Impact of effective rainfall on net irrigation water requirement: The case of Ethiopia

Andualem Shigute Bokke and Keneni Elias Shoro

Jimma Institute of Technology, Department of Hydraulic and Water Resources Engineering, Jimma University, Jimma, Ethiopia

ABSTRACT
Irrigation is one means to increase food supply besides the rain fed agriculture. During designing irrigation schemes most of the time effective rainfall is needed to be estimated in order to know the amount of water that should be supplied from irrigation. The problem is which effective rainfall determination method to be used is not clear among the available four built in methods in CROPWAT 8.0. Therefore, in this study analysis was made for Ethiopia case by considering selected 11 (eleven) small scale schemes from different parts of the country designed by different consultant companies. The finding shows most of the schemes designed in Ethiopia use either USDA-SC method (gives minimum net irrigation water requirement) or dependable rain method (results maximum net irrigation water requirement) in determination of effective rainfall. Moreover, additional study need to be conducted to test using soil–water balance method to identify which effective rainfall determination is the correct in planning and designing of irrigation schemes.

Introduction
Rainfall is the main source of water for the globe, including for agricultural production. The three most important properties required about rainfall are amount, frequency, and intensity; and which varies from one place to the other and from time to time as well (Dastane, 1978).

Now a day the concept of effective rainfall is increasing and it is important to consider the contribution of natural rainfall made in design and operation of modern irrigation systems as natural rainfall contributes significantly in satisfying the consumptive demands of crops (Patwardhan, Nieber, & Johns, 1990).

Computation of effective rainfall
In the past, different methods were proposed for effective rainfall estimation and these methods are direct measurement method, empirical method, or soil water balance methods; and the best result is obtained by soil water balance methods (Patwardhan et al., 1990). Among these methods, CROPWAT 8.0 model used four built in empirical equations in estimating effective rainfall for irrigation planning and design (Kuo, Lin, & Shieh, 2001; Smith, 1991). These methods include: fixed percentage of rainfall, dependable rainfall, empirical formula and USDA Soil Conservation Service Method. Detail description of each of these empirical methods is given in Smith (1991) and Kuo et al. (2001).

Net Irrigation Water Requirement (NIWR)
The net amount of irrigation water required to satisfy the crop water demand is called the NIWR and represented by the following equation according to (USDA, 1993):

\[ \text{NIWR} = \text{ETc} - \text{P}_e - \text{GW} - \text{DSW} \]  

where: NIWR = net irrigation water requirement

ETc = crop evapotranspiration

Pe = effective precipitation

GW = ground water contribution

ΔSW = soil water depleted

Project efficiency
The factors which affect the project efficiency of a given irrigation project includes: Method of irrigation, type of canal (Lined and/or Unlined), method of operations (simultaneously and continuous or Rotational water supply), and availability of structures (for controlling and distribution and measuring and monitoring) (Amhara Design and Supervision Work Enterprise, 2014).

Project efficiency is the product of conveyance, canal and application efficiencies (Amhara Design and Supervision Work Enterprise, 2014)

Gross irrigation water requirement
Gross irrigation water requirement is the total amount of water including net irrigation and losses along the
way. It is related with net irrigation and project efficiency according to the following formula (Amhara Design and Supervision Work Enterprise, 2014):

\[ \text{GIWR} = \frac{\text{NIWR}}{P.E} \]  

(2)

where P.E – project efficiency  
NIWR – Net Irrigation Water Requirement

**Duty**

According to Amhara Design and Supervision Work Enterprise (2014), Duty is the area of land that can be irrigated by unit rate of flow or one cubic meter of water per second.

\[ \text{Duty (D)} = \frac{\text{GIWR} \times 1000 \times 10}{(t \times 60 \times 60)} \]  

(3)

where:
  GIWR: Gross Irrigation Water Requirement (mm/day)  
  t: daily irrigation hour (or flow hours)  
  D: Duty (l/s/ha)

**Materials and methods**

**Description of study area**

The location of the study area is East Africa, Ethiopia. The country has complex variation in topography and geology; and the elevation ranges from 126 m below sea level (Dalol depression) and 4620 m above sea level (Mount Rash Dashen). The surface area of the country is 1.13 million square kilometers and 99.3% (land) and 0.7% is covered by water bodies like lakes (natural and artificial) and rivers. The water resources potential of the country is 122BCM and 2.6–6.5BCM from surface and groundwater, respectively. This water resource is generated from 12 river basins, 9 wet and 3 dry (Awulachew et al., 2007). The other important point is that there is very high spatial and temporal rainfall variation across the country which resulted in uneven distribution of the water resources of the country throughout the year. The population of the country is 104,195,491 (19.8% in urban and 80.2% in rural areas) by 2017 according to Worldometers (Worldometers, 2017).  

Geographic location of the study area map is shown on Figure 1 and coordinates of each of the selected small scale irrigations were summarized in Table 1.

**Materials**

**CROPWAT 8.0**

According to FAO (2006), it is a decision support system developed by FAO for different purposes such as follows:

- Calculation of reference evapotranspiration (ETo) using FAO-Penman-Monthieth method, estimation of crop water requirements and crop irrigation requirements.

**Table 1. Geographic location of selected irrigation schemes.**

| S.No | Scheme Name | X(deg.) | Y(deg.) | Z(m) |
|------|-------------|---------|---------|------|
| 1    | Abdi Boru (Abdi.) | 39.25   | 7.53    | 2680 |
| 2    | Adirkayna (Adirk.) | 37.41   | 12.55   | 2380 |
| 3    | Aleltu Tiko (Alelt.) | 38.4    | 9.8     | 2460 |
| 4    | Ashiro (Ashir.) | 39.4    | 7       | 2320 |
| 5    | Atesa (Ates.) | 39.3    | 10.08   | 2080 |
| 6    | Bedessa (Bed.) | 40.05   | 11.21   | 1320 |
| 7    | Burk (Burk.) | 39.88   | 11.37   | 1800 |
| 8    | Chach-2 (Chac.) | 39.5    | 9.63    | 2600 |
| 9    | Cheleleki (Chel.) | 38.75   | 9.8     | 2080 |
| 10   | Genet (Gen.) | 39.18   | 6.96    | 2420 |
| 11   | Masta (Mas.) | 37.63   | 6.08    | 1280 |

Figure 1. Study area map (scheme locations)
To develop irrigation schedules under various management conditions and estimate Scheme water supply for a given irrigation scheme.

- It has five input modules (ETo/climate, rainfall, crop, soil, cropping pattern) and three calculation modules (CRW, Schedules and Schemes).

**Data**

The type of data used in this study is secondary data and were collected from feasibility study report of small scale irrigation projects selected for analysis. The data used are climatic data such as average monthly rainfall, maximum and minimum temperature, relative humidity, sunshine hours and wind speed. Soil data is the type of soil of the command area of each of the corresponding schemes; and the crop type used here is maize as common crop for all the analysis.

**Methods**

**Data collection**

Data collected includes climatic data, soil data and geographic location data were collected from Regional offices and obtained from chair of hydrology and hydraulic engineering of Jimma Institute of Technology which are collected for the purpose of research.

**Data analysis**

In this study small scale schemes from Amhara, Oromia and South Regional States were used to see the impact of effective rainfall on irrigation water requirement. First, review of methods used in the different schemes in determining effective rainfall was carried out and then impact analysis was done using CROPWAT 8.0 software. The common assumptions used in this study includes:-

1. Common crop type (maize grain) and common plating date (December 30) for dry season were selected for impact analysis using input data of maize given in Table 2 and 3.
2. The common parameter used in impact analysis is NIWR since Gross Irrigation Water Requirement (GIWR) is dependent on project efficiency, which differs from one project to the other project.
3. Soil types of the command area for each scheme were used.
4. The FAO recommendations (Allen et al., 1998) for Length of crop development stage (days) and planting date; and crop coefficient and other parameters for Maize was used in analysis (Table 3 and table 4). 
5. To conduct comparison of the result from the four built in methods in CROPWAT8.0 software for the selected eleven (11) schemes, the same input for each scheme were used to see the result from these four methods.

The summary of methodology used in this study is shown on Figure 2.

**Results and discussion**

**Commonly used effective rainfall determination methods during designing small scale irrigation project (SSIP) in Ethiopia**

Small scale irrigation scheme designed and implemented were reviewed from effective rainfall methods selection

**Table 2. Commonly used effective rainfall determination methods during designing small scale irrigation project (SSIP) in Ethiopia.**

| S.No | Scheme Name | Client | Consultant | Year of Study | Meteorological station | Method used |
|------|-------------|--------|------------|---------------|------------------------|-------------|
| 1    | Chacha-2    | ANRS, WORDB | ANRS, BOWRD/IDCP | 2008 | Debre Birhan | Dependable rainfall |
| 2    | Bedessa     | ANRS, WORDB | ADSWE | 2014 | Kemissie | USDA SCS |
| 3    | Burka       | ANRS, WORDB | ADSWE | 2014 | Bokoksa | USDA SCS |
| 4    | Abdi Boru   | OIDA | OWWDSE | 2014 | Bokoji | Dependable rainfall |
| 5    | Adirkayna   | ANRS, WORDB | ADSWE | 2014 | Gondar and Arbaya | USDA SCS |
| 6    | Aletu Tiko  | OIDA | OWWDSE | 2014 | Gebre Guracha | Dependable rainfall |
| 7    | Ashiro      | OIDA | OWWDSE | 2014 | Adeba | Dependable rainfall |
| 8    | Attesa      | ANRS, WORDB | ADSWE | 2014 | Alem Keteema | USDA SCS |
| 9    | Cheleleki    | OIDA | OWWDSE | 2014 | Fiche | Dependable rainfall |
| 10   | Genet       | ANRS, WORDB | ADSWE | 2011 | Ibinat | Dependable rainfall |
| 11   | Masta       | SNNP, WIB | SDCSE | 2017 | Arba Minch | USDA SCS |

SSIP: Small scale irrigation project
ADSWE: Amhara Design and Supervision Work Enterprise
OWWDSE: Oromia Water Works Design and Supervision Enterprise
ANRS: Amhara National Regional State
BOWRD: Bureau Of Water Resources Development
IDCP: Irrigation and Drainage Core Process
OIDA: Oromia Irrigation Development Authority
USDA: United States Department of Agriculture, SCS: Soil Conservation Service
SNNP: South Nation Nationalities and Peoples, WIB: Water and Irrigation Bureau
SDCSE: South Design and Construction Supervision Enterprise

**Table 3. Length of crop development stage (days) and planting data for Maize(Allen et al., 1998).**

| Initial stage | Dev. Stage | Mid stage | Late stage | total | Planting date | Region |
|---------------|------------|-----------|------------|-------|---------------|--------|
| 20            | 35         | 40        | 30         | 125   | April         | East Africa |
perspective and it was found that ADSWE used USDA-SC method in designing five small scale irrigation projects in 2014 and dependable rainfall method in designing one project in 2011. OWWDSE used dependable rainfall method during conducting feasibility study of four small scale irrigation projects using design manual prepared by Japan International Cooperation Agency (JICA) and Oromia Irrigation Development Agency (OIDA) (JICA and OIDA, 2014). ANRS, BOWRD, IDCP used dependable rainfall method in 2008 during feasibility study was conducted. SDCSE designed one small scale irrigation in 2017 using USDA-SC method in estimating effective rainfall.

The summary of all the selected schemes and corresponding methods used is shown in the Table 4.

**Table 4.** Single (time-averaged) crop coefficient, Kc, mean maximum plant heights, maximum root depth (m) and depletion fraction for maize (Allen et al., 1998).

| Stage       | Crop Height (m) | Maximum Root Depth (m) | Depletion Fraction |
|-------------|-----------------|------------------------|--------------------|
| Initial     | 0.3             | 2                      | 0.55               |
| Mid         | 1.2             | 0.35                   | 1.35               |
| End         | 0.35            | 2                      | 0.55               |

Impact of effective rainfall determination methods on NIWR

Irrigation water requirements is defined as the quantity, or depth, of irrigation water required in besides effective rainfall required to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone (USDA, 1993).

In design of irrigation schemes, one of the steps is to carry out water demand assessment of crops; and mean while determination of effective rainfall is done. According to (Raes, 2011; Shirazi et al., 2011), the relationship of effective rainfall, crop water requirement and NIWR as it is shown in eq.(1).

Results from the four methods (fixed percentage of rainfall, dependable rainfall, empirical formula and USDA-SC) used for effective rainfall computation were shown in Figures 3–13. The input data for each scheme is the same and the result varies for each method used in estimating the effective rainfall in CROPWAT 8.0.

According to the analysis results shown in Figure 3–13, maximum NIWR per hectare is obtained from dependable rain method in all the 11 schemes. Whereas the minimum result is from USDA SC method (Figure 3–13). Dependable rain method results in higher amount of water to be delivered from source to command area through canal and the duty used for design of canal is higher. Consequently, sufficient water to be supplied to crop on the command area even though the cost of canal construction is expected to be high as compared to USDA SC method. Besides this, sufficient drainage facilities should be provided in order to avoid water logging in the farm.

Whereas, when USDA SC method is used least amount of duty to be used in fixing dimensions of canals and this results in shortage of water for crops. As a result, yield expected from the production is less even though the cost of canal construction is less as compared to dependable rain method. However, USDA SC method is good for water scarce areas and Dependable rain method is preferable in water sufficient areas.

Therefore, the feasibility study conducted in the country by ADSWE, OWWDSE and SDCSE (meaning of this
abbreviation is shown in Table 4) do agree with the findings of the study.

This shows that during selecting effective rainfall determination method from CROPWAT 8.0 software, care has to be made since different methods give different results. The difference of irrigation water requirement from these methods increases as the size of the scheme increase. Therefore, the influence is larger on large scale irrigation schemes than medium scale and small scale irrigation schemes. The impact of each of effective rainfall estimation methods on NIWR for 11 selected small scale schemes from different part of the country is shown on Figures 3–13.

Conclusion

- The four effective rainfall determination methods built in CROPWAT 8.0 includes Fixed percentage, Empirical formula, USDA-SC and Dependable rain.
According to the analysis result ADSWE and SDCSE use USDA SC method; and OWWDSE uses Dependable rain method in determination of Effective rainfall during design of small scale irrigation schemes. USDA SC method is good for water scarce area and Dependable rain method is preferable in water sufficient areas. 

- Fixed percentage and empirical formula methods are not used in the above-mentioned consultant offices. 
- The effective rainfall determination methods used in CROPWAT should be tested using soil–water balance method before selecting specific method to be used in irrigation planning and design.
Figure 9. Burka scheme impact analysis

Figure 10. Chacha-2 scheme impact analysis

Figure 11. Cheleleki scheme impact analysis
Until testing the methods with soil-water balance method, it is recommended to use Dependable rain method in water sufficient area and USDA-SC method in water scarce area in estimating effective rainfall so as to be safe from shortage of water that can results yield reduction. At the same time sufficient drainage facility should be provided to the scheme so as to avoid water logging that reduces yield.

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**ORCID**

Andualem Shigute Bokke [http://orcid.org/0000-0002-5819-0826](http://orcid.org/0000-0002-5819-0826)

Keneni Elias Shoro [http://orcid.org/0000-0002-0182-9676](http://orcid.org/0000-0002-0182-9676)

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