Asian Research Journal of Agriculture

7(1): 1-12, 2017; Article no.ARJA.36812
ISSN: 2456-561X

Effective Rainfall Calculation Methods for Field Crops: An Overview, Analysis and New Formulation

M. H. Ali[1*] and S. Mubarak[2]

[1]*Agricultural Engineering Division, Bangladesh Institute of Nuclear Agriculture (BINA), BAU Campus, Mymensingh, Post Code: 2202, Bangladesh.*
[2]*Department of Irrigation and Water Management, Bangladesh Agricultural University, Mymensingh, Bangladesh.*

Authors' contributions

This work was carried out in collaboration between both authors. Author MHA designed, analyzed, interpreted and prepared the manuscript. Author SM made literature review, analyzed some data, prepared the graph and made initial draft of the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/ARJA/2017/36812
Editor(s):
(1) Rusu Teodor, Department of Technical and Soil Sciences, University of Agricultural Sciences and Veterinary Medicine, Cluj-Napoca, Romania.
Reviewers:
(1) Masmoudi-Charfi Chiraz, Olive Tree Institute, Tunisie.
(2) Alefe Viana Souza Bastos, Federal Institute Goiano, Brazil.
Complete Peer review History: http://www.sciencedomain.org/review-history/22085

Review Article

Received 18th September 2017
Accepted 27th October 2017
Published 28th November 2017

ABSTRACT

Effective precipitation is important in irrigation scheduling decisions, is used to design new irrigation systems, and is a guiding factor for planning crop production practices. The methods for calculating effective rainfall for dry-land and wet-land crops were overviewed, analyzed and summarized in this paper. It is evident that the calculation methods have certain limitations, and also have merits and demerits. Performance of different methods was evaluated for effective rainfall of rice and deviations of results were found. As the methods are mostly empirical, such variation is expected other than the situation where they are developed/formulated. Process based formulation, particularly which considered crop ET, may suit under diverse situations. Under the current condition, Indian-1 and Japanese method estimated closer value, but may not yield better result under other conditions. The new formulation, which is based on the actual water expense, gave better/perfect estimation. New formulations pertinent to different practical/field situations are suggested, which will be useful for calculation of effective rainfall under different field and climatic conditions.

**Corresponding author: E-mail: mha_bina@yahoo.com, hossain.ali.ina@gmail.com;*

Keywords: Irrigation scheduling; rainwater; crop water requirement; crop planning.

1. INTRODUCTION

Irrigation water use for crop production is depended on the interaction of climatic parameters that determine crop evapotranspiration (ET) and water supply from rainfall. Rainfall may be separated into components: runoff, infiltration, interception (rainfall that is caught on the plant surfaces), and evapotranspiration (ET). The effective rainfall (R_e) for field crops is the portion of rainfall which is useful directly and/or indirectly for crop production at the site where it falls (Dastane, [1]). Factors that influence effective rainfall are soil slope, soil texture and structure, plant cover or crop residue, storm intensity and duration, etc. If the rainfall is sufficient to cover the water needs of the crops, irrigation is not required. If there is some rainfall, but not enough to cover the water needs of the crops, irrigation water has to supplement the rain water in such a way that the rain water and the irrigation water together cover the water needs of the crop. According to Dastane [1], the R_e includes the part of total rainfall (seasonal or annual) that intercepted by vegetation; lost by evaporation from the soil surface; lost by evapotranspiration (ET) during plant growth and yield formation; contributing towards intended/beneficial leaching; facilitating other cultural operations either before or after sowing, which is useful to yield and quality of crop. A method for estimating effective rainfall should therefore account for crop characteristics, crop ET, water storage change in the crop root zone, and surface storage capacity (or surface runoff amount, on the other hand). The analysis of effective rainfall for crop water use and crop production constitutes a key element in developing strategies to optimize the use of rainwater for effective water management practices.

2. FACTORS AFFECTING RAINFALL AND DIFFERENT SITUATIONS

2.1 Factors Affecting Effective Rainfall

Effective rainfall depends on the preceding soil moisture status or irrigation amount, crop characteristics (crop root zone depth, crop canopy cover), soil characteristics (water storage capacity of the soil, subsoil condition - sandy or impervious layer), land slope, climatic parameters (e.g. air temperature, humidity, wind speed, etc.) or atmospheric water demand, rainfall characteristics (intensity, amount, frequency, spatio-temporal distribution), and preceding soil-moisture condition *or* ponding water depth. If rainfall occurs just after an irrigation, maximum of its amount will become non-effective.

In FAO-25 guideline (Dastane, [1]), it is assumed that daily rain <5 mm would not be considered effective (during dry period), as this amount of precipitation would likely evaporate from the surface before soaking into the ground. But this is only valid for summer (extreme hot period), and for deep rooted crops only. For shallow (e.g. onion) or even medium rooted crop (e.g. wheat), at the early stage, 5 mm rain (specially at cold weather) can contribute to ET demand. In essence, the precipitation that only moist the surface soil, but not entered into soil profile, also effective, because it takes part in consumptive use (i.e. in fulfilling evaporative demand).

2.2 Different Situations of Rainfall and its Effectiveness

During extended periods of cool wet weather, less evaporation takes place and the smaller rainfall events may be effective precipitation, and also vice versa.

<u>2.2.1 Situation 1 – wet periods with small rainfall events</u>

During prolonged cool wet periods, precipitation in the form of daily showers can be considered effective. This is because the soil and air temperatures are cooler and humidity is higher allowing the rainfall to soak into the soil before it evaporates. The judgment as to how much rainfall is effective would have to be made after a number of cool days. Soil moisture monitoring could be helpful in determining how much of the rainfall is effective.

<u>2.2.2 Situation 2 – dry periods with small rainfall events</u>

During prolonged dry periods, precipitation in the form of daily showers can be non-effective. This is because the soil and air temperatures are drier and humidity is lower allowing the rainfall to evaporates. The judgment as to how much rainfall is non-effective would have to be made depending on the total situations including crop type (root type- shallow or deep, vegetative cover). Soil moisture monitoring could be helpful in determining how much of the rainfall is effective.

2.2.3 Situation 3 – large amounts of precipitation

Very large rainfall events may supply more moisture than the soil's water holding capacity and daily atmospheric (ET) demand. For large rainfall events, a portion of the precipitation may be lost due to moisture moving deep into the soil below the crop rooting depth, being lost by surface runoff or removed from the field through a subsurface drainage system. A certain (fixed) percent of rainfall is considered effective in some approach/method, which has no scientific basis. If using water budgeting and ET to schedule irrigation, the budget process must be restarted after large precipitation events.

From the above discussion, it is clear that, the effective rainfall (R_e) should be based on the crop, climate, and soil specific.

2.3 Rationale of Using Actual Evapotranspiration (ET_a) in Effective Rainfall Estimation

A step forward could be to incorporate two major meteorological parameters such as precipitation and evapotranspiration in calculating effective rainfall. Obviously the actual (ET_a), and not the potential evapotranspiration (PET), is the real input; but for future prediction, PET may be used. Both the precipitation and ET_a are variables which differs from climate area to climate area, and depends on the time scale. Both are characterized by seasonality in almost all climatic region. The ET_a is the key parameter representing the need of the atmosphere for successful crop growth. Any excess amount of this does not represent the useful need, but a wastage. Therefore, we cannot consider this excess amount as effective for the plant, indeed whatever may the rainfall amount. Similarly, any moisture/rainfall above Field Capacity (FC) at - and after- the 'soft-dough stage of crop seed' (*or* physiological maturity) also ineffective for the crop (Ali, [2]; Ali et al, [3]; Oweis et al, [4]; Zhang and Yang [5]).

3. EXISTING METHODS FOR CALCULATION OF EFFECTIVE RAINFALL

Numerous approaches for estimating effective rainfall have been proposed in the past, including: direct measurement techniques, empirical relationships, and soil water balance approach (including modeling approach) (Mohan et al. [6]; Obreza and Pitts, [7]; Patwardhan et al., [8]; USDA, [9]; Uribe et al. [10]). The approaches also used variable time-frame for such calculation. The direct monitoring or measurement provides the most accurate results for estimating effective rainfall. But it is expensive, require some level of technical knowledge. Some researchers calculated effective rainfall for year-round, based on long-term average weather condition, but without considering crops or crop period (e.g. Rahman et al. [11]). But this type of calculation has little value for present *or* future crop, as the present or future weather condition and crop type may differ significantly from past conditions. A good method must account satisfactorily for surface run-off, water storage changes in the soil, evapotranspiration and crop characteristics. For field use, the method should be simple, inexpensive, rapid and accurate. It should be useful for broad regional planning, as well as for precise irrigation scheduling under a given set of conditions.

There are relative merits and limitations of different methods. Before going to critical evaluation and suggestions for improvement, an overview of the methods would be useful. Hence, a brief overview of the common methods is given below.

3.1 USDA-SCS Method

The USDA-SCS R_e method was developed with water balance calculations based on 50 years of weather data from 22 stations within the United States (USDA-SCS "Irrigation" [9]). A daily soil moisture balance incorporating crop evapotranspiration, rainfall, and irrigation was used to determine the evapotranspiration effectiveness. The resulting equation for estimating effective precipitation is:

$$P_e = SF\,(0.70917\ P_t^{\ 0.82416} - 0.11556)\,(10^{\ 0.2426ETc}) \qquad (1)$$

Where, P_e is the average monthly effective precipitation (inch); P_t is the monthly mean precipitation (in); ET_c is the average monthly crop evapotranspiration (in); SF is the soil water storage factor. The soil water storage factor was defined by:

$$SF = (0.531747 + 0.295164\ D - 0.057697\ D^2 + 0.003804\ D^3) \qquad (2)$$

Where D is the usable soil water storage (in inches). The term D was generally calculated as 40 to 60 percent of the available soil-water capacity in the crop root zone, depending on the irrigation management practices used.

The average monthly effective precipitation calculated by the above equation cannot exceed either the average monthly rainfall (P_m) or average monthly evapotranspiration (ET_m). If application of this equation results in a value of P_e that exceeds either one, the P_e must be reduced to the lesser of the two.

The procedures in USDA-SCS were designed for a monthly time step and did not include rainfall intensity or frequency factor, irrigation, and soil slope factor. The USDA-SCS method is generally recognized as applicable to areas receiving low intensity rainfall and to soils that have a high infiltration rate (Dastane [1]). As this method does not take into account the soil type and the net depth of irrigation, it gives a lower estimation of effective rainfall compared to the water balance approach (Mohan et al. [6]) and is not very accurate.

3.2 ET-rainfall Ratio Method

This simple semi-empirical method used in some projects in India. A ratio of potential evapotranspiration (taken as 0.8 of the U.S. Class-A pan data), to the total rainfall for a certain group of days during the growing season is computed. The number of days in a group is based broadly on a soil type *or* soil moisture properties as well as general weather conditions or ET rates (Table 1).

The maximum number of days in a group is 15 during warm weather and 30 during cool weather for crops other than rice. The lower the water holding capacity of the soil and/or the higher the ET rate, the shorter the period in the group. The ratios (r_i) are expressed in a percentage for each period. Rainless periods are deleted from the calculations. The monthly means (r_m) are then computed and from these (r_i), and then the grand mean ratio (r_g) is obtained for the entire growing season:

$$r_i = 100\,(PET/R_i) = (100 \times 0.8\,E_{pan})\,/R_i$$
$$r_m = \Sigma r_i\,/n$$
$$r_g = \Sigma r_m\,/m$$
$$R_e = r_g \times R_t \quad (3)$$

Where, R_i is the total rainfall for the group-days; R_e is the effective rainfall for the growing period; R_t is the total growing season rainfall; n is the number of group in a month; m is the number of months in the growing period.

Precise knowledge on soil properties or aridity is not essential for the method. There can be some under- or over-estimation depending upon the distribution of rainfall. This method may be good for broad planning purposes, but may not be suited for instantaneous uses in different crops under different soil and climatic conditions.

3.3 U.S. Bureau of Reclamation Method

This method is recommended for arid and semi-arid regions. It uses mean seasonal precipitation of the five driest consecutive years. In this method (Stamm, [12]), percentage marks are given to increments of monthly rainfall ranging from greater than 90 percent for the first 25 mm or fraction thereof, to 0 percent for precipitation increments above some 150 mm, as is shown in Table 2.

For example, if monthly rainfall during the past 5 years in the month of April is 50, 55, 60, 65 and 75 cm, the mean is 61 cm. From the table, the effective rainfall value for the month of April will be 67 mm.

It is an empirical method. The method does not take into account the type of soil, nature of the crop, frequency and distribution of rain, and degree of aridity. This method can be used for broad planning purposes, but may not be suited for instantaneous uses as climatic condition in the present or future may greatly deviate from the past. In addition, there can be some under- or over-estimation depending upon the distribution of rainfall. The method is not considered satisfactory.

3.4 Soil Water Balance Approach (or Water Balance Method)

Soil-water balance is an accurate way to estimate effective rainfall. This approach requires evapotranspiration (ET), soil water storage (SWS) and runoff characterization. The ET computation requires significant input of meteorological data; SWS requires frequent monitoring of moisture within crop root zone; and runoff estimation requires detail knowledge of soil-crop-rainfall intensity and their interactions. Overall, the water balance approach is highly data demanding. Although models can be used to calculate R_e, the accuracy of R_e depends of the accuracy of the above inputs.

Table 1. Number of days in a group for different soil types and climatic conditions

Crop	Mean monthly ETp (mm/day)	Number of days for soil texture and water storage capacity (mm/m)			
		Light (below 40)	Medium (40 to 80)	Heavy (80 to 120)	Very heavy (over 120)
Rice	3 to 12	2	3	4	7
Other	Over 6	4	7	10	15
crops	Below 6	7	10	15	30

Table 2. Effective precipitation based on increments of monthly rainfall (U.S. Bureau of Reclamation' method)

Precipitation increment range (mm)	Percent	Effective precipitation accumulated range (mm)
0.0 - 25.4	90-100	22.9 - 25.4
25.4 - 50.8	85 - 95	44.4 - 49.5
50.8 - 76.2	75 - 90	63.5 - 72.4
76.2 - 101.6	50-80	76.2 - 92.7
101.6 - 127.0	30-60	83.8 - 107.9
127.0 - 152.4	10 - 40	86.4 - 118.1
Over 152.4	0-10	86.4 - 120.6

3.5 Renfro Equation

Renfro, as quoted by Chow (1964) [13], suggested the following equation for estimating effective rainfall:

$$R_e = (E \times R_g) + A \qquad (4)$$

Where, R_e is effective rainfall, R_g is growing season rainfall, A is average irrigation application, E is the ratio of consumptive use of water (CU) to rainfall during the growing season (*values are given by Renfro*). The E value implies degree of rain likely to be utilized in meeting consumptive water needs. The greater the E value, the higher the value of effective rainfall.

The method is empirical and may not suit in many situations.

3.6 Other Empirical Methods

Different empirical methods of estimating effective rainfall for irrigation schedules are used in different countries, both for non-rice and rice crops (Dastane, [1]). They are based on long experience and have been found to work quite satisfactorily in the specific conditions where they were developed, but may not work in other conditions. Here, some of the empirical formulae are described.

3.6.1 For rice

3.6.1.1 Indian-1 method

In this approach, a percent of total rainfall varying from 50 to 80 percent is assumed effective. That is,

$$Re = P \times a \qquad (5)$$

where,
P is the growing season rainfall
'a' is coefficient (0.5 – 0.8)

3.6.1.2 Indian-2 method

In this approach, rainfall less than 6.25 mm on any day is considered as ineffective. Similarly, any amount over 75 mm/day, and rainfall in excess of 125 mm in 10 days is treated as ineffective. That is,

For daily case:

$$\begin{aligned} Re &= 0 && \text{when } P<6.25 \text{ mm} \\ Re &= P && \text{when } 6.25<P<=75 \\ Re &= P-(P-75) && \text{when } P>75 \end{aligned} \qquad (6)$$

For 10 days:

$$\begin{aligned} Re &= P && \text{when } P<=125 \text{ mm} \\ Re &= P-(P-125) && \text{when } P>125 \text{ mm} \end{aligned} \qquad (7)$$

3.6.1.3 Japanese method

In this approach, for submerged rice, the year having the lowest rainfall over the past 10 to 15 years is selected. Depending upon local conditions, an amount of 50 to 80 mm is considered as ineffective. The rest is all effective. That is:

$$Re = P_{min\text{-}15} - Pc \quad (8)$$

where:

$P_{min\text{-}15}$ = lowest rainfall over the past 10 to 15 years
Pc= ineffective rainfall = 50 ~ 80 mm

3.6.1.4 Vietnam method

The water holding capacity of rice soils is assumed to be 50 mm. Daily rainfall below 5 mm and above 50 mm is disregarded. If daily evapotranspiration is 10 mm, a two-days' successive rainfall of up to 60 mm is taken as effective and excess over this limit is disregarded. Similarly, three days' successive rainfall of up to 70 mm is taken as effective and the excess is disregarded. The same procedure is followed for more rainy days.

For daily case:

$$\begin{aligned} Re &= 0 && \text{when } P<5 \text{ mm} \\ Re &= P && \text{when } 5<P<50 \text{ mm} \\ Re &= P - (P-50) && \text{when } P>50 \end{aligned} \quad (9)$$

For 2 days consideration:

$$Re = P \quad \text{when } P<=60, \text{ and } ET = 10 \text{ mm} \quad (10)$$

3.6.1.5 Burma method

Here, rainfall below 0.5 in is considered as ineffective. Above 0.5 in, 80 percent of the amount in excess is considered as effective. That is,

$$\begin{aligned} Re &= 0 && \text{For } P<0.5 \text{ inch} \\ Re &= (P-0.5) \times 0.8 && \text{For } P> 0.5 \text{ inch} \end{aligned} \quad (11)$$

3.6.1.6 Pakhale et al (2010) equation

Pakhale et al. [14] used the following form of eqn.:

$$Re = 0.0011\, P^2 + 0.4422\, P \quad (12)$$

where:

P is the total rainfall in mm.

3.6.1.7 Chapagain and Hoektra [15] eqn.

Chapagain and Hoektra [15] used the following form of USDA-SCS equation:

$$Re = (125 + 0.1 \times P) \quad \text{For } P>=250 \text{ mm} \quad (13)$$

where:

P is the total rainfall in the concern period.

4. REVIEW OF COMPARATIVE STUDY OF EXISTING METHODS

Rahim et al. [16] performed a comparative study on empirical methods for estimating effective rainfall (Re) for rainfed wheat crop in different climates of Iran. The methods included Renfro equation method, USBR Reclamation method, PET/Precipitation Ratio method, USDA-SCS method, FAO method, and TR21/SCS method. The data included 21 agro-meteorological stations representing arid, semi-arid, semi-humid, and humid region of the country. They also adopted a two-layer soil-water balance (SWB) model in their study. They found best result (compared to SWB model) for arid and semi-arid climates by PET/Precipitation method (d-index = 0.8), and for semi-humid and humid climates by FAO method (respectively 0.9 and 0.8), and USDA-SCS method (respectively 0.8 and 0.7). They also observed that the higher the values of de Martonne Aridity Index, the lower is the value of “effective rainfall /rainfall during the cropping seasons”.

Obreza and Pitts [7] evaluated USDA’s TR-21 method of effective rainfall for south Florida micro-irrigated citrus by monitoring rainfall, irrigation, water-table depth, ET and soil-water content inside and outside of the micro-irrigated weted pattern in four orchards. They developed a linear correlation between ‘water budget Re’ and ‘TR-21 Re’ using pooled data from all sites: WB Re (mm) = 0.79 [TR-21 RE (mm + 17.7], r = 0.84. They performed a hypothetical Re comparison using 30-yr mean rainfall and ET data. They found that annual Re calculated by TR-21 amounted to 673 mm, while water budget Re totaled 744 mm, or +10.5. They suggested that the TR-21 method had the level of accuracy needed to allocate water for micro-irrigated citrus on poorly drained south Florida soils.

Rahman et al. [11] studied Re for irrigated agriculture in south-eastern part of Bangladesh. They estimated Re for two crop growing seasons (Kharif and Rabi), using Renfro equation, USBR Reclamation method, PET/precipitation ratio method and USDA-SCS method. They observe variation of Re value under different method in the same season, and also variation with season under the same method. They also observed that as the distance from sea increased, the value of effective percentage also increased.

Adnan and Khan [17] studied the effective rainfall for irrigated agriculture plains of Pakistan, in different climatic zones (extremely arid to very humid). They used four methods for Re calculation described by Dastane [1]: Renfro equation method, USBR Reclamation method, PET/Precipitation Ratio method, and USDA-SCS method. They calculated effective rainfall for two crop growing seasons, i.e. Rabi (October to April) and Kharif (May to September). They observed that effective rainfall values for Rabi and Kharif season varied widely from 13.03% and 21.31% at humid zone of northeastern Punjab to 100% at several stations by Renfro Equation method, 43% and 30% at humid zone of northeastern Punjab, 99.86% to 100% was at central Sindh by U.S Bureau of Reclamation Method. 17.57% at humid zone of northwestern NWFP, 98.98% and 99.93% at arid zone of southwestern Sindh and Balochistan by Potential Evapotranspiration /Precipitation Ratio method and 54.40% and 60% at arid zone of southern Balochistan to 100% at several stations by USDA-SCS method respectively. Murree has the lowest amount of effective rainfall. They noted that effective rainfall was directly proportional to consumptive use, water storage capacity and irrigation application. They concluded that, Renfro equation is not suitable for short term planning. USBR method was recommended for regions of heavy amount and high intensities of rainfall. PET/ Precipitation Ratio method was found as most effective for preliminary planning than the rest and USDA-SCS method was for areas, which receive low intensity of rainfall like southern parts of Pakistan. They also observed that, as the distance from the sea increases the value of effective rainfall decreases except northern areas.

A comparative study of Re estimation methods was carried out by Mohan et al. [6] for low-land paddy rice in South India. The methods included: Indian-1 method (i.e. a percent of total rainfall varying from 50 to 80 percent is assumed effective), Indian-2 method (i.e. rainfall less than 6.25 mm on any day is considered as ineffective. Similarly, any amount over 75 mm/day, and rainfall in excess of 125 mm in 10 days is treated as ineffective), Vietnam method, ET-rainfall ratio method, USDA-SCS method. These methods were compared against a physically based water balance model. They carried out the analysis using daily data of ET and rainfall. They concluded that among the methods, the ET-rainfall ratio method and Indian-2 methods estimate the effective rainfall values closer to those by the water balance method. The USDA-SCS method under-predicted values of effective rainfall compared to other methods. They also noted that, ET-rainfall ratio and Indian-2 methods can be used in estimating irrigation requirements for lowland rice.

In a study regarding crop water requirement for irrigation planning in a semi-arid region (Marathwada) of India, Chavan et al. [18] calculated the effective rainfall at 70 percent probability by taking the ratio of ET0 and rainfall both at 70% probability. The week-wise effective rainfall at 70% chance of occurrence was estimated.

5. NEW FORMULATION FOR EFFECTIVE RAINFALL

The current method is developed taking into consideration of the limitations of earlier methods, to be used as generalized form and also in mathematical/simulation models. The new formulation for R_e is based on the crop, climate, and soil specific situation. For proper analysis, effective rainfall can be separated for dry-land crops and wet-land crops. The theoretical approaches under dry-land and wet-land conditions are:

Dry-land crops: Consideration of rainfall amount, root-zone capacity, ET rate, 'carryover system' or 'storage from previous event'.

Wet-land crops: Water balance approach considering spillway height, drainage/percolation rate. Rice is considered as wet-land crop.

The main principle of the proposed method is that the R_e can not exceed the rate of consumptive use (CU) for the specified time step plus the storage capacity of the root zone soil, taking into consideration of the crop characteristics (shallow or deep rooted, dry-land or wet-land crop) and climate (dry or wet environment).

Normally, rice grows under abundant water supply that is, the practice of land subsidence. Depth of flooding depends on various factors – the cultivar and its characteristics (e.g. height, drought tolerance, etc.), weed infestation, soil type, height of field bunds (levees), and availability of water. Due to flooding condition, the water requirement of rice include ET and percolation. Thus, the R_e in this case implies the contribution in water use by CU (i.e. $ET+d_p$).

The R_e under different situations are:

5.1 Dry-land Crops (Crops Other than Rice)

5.1.1 Dry/arid environment

(a) Shallow rooted crops:

If $R_t < 5mm$, $R_e = 0$
If $5mm < R_t < (ET_a + RT_d)$, $R_e = C \times R_t$

where, C is the coefficient representing the percentage term (~ 0.8- 0.95).

$$\text{If}\quad R_t \geq (ET_a + RT_d),\quad R_e = ET_a + RT_d = ET_a + (SMC_p - SM_i - I_r) \tag{14}$$

Where,

R_t= Total rainfall (for a considered/particular time period) (mm)
R_e = Effective rainfall (for that period) (mm)
ET_a = Actual evapotranspiration (for that period) (mm)
RT_d = Crop root zone deficit = $(SMC_p - SM_i - I_r)$ (mm)
SMC_p = Soil moisture storage capacity (or FC) of the root zone soil (mm)
SM_i = Initial (at the starting of the considered period) soil moisture content (mm)
I_r = Amount of irrigation (if applied within the considered period) (mm)

The essential condition for the above equation (5) is that, the effective rainfall must not be greater than the sum of evapotranspiration demand and the root zone storage capacity.

The 'appearance and feel method' for determining soil moisture status can provide a quick estimate. Here, $ET_a = ET_0 \times K_c$; K_c is crop coefficient for that period (crop growth stage). The ET_0 can be calculated from FAO temperature method, which requires only temperature data. This data could be easily taken everywhere. Another way to upgrade the estimate is to adapt the FAO temperature method with the Penman-Monteith [19].

(b) Medium/deep rooted crops

If $R_t < 10mm$, $R_e = 0$
If $10mm < R_t < (ET_a + RT_d)$, $R_e = C \times R_t$

where, C is the coefficient representing the percentage term (~ 0.7- 0.9).

$$\text{If}\quad R_t \geq (ET_a + RT_d),\quad R_e = ET_a + RT_d = ET_a + (SMC_p - SM_i - I_r) \tag{15}$$

The definition of the symbols is same as that of earlier ones.

5.2 Humid/sub-humid Environment

(a) Shallow rooted crops:

If $R_t < 3$ mm, $R_e = 0$
If $3\ mm < R_t < (ET_a + RT_d)$, $R_e = C \times R_t$

where, C is the coefficient representing the percentage term (~ 0.85- 0.95).

$$\text{If}\quad R_t \geq (ET_a + RT_d),\quad R_e = ET_a + RT_d = ET_a + (SMC_p - SM_i - I_r) \tag{16}$$

(b) Medium/deep rooted crops

If $R_t < 5$ mm, $R_e = 0$
If $5mm < R_t < (ET_a + RT_d)$, $R_e = C \times R_t$

where, C is the coefficient representing the percentage term (~ 0.8- 0.9).

$$\text{If}\quad R_t \geq (ET_a + RT_d),\quad R_e = ET_a + RT_d = ET_a + (SMC_p - SM_i - I_r) \tag{17}$$

5.3 Wet-land Crops (rice)

Rice is normally grown under wet-land condition (i.e. irrigated, ponded or saturation condition) and thus, deep percolation is an essential part of total water requirement. In case of irrigated or rainfed, the surroundings of the rice plot is bounded by levee (or bunds). The estimation of effective rainfall should therefore be based on the levee height. So, the formulations are:

If $R_t < 15$ mm, $R_e = 0$
If 15 mm$< R_t \leq (CU + ST_d)$, $R_e = C \times R_t$ (18)

where,

CU = Consumptive use of water (= $ET_a + P_d$) (mm)
C is the coefficient representing the percentage term (~ 0.85- 0.95).
ST_d = Water storage deficit (mm)
= [(Levee *or* Bund height - Initial ponding depth of water)] (mm)
P_d = Percolation depth (mm)

If $R_t > (CU + ST_d)$, $R_e = (CU + ST_d)$ (19)

In 'water storage deficit' estimation, 'soil moisture deficit' was ignored, as in most cases, rice is grown under saturated/ponding condition. For short-term estimate (5-10 days), 'Effective Rainfall' cannot exceed the sum of consumptive use and storage deficit. For different types of soil, the percolation rate is available in the literature.

For seasonal (or long-duration) estimates, the term 'ST_d 'may be neglected, thus eqn. (19) reduces to:

$$R_e = CU = ET_a + P_d \qquad R_t > CU \qquad (20)$$

If irrigation is applied during intermittent dry period, then,

$$R_e = ET_a + P_d - I_r \qquad (21)$$

where, I_r is the irrigation amount applied within the stipulated period.

6. COMPARATIVE STUDY OF DIFFERENT METHODS

6.1 Data Used and Climatic Condition of the Area

Different methods were tested/compared from the data of rice field [20], grown during March – June, 2015. The climate at the site (north-eastern Mymensingh, Bangladesh, $24^o43'$ North and $90^o26'$ East) is humid sub-tropic. The mean monthly ET_0 rate (mm/d) at the study site during 2015 is depicted in Fig. 1. The ET_0 and rainfall during the specified rice crop are depicted in Fig. 2.

6.2 Comparative Results

The calculated effective rainfall during the rice rowing period under different methods/equations is summarized in Table 3. Deviation from standard (season consumptive use of water by rice) ranged from +95.7% to -59.8%. As the methods are mostly empirical, such variation is expected other than the situation where they are developed/formulation. Process based formulation, particularly which considered crop ET, may suit under diverse situations. Under the current condition, Indian-1 and Japanese method estimated closer value, but may not yield better result under other conditions. The new formulation, which is based on the actual water expense, gave better/perfect estimation.

Table 3. The calculated effective rainfall under different methods/equations for the rice growing period (total rainfall = 764.6 mm)

Sl	Method	Eqn. No.	Re (mm)	% Deviation from standard
1	Indian-1	5	535.2	6.8
2	USDA-SCS	1	(unrealistic by formula, 5418 mm) 331.4 mm(as lowest ETc)	-33.9
3	USBR	Table 2	361.8	-27.8
4	Renfro	4	627	25.1
5	Japanese	8	490	-2.2
6	Pakhale et al	12	981	95.7
7	Chapagain and Hoektra	13	201.5	-59.8
8	Burma	11	601.5	20
9	New formulation	20	501.2	0.0
10	From rice crop (as Standard)	Consumptive water use by rice (ETc + percolation)	501.2	-

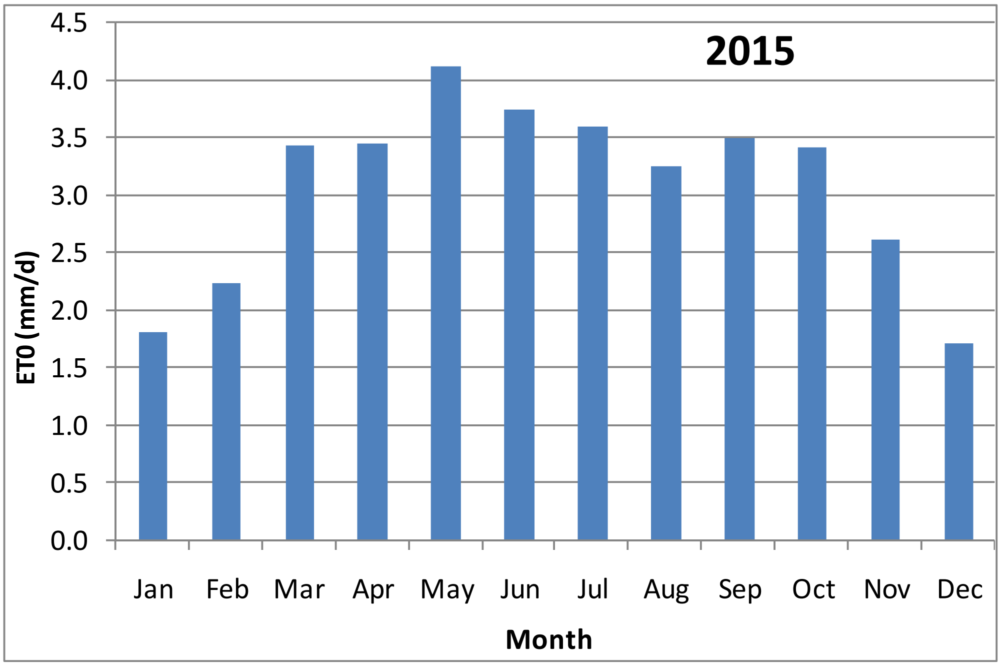

Fig. 1. ET_0 rate in different months at the study site

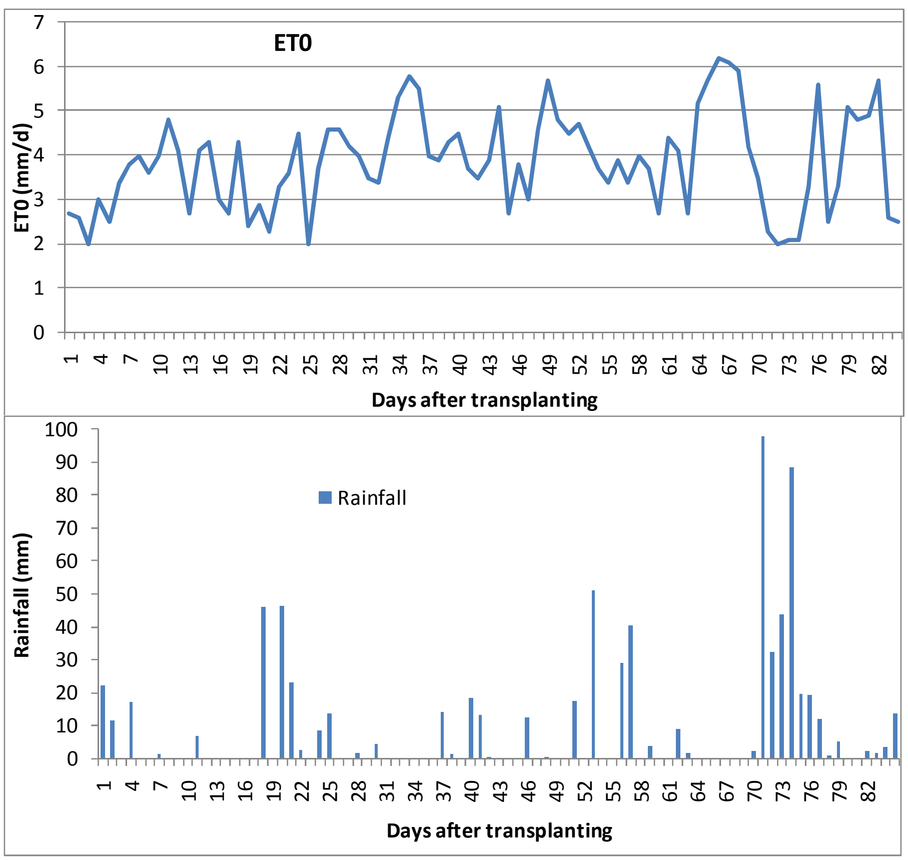

Fig. 2. The ET_0 and rainfall during the rice growing period

7. CONCLUSION

Effective precipitation is important in irrigation scheduling decisions, is used to design new irrigation systems, and is a guiding factor for planning crop production practices. Effective rainfall depends on the preceding soil moisture status (or irrigation amount), crop characteristics, land and soil characteristics, and rainfall characteristics. For a particular soil condition, it is particularly dependent on ET and rainfall. In this paper, the methods for calculating effective rainfall for dry-land and wet-land crops were overviewed and analyzed. It is evident that the calculation methods have certain limitations, and also have merits and demerits. Performance of different methods was evaluated for effective rainfall of rice. New formulations pertinent to different practical / field situations are suggested, which will be useful for calculation effective rainfall under different field and climatic condition.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Dastane NG. Effective rainfall in irrigated agriculture. F.A.O. Irrigation and Drainage Paper 25, Flood and Agriculture Organization of the United Nations, Rome, Italy; 1974.
2. Ali MH. Crop water requirement and irrigation schedulling. In: Fundamentals of Irrigation & On-farm Water Management. Springer-Verlag, New York. 2010;1.
3. Ali MH, Hoque MR, Hassan AA, Khair MA. Effects of deficit irrigation on wheat yield, water productivity and economic return. Agric. Water Manage. 2007;92:151-161.
4. Oweis T, Zhang H, Pala M. Water use efficiency of rainfed and irrigated bread wheat in a Mediterranean environment. Agron. J. 2000;92:231-238.
5. Zhang J, Yang J. Improving harvest index is an effective way to increase crop water use efficiency. In: Proc., 4th Int. Crop Sci. Congress, held at Brisbane, Sept. 2004, on the theme "Crop Science for Diversified Planet"; 2004.
6. Mohan SB, Simhadrirao B, Arumugam N. Comparative study of effective rainfall estimation methods for lowland rice. Water Resources Management. 1996; 10(1):35-44.
7. Obreza TA, Pitts DJ. Effective rainfall in poorly drained micro-irrigated citrus orchards. Soil Sci. Soc. Am. J. 2002;66: 212-221.
8. Patwardhan AS, Nieber JL, Johns EL. Effective rainfall estimation methods. J. Irrig. Drain Eng. 1990;116(2):182-193.
9. USDA. Irrigation water requirements. Tech. Release No. 21, United States Dept. of Agr., Soil Manage. 1967;59:67–75.
10. Uribe HL, Moraga JA, Zazueta FS, Smajstrla AG. A comparison of effective rainfall calculations using the SCS TR-21method and AFSIRS.no. FL-95-101, Am. Soc. OfAgric. Eng., St. Joseph, MI; 1995.
11. Rahman MM, Islam MO, Hasanuzzaman M. Study of effective rainfall for irrigated agriculture in South-Eastern Part of Bangladesh. World Journal of Agricultural Sciences. 2008;4(4):453-457.
12. Stamm GG. Problems and procedures in determining water supply requirements for irrigation projects. Chap. 40 in irrigation of agricultural lands by Hagan et al. Wisconsin, Amer. Soc. Agron. Agronomy II; 1967.
13. Chow VT. Handbook of applied hydrology. New York, McGraw Hill Book Co; 1964.
14. Pakhale G, Gupta G, Nale J. Crop and irrigation water requirement estimation by remote sensing and GIS: A case study of Karnal District, Haryana, India. International Journal of Engineering and Technology. 2010;2(4):207-211.
15. Chapagain AK, Hoekstra AY. The green, blue and grey water footprint of rice from both a production and consumption perspective. Value of Water Research Report Series No. 40, UNESCO-IHE Institute for Water Education, Delft, the Netherlands. 2010;62.
16. Rahim J, Bazrafshan J, Khalili A. Physical Geography Res. Quarterly. 2013;45(3):6-8.
17. Adnan S, Khan AH. Effective rainfall for irrigated agriculture plains of Pakistan. Pakistan J. of Meteorology. 2009;6(11): 61-72.
18. Chavan ML, Khodke UM, Changade NM. Estimation of crop water requirement for irrigation planning in a semi arid region. Int. J. of Agril Engg. 2010;2(2):236-242.

19. Ali MH, Islam AKMR, Hassanuzzaman M, Bhuiya SH. Adaptation of FAO temperature method for estimating reference crop evapotranspiration (ET_0) under Bangladesh condition. Bangladesh J. Env. Sci. 2005;11(1):22–24.

20. Ali MH. Comparative assessment of water saving in Binadhan-14 (A Braus variety). In: Annual Report for 2015-16, Bangladesh Institute of Nuclear Ariculture, Mymensinh, Bangladesh; 2016.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/22085