranspiration for effective design and management of irrigation system. Knowledge of exact amount of water required by different crop in a given set of climatic conditions is of great help for planning of irrigation schemes irrigation scheduling and midterm planning in case of mid season drought.

Therefore crop water requirement is based on evapotranspiration or consumptive use of crop i.e the depth of water consumed by evaporation and transpiration during crop growth. When the consumptive use of crop is known the water use of lager units can be calculated.

The consumptive use or evapotranspiration can be measured by direct measurement or by based on climatological data. Based on extensive studies of climatic and measured grass evapotranspiration data from various research stations in the world and available literature on the prediction of evapotranspiration, Doorenbos and Pruitt (1977) has proposed Modified Penman Method for estimating accurate reference evapotranspiration. The stepwise procedure calculation of crop water requirement is given in respective chapter.

Table 1. Average Annual Rainfall of the States of India

Sl. No.	State	Meteorological Division	Average annual rainfall (mm)
1.	Andaman and Nicobar Islands	Andaman and Nicobar Islands	2,967
2.	Arunachal Pradesh	Arunachal Pradesh	2,782
3.	Assam	Assam and Meghalaya	2,818
4.	Meghalaya	Assam and Meghalaya	2,818
5.	Nagaland	Nagaland, Manipur, Mizoram and Tripura	1,881
6.	Manipur	Nagaland, Manipur, Mizoram and Tripura	1,881
7.	Mizoram	Nagaland, Manipur, Mizoram and Tripura	1,881
8.	Tripura	Nagaland, Manipur, Mizoram and Tripura	1,881
9.	West Bengal	Sub-Himalayan West Bengal and Sikkim ▪ Gangetic West Bengal	2,739 1,439
10.	Sikkim	Sub-Himalayan West Bengal and Sikkim	2,739
11.	Orissa	Orissa	1,489
12.	Bihar	▪ Bihar Plateau ▪ Bihar Plains	1,326 1,186
13.	Uttar Pradesh	▪ Uttar Pradesh ▪ Plain of West Uttar Pradesh ▪ Hills of West Uttar Pradesh	1,025 896 1,667
14.	Haryana	Haryana, Chandigarh and Delhi	617
15.	Delhi	Haryana, Chandigarh and Delhi	617
16.	Chandigarh	Haryana, Chandigarh and Delhi	617
17.	Punjab	Punjab	649
18.	Himachal Pradesh	Himachal Pradesh	1,251
19.	Jammu and Kashmir	Jammu and Kashmir	1,011
20.	Rajasthan	▪ West Rajasthan ▪ East Rajasthan	313 675
21.	Madhya Pradesh	▪ Madhya Pradesh ▪ East Madhya Pradesh	1,017 1,338
22.	Gujarat	▪ Gujarat region	1,107

		▪ Saurashtra and Kachchh	578
23.	Goa	Konkan and Goa	3,005
24.	Maharashtra	▪ Konkan and Goa ▪ Madhya Maharashtra ▪ Marathwada ▪ Vidarbha	3,005 901 882 1,034
25.	Andhra Pradesh	▪ Coastal Andhra Pradesh ▪ Telengana ▪ Rayalaseema	1,094 961 680
26.	Tamil Nadu	Tamil Nadu and Pondicherry	998
27.	Pondicherry	Tamil Nadu and Pondicherry	998
28.	Karnataka	▪ Coastal Karnataka ▪ North Interior Karnataka ▪ South Interior Karnataka	3,456 731 1,126
29.	Kerala	Kerala	3,055
30.	Lakshadweep	Lakshadweep	1,515

Source: www.rainwaterharvesting.org

Table 1.2:Details of Average Rainfall (mm)

District	Month												Total Average
	Jan.	Feb.	March	April	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.	
Nagpur	12.85	8.89	11.86	7.45	3.34	179.38	298.35	288.87	119.29	54.92	13.06	16.96	84.72
Bhandara	30.05	13.96	13.12	12.26	17.12	209.84	334.08	335.8	176.37	51.25	36.53	9.93	103.34
Gondia	23.40	14.50	8.70	9.32	12.37	192.67	319.16	316.04	173.70	39.27	13.47	7.32	95.16
Wardha	23.14	7.71	9.78	7.08	13.58	201.65	273.22	317.35	155.90	54.79	11.76	9.42	87.02
Chandrapur	22.90	11.02	4.96	14.15	14.60	201.58	305.63	309.26	149.50	66.98	10.8	3.98	92.94
Gadchiroli	20.17	11.01	4.89	17.48	13.00	212.73	400.95	455.04	179.88	55.78	11.02	5.27	115.59

Table 1.3:Details of Scarcity of Water (mm)

District	Month											
	Jan.	Feb.	March	April	May	June	July	Aug	Sept.	Oct.	Nov.	Dec.
Nagpur	71.89	75.83	72.86	77.27	81.38	--	--	--	--	29.80	71.66	67.76
Bhandara	73.29	89.38	82.04	91.08	86.22	--	--	--	--	52.09	66.81	93.41
Gondia	77.16	82.00	86.40	85.80	82.79	--	--	--	--	55.89	81.69	87.84
Wardha	63.88	79.31	77.24	79.94	73.44	--	--	--	--	32.33	75.26	77.40
Chandrapur	76.04	81.92	87.98	78.79	78.34	--	--	--	--	25.96	82.14	88.96
Gadchiroli	95.42	104.58	110.70	98.11	102.59	--	--	--	--	59.81	104.57	110.32

1.2. Purpose:-

The main aim to carry out this project is to standardize the crop water requirement by modified penman method

To plan a new irrigation project at any place, it is necessary to give more attention towards the crop water requirement in the concerned region, which needs climatological data such as rainfall, relative humidity, wind speed, sunshine hours etc.of previous 15 to 20 years These data are required to collect from nearby meteorological stations i.e. may be 150 to 200 km away from the irrigation project. As the location of the project command in most of the irrigation project are normally distant from climatological stations. Therefore the crop water requirement calculated will not give any realistic value. Thus if of two meteorological stations around the command are considered and crop water requirement is evaluated individually. As the command lies in between, then the intermediate value give true representation.

To achieve this it is decided to establish the pattern of crop water requirement lines in between the stations within Nagpur region. These lines will help to find more precise and realistic value of crop water requirement at a particular location. This is termed as iso crop water requirement lines.

If such is requirement lines are available for all crops then it can be used as a ready reckoner. This will give an idea about the crop water requirement at plant level.

This will also be useful in preparation of crop calander which helps the farmers about the crop water requirement. This will become the basis for planning design and water management of irrigation system.

1.3 Historical Development

India is an agriculture country. Most of the community is having agriculture as an occupation. Therefore they need a water either from natural resource or be supplied through by canal by Irrigation Dept.

Irrigation is the artificial application of water to soil for the purpose of crop production. It is an age old art as civilization. The increasing need for crop production for growing population is causing the rapid expansion of irrigation through out the world and India is the second largest area under irrigation

In designating the water use by crop, the evaporation and transpiration are combined into one term evapotranspiration (ET) as it is difficult to separate these two losses in crop fields. The term consumptive use is used to designate the losses due it evapotranspiration and the water that is used by the plant for its metabolic activities.

To find out the crop water requirement it is essential to know evapotranspiration of crop.

Initially there five principles method for direct measurement of evapotranspiration.

1.3.1 Field Experimental method

Lysimeter Experiment: - Lysimeter studies involve the growing of crops in large container and measuring the water loss and gain. It is an device in which volume of soil planted and vegetation is located in a container to isolate it hydrologically from planted soil. The soil and crop condition in lysimeter should be close to the natural conditions from Irrigation point of view. Weighing lysimeter are set up to enable the operator to measure the water balance, water added, water retained by the soil and water lost through all sources.

Lysimeter though provides a means of precise and direct measurement of the amount of water supplied and lost by the crop often encounter a number of problems. The major limitations are the reproduction of physical conditions such temperature, water table, soil texture and density within lysimeter comparable to those outside in the field. In some cases the soil temperature in the lysimeter is raised to such an extent that air condition of whole system becomes a necessity.

Field experimental plots

Measurement of water supplies to the field and change in soil moisture more dependable for computing seasonal water requirement of crop than measurement with small lank or lysimeter. The seasonal water requirements are computed by adding measured quantities of irrigation water, effective rainfall received during season and the contribution of moisture from the soil. This method requires that the amount of water applied to a field accurately. This method though satisfactory for computing seasonal water requirements, does not provide information on intermediate soil moisture condition, deep percolation losses, peak use rate of the crop.

Soil moisture depletion studies

The soil moisture depletion method is usually employed to determine consumptive use of irrigated field crops grown on fairly uniform soils when the depth to the ground water is such that it will not influence the soil moisture fluctuation within root gone. These studies involve measurement of soil moisture from various depths at a number of times through out the growth period.

Water balance method

The water balance method also called as inflow outflow method is suitable for larger areas (watershed) over long periods it may be represented by the following hydrological equation.

Precipitation = evapotranspiration + surface run off + subsurface drainage
+change in soil water content. (1.1)

This method necessities adequate measurement of all factors except evapotranspiration. The value of evapotranspiration is computed from measured data.

1.3.2 Analytical method

Estimating Evapotranspiration from Evaporation data:-

Due to difficulties in direct estimation of evapotranspiration the standard US Buren class A open pan evaporimeter or sunken screen open pan evaporimeter (1966) is used for the measurement. The relationship between evapotranspiration and pan evaporation is given by crop factor.

Evapotranspiration = Pan evaporation x crop factor. (1.2)

Owing to the difficultly in obtaining accurate value of evapotranspiration the approaches followed are to relate magnitude and variation of evapotranspiration to one or more climatic factor.

Thornwaite (1948) assumed that an exponential relationship existed between mean monthly temperature and mean monthly consumptive use. The relationship was based largely on experience in the central and eastern united state. The formula was developed originally for the purpose of rational classification of the broad climatic pattern of the world locally for reliable estimation of crop ET values. But this formula gives a reasonable estimation of crop ET values in temperature continental of North America where the formula was originally derived because the temperature and radiation are strongly correlated while in other part of the world this approach has been less successful.

Blaney Criddle (1950) observed that the amount of water consumptively used by crops during their growing season was closely correlated with mean monthly temperature and day night hours.

$$U = KF \qquad (1.3)$$

Blanney Criddle has generally given sufficiently accurate estimate of seasonal consumptive use owing to the inclusion of locally developed crop coefficient (K), but Doorknobs & Pruitt (1975) have rejected the use of crop coefficient normally applied in original Blaney-criddle approach because the original crop coefficient are heavily dependant on local condition and they also pointed out that the Blaney-criddle method to calculate the mean daily PET should normally applied form periods not shorter than one month and for each calander month for each year of record instead of using mean temperature from several years record. According to them this formula is not suitable for use in 1) equatorial regions where temperature remains fairly constant but other weather parameter changes. 2) Small island where air temperature is affected by the surroundings sea temperature showing little response seasonal change in radiation. 3) High altitude where daytime radiation is practically independent of night temperature.

Penman (1948) proposed an equation for evaporation from open water surface based on a combination of energy balance and sink strength

$$Ea = \Delta\, Qn \qquad + --- \qquad (1.4)$$

Since the penman equation estimates evaporation from free water surface, the result must be modified to provide evapotranspiration estimate for crops. This is obtained by multiplying the estimated value of evaporation by the crop coefficient (k) for short grasses. This value is different in different month. Therefore penman formula can be used for direct estimation of PET by using appropriate value of refection coefficient for fresh green vegetation which is taken on 0.25 for most crops. For greater accuracy, plant resistance to transpiration and wind functions also need to be included but this leads to many complexion. Several other constants used in penman equation also need evaluation with reference to climatic condition of a place.

Christiania (1968), proposed revised empirical formula originally developed by him in 1960 to estimate pan evaporation from climatic data when reliable measured pan evaporation data is not available for estimation of evapotranspiration. Because of variation in size and shape of pans, their exposure, the preserve of algae in water, the specific methods of measuring the loss of water from pans and the protection against use of water by birds and animal, available pan evaporation data may not sometimes be reliable to make estimates of evapotranspiration. In such a cases pan evaporation estimated by means of a reliable formula may give more accurate results than the reported pan evaporation. The Christiansen revised equation for estimating pan evaporation.

$$Ev = Kev.\ R.\ Ce.\ Cw.\ Ch.\ Cs.\ Ce.\ Cm. \qquad (1.5)$$

Each coefficient is represented by an equation that may either linear second degree. This equation provides a better fit for the data from which they were developed. Each equation expresses the coefficient as a function of ratio actual value of the parameter to its standard value. The standard value chosen that approximately the mean values for the data analyzed. The value of constant Kev depends on the selection of standard values for each climatic factor. But it is observed that the equation for the coefficient given by christanien may not yield desirable results when the mean value of climatic factors of a place differs much from standard value. For reliable estimates, the standard values of the climatic factors must be worked out for the local data and the same may be used to derive the equation for the coefficients of those factors.

Later on Radiation method came into existence considering the radiation reaching the earth contributing or influence factor evapotranspiration. The measured data required for this method is air temperature and sunshine hours. If the measured date for sunshine hours is not available the general level of cloudiness can be used. This method has less accuracy.

In Hargreaves (1975) has suggested a method for measuring evapotranspiration considering only radiation and temperature.

$$ETo = 0.0023\ Ra\ (T^{o}c + 17.8) \times TD \times 0.58 \qquad (1.6)$$

This equation is comparatively simple and requires only temperature data apart from latitude. The equation claims to be superior to be many more equations at least for interior location with plain topography where growing season of the crops are frost free.

1.4 Brief outline of thesis

Good irrigation management is a combination of answer of

1) How to irrigate?
2) When to irrigate?
3) How much to irrigate?

The present study is related to question No 2 and question No. 3. The last 2 question are inter related and have to be considered together. This study is an analytical approach based climatological data. The modified penman is used to standardize the crop water requirement. To arrive at crop water requirement for different crops from different season. The baric objective of research work in this thesis summarized is on follows.

Sr. No.	**Work Planned**	**Work carried out**
1.	Literature review regaling reference evapotranspiration crop water requirement.	Literature review regarding reference evapotranspiration, methodology of crop coefficient, crop water requirement are done and presented in chapter II.
2.	Collection of Data	The climatological data like temperature, relative humidly, wind speed, rainfall, was collected from 1990 to 2004 from 1) HDUG group 2) Indian meteorological stations
3.	1) Analysis of collected	**1)** The fortnightly reference

	data. 2) Estimation reference evapotranspiration. 3) Estimation of crop coefficient 4) Estimation crop evapotranspration 5) Preparation of crop water requirement for ready recknoer.	evapotranspiration for Nagpur, Wardha, Chandrapur, Gondia was determined using the data collected and are presented in **Annexure 1.** The research carried out in this A) mathematical modeling for the adjustment factor C in modified penman method B) comparative study of different method of reference evapotranspitation and to develope the interrelationship of Modified Penman Method and other method 2) The methods for fortnightly crop coefficient is discussed for different crops of all districts in the region and are presented in **Annexure2** The research carried out in this A) Development of equation between crop coefficient and days. The crop evapotranspiration of each district is calculated as in annexture4 The average rainfall of all districts was determined for all districts by using Thiessen polygon method as discussed in chapter 6and presented in **Annexure 3** The effective rainfall computation based upon USD.GSDA method is discussed. in chapter 7. related to average rainfall and crop evapotranspiration. The research carried out in this Development of an empirical equation is suggested for determination of effective rainfall 6) The procedure and research available to find out the crop water requirement is discussed in chapter. The fortnightly crop water requirement(Net irrigation requirement) of all districts is determined and presented in **Annexure 4** The research carried out in this

		a) New concept for evaluating crop water requirement is suggested as in **Annexure 5** b) To study the accuracy of the concept suggested a case study is undertaken to evaluate crop water requirement in Shirud tank of Wardha district 7) Scope of further research work is discussed in Chapter 9

1.5 Study Area

The study is carried out for Nagpur zone in Maharashtra of India which covers six district as Nagpur, Wardha, Chandrapur, Gondia, Bhandara, Gadchiroli district. There are four meterological stations at Nagpur Wardha Chandrapur Gondia and Bhandara and 56 rain gauge stations in all districts as shown fig. [1].

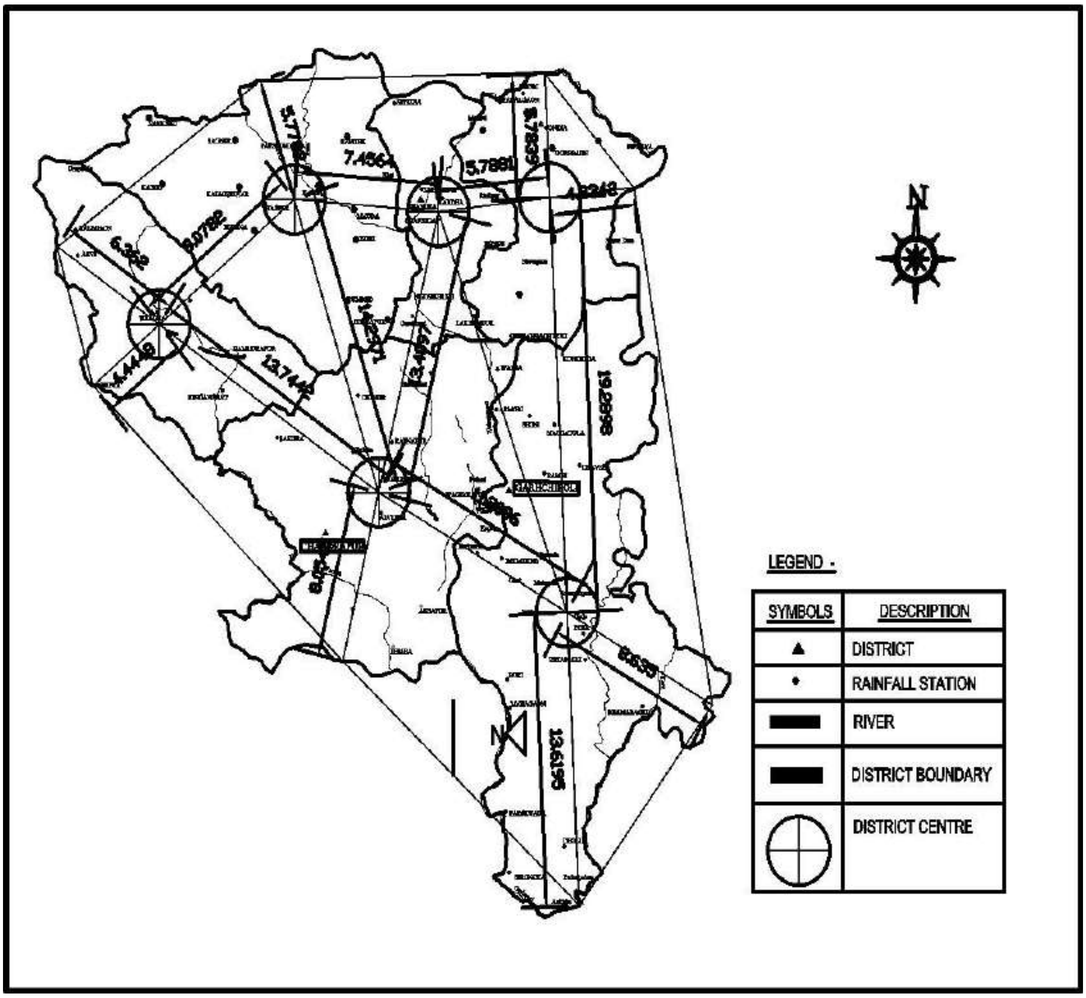


Fig 1.1 Nagpur region

b) Data collection

1) The meteorological data is collected from 1999-2004 (15 yrs)
2) Max and Min temperature
3) Max and Min Relative Humidity
4) Wind speed
5) Sunshine hours
6) Rainfall

B) Source

a) Meteorological station vide letter no –TO243 (E) 2007/124

b) Hydrological data users group, Nashik vide letter no – SDSC/NSK/DFL/231/2006/1942

C) Meteorological stations

Meteorological station with latitude and longitude

S.No	Station	Latitude	Longitude
1	Nagpur	21° 09’	79° 09’
2	Wardha	20° 45’	78°33’
3	Chandrapur	20° 07’	78° 46’
4	Gondia	21°28´	80°12´

D) Crop Chosen

1. Jowar Hybrid
2. Wheat
3. Sunflower
4. Cotton
5. Potato
6. Soyabean
7. Bajara
8. Onion
9. Pulses
10. Moong
11. Ground nut
12. Maize
13. Rice
14. Chili
15. Sugarcane

Chapter-2

Literature Review

2.1 Introduction:

The concept of crop water requirement is not very new. As the irrigation resources are limited and therefore knowledge of the optimum and efficient utilization of available irrigation resources is essential for maximizing the agricultural production. In the past department of agriculture has published some data about the water requirement. With recent advance techniques, the data is found to be inadequate. As the new concept is based on climatological data. It has been found necessary to review the present practice of determination of crop water requirement.

Most of the research work done is in the recent year only. Many researchers carried out the work is based upon different analytical method of reference evapotranspiration as well as field experimental method.

Therefore, an attempt has been made to review the available research data in estimating the water requirement of crop under the topic like reference evapotranspiration, crop evapotranspiration, effective rainfall, net irrigation requirement (crop water requirement)

2.2 Reference evapotranspiration and Crop evapotranspiration:

Wright (1982) had developed crop coefficients for various pacific North West irrigated crops for estimating crop evapotranspiration from measurement of reference ET. Reference ET was based on that for well watered, actively growing alfalfa with sufficient growth for near maximum ET in acid, irrigated regions. ET for alfalfa reference crop and other crops was measured with sensitive weighing lysimeter at the field soil near Kimberly, Idaho. The new crop coefficient are basal coefficient for conditions when soil evaporation is minimum but root zone soil moisture is adequate when combined with improved estimates of evaporation from wet soils, they should permit more accurate estimate of daily crop ET, more accurate irrigation scheduling, more reliable estimate of crop water requirement. Curves were developed for alfalfa, potatoes peas.

Hill, Johns, Frevert (1983) has compared the equation used for estimating agriculture crop evapotranspiration with field research in the Western United States. Research alfala yield and corresponding evapotranspiration were assumed 20% greater than field attained yields based on experience.

Batchelor (1984) has estimated the evapotranspiration for North-East Sri Lanka to illustrate the importance of empiricism in F.A.O. modified Penman equation. It was shown that different empirical relationship used to estimate net radiation and wind function in the FAO modified Penman equation and in the Pennman (1963) equation produce a 23% difference in the estimate of annual reference crop evapotranspiration.

Faulkner R.D. (1988) used to energy balance method to determine actual evapotranspiration occurring over crops in Egypt. It was found that modified form of Penman equation overestimated evapotranspiration by approximately 30%.

Patwardhan, Neber, Johns (1990) has estimated effective rainfall by numerous methods. The best estimated rainfall can be obtained by soil water balance computation. A soil water balance method was used to test the accuracy of United States department of agriculture conservation services & Hershfield effective rainfall estimation method for a poorly graded soulation of irrigation water requirement model for some major crops such as paddy, Sugarcane chilly etc. The model so developed includes water requirements for consumptive use only and other water used for leaching, seedbed preparation etc. was added to it. This was suggested to use the model so developed for the same crop grown in other region having same hydrometrological character.

Asher and Phene (1992) has used infrared thermometry which have enabled the development of new method for calculating ETc on daily basis under local field conditions may be guide for calculating et as This method was considered as experimental method which has been validated using selected field crop data in central California.

Mohan (1992) has studied the four different methods (Penman, Radiation, Blaney Criddle, Hangreavness and Pan evaporation) for their applicability under different climatic condition. The

Penman method was taken on standard & other four methods were compared against this method. Regression equations were developed to correct those differences in magnitude. The method suitable for the estimation of reference evapotranspiration for each climatic condition was also suggested.

Jiftah, Bess Asher, Phene (1992) used infrared thermometry which enabled to develop a new method for calculation of crop evapotranspiration on daily basis under local field crop conditions. This will benefit to growth for calculation of daily crop water requirement under specific local environmental conditions and crop water stress can be prevented, which can improve water use efficiency and potentially improve yields.

Krinner, Gracia, Estrada (1994) did the investigation with conveyance efficiency, and global hydraulic efficiency in Spanish irrigation system. The values of conveyance efficiency are calculated for five channels. Due to lack of reliable data, it makes impossible to calculate global efficiency. The method developed that is based on the comparison between theoretical crop water requirement and volume released at the head of channel. Values are calculated in 38 irrigation system (fifth of total irrigated surface in Spain). It was demonstrated that most of water loss occurs in distribution and application.

Hashimi, Garcia, Fontane (1995) has developed a system s to estimate regional evapotranspiration, considering the spatial variability of parameters. To consider variability, spatial databases were developed for agriculture land use, relevant climate factor, and topographic data using GIS in Cache la poudre basin in Colorado. This eliminated the use of current method of computing regional crop evapotranspiration.

Bausch (1995) has indicated that reflectance based crop co-efficient for corn responded to crop growth anomalies and should improve irrigation scheduling. This helps to improve irrigation water management which requires accurate scheduling of irrigations which in turn requires an accurate calculation of daily crop evapotranspiration.

Slcop and Acquarone M (1997) used a soil map, land rise map ,time and series of monthly precipitation and potential evapotranspiration in regression model to estimate spatially distributed actual evapotranspiration for the Vejle Fjord watershed.

A comparison of computed catchments average evapotranspiration based on spatially distributed precipitation with computed catchments average evapotranspiration based on catchments average precipitation revealed significant discrepancies which suggest that spatially variable approach is required to asses catchments average actual evapotranspiration.

Haman, Pritchard, Smajstrala (1997) conducted a experiment on two rabbit eye and one high bush variety of blueberries. Water was supplied to the plants using micro irrigation system irrigation. Water use for both species was monitored using drainage type lysimeter and water budget method. Irrigation was triggered at 10 KPa soil water tension. Grass reference crop modified coefficient for the modified Penman equation during first three year of establishment were developed for both species. Modified crop coefficient for high bush blueberry was below 0.2 during first two years and raised to 0.35 in third year. Crop coefficient for rabbit eye blueberry was higher during all three years, reaching 0.5 in third year.

Heilman, Moore (1998) had carried out field study in four differentially irrigated plots of alfalfa planted in shiprock sandy loam to assess spectral reflectance for estimating crop coefficient (Kc). A bidirectional reflectance factor was measured using radiometer to find out perpendicular vegetation Index (PUI). Actual evapotranspiration was measured by water balance method & potential evapotranspiration was measured using Penman equation. Significant Linear relationship was found between PUI and percent cover as well as between KC and percent cover.

Allen, Pereria, Smith (1998) has presented crop water requirement as Kc* ETo approach whereby the effect of the climate on crop water requirement is given by reference evapotranspiration and the effect on the crop by the crop coefficient. The procedure regarding the crop water requirement is given in the IAO irrigation and Drainage Paper No.24. It suggested that more accurate assessment of crop water use have revealed the need to update FAO methodologies for calculating ETo. FAO Penman method over estimate evapotranspiration while other methods showed variable adherence to reference evapotranspiration.

Laktos (1998) has suggested crop load as modifying factor in crop evapotranspiration model for irrigation scheduling in orchard.

Bruin, Lablans (1998) has calculated reference evapotranspiration using modified making equation which showed the alternative for Penman formula for determination of crop reference evapotranspiration so called crop factor approach. Makkink requires solar radiation and temperature data only and still used in Royal Netherlands Metrological institute since 1987.

Wardlaw, Barnes (1999) has presented an evaluation of the potential of optimization approach in improving real time irrigation water management in system with complex distribution Network. The optimization approach was based on quadratic programming to maximize crop production through appropriate water allocation. The approach has been evaluated through application to the irrigation system in lower Ayung River basin in Bali, Indonesia. The results indicated that optimization approach does have potential and can significantly improve crop production at basin scale.

Michael and Bastiaanssen (2000) discussed the estimation of crop evapotranspiration from remote sensing data to deduce variable and regional crop coefficient. Maps of crop coefficient avoid the need to frequently use of remote sensing data. This method is applied to Landsal -Tm satellite data covering lake Naivashva Basin, Kenya and spatially variable crop coefficients were determined. This simple technique will improve the planning of irrigation water resources.

Allen, Smith, Wright (2000) has compared daily evapotranspiration for three agricultural crops between bysimeter measured ETo and basal Kc method in dry soil surface. The error of estimate and accuracy were similar between the two methods and averaged about 0-77 mm / day or 15%.Kang, Zhang, Hu (2001) has conducted an experiment to study the impact of ground water lable on capillary contribution, evapotranspiration and crop coefficient of maize and winter wheat grown in semi acid region in loess loan soil. It was observed that evapotranspiration was decreased with increasing ground water table in early growth period and harvest period. The maximum evpotranspiration occurred at 1.2 m ground water table in the other periods. Values of crop coefficients were calculated based in measured evapotranspiration and reference evapotranspiration by Penman method. The results show that crop coefficient was significantly varied with ground water table. Relationship was established between crop coefficient and depth of ground water table using mean crop coefficients.

Kashyap, Panda (2001) has carried out experimentation in the farm of agricultural and food engineering department institute of technology, Kharagpur, India in sub humid climate by installing lysimeter for measurement of daily reference evapotranspiration. A total of 10 climatological stations were selected for reference crop evapotranspiration on daily basis. An attempt was made to develop regional relationship between evapotranspiration measured by bysimeter and that estimated by climatological method. Crop coefficient was estimated for potato crop at different stages of growth at same location based on bysimeter measured ET and reference evapotranspiration measured by various methods. The crop coefficient for potato was 0.42, 0.85, 1.27 and 0.57 for respective stages of growth.

Garg, Venkateshwar (2001) has developed a mathematical model to determine optimal spacing of shallow tube wells and optimal length of field channel lining to minimize the total cost. The model takes into account the monthly varying crop water requirement.

Sheng-Feng-Kuo, Borjangjn and Horng-Je-Shieh (2001) has collected and analyzed field experimental data from Hsuehchia experimental station of Chia Nan Irrigation Association in Taiwan and then input the results to CROPWAT irrigation management model developed by Food Agriculture organization. It was shown that irrigation model can effectively and efficiently estimate the crop water requirement. It was also suggested a need for further study to fit the model to the complicated situation in cropping pattern, for upgrading the ability of irrigation management of irrigation association in Taiwan.

Trajkovic, Todorovic and stankovic (2001) reviewed estimation of adjustment factor in the modified Penman method to improve the validity of evapotranspiration estimate as table interpolation for calculation of adjustment factor C can lead to a considerable error which is directly transferred to the estimated evapotranspiration. He has calculated C values by RBI network and were compared to the appropriate C values by interpolation. It was shown that RBF network ensured a better agreement with table C values.

XU and Singh (2002) evaluated and compared various popular empirical evapotranspiration equations with data from Switzerland that belonged to three categories 1. Mass transfer based method, 2. Radiation based method, 3. Temperature based method. In this study cross comparison of the best or representative equation forms selected from each category was made. Five representative empirical potential evapotranspiration equations were selected from the three categories. He has given the rank of accuracy to each method from different category.

Kumar, Raghuwanshi, Wallande, Pruitt (2002) studied the utility of artificial neural network for estimation of daily grass evapolranspiration and compared the performance of ANN with connectional method to estimate evapolranspiration. This method was validated and tested using lysimeter method Based on the results, it was concluded that ANA predict ETO better than the conventional method.

Itenfisu, Elliot, Allen, Walter (2003) has compared the reference evapotranspiration equation in united states and recently recommended ASCE standardize reference ET equation as a part of ASCE standardization effort. Analysis used hourly and daily weather data from 49 sties of United States. Calculations were performed for both grass and alfalfa reference crop. Comparison were made between reference ET computed by various methods and ASCE standardized equation agreed best with ASCE PM equation.

Abdullah and Munir (2003) have prepared decision support system for supporting irrigation management in sugarcane plantation in Indonesia. The input data is climatic data, soil, crop data as well as infrastructure data related to sugarcane plantation area. The model is composed of four units. 1) Database management system 2) Forecasted simulation unit 3) Soil water balance unit 4) Geographic information system. Using this model, the right time, place, and amount of water to be applied can be decided. It will prove an interactive software package to assist irrigation manatee in scheduling of water in sugarcane plantation.

Michalopoulou and Papioannu (2003) have estimated monthly evapotranspiration for 31 locations in Greece by Penman, Priestdey-Taylor and Thornwaite method. The analysis of 27 years of routine meteorological data indicates that annual ET obtained Pristley–Taylor or Thornwaile method do not generally agree well with penman ET prediction. Priestly-Taylor and Thornwoile monthly estimate are very close to penman ET for the wet stations and underestimate to a great degree for the medium wetness and dry stations.

Hunsakar (2003) has developed a model for estimation of basal crop coefficient on the observation of normalized difference vegetation Index (NDVI) for full season cotton grown in the desert southwestern USA. The kcb data were used in developing the relationship with NDVI were derived from back calculations of FAO dual crop coefficient procedures using field data obtained during two cotton experiments conducted during 1990 and 1991 at site in leewhal Arizong. Preliminary results indicate that ETc based on NDVI – kcb model provided close estimate of actual ETc.

Jacob, Jia, Dukes (2003) has reviewed the approach to prioritize data, experimental needs, described an experiment conducted to address these needs and provide preliminary crop coefficient experimental results necessary to enhance estimate of agricultural consumptive use. The results from regional modeling showed that crop water estimate is highly sensitive to crop coefficients. To develop crop coefficient an eddy flux system was installed in Bahia grass field.

Alexandris, Kerkides (2003) has proposed new empirical formula for estimating hourly reference evapotranspiration. The equations requires data for three pertinent meteorological attribute i.e. radiation, air temperate humidly. A routine regression analysis in three stages is employed in order to estimate the factor of entering the empirical model. For the calibration of the proposed model, data set from copais (Greece) was collected. A comparative evaluation of the model was performed against some of the most widely used and strongly recommended models for estimating Hoursly ETo, Results indicated that new empirical equation operate quite satisfactory for both region.

Sudheer, Gosain, and Ramsastri (2003) examined the potential of artificial neural network in estimating the actual crop evapotranspiration from limited climatic data. The main aim was to set up a model to compute the daily values of ET for rice crop and the results were compared with measured lysimeter ET. The result of the study demonstrated the proficiency of ANA method to estimate ET.

Jia, Martin, Slack (2004) has examined the appropriateness of applying the conditions set forth by Allen to temperature data in central Arizona. Two weather stations were set up in 935.5 ha field in Central Arizona to measure dry bulb and we bulb temperature. Plant temperature data were collected to verify field conditions of the 611 days of data collected, the difference between Tmin & Tdew was greater than 3^0c on 329 days indicating that these data were not taken under reference conditions. Among these data, 178 days were verified as non reference but 151 were verified as non reference but 151 were verified as actually being under reference conditions. It was suggested to make temperature adjustment for 151 days, resulted in 47 mm decrease in ET estimation which generally secured during summer

Peter Doll, Stefan Siebert (2002) has presented global model for irrigation requirement which is based on new raster map of irrigated area. With spatial resolution of 0.5^0, the model simulates the cropping pattern, growing season, net and gross irrigation requirements for rice and other than rice crops. Using long time series of monthly climatic variable, the irrigation requirement under present day climatic conditions were computed and impact of climate variability is analyzed, The correspondence between model results and independent estimates is irrigation water was judged to be good enough for applying model in global and continental studies

Baltas and Papmichail (2005) have dealt with estimation of reference crop evapotranspiration in the Florina region, Greece by various methods. The results of each method were compared with the results of the other method and were observed that differences between some methods were upto 50%.

Mallikarjun, Pradeepkumarar and Chandrashekhar (2005) proposed a empirical model for reasonable estimation of crop evapotranspiration for different regions of Andhra Pradesh. The influence of climatic factor such on humidity temperature, wind velocity sunshine hours and vapour pressure on daily crop evapotranspiration was also studied to develop relationship among them for different crops for these regions etc. has suggested specific method for evapotranspiration for particular region for particular crop.

Waikar and Dhoot (2005) carried out the evaporation studies for Vishnupuri Irrigation project at Marathwada in Maharashtra to identify the suitable method for estimating reference evapotranspiration. It was suggested that in the absence of adequate climatic data for other method. Modified Penman method ha been found more suitable than other method

Allen, Pereria, Smith and Wright (2005) studied the dual crop coefficient & suggested that dual Kc procedures although relatively simple but estimate daily evaporation measured by lysimeter relatively well for periods of bare boil.

Attarod, Aoki (2006) has made an attempt to present empirical equations including easily available meteorological parameters for estimating crop coefficients and actual evapotranspiration.

Bowen ratio method was used to measure actual evapotranspiration (AET) & Penman monieth method was employed to compute reference evapotranspiration (ETo) and Kc was calculated by ratio of AET to ETo. Measurement was carried out in three popular vegelation in Thailand. The co-relation between crop coefficient and individual as well as combination of meteorological parameter wave established.

Abdul Salem and Suad Al Mazrooci have estimated the crop water and irrigation water requirement for potatoes in the loamy sand of Kuwait and with the help of F.A.O.CROP wat model based on 43 years agro metrological data.

Vruppala, Asadi Reddy had carried out the study in drought prone area of Anantpur district in India to explore for cost effective and sustainable method to increase the crop yield by increasing the ground water potential artificially. This study was conducted to map all natural resources and existing cropping pattern using remote sensing data and integrated with ARC / INFO GIS. The map water requirement was estimated using modified Penman method. The correlation of existing ground water resources and its corresponding draft and the requirement of water for the existing cropping pattern were studied which revealed that the requirement of water for the existing cropping pattern is less than the water available. Therefore, investigator has made an attempt to utilize the ground water by increasing the potential by means of artificial recharge structure. All the thematic maps by interpreting satellite imageries were prepared, which shows the favourable site for artificial recharge, ground water development. It was recommended that ground water potential can be improved through this artificial recharging of water so as to meet the requirement of water for existing cropping pattern. This ultimately led to increase in crop yield and in turn increase the per capita for sustainable development of this chronically drought prone area.

A National workshop( ) was convened by National Programme for irrigation research and development to establish the national standards for irrigated crop water balance and crop evapotranspiration field methodologies.
Makrantonaki, Vagnese (2006) has proposed a map for reference evapotranspiration and rainfalls to estimate the crop water requirements in central Greece. This is useful for research as well as corresponding administrator that deals with constriction of irrigation network, tanks and dams to estimate the water requirement of crops for the areas of interest with the help of given map. It can also contribute to the proper functioning of existing irrigation network and more generally in national use and management of water resources.

Prasad, Umamahesh, Vishwanath (2006) has developed optimal planning strategies for Nagarjun Sagar right canal of semiarid region of south India. The main objective of this study was to allocate the available land and water in multicrop & Multiseason environment so as to obtain irrigation weeks requiring for irrigation of fixed amount in mm. The problem was solved in four stages. The result reveals that theoptimization approach can significantly improved annual net benefit with deficit irrigation strategy under water scarily.

Simon, Connollez and Sinder (2006) have estimated the evapotranspiration of different sized Navalorange tree orchard using energy Balance method and compared the crop coefficient for different irrigation system.. The estimated crop coefficient values ranged from 0.45 to 0.93 for canopy covers having between 3.5 land 70% ground shading. The crop coefficient values were slightly higher than crop coefficient for clean cultivated orchard with high frequency drip irrigation in Arizona and were slightly lower than for non tilled orchard in Florida.

Cornelo, Haman, Jordan (2006) has carried out the study to determine irrigable area in the Santa Elena Peninsula water Delivery system under several land use scenarios based on an ample water budget model requiring estimation of 1) crop water requirement 2) irrigation efficiency 3) dams and canals evaporation utilizing weather data. CROPWAT model was used to calculate crop water requirement and irrigation requirement. The total calculated irrigable area during dry season was compared to estimate from commission for the development of Guayas River Basin in Equator and to the average estimate done by the farmer. The commission estimate48% more whereas farmer estimate 0.06% more than the most water conservative scenario. This method requires minimum climate and Geographic information coupled well established with FAO models to produce tangible results.

Lecina, Playin (2006) has developed model for the simulation of water blows in irrigation districts. The objective was to calibrate, validate and apply the model in irrigation districts Bardenas of Spain as study area. Two years study was used for the analysis to 2000 and 2001. Model calibration was performed in one of the 11 hydrological sectors in which district are divided. The seasonal differences in observed and simulated water demand amounted to 0.9% and 1.9% for 2000 and 2001 respectively .Model validation was performed in rest of sector. Model application explored scenarios based on management improvement and structural improvement. This will permit to reduce water demand, halve the irrigation return flow and reduce daily irrigation period from 24 to 16 hours.

Alexandris, Liakatas (2006) has proposed new empirical equation for estimating daily evapotranspiration. Results are compared with corresponding estimate obtained by the widely used and recommended models. Comparison shown that the new empirical function operate quite consistently, slightly underestimating the summed hourly estimate.

Zhang, Liu, Tang (2007) has studied the trends in pan evaporation, reference evapotranspiration and actual evapotranspiration across Tibetan plateau. To carry out the study, they examined Penman

Moneith reference evapotranspiration and pan evaporation from 20cm pan by using data set from 75 methodological ste observatories across the plateau from 1966 to 2003. Actual regional evapotranspiration was estimated in 16 catchments across the plateau during 1966 to 2001. The analysis showed that the decreasing trend in reference evapotranspiration was due to decrease in wind speed and decrease air temperature. Regional actual evapotranspiration and reference, potential evapotranspiration or pan evaporation exhibit complementary behaviors which does not support Bouchets complementary hypothesis. This study has suggested Bouchets complementary relationship needs to be considered at high elevation.

Chaunyan, zhongren (2007) estimated the water needs of maize using dual crop coefficients in the region of North Western China. The actual evapotranspiration ration was estimated using FAO penman moneith equation by using basal crop coefficient. The result showed that ETc values were very low during initial stages of crop growth. The ETc values increases during crop development stage and reached its peak during the mid season stage and then it decreases rapidly during last growth stage.

Ozdogan, Salvucci has investigated the feedback between changes in potential evaporation and future irrigated acreage in South Eastern Turkey using observed and simulated meteorological variables. Under the framework provided by the complementary relationship, the results demonstrated the existence and quantify the magnitude of scale dependence in the relationship between irrigated area and amount of water required the unit area assuming that the changes in future evaporation condition will be similar to the observed changes. Water use for irrigation is expected to decrease over 50 percent in selected irrigation etc. Therefore it is suggested the future land use modification in the form of irrigated agriculture in South Eastern Turkey.

Porey, Ghare (2007) has computed reference evapotranspiration for Nagpur region using all five conventional method and also by using all five conventional method and also by using simplified model proposed by Synder (2003). The overall result showed that monthly average ETO values were close to each other.

The review of literature shown that there is a scope for research in the reference evapotranspiration, crop coefficient and crop water requirement. This thesis is aimed to cover these areas for the research work

Chapter 3

Evapotranspiration

3.1 Introduction

The effect of climatological factor on crop water requirement are given try reference evapotranspiration which is defined as the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall green grass cover of uniform height actually growing completely shading the ground and not short of water.

An estimation of crop water requirement is an integral aspect of the design and management of an irrigation system. The output of crop is maximum when water is applied optimally and any deficient or excess amount of water usually reduces the output. The optimal crop water requirement mainly depends upon accurate estimation of evapotranspiration.

A number of climatological methods are available for estimation of crop water requirement. These methods are mostly empirically derived relationship bet ETo and climatological factors based on data collected from certain weather stations and actual observations of evapotranspiration under controlled conditions. The weight age given to various factors in different method vary according to the locations where the methods are developed and the data available. Each method has its advantage and Limitations under a set of conditions. Any method must therefore be used with conscious understanding of available data, its reliability and the limitation of the method. The detail description of each method is given **Chapter-I.**

This work recommends Modified Penman Method for standardization of crop water requirement as it is globally accepted as well as it considers all the factors relatively radiation and aerodynamic term.

This chapter contains the determination of fortnightly reference evapotranspiration for Nagpur, Wardha, Chandrapur Gondia The data collected are max and min temperature , max and min relative humidity , wind speed , sunshine hours etc for the duration of 15 years from 1999-2004. The data was collected from meteorological center

3.2 Work carried out by various researchers

Sudhir, Gosain, Ramshastri (2003) examined the potential of artificial neural network in estimating actual evapotranspiration from limited climatic data. Batchelor (1984) has estimated the evapotranspiration for north East Sri Lanka to illustrate the importance of empiricism in F.A.O. modified penman method.

Baltas and Paloachimal (2003) has studied the reference crop evapotranspiration in Florina region Greece try various methods? Results of each method were composed. Waikon and Dhoot (2005) carried out the evapotranspiration for Vishnupuri Project at Marathwada to identify the suitable method for estimating reference evapotranspiration suggested the Modified Penman Method is more suitable than any other method.

3.3 ANALYTICAL METHODS

The evapotranspiration from a reference surface not short of water is called Reference evapotranspiration (ET_0). The reference evapotranspiration concept is use to study the evaporative demand of atmosphere independent of crop type, crop development and management practices. The value thus obtained is then multiplied by coefficients established for particular crop and area to give actual ET value.

Following are the few widely used methods for calculating ET_0 values

1. Blaney – Criddle Method (BCM)
2. Radiation Method (RDM)
3. Modified Penman Method (MPM)
4. Thornthwaite Method (THM)
5. Hargreaves Method (HGM)
6. Christiansen Method (CNM)

3.3.1 The Thornthwaite Method

Thornthwaite (1948) using metrological observations from the Eastern USA, found that under conditions of limited availability of water there is an explicit relation between the evapotranspiration and the temperature of atmosphere, longitude and the season. The empiric equation he give is:

$$ET = 16\, L_d\, [10\, T / I\,]^a \qquad (3.1)$$

Where:

ETo reference crop evapotranspiration T

temperature in degree Celsius

N daylight hours, a function of latitude and the day of year.

L_d is the ratio of the mean duration of the days of each month to the 12-hour day [μ / 360],

μ number of days in each month

3.3.2 The Thornthwaite Method

Thornthwaite (1948) using metrological observations from the Eastern USA, found that under conditions of limited availability of water there is an explicit relation between the evapotranspiration and the temperature of atmosphere, longitude and the season

.The empiric equation he gave is as

$$ET = 16\, L_d[10T/I]^a \qquad (3.2)$$

Where:

ETo reference crop evapotranspiration T

temperature in degree Celsius

N daylight hours, a function of latitude and the day of year.

L_d ratio of the mean duration of the days of each month to the 12-hour day [μ/360], μ number of days in each month

I annual indicator of the air temperature that is calculated with the equation I =

$\sum^{12} i_j = \sum [T_j/5]^{1.154}$

I_J is I corresponding monthly indicators of heat, exponent α is the empirical coefficient estimated from the equation:

$\alpha = 0.016\, I + 0.5$

This method gives good results for climate like Eastern USA. The main characteristic is that the rain period takes place at the summer, so there is high humid.

3.3.3 Christiansen Method:

Christiansen (1968) proposed a revised empirical formula, originally developed by him in (1966), to estimate pan evaporation from climatic data when reliable measured pa evaporation data are not available for estimating of evapotranspiration. Because of variations in size and shape of pan, their exposure, the presence of algae in water, the specific methods of measuring the loss of water from the pans and the protection against use of water by birds and animal, available pan evaporation data may not sometimes be reliable to make the estimate of evapotranspiration .In such cases of pan evaporation, estimate by means of a reliable formula may give more accurate results than the reported evaporation. The following is the Christiansen's revised equation develops at Logan (Utah), USA, for estimation pan evaporation:

$$E_s = K_{ev} \,.\, R \,.\, C_t \,.\, C_w \,.\, C_h \,.\, C_s \,.\, C_e \,.\, C_m \qquad (3.3)$$

Where:

E_v is the computed pan evaporation equivalent to Class A pan evaporation

K_{ev} is a dimensionless empirically developed constant, the value of which is given by Christiansen as 0.473, R is the extra-terrestrial radiation in the same evaporation units as E_v and C_t, C_w, C_h, C_s, C_e coefficient for temperature, wind velocity, relative humidity ,percentage of possible sunshine and elevation ,respectively and C_m is a monthly coefficient or basic factor by which all the basic formula would have to be multiplied to obtain the measured evaporation and averaged to obtain mean monthly values of C_m . The values of C_m mostly range between 0.90 to 1.10 and vary from latitude to latitude.

The value of constant K_{ev} depends on the selection of standard values for each climatic factor.

3.3.4. Hargreaves Method: (1983)

Hargreaves established that amongst all the climatological data, temperature and radiation given more accurate value of evapotranspiration.

$$ET_o = 0.0023 \times Ra\,(T + 17.8) \times TD \times 0.5 \qquad (3.4)$$

ET_o = reference crop evapotranspiration in mm/day Ra

= extraterrestrial radiation

T = mean air temperature

TD = difference of maximum and minimum temperature

This method is comparatively very simple and requires only temperature data apart from latitude. The equation gives more accurate results at interior locations with plain topography where the growing season of the crops are frost free.

3.3.5 Radiation Method:

This method considers the radiation reaching the earth as the major contribution or the influence factor for evapotranspiration. The FAO recommended

$$ET_o = c\ (W \times Rs) \qquad (3.5)$$

Where,

ET_o = reference crop evapotranspiration in mm/day

Rs = Solar radiation in equivalent evaporation (mm/day)

Rs = (0.25 + 0.50 n/ N) Ra

Ra = extraterrestrial radiation in equivalent evaporation in mm/day

N = actual measured bright sunshine hours

N = maximum possible sunshine hours

W = Temperature and altitude dependent weightage factor

C = Adjustment factor made graphically on W

This method is used when the data of air temperature and sunshine hours are available and calculation should be done for each month of record and not for yearly records

3.3.6. Blaney Criddle Method: (1950)

The original Blaney – Criddle equation involves the calculation of the consumptive use factor from mean temperature and percentage of the total annual daylight hours occurring during the period being considered. But the effect of the climate on crop water requirement is insufficiently defined by temperature and day length. ET_o also varies widely with the climatic conditions, which are humidity, sunshine hour, and wind. The relation recommended by FAO representing mean value over the given month is expressed as

$$ET_o = cp\,(0.46\,T + 8)) \qquad (3.6)$$

ET_o - reference crop evapotranspiration

T - daily temperature for the month in C

p - Daily percentage of total annual daytime hours c -

Adjustment factors

This method is useful where only the temperature data is available. The ETo should be adjusted 10% downward for each 1000m altitude changes above sea level

3.3.7 **Modified Penman Method**

The original penman method was developed in 1948. It gave values of evaporation losses related to radiation, wind and humidity. A coefficient ranging from 0.6 in winter to 0.8 in summer give the evapotranspiration of grass. The modified penman equation consists of two Tems, one is the energy or radiation term and other as aerodynamic term which gives evaporation due to wind and humidly considered together.

Under the calm weather condition the energy term is more important while the aerodynamic terms is relatively more important under windy conditions. The predictions of ET_0 was satisfactory under calm weather not only in cool humid regions like England but also in hot, semi arid regions.

A modified form of this method was presented in 1977 by J. Dorrenboss and W.O. Pruitt which introduced a somewhat simplified form of the equation alongwith correction factor considering day and night weather condition. This modified form is known as Modified Penman Method, now widely used. The original penman method calculates evaporation from open water surfaces while modified penman method computes reference crop evapotranspiration.. The original penman method has several components which have further relationship with weather parameters. All these have been accommodated in modified formula. Several tables are prepared for ease in computation.

The modified penman equation is

$$ET_0 = C\,[(W \times Rn) + (1 - W)\,f(u)\,(eq - ed)] \qquad (3.7)$$

Where

ET_0 = reference crop evapotranspiration in mm/day

C = Adjustment factor for day and night wind velocities and different humidity levels

W = weighing factor for altitude and temperature effect on radiation.

Rn = Net radiation in equivalent in mm/day

(1-w) =Weighing factor for altitude and temperature effect on wind and humidly f(u) = wind function or effect of wind on ET_0 expressed in terms of equivalent evaporation mm/day

(eq-ed) =Vapour pressure deficit expressed in m bar

(W x Rn) radiation contribution to the evapotranspiration and is known as or energy term.

(1 – w) + (u) (eq – ed) contribution of wind humidity and referred to as the aerodynamic term.

W & (1 – w) :-

These are the weightage factors for the radiation and aerodynamic terms respectively. The original Penman equation is derived in England under calm weather conditions. The radiation term in the original equation was $\frac{\Delta Q 1}{\Delta + Y}$. The Qn is equivalent to Rn in the modified equation and this term is simplified as W. Rn. Similarly the aerodynamic term in the original penman equation was $\frac{YEa}{\Delta + y}$ or $\frac{Y}{\Delta + r}$ is equivalent ~~to~~ (1 – w) in the modified equation. Thus penman equation envisages the ET_0 as the weighted average of the radiation term and the aerodynamic term. Term Δ is the slope of the curve of saturated vapour pressure vs, the temperature. St is seen from the graph that the value of Δ increaser from 0.50 @ 6^0c to about 3 for 40^0c. The change in the value of 4 is comparatively negligible. Δ also increases with the increase in altitude. w, therefore, increaser with increase in temperature and altitude and approaches to 1 though it cannot be equal to 1. This means that the radiation term assumes more and more influence on ET_0 as the temperature and altitude increases. For convenience of computation, the values of w and (1 – w) are given in WALMI (1994)

Adjustment factor C:-

There is no adjustment factor in the original penman equation. The equation was derived under calm weather conditions where the day and right wind ratio was between
1.5 to 2 and maximum relative humidity was about 70%. The equation was found to predict erratic values where the wind conditions and maximum relative humidity varied. It was also noticed that errors were also related to the increase in Rs. The modified equation therefore suggested an adjustment factor for these variations. The modified penman considers the average conditions for 24 hrs.

Radiation Term:-

Rn: The radiation term of modified penman equation consists of W x Rn, where W is the weight age factor as explained above and Rn is the net radiation at earth surface.
Ra: It is the extraterrestrial radiation depending only on latitude and time of the year. The values are given in table for different latitude and months.
Rs: It is the part of extraterrestrial radiation reaching the earth.
Rs = (0.25 + 0.50 n/N) part of this radiation is reflected back into atmosphere, the quantity reflected being dependant on the nature of surface. Their reflection coefficient for cropped soil is 0.25 i.e. 25% of Rs is reflected back into the atmosphere. Therefore net solar radiation denoted by

Rns = $(1 - \alpha) Rs$ x $(1 - 0.25)(0.25 + 0.50 \frac{\alpha}{N})$ (3.8)

<u>Aerodynamic Term :-</u>

The aerodynamic term of modified Penman equation is (1 – w). It is the weightage factor. The value of (1 – w) can be obtained directly from table given in Walmi (1994) If the mean temperature and altitude is provided on data

F(u) is the wind function where

$$f(u) = 0.27\,(1 + \frac{u2}{100} \quad (3.9)$$

u_2 is the wind velocity in Kms/day. It may again be stressed that modified penman method uses the mean of 24 hrs and u_2 is the wind run for 24 hours at 2m height if the velocity is measured at different height, the corrected value of velocity has to be adopted.

The correction factor is given in table in walmi(1994). (ea – ed) is the vapour pressure deficit i.e. difference between saturation vapour pressure and the actual pressure. The saturation vapour pressure ea is dependant on air temperature. Form fig of Tmax and Tmin provided, the mean air temperature, T mean is calculated. Values of ea against T mean is provided in given in reference----

$$ed = ea \times \frac{Rh \text{ mean } 100}{} \qquad (3.10)$$

3.4 Work carried out:

The present study is carried out to calculate fortnightly reference evapotranspiration by modified penman method for Nagpur region which includes Nagpur, Wardha, Charndapur, and Gondia as meteorological center. The data collected for is maximum and minimum temperature, maximum and minimum relative humidity, wind speed, sunshine hours from Hydrological Data users group,Nashik and Meteorological center, Nagpur.. The data is collected for 1999 - 2004 i.e 15 years. As this region consists of Nagpur, Wardha, Chandrapur, Gondia, Bhandara, Gadchiroli districts, therefore Meteorological center at Nagpur, Wardha, Chandrapur, Gondia are considered for concerned district , but for Gadchiroli and Bhandara district, Chandrapur and Gondia are taken as meteorological center. The fortnightly reference evapotranspiration for the above said mention meteorological center is in annexure 1.1- 1.4

3.5 Research

3.5.1 Development of Mathematical Equation

To determine reference evapotranspiration, it is essential to have an accurate value of adjustment factor C as it is used to consider the day and night wind speed which was not in the original penman method. The adjustment factor c is an integral part in the evapotranspiration which is determined by using table given by Doorknobs and Pruilts (1977). The value of c has to be obtained by using table interpolation. However it is necessary to make 15 times interpolation to obtain the adjustment factor c which makes 45 different numbers into calculation. This leads to an error which is directly transferred in crop water requirement.

Trajkovic, Todorovic and Stankovic (2001) reviewed estimation of adjustment factor c in modified penman method to improve the validity of evapotranspiration. He has calculated c values by RBF network and were compared to the appropriate c values by interpolation.

To avoid table interpolation, Hajare, Raman and Dharkar (2008) has suggested empirical model for adjustment factor c. This study has been carried out for Wardha meteorogical center of Maharashtra region in India. The multiple regression analysis is used to develop relation between three or more variables by analyzing the dependence among them.

The equations one developed by regression analysis which is carried out by omitting one of the independent variable each time. Various alternatives like quadratic, cubical have been applied but linear equation was found to be best suited in which regression coefficient R^2 is equal to 0.95. The adjustment factor c is developed by using MAT LAB programme

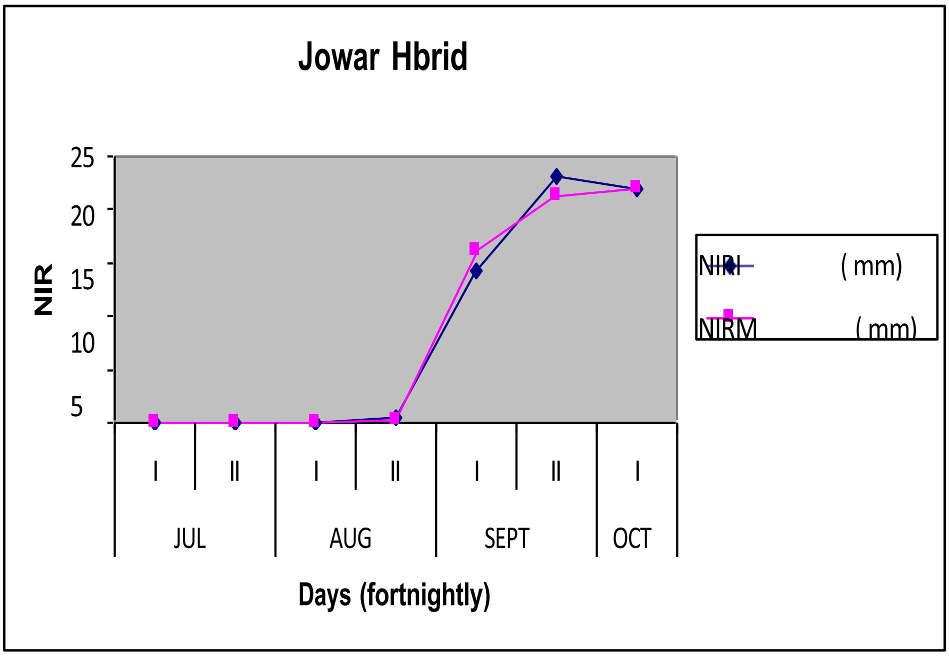
$$C = (AU + B)\, Rs + WU + Z \qquad (3.11)$$

Where A, B, W and Z are the constants ,expressed in terms of relative humidity, are different for different u day/night ratio are shown in table 3.1

To evaluate appropriateness of equation 3.11, the crop water requirement for different crop by F.A.O. method in which adjustment factor c, calculated by using table interpolation is compared with the adjustment factor by empirical equations. The graph were plotted and it observed crop water requirement estimated by both these method depicts the closeness of the value thereby reflects appropriateness of the equations suggested. It is also observed that error of 1.97% in the value of c has very little effect on fortnightly crop water requirement as shown in fig 3.1. This eliminates manual error in table interpolation as well as saves the time.

Table – 3.1 Adjustment Factor C In Modified Penman Method

	Rh=30%				Rh=60%				Rh=90%			
Rs	3	6	9	12	3	6	9	12	3	6	9	12
U m/s	Uday/night=4											
0	A=0.002002Rh+0.001973											
3	B=.003767Rh+0.01393											
6	W=.0264Rh-0.04985											
9	Z=0.2542Rh+0.7613											
	Uday/night=3											
0	A=0.001388Rh+0.002382											
3	B=0.003333Rh+.0137											
6	W=0.02833Rh-0.05172											
9	Z=0.2392Rh+0.7648											
	Uday/night=2											
0	A=0.00050Rh+0.0029											
3	B=0.0054Rh+0.018											
6	W=0.03167Rh-0.0729											
9	Z=0.2825Rh+0.731											
	Uday/night=1											
0	A=-0.00045Rh+0.003703											
3	B=-0.0111Rh+0.0205											
6	W=0.03943Rh-0.08799											
9	Z=0.3083Rh+0.7083											


Jowar Hbrid
NIR
25
20
15
10
5
I
II
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II
I
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I
JUL
AUG
SEPT
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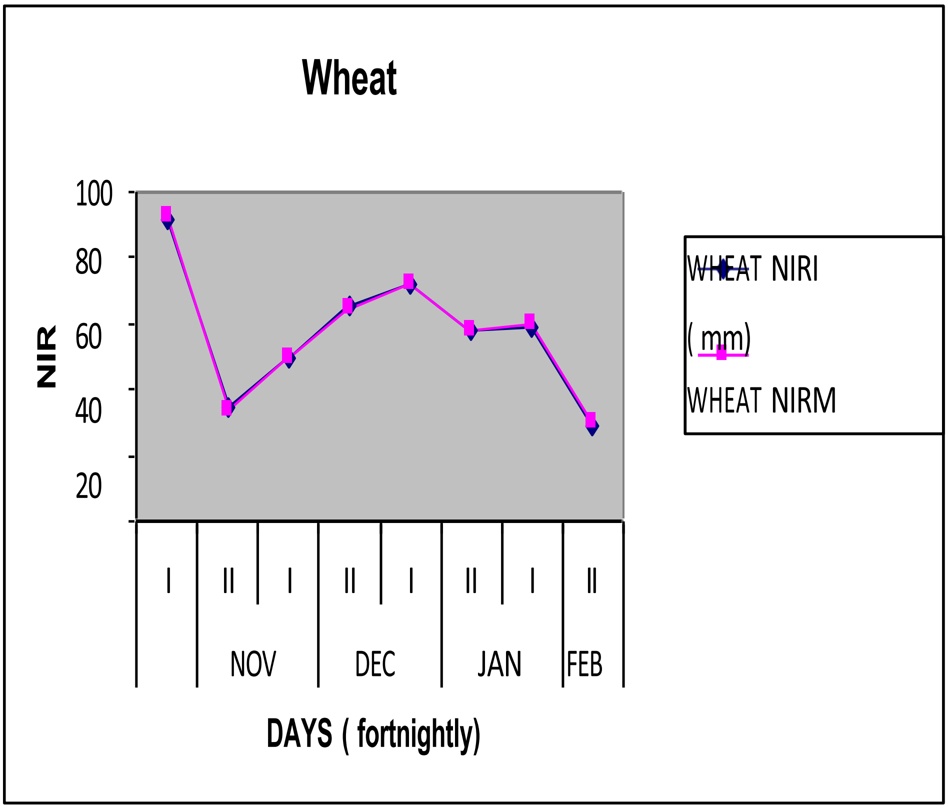
Days (fortnightly)
NIRI (mm)
NIRM (mm)


Wheat
NIR
100
80
60
40
20
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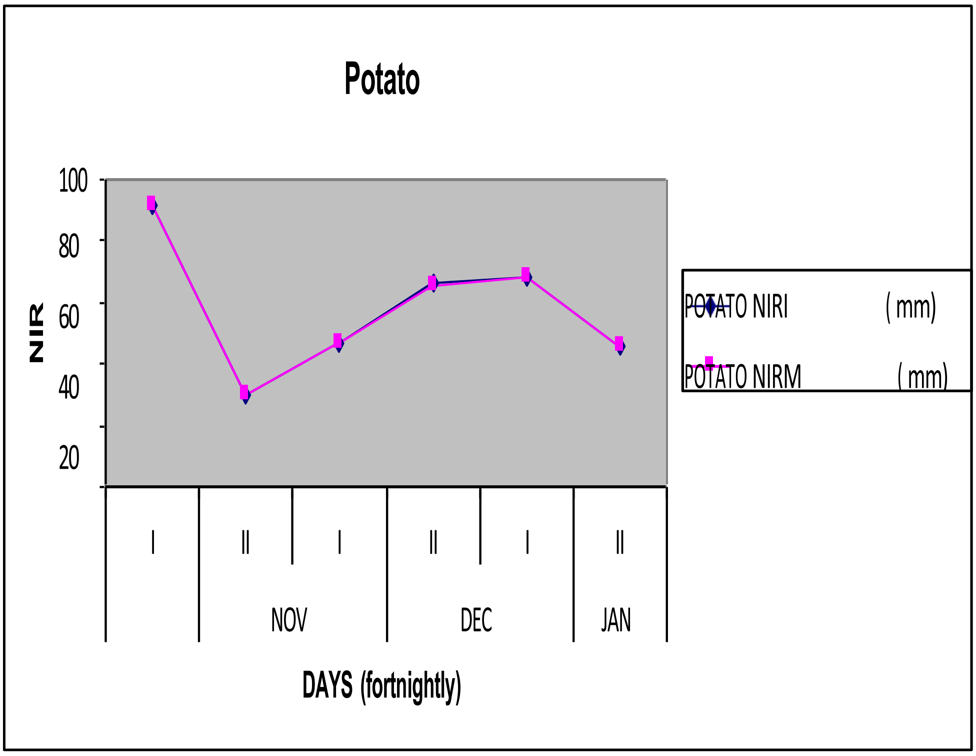
DAYS (fortnightly)
WHEAT NIRI
(mm)
WHEAT NIRM



Potato
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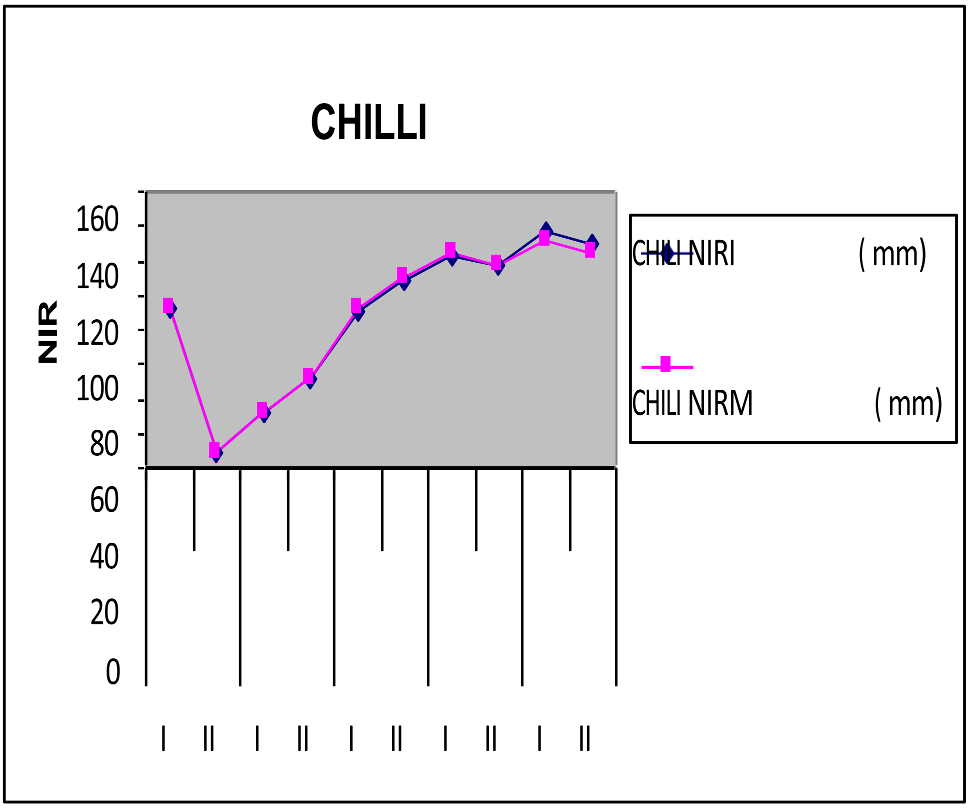
DAYS (fortnightly)
POTATO NIRI (mm)
POTATO NIRM (mm)



CHILLI
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CHILI NIRM (mm)

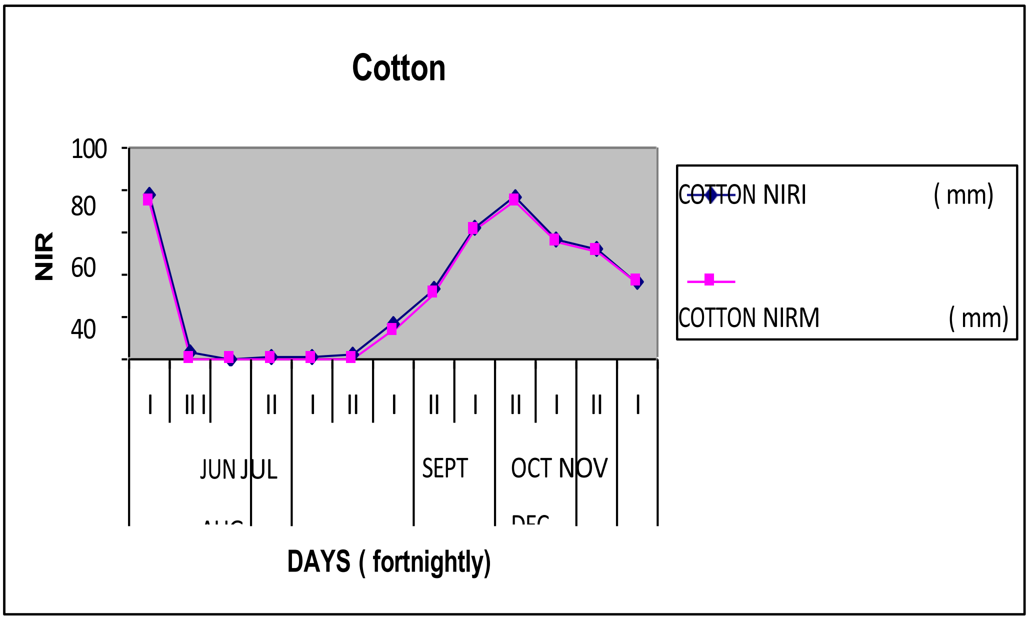


Fig 3.1 Crop water requirement by both methods

3.5.2 Computation of Reference evapotranspiration by Various Method

Average daily ET0 values are determined by various methods, discussed in 3.3 with the available climatological data shown in Table 3.2 for Nagpur meteorological station. Table 3.3 gives the estimated daily average ET0 values for all months by different method. These values are them used to develop inter relationship among different empirical method considering MPM as standard.

It can seen ET0 values obtained from RDM is minimum while in other methods it is closely matched with each other., even though it is suggested to use Modified Penman Method because it considers all parameters which affects monthly ET0 values .

Table 3.2 Average Climatic Data of Nagpur (2002-04)

Month	Max temp	Min temp	Max RH	Min RH	Wind velocity	n
January	26.15	14.34	40.60	16.53	3.49	7.49
February	30.30	16.05	47.86	18.62	4.08	9.63

March	34.50	20.60	57.18	20.47	4.71	8.77
April	38.15	25.52	66.17	20.70	5.24	8.46
May	40.89	30.00	73.21	22.66	5.20	8.95
June	38.27	29.75	68.88	24.86	5.90	5.21
July	29.22	24.72	54.17	25.50	5.07	2.15
August	29.21	24.55	54.54	25.17	5.30	3.98
September	30.12	24.63	55.25	25.42	4.77	5.49
October	29.59	21.63	52.44	23.00	3.46	7.40
November	27.67	14.73	42.70	18.00	3.34	9.44
December	26.21	12.67	37.83	15.70	3.33	9.38

Table 3.3. ET_o Values Using Different Methods In mm/Day

MONTH	MPM	HGM	BCM	RDM	THM	CNM
January	2.44	3.45	3.55	2.09	1.72	3.28
February	2.87	4.39	4.19	2.59	1.81	4.68
March	3.33	5.81	4.90	3.23	2.39	4.94
April	4.36	6.28	5.99	3.57	2.92	5.52
May	4.73	7.00	6.52	3.42	3.36	6.17
June	5.00	5.57	6.33	3.91	3.17	3.47
July	4.54	3.88	5.60	3.21	2.69	1.54
August	4.45	3.39	5.14	3.24	2.50	1.81
September	3.93	3.62	5.05	2.97	2.37	2.54
October	2.94	3.86	4.59	2.81	2.21	3.89
November	2.62	3.58	4.00	2.30	1.84	4.48
December	2.30	3.31	3.44	2.16	1.72	4.10
Average	3.62	4.51	4.94	2.96	2.39	3.86

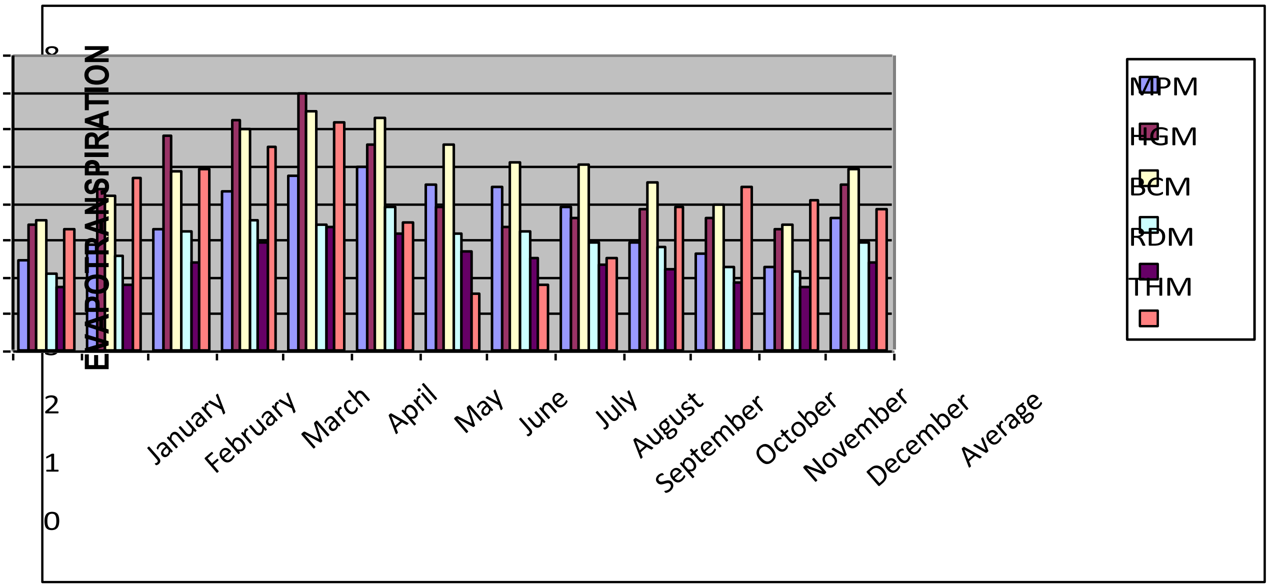


Fig 3.2 Evapotranspiration by different method

3.5.3 Relationship of various methods with MPM

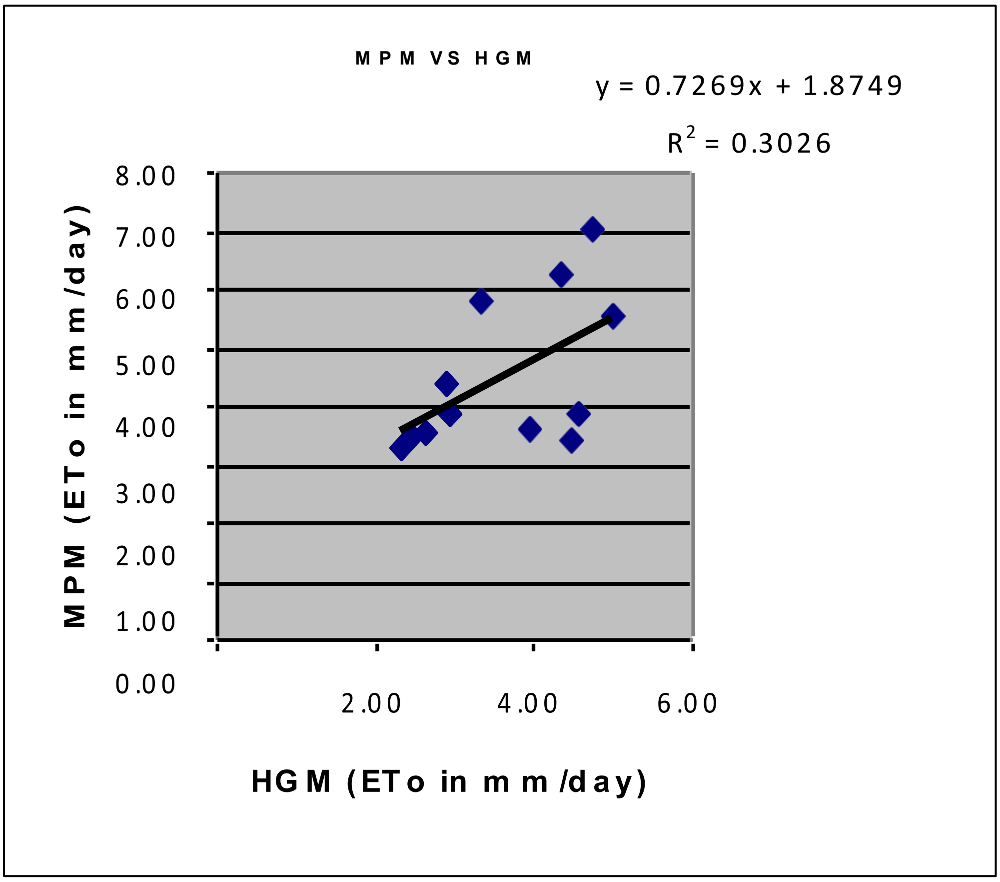
For the present study modified penman method MPM is used to calculate ET_0 , Further the relationship is also developed of MPM with other method to facilate the calculation using MPM in case of nonavailaibily of all required data for the use of MPM . Graphs have been plotted between MPM and other methods to establish the relationship as shown in fig 3.2

Table3.4 gives the equation for relationship of various method with MPM. It can be noted that coefficient of correlation value is more to RDM and HGM therefore more suitable in the absence of adequate climatic data for the MPM for this climatic region.

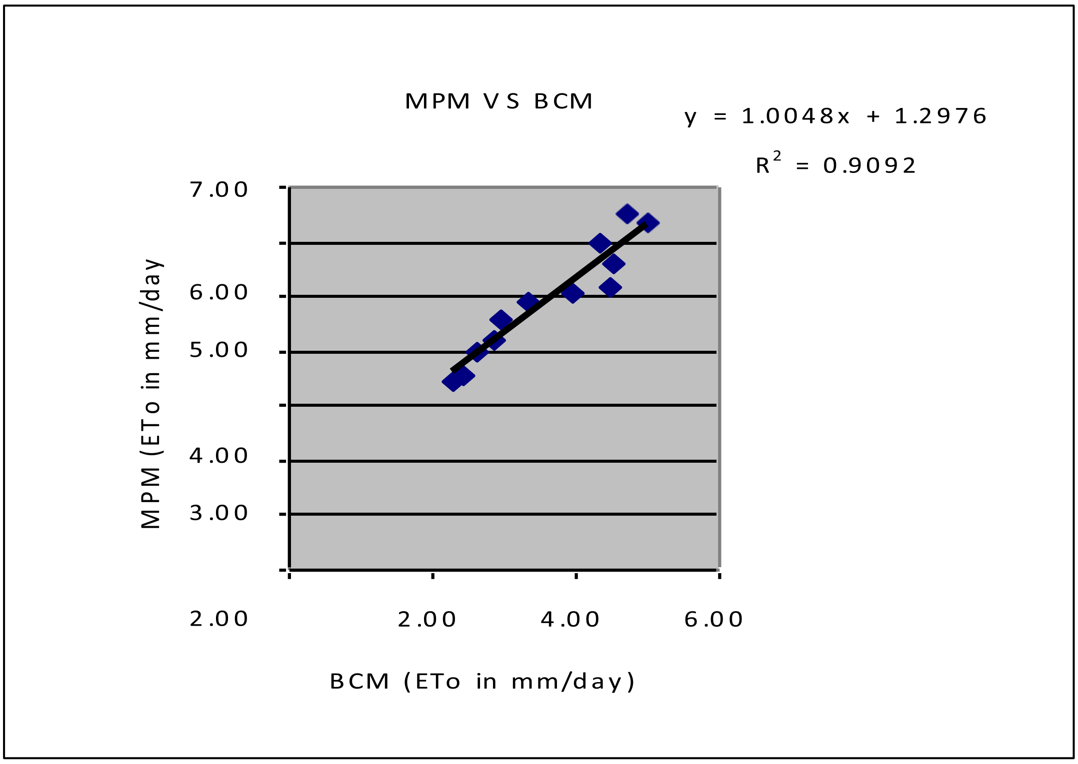
Linear regression analysis has been done using Microsoft Excel to develop interrelation among the result of the selected methods. This interrelationship provides an 'easy to use' method to obtain the ET_o values by methods for which metrological data are available and then to get accurate results in terms of desired method

Fig 3.3 Comparison of Different method with MPM

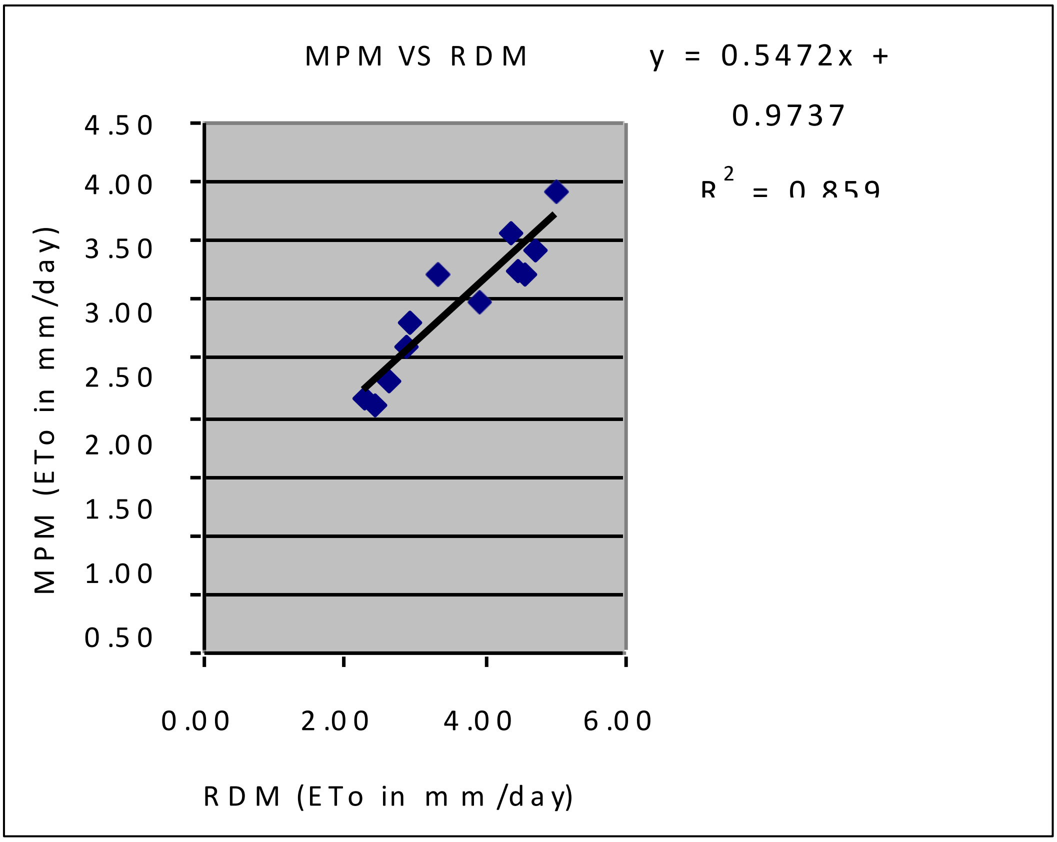
Modified Penman Method and Hargreaves Method



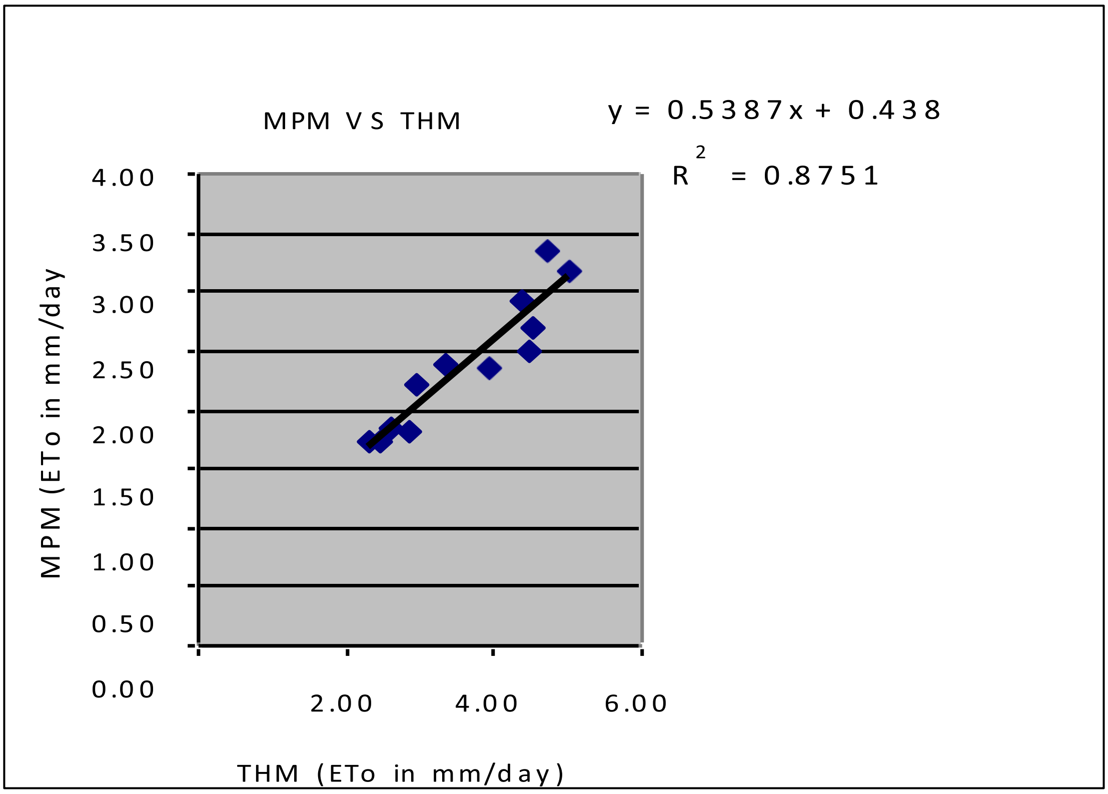
Modified Penman Method and Blaney Criddle Method



Comparison of Between Modified Penman Method and Radiation Method



Modified Penman Method and Thornthwaite Method



Modified Penman Method and Christiansen Method

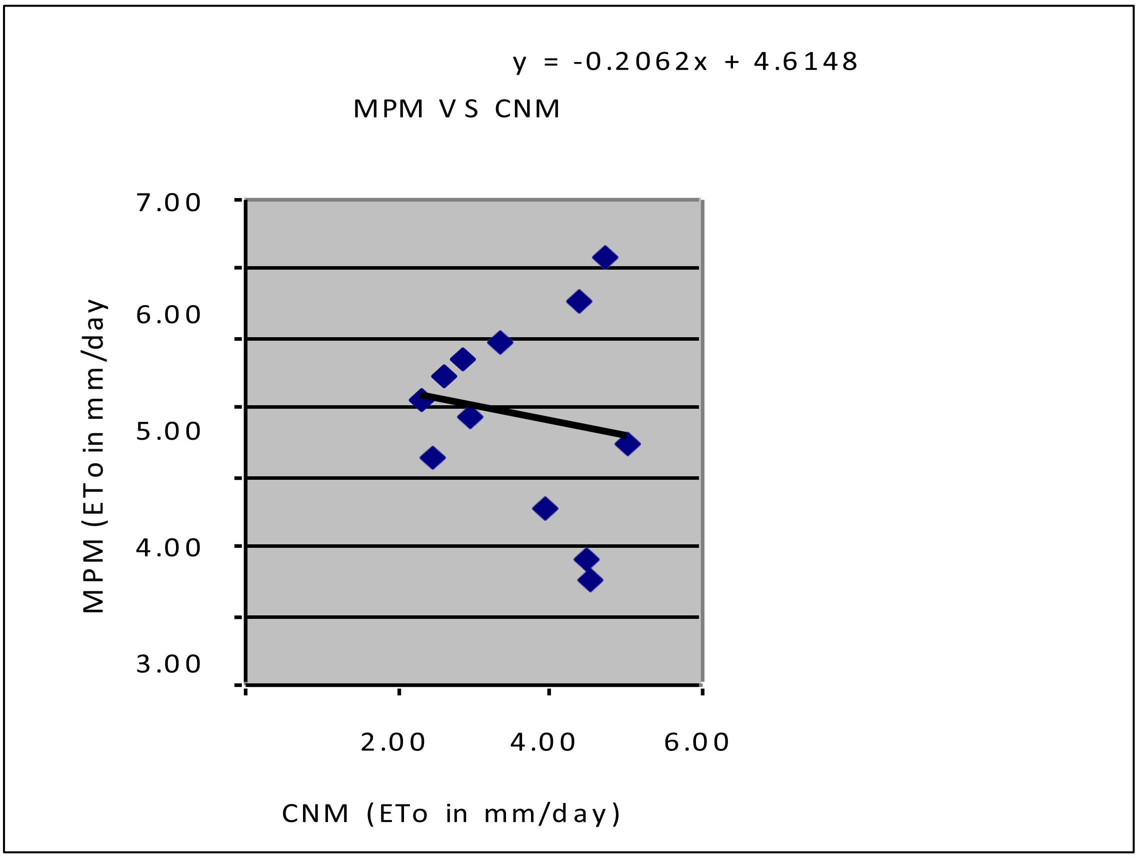


TABLE 3.4 Relation of modified Penman Method with other method

S.N.	RELATIONSHIP	R^2	R
1.	MPM = 0.7269 HGM + 1.8749	0.3028	0.550
2.	MPM = 1.0048 BCM + 1.2978	0.9092	0.953
3.	MPM = 0.5472 RDM + 0.9737	0.8590	0.926
4.	MPM = 0.5387 THM + 0.4380	0.8751	0.935
5.	MPM = 0.2062 CNM + 4.6148	0.0203	0.142

TABLE 3.5 Percentage Variation Of Evapotranspiration Of Different Methods Over MPM.

MONTH	HGM OVER MPM	BCM OVER MPM	MPM OVER RDM	MPM OVER THM	CNM OVER MPM
January	41.39	45.49	16.75	41.86	34.43
February	52.96	45.99	10.81	58.56	63.07
March	74.47	47.15	3.10	39.33	48.35
April	44.04	37.39	22.13	49.32	26.61
May	47.99	37.84	38.30	40.77	30.44
June	11.40	26.60	27.88	57.73	-30.60
July	-14.54	23.35	41.43	68.77	-66.08
August	-23.82	15.51	37.35	78.00	-59.33
September	-7.89	28.50	32.32	65.82	-35.37
October	31.29	56.12	4.63	33.03	32.31
November	36.64	52.67	13.91	42.39	70.99
December	43.91	49.57	6.48	33.72	78.26
Average	28.15	38.85	21.26	50.78	16.09

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3.6 Conclusions

- The net irrigation requirement for different crop using FAO method in which adjustment factor c is calculated by using interpolation .Similarly the net irrigation requirement is also calculated by using empirical modeling for adjustment factor. The comparison for crop water requirement by interpolation and empirical equations are presented in fig 3.3.It is observed from curves that crop water requirement estimated by both these methods depicts the closeness of the value thereby reflects the appropriateness of the method. The multiple correlation analysis for adjustment factor with climatic factor is carried out by omitting the one of the climatic factor each time. However to establish the relationship proposed , it is noted that some more sample of data pertaining to the crops selected for the present study and also the other crops within the study area may be analyzed on similar lines.

- It is observed that error of 1.97% in the value of adjustment factor c, used in modified penman method to calculate evapotranspiration which is uses to calculate the crop water requirement, have very little effect on the fortnightly crop water requirement as shown in annexure ----Therefore it is suggested to use empirical equation to find out adjustment factor c which is directly transferred to estimate crop water requirement. This eliminates the manual error in interpolating the values as well as saves time

- For the present case study MPM is used to calculate ETo. Further the relationship is also developed with other methods to facilitate the calculations using MPM in case of non availability of all required data for the use of MPM. Table 3.4 gives the equations for relationship of various methods with MPM. It can be noted that coefficient of correlation value is more for BCM, RDM and HGM and therefore more suitable in the absence of adequate climatic data for the use MPM for this climatic region. It can also seen that the ETo values obtained from BCM are maximum and from THM, It is minimum. MPM and CNM methods give values, closer to each other.

Linear regression analysis has been done using Microsoft Excel to develop interrelation among the result of the selected meth ods. This interrelationship provides an 'easy to use' method to obtain the ET_o values by methods for which metrological data are available and then to get accurate results in terms of desired method

Chapter – 4

Crop Coefficients (Kc)

4.1 Introduction

The evapotranspiration of any crop is related to the ETo by

Etc = Kc x ETo (4.1)

Where

Etc evapotranspiration of crop in mm/day

Kc crop coefficient

The crop coefficient varies according to crop characteristics, dates of planting, stage of growth and climatic conditions. The wide variation in the crop coefficients are due to resistance of different crops to transpiration such as closing of stomata's during day, waxy leaves, difference in crop heights, crop roughness, reflection from water and soil. Canopy cover can also be reasons for different growth periods and different crop coefficient in the growth period as the rate of crop growth is different. The frequency of availability of water either due to rains or due to irrigation also affects the crop coefficients especially in the early growth period.

The crop coefficient of the crop is therefore to be decided for a particulars set of conditions of sowing date. The procedure to find out crop coefficient as per F.A.O. Paper No. 24 is given below.

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The crop coefficients are dependant on the stage of growth and rate of growth of the crop. The growth period is therefore divided into four stages.

i) **Initial stage**: -Germination period and early growth of the crop when the soil cover by the crop is less than 10%

ii) **Crop development stage**:-

The end of initial stage till the soil cover by the crop is about 70 to 80%

iii) **Mid season stage**:-

From the end of crop development stage to the start of maturing which is indicated by discoloring of leaves or falling of the leaves.

iv) **Late season stage**:-

From end of the mid season stage to the full maturely of harvesting.

4.2 F.A.O. Procedure to calculable crop coefficients crop coefficient during initial stage (Kc)

During initial stage when the crop is in seeding stage and ground cover by the crop is less than 10%, the evaporation from soil surface plays an important part on the value of Kc. Comparatively Kc is small and depends on the moisture in the soil surface and reference evapotranspiration (ETo) mm/day. This consequently depends on the frequency of irrigation or significant rains. Kc values against the different frequencies of irrigation are given in WALMI (1994)

4.2.1 Crop coefficient values during crop development stage.

The Kc values during this stage always varies with time and reaches stable value when it approaches the mid season stage. For any particular period it has to be interpolated from the Kc value of initial stage and mid season stage.

4.2.2 Crop coefficient value during mid season stage.

During this stage transpiration by the crop and the evaporation from the soil both play an equal role on the Kc values. The Kc value is dependant on wind velocity and humidity. Kc values for different crops a for different wind and humidly conditions are given in WALMI(1994) The midseason values is almost constant for the stage.

4.2.3 Crop coefficient value for late season stage or maturely stage

The Kc values decreases from the midseason stage to the end of late season stage. The minimum values are again listed in the table as given in WALMI for various crops for different using and humidly conditions.

A graph is potted with days on x axis and Kc values on Y axis.

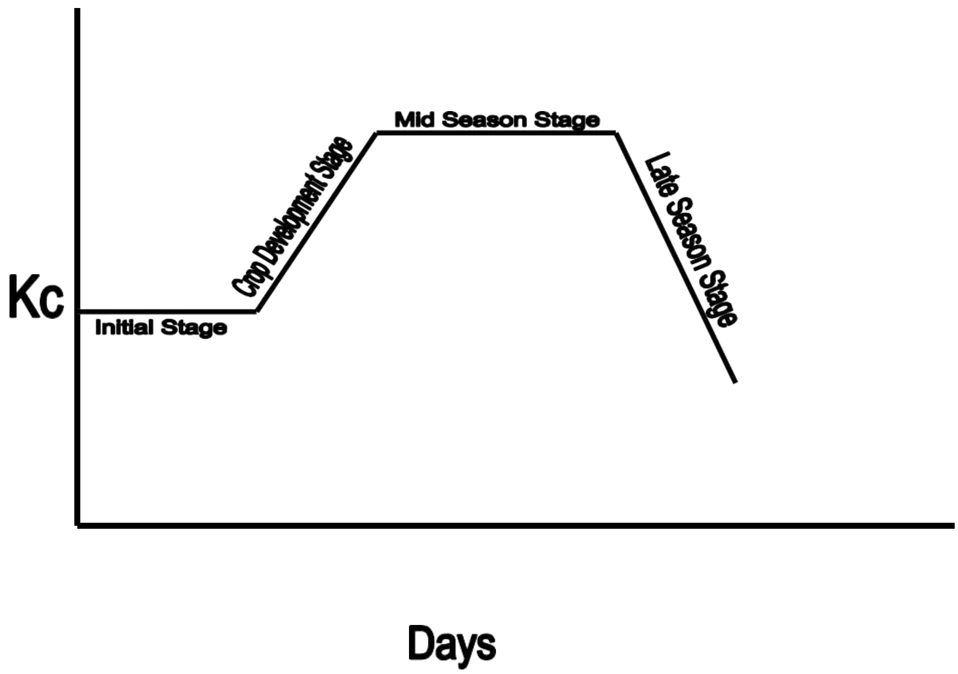


Fig. 4.1 Crop Coefficient suggested by F.A.O.

For the initial period the graph is a straight line parallel to x-anis. The second part of the graph is a straight line joining Kc value at the end of initial stage and Kc value during midseason stage.

This straight line indicates the increasing Kc values during crop development stage. The third part of the graph is again a straight line parallel to x anis. This indicates that Kc values almost constant during this stage.

The fourth section is a straight line from midseason Kc value to the minimum Kc values at harvest indicating decreasing Kc values during late season stage. A smooth curve is drawn to represent the Kc value during whole period.

4.3 Work carried out by various researchers

James right (1982)had suggested improved crop coefficient in which ETo for alfalfa reference crop and other crops was measured with sensitive weighting lysimeter at field site Kimbely, Idaho. This crop coefficient for when combined with improved estimate of daily evaporation from wet soil should permit more accurate estimate of daily ETo. Pedrom Attrod, Masatoshi Aoki (2006) has calculated the crop coefficient by relation of actual evapotranspiration by Bowen Ratio method to reference evapotranspiration in different vegetation area of Thailand. Michael and Bastiaanssen (2000) discussed the estimation of crop evepotransprition from remote sensing data to deduce regional scale crop coefficients. Chuanyan and Nan zhongren (2007) has studied dual crop coefficient method to predict seasonal changes Etc for maize field in Northwest China

4.4 Research carried out:

Empirical relation between days and crop coefficient for different crop of (Nagpur District) is established by using Microsoft excel The relation between crop coefficient and days for are given in table 4.1 The crop coefficients for different crops by F. A. O. procedure as well as empirical relations suggested are calculated and the results are compared as shown in **Annexure 2**

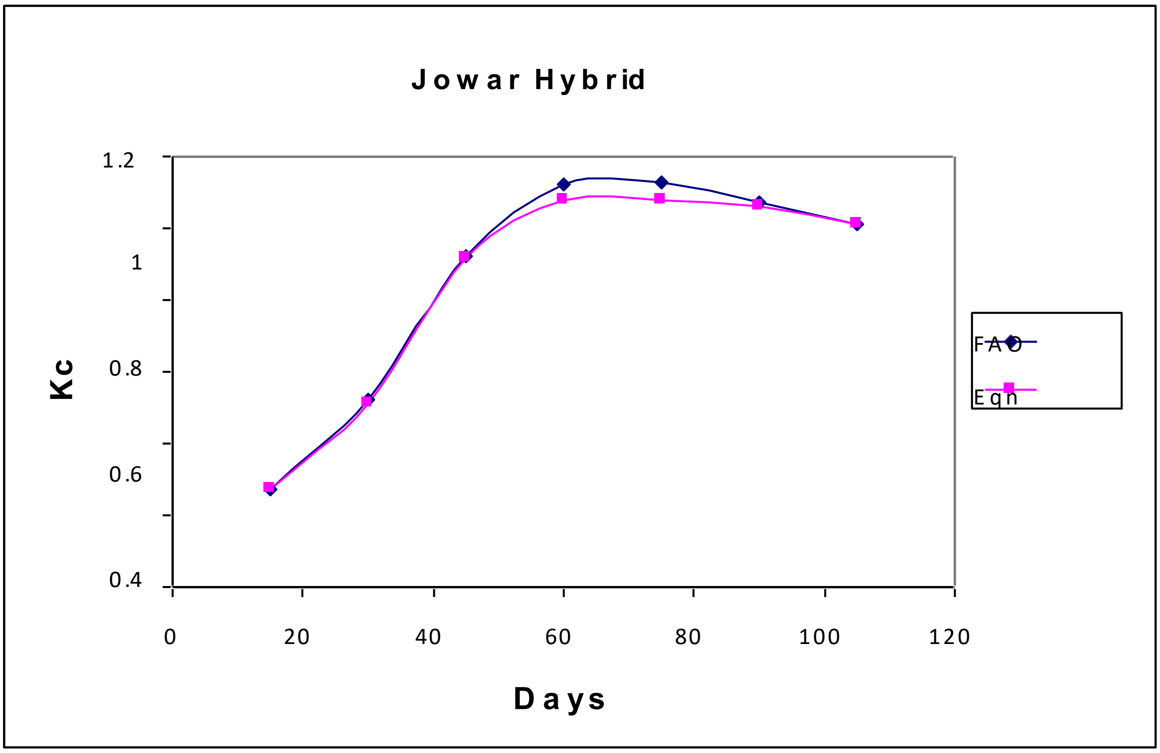
By using the empirical equation suggested, the crop coefficient for different crop are calculated for different district and are shown in

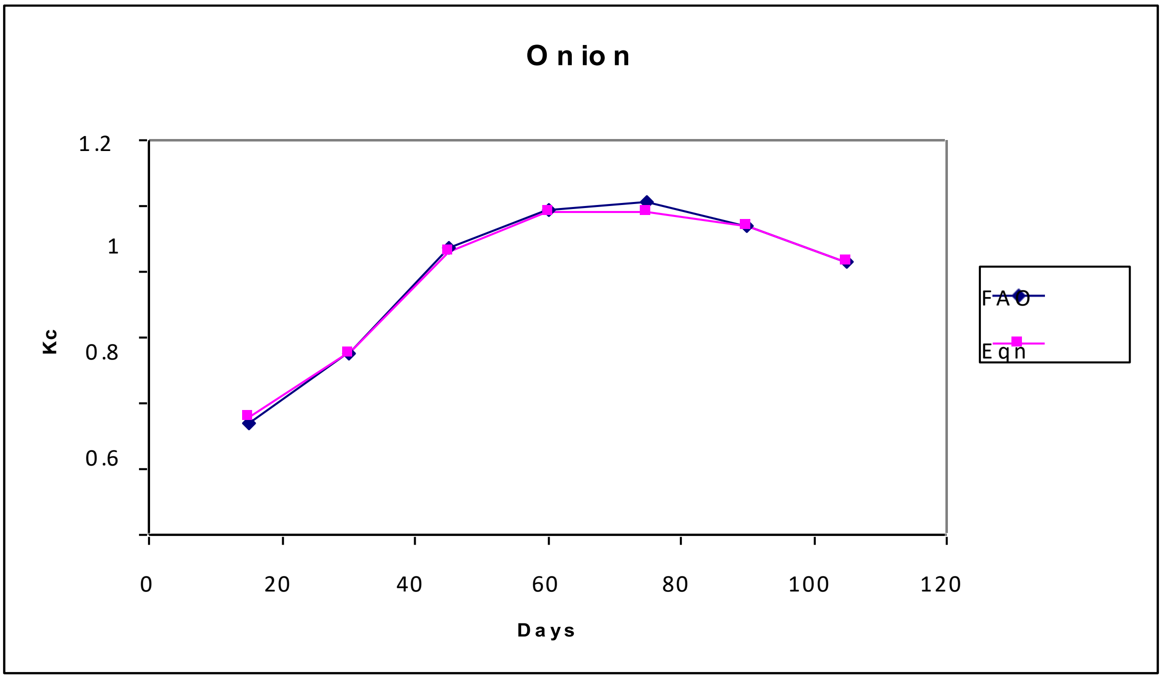
Annexure 4

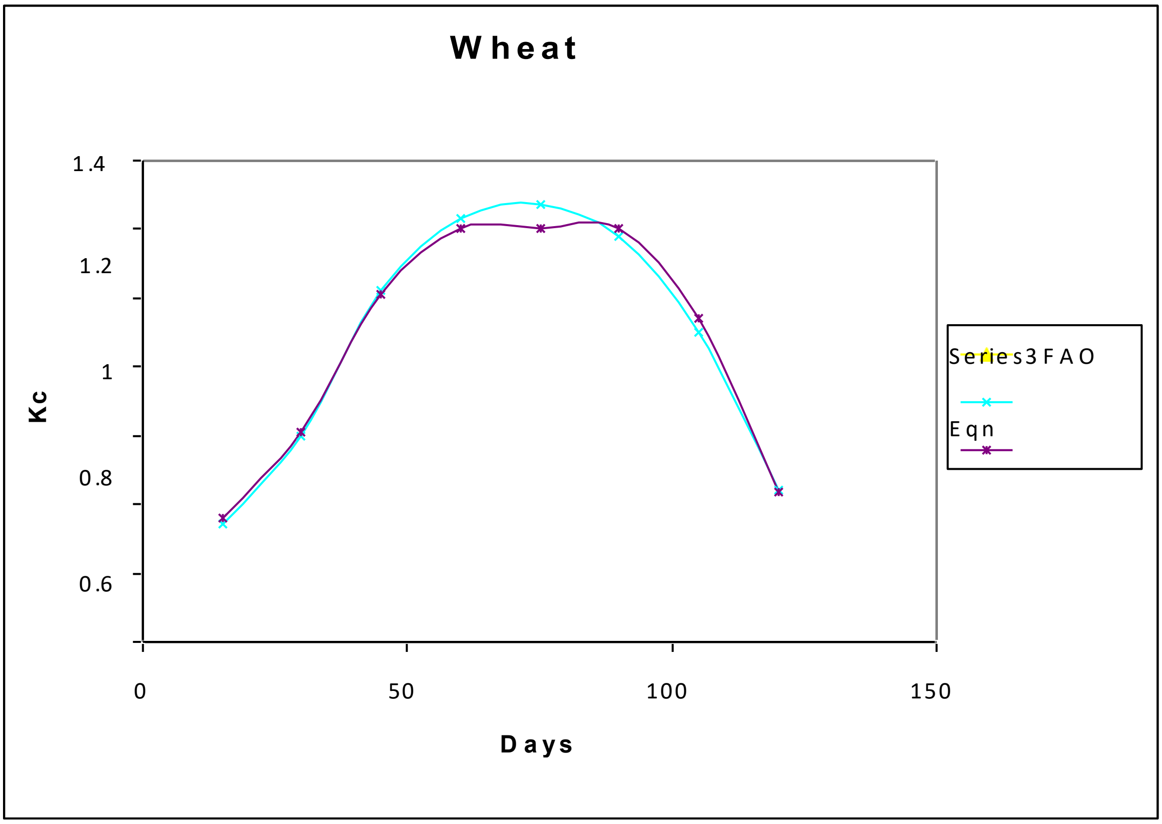
Table-4.1 Stage wise Crop Coefficient Equation for Various Crops

S. N.	CROP	Initial Stage	Range	Crop Development Stage	Range	Mid Season	Range	Late Season Stage	Range
1	Wheat	Kc=0.36	D=0-15	Kc=0.0336D-0.144	D=15-40	Kc=1.2	D=40-90	Kc=-0.034D+4.26	D=90-120
2	Cotton	Kc=0.24	D=0-30	Kc=0.0188D-0.324	D=30-80	Kc=1.18	D=80-140	Kc=-0. 0096D+2.5	D=140-195
3	Jowar Hybrid	Kc=0.27	D=0-15	kc=0.0324D-0.216	D=15-40	Kc=1.08	D=40-80	Kc=-0.004D+1.4	D=80-105
4	Ground nut	Kc=0.27	D=0-20	Kc=0.0237D-0.2033	D=20-50	Kc=0.98	D=50-95	Kc=-0.0164D+2.5	D=95-120
5	Maize	Kc=0.27	D=0--20	Kc=0.0237D-0.2033	D=20-50	Kc=0.98	D=50-90	Kc=-0.0137D+2.2	D=90-120
6	Sunflower	Kc=0.36	D=0--20	Kc=0.0375D-0.39	D=20-40	Kc=1.11	D=40-70	Kc=-0.037D+3.7	D=70-90
7	Potato	Kc=0.36	D=0--20	Kc=0.037D-0.38	D=20-40	Kc=1.1	D=40-70	Kc=-0.0185D+2.3	D=70-90
8	Soya bean	Kc=0.27	D=0-20	Kc=0.019D-0.11	D=20-60	Kc=1.03	D=60-90	Kc=-0.0193D+2.7	D=90-105
9	Bajara	Kc=0.27	D=0--	Kc=0.041D-0.345	D=15-35	Kc=1.09	D=35-	Kc=-0.0284D+2.9	D=65-

			15				65		90
10	Onion	Kc=0.36	D=0--15	Kc=0.0248D-0.012	D=15-40	Kc=0.98	D=40-80	Kc=0.98	D=80-105
11	Pulse	Kc=0.32	D=0--15	Kc=0.0365D-0.2275	D=15-35	Kc=1.05	D=35-60	Kc=-0.0507+4.09	D=60-75
12	Mung	Kc=0.27	D=0--15	Kc=0.0405D-0.3375	D=15-35	Kc=1.08	D=35-60	Kc=-0.0533D+4.2	D=60-75
13	Chili	Kc=0.36	D=0--30	Kc=0.016D-0.12	D=30-70	Kc=1.00	D=70-120	Kc=-0.0057D+1.6	D=120-150
14	Rice	Kc=1.1	D=0--30	Kc=-0.0017D+1.15	D=30-60	Kc=1.05	D=60-120	Kc=-0.0033D+1.4	D=120-150



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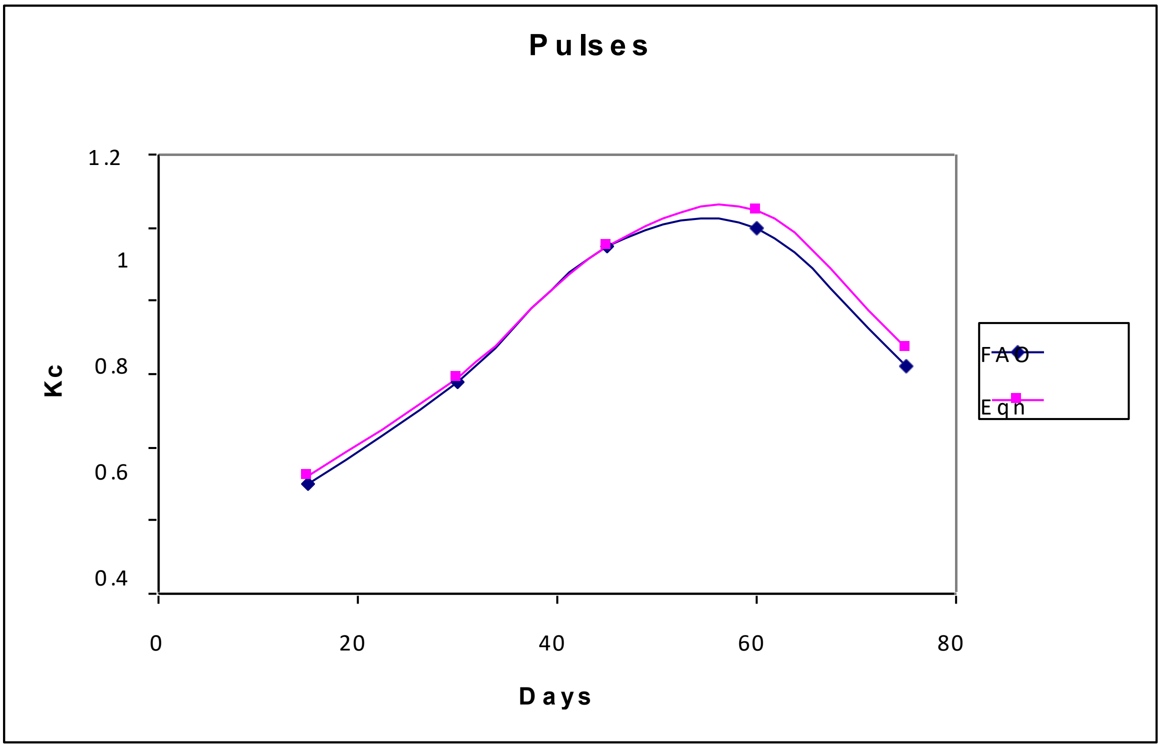
1.2
1
0.8
0.6
Kc
0
50
100
150
Days
Series3 FAO
Eqn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1
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0.6
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Kc
0
20
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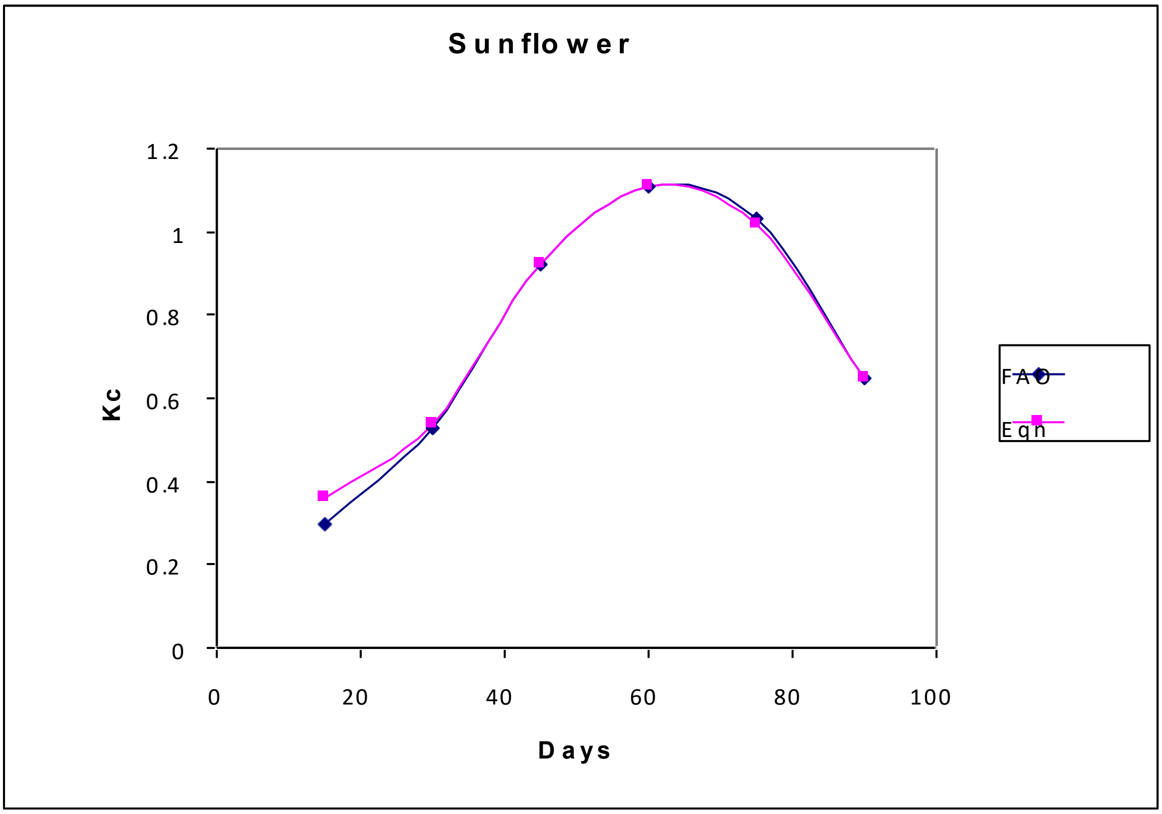
60
80
Days
FAO
Eqn


Sunflower
Kc
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0.2
0
0
20
40
60
80
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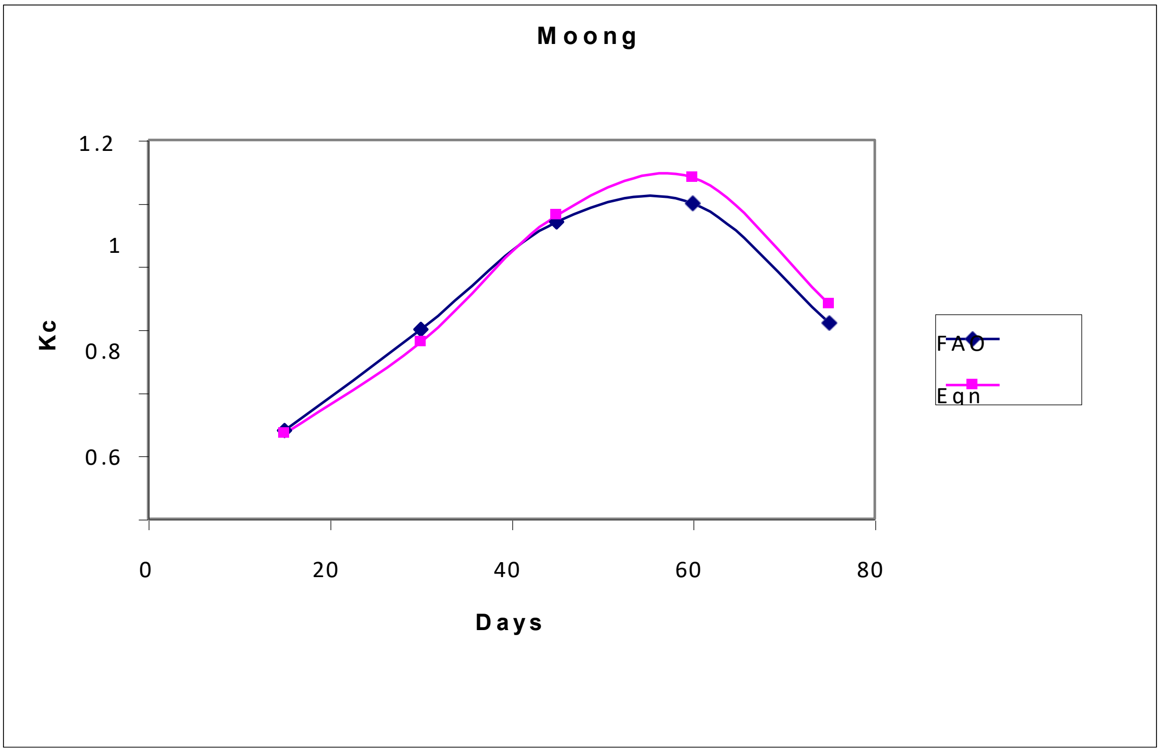
Days
FAO
Eqn


Moong
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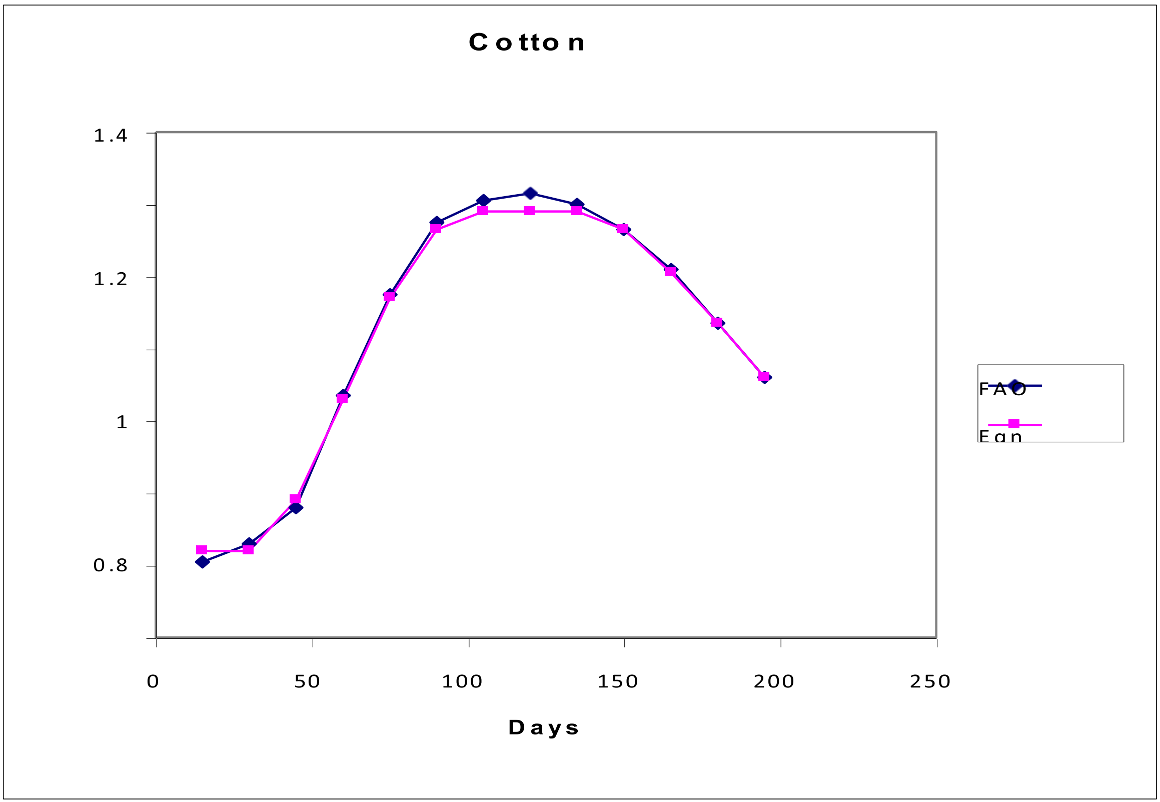


4.5 Discussions and conclusions

The charging climate plays significant effect on evapotranspiration and hence there is a need to estimate continuously updated evapotranspiration.As this study is carried out to find forthrightly Net irrigation requirement. Therefore it is must to calculate crop coefficient also fortnightly. This study recommends to use empirical relation for finding crop coefficients. This inter relationship provides an 'easy to use' method to obtain crop coefficient as well as it saves the time and reduces tedious work of drawing graph suggested by F.A.O This empirical equations can be used on as a tool for other climatically similar regions. From fig 4.1 It depicts the closeness of values and thereby reflects the appropriateness of the method

Chapter 5

Crop Evapotranspiration

5.1 Introduction:-

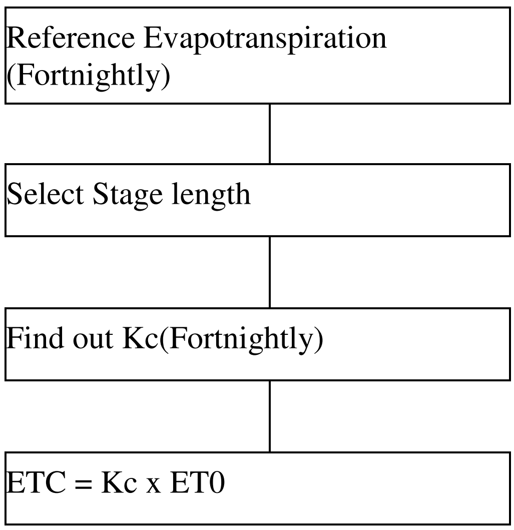
This is the evapotranspiration from disease free, well fertilized crop – grown in large fields under optimum soil water conditions and achieving full production under given climatic condition. The effect of various weather conditions on evapotranspiration are incorporated into reference evapotranspiration (ETo), discussed in chapter 3 . The effect of characteristic that distinguish the cropped surface from reference surface are integrated into crop coefficient, therefore crop evapotranspiration is a product of reference evapotranspiration on and crop coefficient. This crop coefficient approach in determination of crop evapotranspiration is useful in irrigation planning, design, and management. The evapotranspiration of any crop is related to the ETo by

$$Etc = Kc \times ETo \qquad (5.1)$$

This chapter contains the determination of fortnightly crop evapotranspiration of different crops and total consumptive use of crop of their growing period

5.2 Flow chart

The figure represents procedure for calculation crop evapotranspiration.



5.3 Work done

As stated in flow chart (5.2), the fortnightly crop evapotranspiration is calculated for different crop for all the districts of Nagpur regions.. Similarly the total crop evapotranspiration during their growth period are determined and are shown in **Table 5.1**

Table 5.1 Distictwise crop evapotranspiration of Nagpur region

S. No	Name of crop	Nagpur	Wardha	Chandrapur	Bhandara	Gondia	Gadchiroli
1	Jowar hybrid	395.17	358.21	338.74	377.17	377.17	338.74
2	Wheat	394.17	421.3	394.19	475.23	475.23	394.19
3	Sunflower	249.26	287.65	273.16	326.8	326.8	273.16
4	Cotton	713.15	686.58	657.82	745.15	745.15	657.82
5	Potato	266.90	303.25	279.34	335.97	335.97	279.34
6	Soyabean	321.89	347.68	329.93	367.82	367.82	329.93
7	Bajara	292.9	304.4	299.45	316.06	316.06	298.81
8	Onoin	336.75	356.69	347.17	404.60	404.6	347.17
9	Pulses	223.73	228.98	226.45	239.74	239.74	226.45
10	Moong	223.22	229.08	220.34	238.6	238.6	22034
11	Ground nut	428.71	432.43	418.28	462.76	462.76	418.28
12	Maize	421.83	430.23	424.04	462.67	773.52	424.04
13	Rice	685.92	716.65	686.21	773.52	773.52	686.21
14	Chilli	720.08	851.48	772.73	889.10	889.10	772.73
15	sugercane	1809.02	1978.29	1795.49	2125.15	2125.15	1795.49

Conclusions:

It is observed from **Table 5.1** the total consumptive use of water varies from crop to crop. It is higher in case of sugercane and lower in case pulses and moong. This is the actual requirement of crop if there will be no rainfall. In such a case **Table 5.1** will provide information about the crop water requirement.

Chapter – 6

Average Rainfall

6.1 Introduction

In order to compute the average rainfall over a basin or catchment area, the rainfall is measured at a number of rain gauge stations suitably located in the area. The network density of rainguage depends upon the user for which the rainfall data is intended. A network should be so planned as to have representative picture of the aerial distribution of rainfall. There should be no concentration of gauges in heavy rainfall areas at the expense of dry areas or vice versa

If the basin or catchments are contains more than one gauge station, the computation of average rainfall may be done by the following methods.

1. Arithmetic average method.
2. Thiessen Poygon method.
3. isohytel method.

In this chapter the average rainfall was calculated for all districts separately by using Thiessen polygon method. To do it, the rainfall data was collected from HDUG, Nashik The total rainfall station is 56 in Nagpur region.

6.2 Thiessen Polygon method

The arithmetic average method is most approximate method is varies in intensely and duration from place to place. Hence rainfall recorded by each rainguage station should be weighed according to the area it is assumed to represent. Thiessen polygon method is a more common method of weighing the rain gauge observations according to the area. Thiesson polygon method is also called weighted mean method and is more accurate than the arithmetic average method.

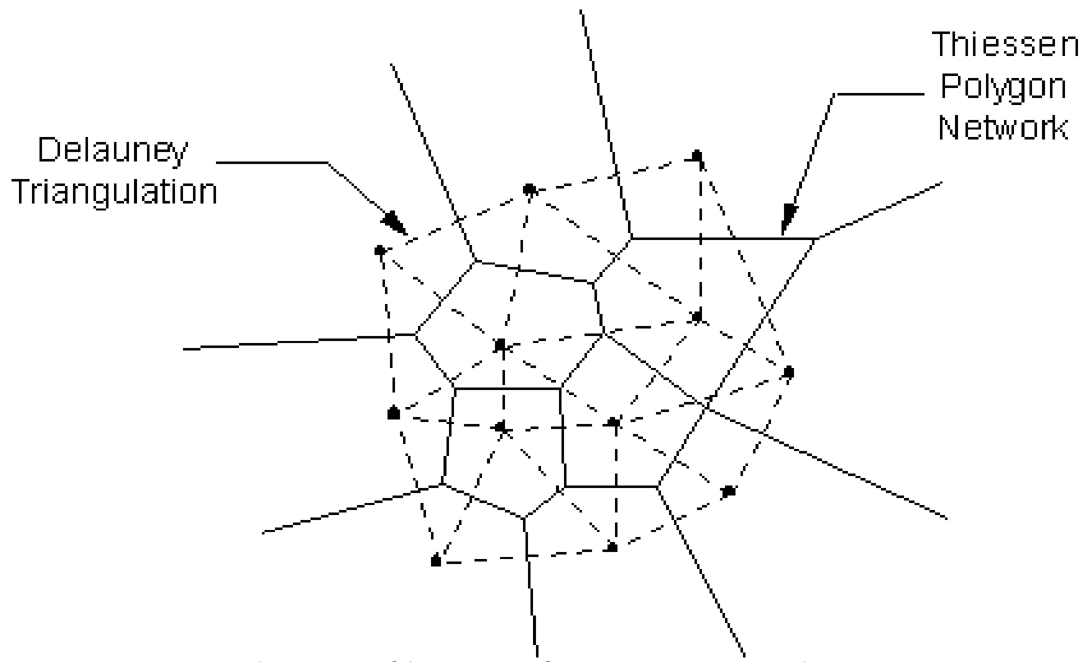


Fig 6.1 Thiessen polygon (www.ems-i.com)

Procedure

1. Join the adjacent rain gauge station
2. Construct the perpendicular bisectors of each of these lines.
3. A Thiesson network is than constructed. The polygon formed by the perpendicular bisectors around a station encloses an area which is everywhere closer to the station than to any other station. Find the area of these polygons by using the plainimeter
4. Multiply the area of each thiesson polygon by the rain gauge value of enclosed station.
5. Find the total area $(\sum A)$ of the basin
6. Compute the average rainfall from the equation as given below.

$$P_{av} = \frac{A_1 P_1 + A_2 P_2 + \dots + A_n P_n}{A_1 + A_2 + \dots + A_n} \qquad (6.1)$$

Where A, A2--- An are the area of each Thiessen polygon

P1, P2 ---- Pn are rain gauge values of enclosed station

6.3 Work carried out:

As Nagpur Zone is a plain terrain. ThereforeTheissen polygon method is used to find out average rainfall. The procedure is followed as given in 3.2.2 and average rainfall is found out for each district of Nagpur zone The aim of this study is to find out fortnightly crop water requirement therefore, it became necessary to find out fortnightly average depth of rainfall.

Chapter -7

Study of Effective Rainfall

7.1 Introduction:

The primary source of water for habitation is rain. The effective rainfall is that portion of the total rainfall which is useful in raising crops planted on soil. There are various methods to find out the effective rainfall. But U.S.D.A. method is widely used as this method takes into accounts the climatologically factors, moisture holding capacity of the soils, irrigation application Depth. Due to its acceptance for estimation of effective rainfall, U.S.D.A. method is also used in India. U.S.D.A. has given the relation between the fortnightly average rainfall and fortnightly consumptive use of crop and effective rainfall.

There are several factors which affect the effective rainfall like, rainfall charlatanistic, Land charlatanistic, soil charlatanistic, crop charlatanistic, climate.

The present study is carried out to develop mathematical equations to arrive at effective rainfall.

7.2 Work carried out by different researcher:

Patwardhan, Neiber and Johns (1990) has used soil water balance model for estimating effective rainfall to test the accuracy of United State Department of Agriculture and Hershield effective rainfall estimation method for well drained as well as poorly drained soil.

S. Mohan, Simhadrirao and Armugam (1990) have compared USDA (SCS) method with water balance method. The effective rainfall are closer to water balance method while USDA under predicts values of effective rainfall.

Plecsis (2004) has presented simple method of modeling effective rainfall in Etosha National Park (Etosho). Results showed that 36 to 57.6% rainfall is effective rainfall.

7.3 U.S. Department agriculture method

The U.S. Department agriculture sore conservation services has developed the relation between effective rainfall, fortnightly average rainfall and fortnightly consumptive use of the crop, and are presented in the form of table given WALMI(1994).The relation developed are the result of comprehensive analysis of rainfall records at 22 in different climates and soil zones for 50 years.

7.4 Work Done

a) This research is carried out for the development of an empirical equation for the determination of effective rainfall. The equation is developed by regression analysis wherein multiple regression analysis is carried out by omitting one of the independent variable each time. Various alternatives like cubical, linear have been attempted but quadratic equation was found to be best suited in which R^2 is equal to 0.95. MATLAB programme is used to develop empirical equation for effective rainfall which is as

$$Re = ARm^2 + BRm + C \qquad (7.1)$$

Where A, B, C are the constants expressed in terms of mean fortnightly crop evapotranspiration as shown in **Table 7.1**

To generate this equations, data was taken of Wardha district of Latitude $20^0\,40^1$ and Longitude $70^0 53^1$

b) With the equation so developed, the effective rainfall for all crops of all districts of Nagpur region is calculated and presented in the Annexure- .

Table 7.1: Equations for constants in terms of crop evapotranspiration

Eto (Range)	Constant	Conditions
12.5 25	A=0.0008094*Eto-0.02484 B=-0.01233Eto+1.115 C=0.1009Eto-3.636	For Eto=12.5,uptoRm=25 then Re=12.5 For Eto=25,Rm=43.75,thenRe=25
25 37.5	A=0.000175Eto-0.008976 B=-0.004256Eto+0.9131 C=0.1002Eto-3.619	ForEto=25,Rm=43.75,thenRe=25 For Eto=37.5,Rm=62.5,thenRe=37.5
37.5 50	A=2.808*POWER(10,-5)Eto-0.003468 B=0.002664*Eto+0.6536 C=-0.03937Eto+1.633	For Eto=37.5,Rm=62.5,thenRe=37.5 For Eto=50,Rm=81.25,thenRe=50
50 62.5	A=5.6*POWER(10,-6)Eto-0.002344 B=0.00432Eto+.5708 C=-0.05005Eto+2.142	ForEto=50,Rm=81.25,thenRe=50 For Eto=62.5,Rm=100,thenRe=62.5
62.5 75	A=-2.16*POWER(10,-6)Eto-0.001859 B=0.002192Eto+0.7038 C=0.01308Eto-1.803	For Eto=62.5,Rm=100,thenRe=62.5 For Eto=75Rm=125,thenRe=75
75 87.5	A=1.312*POWER(10,-5)Eto-0.003005 B=0.001112Eto+0.7848 C=0.03485Eto-3.436	For Eto=75Rm=125,thenRe=75 For Eto=87.5,Rm=137.5,thenRe=87.5
87.5 100	A=-3.072*POWER(10,-5)Eto+0.000831 B=.007408Eto+0.2339 C=-0.05187Eto+4.152	For Eto=87.5,Rm=137.5,thenRe=87.5 ForEto=100,Rm=175thenRe=100
100 112.5	A=7.04*POWER(10,-6)Eto-0.002945 B=0.002504Eto+0.7243 C=0.05057Eto-6.092	ForEto=100,Rm=175thenRe=100 For Eto=112.5,Rm=187.5,thenRe=112.5
112.5 125	A=-8.48*POWER(10,-6)Eto-0.001199 B=0.00456Eto+0.493	For Eto=112.5,Rm=187.5,thenRe=112.5 ForEto=125,Rm=225,thenRe=125
	C=0.03644Eto-4.503	

7.4.2 Conclusions

To calculate the effective rainfall suggested by USDA, require four time interpolation. This may lead to an error and also consumes time in the problems involving number of calculation for effective rainfall.

This empirical equation developed, gives accurate value of effective rainfall which is directly transferred on crop water requirement. This is very important for irrigation planning, scheduling and water management.

The equations for constants A, B, C shown in Table-7.1 are different for different range of evapotranspiration and mean fortnightly rainfall. The percentage average error in finding the effective rainfall by equations suggested is within 4%.

Chapter-8

Net Irrigation Requirement

8.1 Introduction:-

A The irrigation requirement (IRR) for crop production is the amount of water in addition to rainfall that must be applied to meet a crop's evapotranspiration needs without significant reduction in yield. Evapotranspiration (ETc) includes water that is needed for both evaporation and transpiration. Evaporation is the change of water from liquid to vapor form. Evaporation occurs from all moist or wet surfaces, including soil, water, plant, and other surfaces. Transpiration is evaporation from plant leaves through small openings in the leaves called stomata. Both evaporation and transpiration occur in response to climate demand. ETc is greatest on hot, dry days and lowest on cool, humid days. ETc must occur to avoid plant water stress. Plant water stress will occur if ETc is limited because water is not available to plants. Water stress will occur quickest on high climate demand days. Water stress is avoided by rainfall or by irrigating to provide a crop with the water needed for evaporation and transpiration.

To avoid water crop water stress, rainfall and surface irrigation application must be sufficient to meet the crop's ETc requirement. This means that for any period of time during the crop growing season, the net irrigation requirement (NIR) is the amount of water which is not effectively provided by rainfall:

$$NIR = ETc - \mathrm{Re} \quad (8.1)$$

Where

NIR = net irrigation requirement,

ETc = evapotranspiration, or consumptive use of crop

Re = effective rainfall.

NIR is irrigation water which is delivered to the field and available for the crop to use. This is primarily water which is stored in soil in the crop root zone, although some of the water which is evaporated from water, soil, and plant surfaces during application also effectively reduces climate demand.

To find the crop water requirement, it as must to know evapotranspiration of crop. Various field methods have been used for direct measurement of evapotranspiration as discussed in Chapter 3.

Estimation of an optimal crop water requirement is an integral aspect of design and management of an irrigation system. The output is maximum when crop water applied optimally and any deficiet or in excess amount usually reduces the output.

This chapter contains the determination of net irrigation requirement at field level and development of graphical representation of NIR in form isolines for crop water requirement. It also contain the a case study of Shirud tank near Hinganghat of Wardha district to evaluate the performance of isolines for crop water requirement

8.2 Work carried out by various researchers

Michele Bernardie (2003) has emphasized on data standardization, collection, analysis and data tools are developed taking into account technical specification of decision support system for irrigation planning and management. Richard G. Allen and Ronal Elliot (2003) have compared reference evapotranspiration calculation as a part of ASCE standardization effort and recommended that the standardization efforts will continue to evolve with time as new information and procedure become available. Dr Wayne Meyer and Alan (2002) to develop National standards as there is a lack of consistency in methodologies to calculate crop evapotranspiation. Peter Mulamba, Larry C Brown (2002) have practised on assessment of micro-irrigation scheduling of cabbage using tensometers indicates that there is an optimal critical point at which optimal yields are achievable. Baisware and Badar (2006) has studied crop water requirement by the use of HYMOS software stated that the crop water supplied in excess could have been utilized for irrigating more land, supplying water to drought prone area.

8.3 Work carried out

A) Since rain water and ground water is very difficult to control, it is only irrigation water the quantity of which can be varied. The requirement of water is first satisfied by rain ground water and only the balance quantity is supplied as irrigation water.

Panigrahi B. & Sharma S. D. (1992) has suggested irrigation water requirement model of some major crops. Allen A.G. and Smith M. in (1998) has proposed the guidelines for computing crop water requirements and giving the updated procedure for calculating reference & crop evapotranspiration. It was stated that FAO Penman method overestimates ETo. While other F.A.O equations, namely Blaney Criddle, radiation method showed variable adherence.

The present study deals with the calculation of the net irrigation requirement for different crops for Nagpur, Wardha, Bhandara, Gondia, Chandrapur, and Gadchiroli

The steps for determination of net irrigation are as follows

1) Fortnightly reference evapotranspiration are calculated for all district and are shown in annexure1
2) Fortnightly crop coefficient are calculated for all district and are shown in annexure4
3) Fortnightly average rainfall are calculated for all district and are shown in annexure 3
4) Fortnightly crop evapotranspiration are calculated for all district and are shown in annexure 4
5) Fortnightly effective rainfall are calculated for all district and are shown in annexure 4
6) Fortnightly net irrigation requirement are calculated for all district and are shown in annexure4

8.4 Research carried out

8.4.1 Concept Development

To plan a new irrigation project at any place, it is necessary to give more attention towards the crop water requirement in the concerned region. To determine the crop water requirement we need climatological data as rainfall, maximum and minimum temperature, relative humidity, wind speed etc. These data is required to collect from nearby meteorological stations i.e may be 150 to 200 kms away from the irrigation project. As the location of the project command in most of the irrigation project are normally distant from the climatological station. Therefore the crop water requirement calculated will not give any realistic value Thus if the two meteorogical stations around the command are considered and crop water requirements evaluated individually, as command lies in between then the intermediate value gives the true representation.

To achieve this, it is decided to establish the pattern of crop water requirement lines in between the stations within Nagpur region. These lines will help to find more precise and realistic crop water requirement. thus if such graphical map will be available, then it can be use as ready recknoer It is an first attempt to develop such iso requirement lines for different crop of Nagpur region.
The Graphical representation for crop water requirement is represented in terms of iso requirement curve is a new concept. This study is carried out for standardization of crop water requirement by modified penman method i.e. by evapotranspiration. There are various methods to find out the crop water requirement. This is first attempt in which method is standardized. Presently, in India, the crop water requirement is evaluated by various methods but as far as in Irrigation department is concerned in study area, they have been using modified Penman method for calculation of evapotranspiration.

This research deals with the development of isolines for crop water requirement for the crops mentioned in chapter 1. The isolines curves are given in the annexture6 If such a isolines are available for rabi and kharif crop then the irrigation department along with the agriculture department may guide the farmer about the sowing of crops as per their water requirement.

8.4.2. Method:

To introduce a new concept of development of iso requirement curve, it is must to undergo the steps as in 8.3 to calculate the crop water requirement First of all the centroid of each district is located as and then located the boundary points of Nagpur region K1, K2, K3, K4, K5, K6, K7, K8 by using method of extrapolation and shown in **Table 8.1**. Using the equations, the crop water requirement for these located stations was determined and assigned to respective stations, shown in annexure-5. By using software named, Soft desk, and AutoCAD 2004 and Microsoft Excel, iso requirement lines (fortnightly) for different c**rops mentioned are established ie for ex Wheat as shown** which will gives direct value of crop water requirement at any location in the region.

TABLE 8.1 Equation of extrapolated station

$K1 = D + \left\{ (D-G) \times \frac{13.6195}{19.2898} \right\}$
$K2 = D + \left\{ (D-C) \times \frac{8.635}{11.2096} \right\}$
$K3 = G + \left\{ (G-B) \times \frac{4.3342}{5.7881} \right\}$
$K4 = G + \left\{ (G-B) \times \frac{5.7839}{12.2898} \right\}$
$K5 = N + \left\{ (N-C) \times \frac{5.7782}{14.2971} \right\}$
$K6 = W + \left\{ (W-C) \times \frac{6.3620}{13.7442} \right\}$
$K7 = W + \left\{ (W-N) \times \frac{4.4448}{9.0782} \right\}$
$K8 = C + \left\{ (C-B) \times \frac{8.0548}{13.4097} \right\}$

8.5 Conclusions:

This attempt to introduce a new concept which will give directly realistic value of crop water requirement. They will become a basis for planning, design and water management of irrigation system. In present practice to find out crop water requirement by modified penman method, the data collection as well as calculation of crop water requirement is a tedious work which requires manpower as well consumes time. This new concept will help in overcoming the conventional approach. Irrigation department may use this as ready reckoner. This concept is developed based on 15 years past data for the present requirement considering that there is little changes in the metrological factors may affect very little on crop water requirement. This will give crop water requirement at required latitude and longitude also it will give an idea about the type of crop to be sown. This is also useful for well irrigation where farmer will supply the required amount of water which may also reduce the wastage of water.

A Case Study of Shirud Water Tank

Introduction:-

To evaluate the performance of the concept of iso lines for crop water requirement for Nagpur region, case study project is undertaken. This shirud water tank is near Hinganghat of Wardha district in Nagpur region of Maharashtra in India. The shinrud tank is approximately 20 Km from Wardha meteorological center and rainguge station is at Hinganghat. The main purpose of this case study is to compare the crop water requirement by conventional method used by Irrigation department and by isoline method as described in Annexure 6. In this study fortnightly crop water requirement is calculated by both method and compared the values of different crop.

Study Area Map:

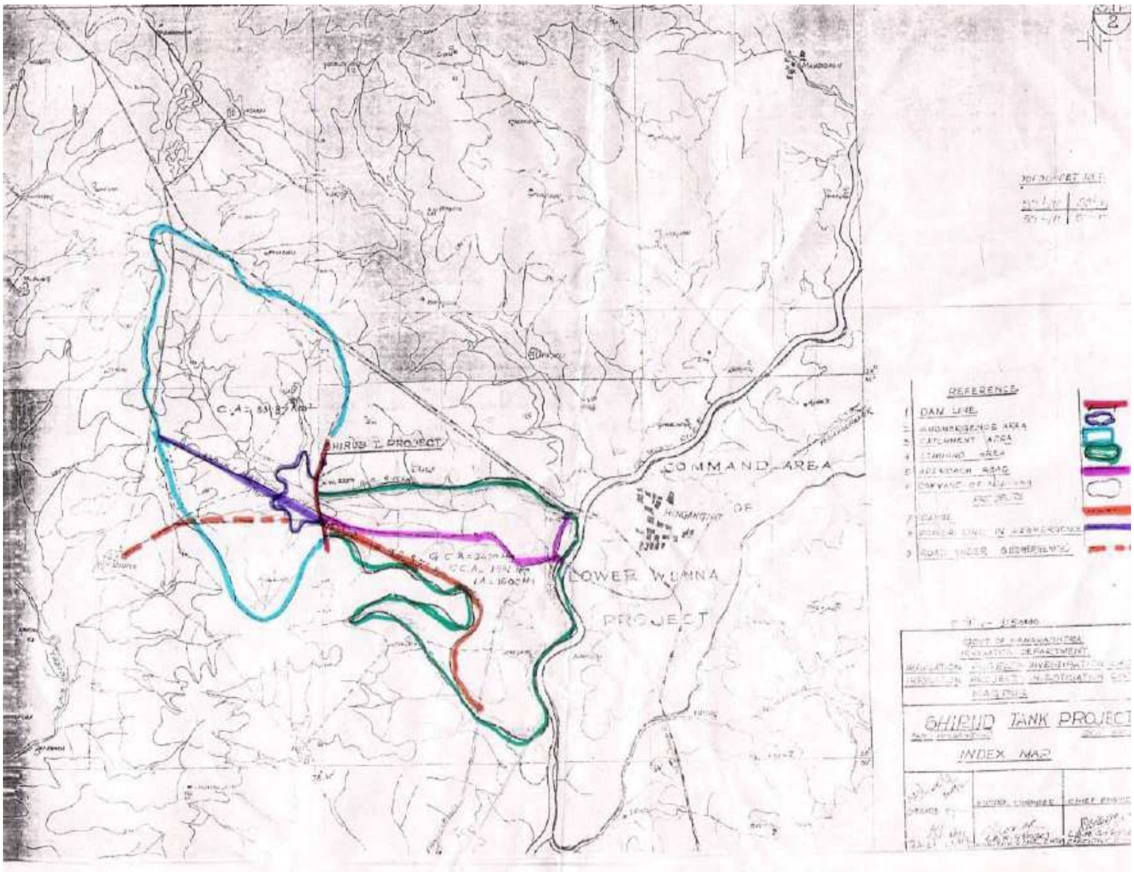


Fig 8.1 Shirud tank

Comparison of crop water requirement.

1) Name of crop:- wheat

Crop period – 1 Nov - 28 Feb.

Sr. No.	Nov		Dec.		Jan		Feb	
	I	II	I	II	I	II	I	II
Conventional Method	94.13	34.76	59.86	56.97	69.22.	75.04	55.16	33.45
iso Line	92.00	34.00	49.00	36.00	71	56.00	59	30.00

2) Name of crop: - Jowar Hybrid

Crop period – June II – Sept. II

sr. No	June	July		Aug.		Sept	
	II	I	II	I	II	I	II
Conventional Method	--	--	--	--	--	12.42	15.40
iso- Line	--	--	--	--	--	14.00	16.00

3) Name of crop:- Cotton

Crop period – 1 June – 15 Dec.

s. no.	June		July		Aug.		Sept		Oct.	
	I	II	I	II	I	II	I	II	I	II
Conventional Method	--	--	--	--	--	--	7.86	44.65	49.52	76.11
iso- Line	--	--	--	--	--	--	12	31	62	76

Discussion

. There is no crop water requirement in June, July, and August as effective rainfall is more than the consumptive use of water but for rest of period water is required for growth. It is observed that crop water requirements calculated by both the methods are approximately same which suggest the use of isoline concept for crop water requirement

Chapter -9

Scope for Further Research

9.1 Introduction:

Estimating Crop water requirement is one of the basic needs for Crop planning on a farm and for planning of any irrigation project in designating the water is by crops evaporation and transpiration are combined into one terms evapotranspiration as it is difficult to separate these two terms in crop fields. The present study of determination of crop water requirement by the use of isoline based upon the climatological parameters only but there are other factors which need to be studied for the accurate estimation of crop water requirement.

1. Agro climatic zoning should be reviewed based on soil covers in the area.
2. After every fifteen or twenty years all the climatological parameters should be reviewed in view of averages considered and accordingly isoline for crop water requirement should be revised.
3. This crop water requirement are calculated by the normal application of ground water to crop but still there is a horizontal flow by which neighbour crop will be benefited. A suitable reduction factor for the crop water requirement can be established.
4. To establish the relationship by drawing isotherms, isohyets, isobars and iso crop water requirement.

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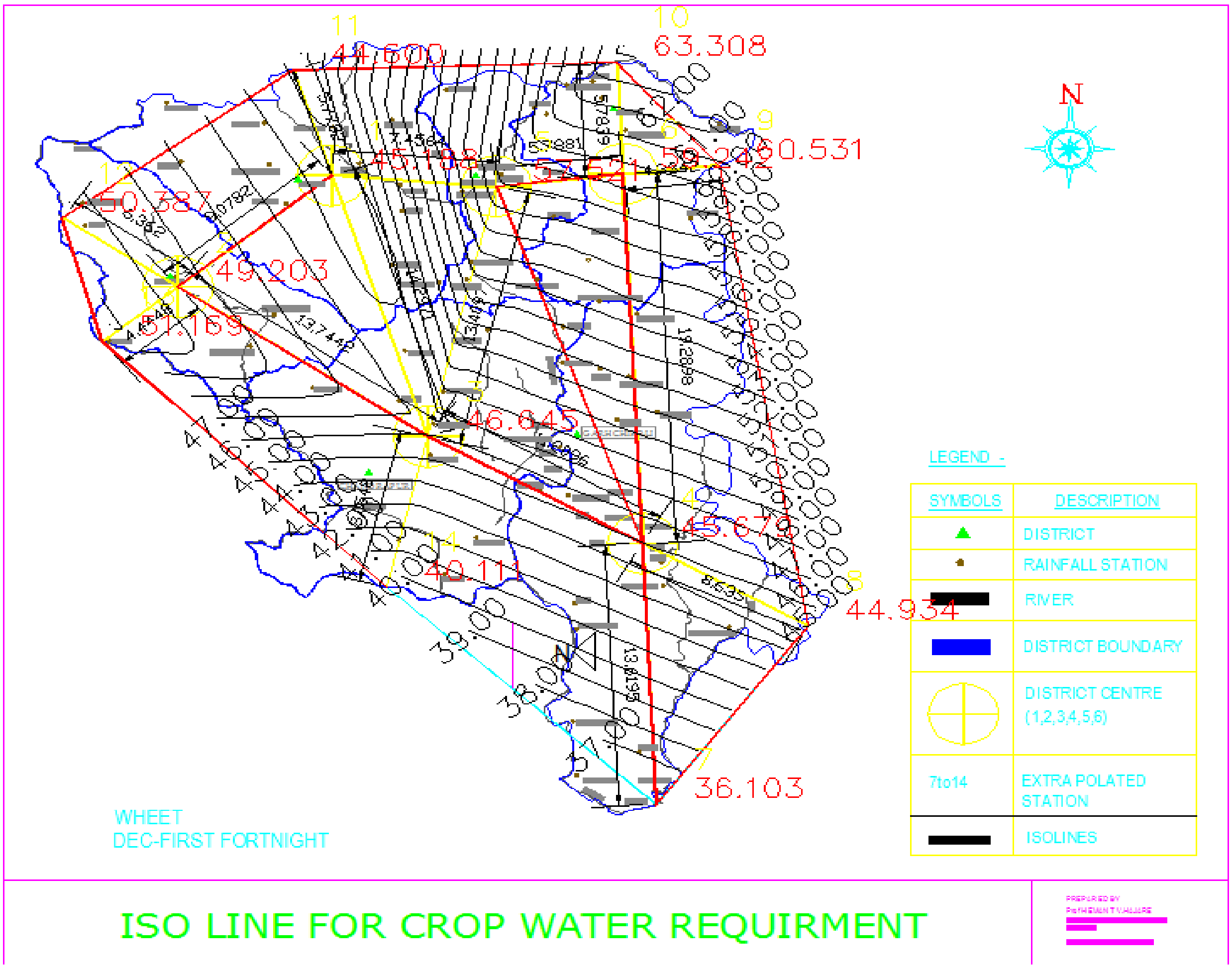
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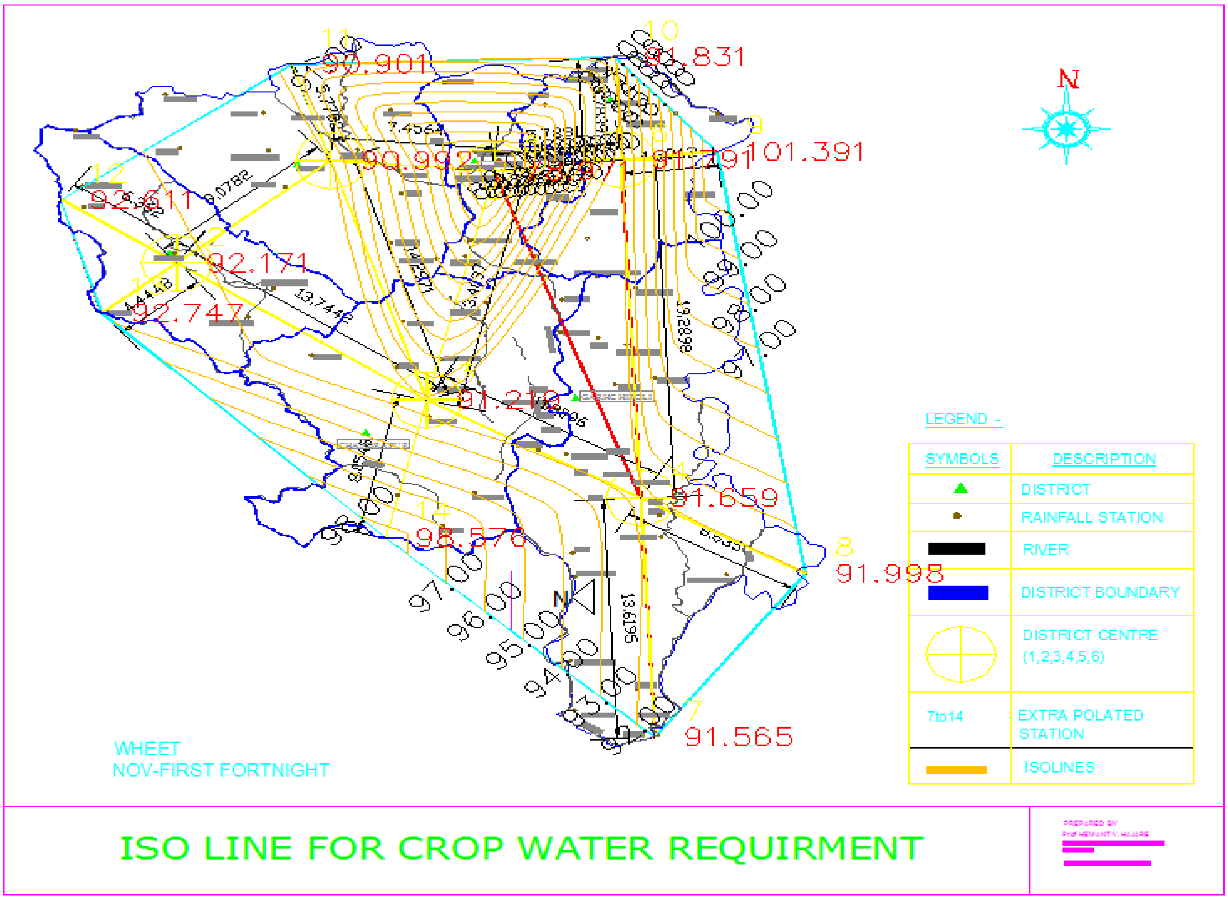
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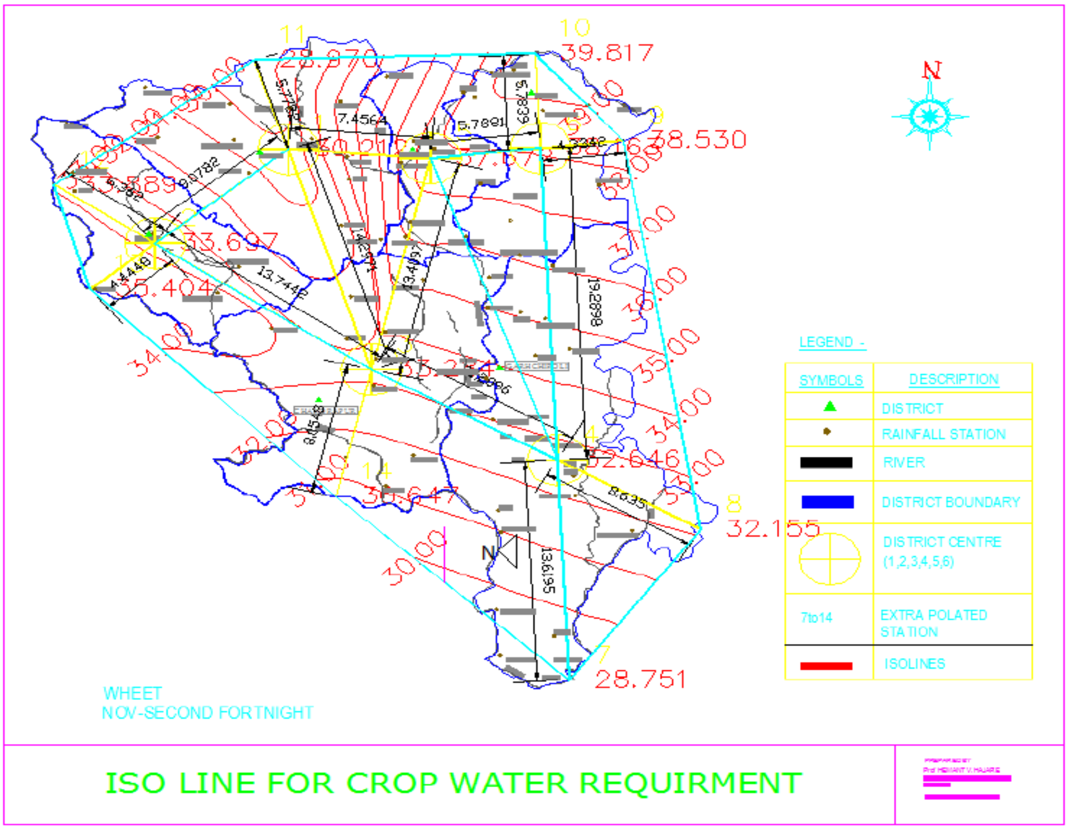
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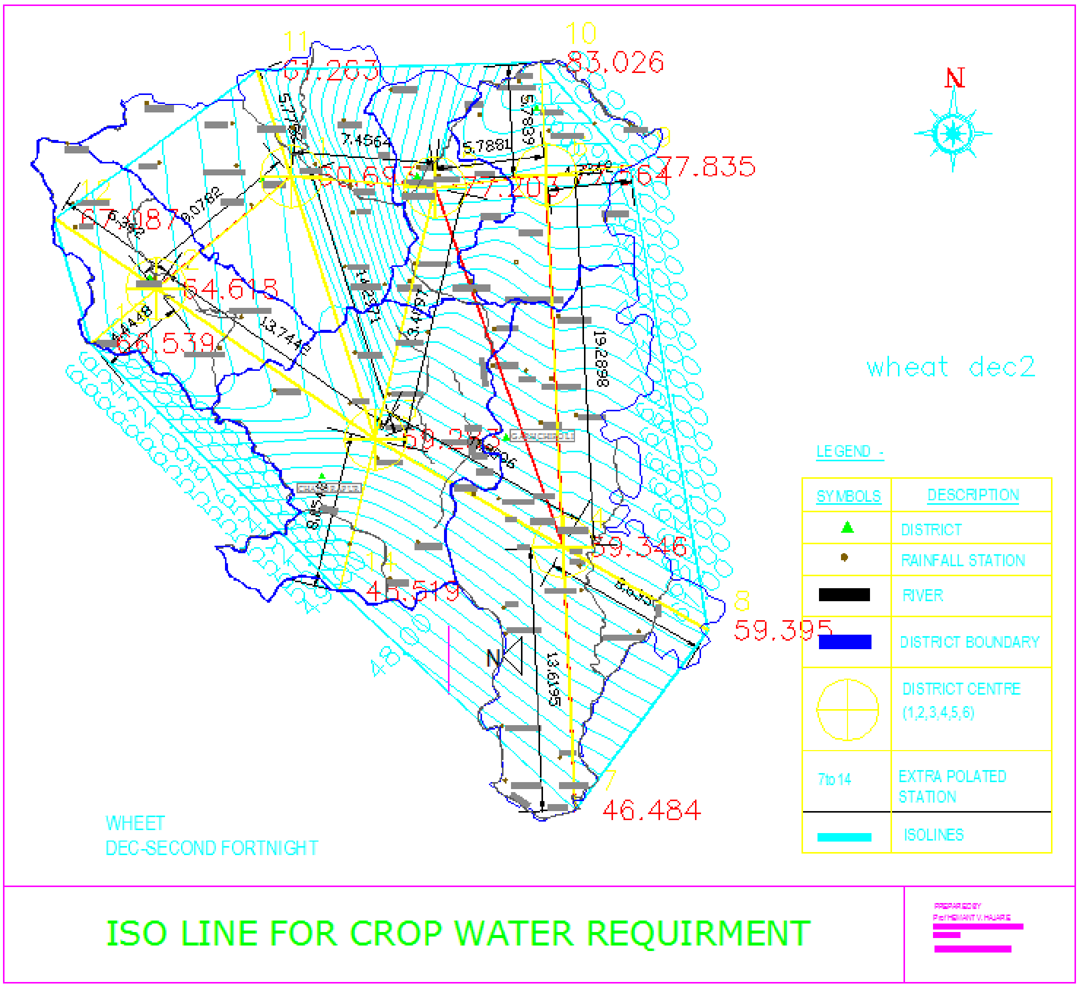
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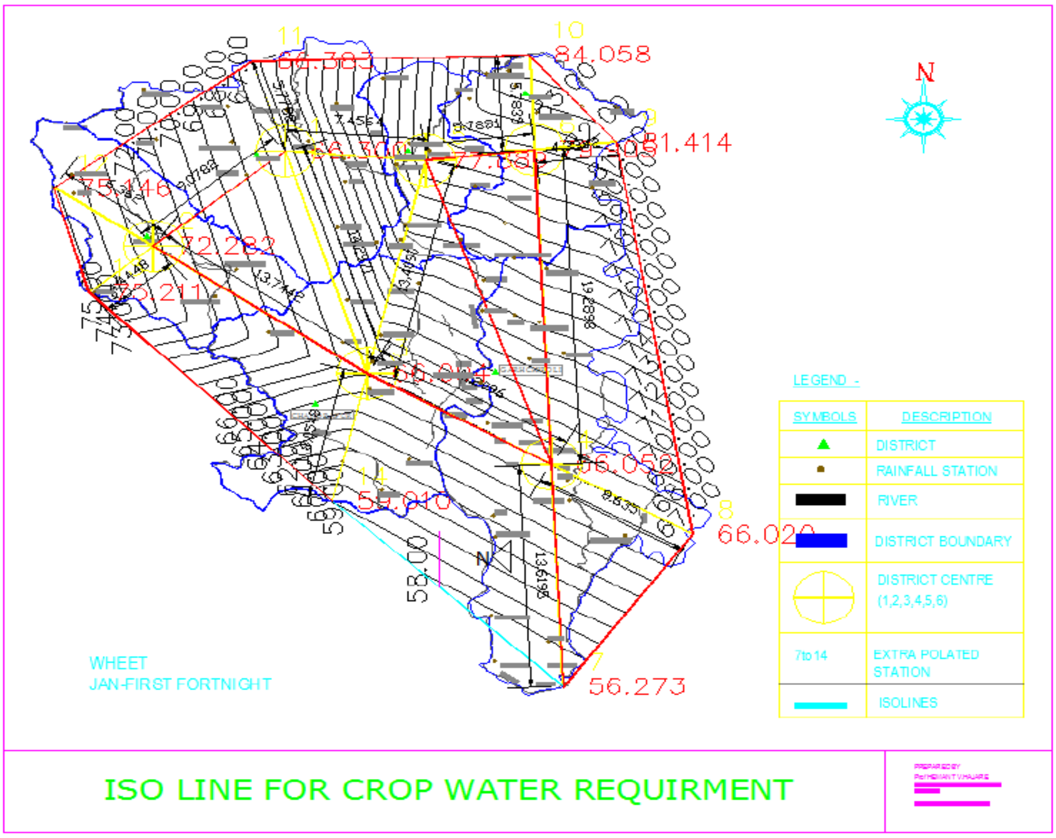
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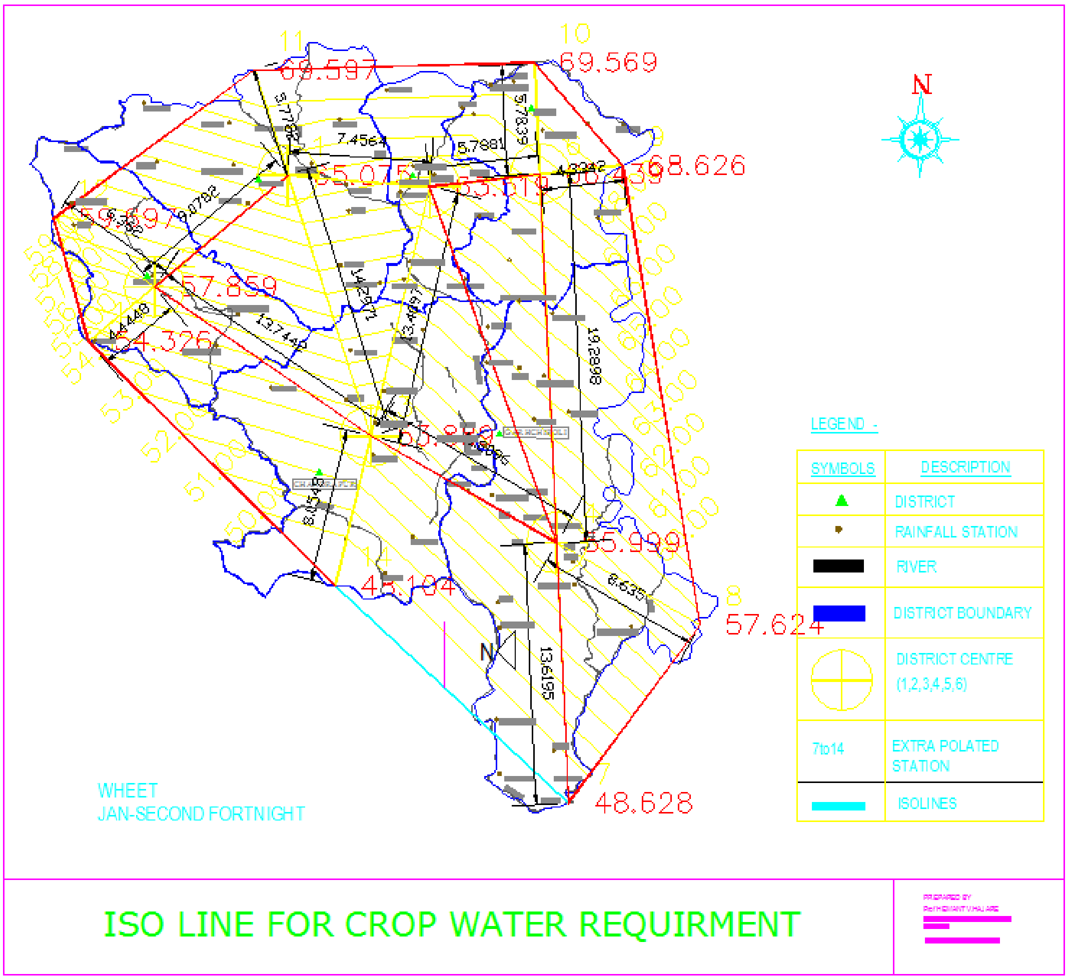
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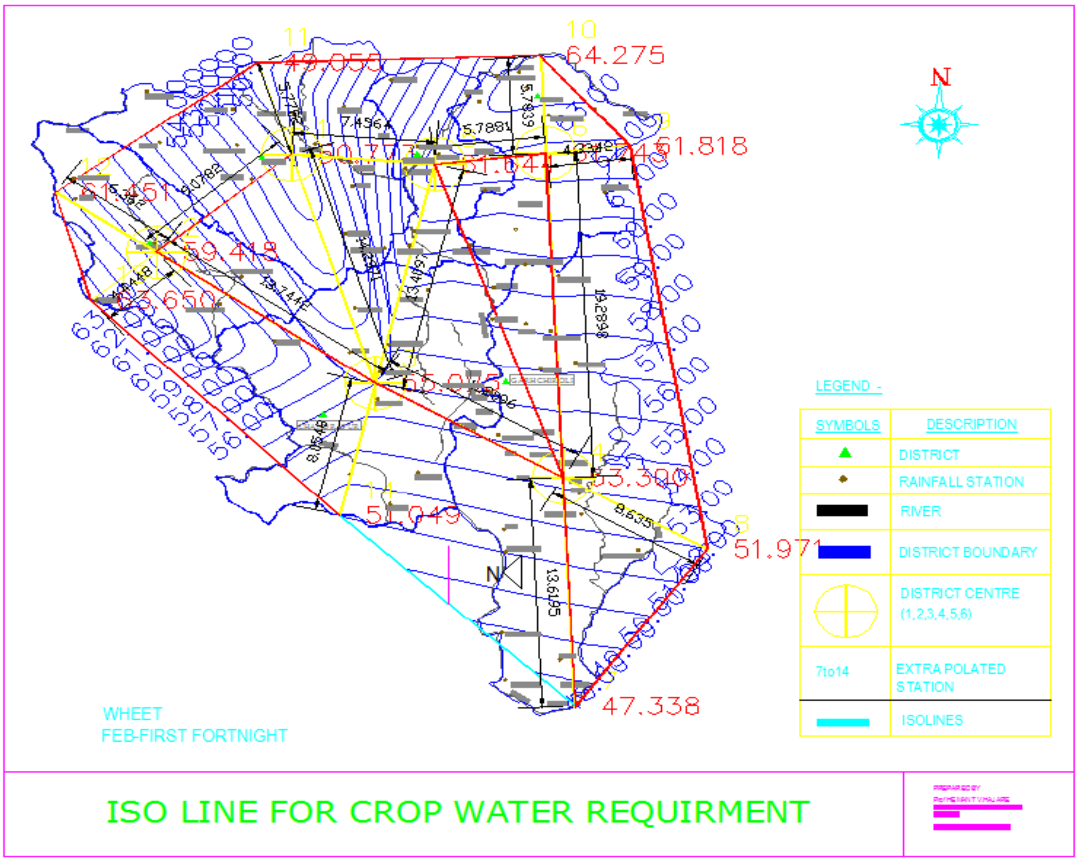

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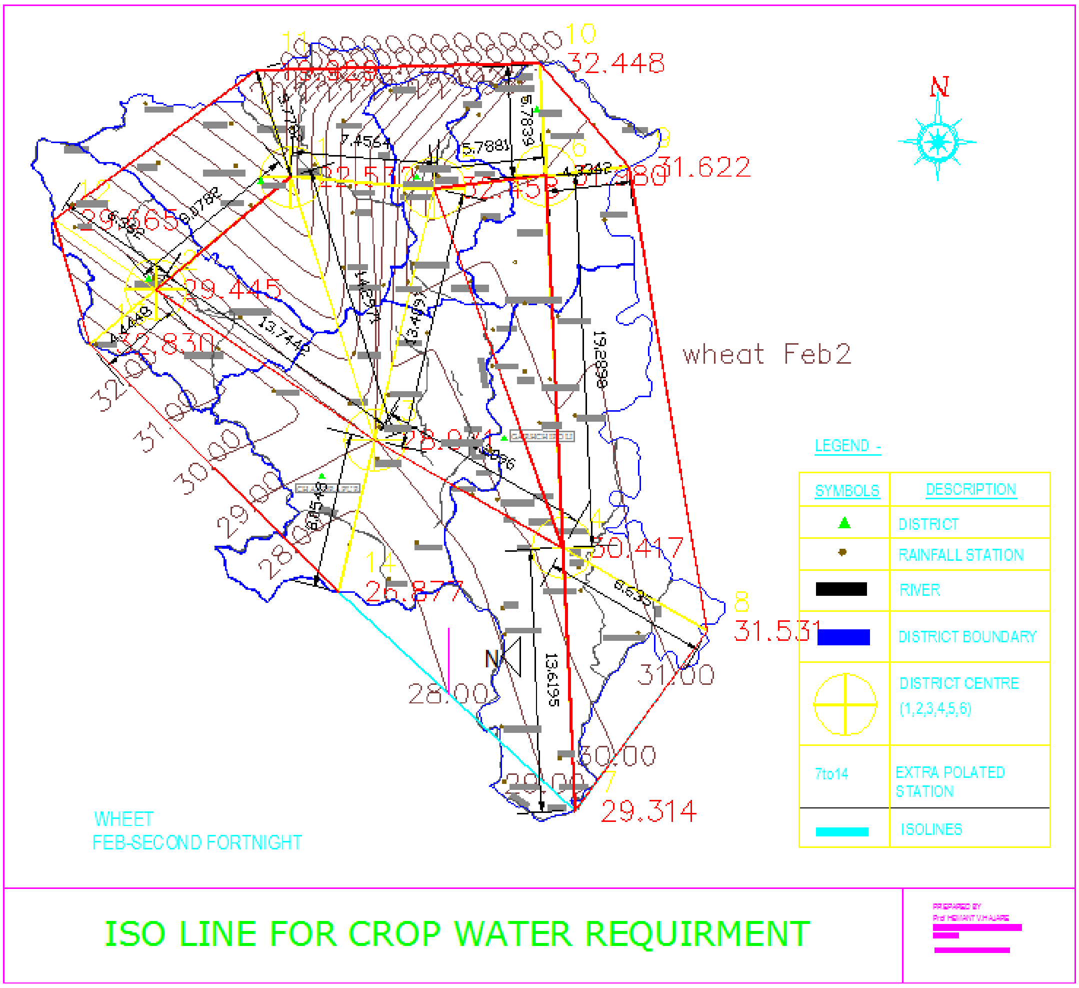

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ISO LINE FOR CROP WATER REQUIRMENT

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