Evaluation of hydraulic performance: a case study of etana small scale irrigation scheme: wolaita zone, Ethiopia

Abstract
The conventional furrow irrigation system is inherently inefficient in wolaita zone, while the suboptimal management and operation (inflow discharge and cutoff time) are considered as one of the main reasons for satisfactory hydraulic performance. Addressing these issues, the furrow irrigation system which is only practiced in the study area was evaluated on three fields under routine farmer management in wolaita zone. The study consisted of field experiments and simulation modeling. Irrigation performance including application efficiency, Potential Application Efficiency, Adequacy and distribution uniformity, runoff ratio and deep percolation ratio of two irrigation events were evaluated using surface irrigation evaluation and simulation Model WinSRFR 4.1.3. The study revealed satisfactory irrigation efficiencies, with higher distribution uniformity and water losses. Therefore, hydraulic performance of the study area had a value of application efficiency (55% to 73%), low quarter adequacy (0.96 to 1.28) and low quarter distribution uniformity (0.89 to 0.96), runoff ratio (7% to 38%) and deep percolation ratio (1% to 25%) on farms. In addition, irrigation over irrigation status practiced was found in study area with the average low runoff ratio (7% to 38%) and deep percolation ratio (1% to 25%) on farms. In addition, hydraulic performance of the study area had a value of application efficiency (55% to 73%), low quarter adequacy (0.96 to 1.28) and low quarter distribution uniformity (0.89 to 0.96), runoff ratio (7% to 38%) and deep percolation ratio (1% to 25%) on farms. In addition, irrigation over irrigation status practiced was found in study area with the average low runoff ratio (7% to 38%) and deep percolation ratio (1% to 25%) on farms. In addition, irrigation over irrigation status practiced was found in study area with the average low runoff ratio (7% to 38%) and deep percolation ratio (1% to 25%) on farms. In addition, irrigation over irrigation status practiced was found in study area with the average low runoff ratio (7% to 38%) and deep percolation ratio (1% to 25%) on farms. 

Keywords: infiltration parameter, irrigation performance, WinSRFR

Introduction
Irrigation system is an artificial application of water to crops by using gravity or pressure to convey water from source to root zone of the crop to fulfill soil moisture deficit. There are three major categories of irrigation systems Surface (or gravity) irrigation systems are one of the three major categories of irrigation systems, the other two being subsurface irrigation systems and pressurized irrigation systems. Evaluation of existing irrigation system performance and improvements of existing status irrigation system can be conducted by different performance indicators. On scientific basis the properties of performance indicators should be based on an empirically quantified, statistically tested causal model of that part of the irrigation process it describes. To facilitate international comparison of performance assessment studies, indicators should be formatted identically or analogously as much as possible. The easily identifiable and evident problems during field evaluation of irrigation system as mentioned by walker are applying too much or too little water, the poor distribution of infiltrated water over the field, excessive tail water runoff or significant deep percolation losses which are also affected by interdependent field parameters like inflow, time of cutoff, field length and so on.

The most important problems in surface irrigation are low application efficiencies and high uniformity vise-versa and excessive runoff and deep percolation with timely and even applications of water was difficult to achieve. Therefore, evaluation of hydraulic performance of existing furrow irrigation system, the ultimate aim of this study is to evaluate hydraulic performance of ETANA small scale irrigation scheme in wolaita zone, and the results shows moderate irrigation efficiency and high irrigation uniformity. But, the results of these studies were only adapted to the free-drainage furrow irrigation. 

Materials and methods
Location of the study area
Methodology: The event analysis tools of WinSRFR are used first to evaluate performance of the irrigation system and estimate its infiltration and hydraulic roughness properties. Among three evaluation procedures the accuracy of an advance-phase volume balance based on Elliott and Walker’s, two-point method results for furrows were fundamentally limited by the omission of wetted-perimeter effects. Infiltration parameters are not determined with Probe Penetration Analysis, insufficient information is provided for further analysis in WinSRFR. Infiltration characteristics must be determined by other means, to perform operational analyses, design studies, or simulations. Therefore Merriam-Keller post irrigation volume balance (MK-PIVB) was selected for infiltration modeling. As mentioned by various parameters and variables are involved in the surface irrigation process, and they can be categorized according to whether they are field parameters, decision variables, or evaluation variables. In order to conduct evaluation of furrow irrigation system,Filed parameters were collected from field experiment, filled in WinSRFR simulation software to estimate infiltration function and then verification and validation were conducted to the estimated infiltration function to get performance indicators by the help of decision variables and for subsequent operational and design analysis. The decision variable in surface irrigation such as the flow rate and the cut-off time was taken for operational analysis.
A furrow evaluation would normally consist of activities before, during and after the irrigation. The pre-irrigation work is largely reconnaissance, equipment installation and soil moisture determination. During the irrigation, measurements of inflow, advance, runoff or ponding; and recession are made. Following the irrigation, furrow cross-sections can be determined as well as follow-up soil moisture sampling if desired. There are no formal rules for the evaluation since different personnel prefer their own order and technique. The methods followed in this research involve pre-field work activities, field experiments and post field works.

**Pre-field work activities:** This includes a careful inventory of all available data related to the study area. The main activities that were followed include searching and reviewing of relevant literature to justify the rationale of the study, collecting necessary working materials from the relevant Bureau in zone/woreda, cost of water per unit volume, collecting the acquired information about the study area such as climate data mainly precipitation, minimum and maximum temperature, sunshine houses, wind speed and radiation.

**Field work/Field experimentation:** The phases of a surface irrigation event include (1) advance; (2) wetting or ponding; (3) depletion; and (4) recession. The field measurements needed to evaluate each of the field work that had been conducted includes measuring and investigating all the input parameters required for the model from the field experiment such as equipment installation and soil moisture determination (e.g., existing moisture content, moisture content at field capacity and permanent wilting point, bulk density and rooting depth of a crop), and determination of soil particle size (texture) in different depths ranges, determination furrow geometry before and after irrigation, determination field slope, measurements of inflow discharge furrow length, furrow spacing, advance time, runoff or ponding volume; and recession time, and calibration of hardware (e.g., Greller and siphon).

**Post field work:** Field data’s were processed by Microsoft excel then, data analysis, execution simulation and interpretation was conducted using WinSRFR model to estimate the parameters of infiltration function and manning’s roughness coefficient, to determine different performance measures, to identify principles (the effect of changes in cut-off time and inflow) that lead to improve performance irrigation system were conducted in addition thesis writing.

**Experimental design**

The experiment was conducted at woldita zone; Boloso Sore Woreda; in case of ETANA Small Scale Irrigation system (SSIS). Among surface irrigation system only furrow irrigation system was practiced by farmers in study area. Therefore, evaluation of irrigation system performance was conducted on furrow irrigation system at three fields occupied by three farmers with in the command area for two irrigation events. In order to check accuracy of infiltration model, selection of soil and vegetation was the same. The soil texture on the study fields was characterized by sandy loam and vegetation grown during study was Tomato. The treatments selected for two irrigation events on three test fields for experimentation were three furrows. From the middle furrow field data’s for evaluation was collected, the other two furrows were taken as Buffer furrow. Field dimension such as furrow length, slope, cross sectional area and furrow spacing taken as it is in addition to Inflow/Outflow discharge measurements were taken. Complete inflow, advance, and runoff measurements are used to accurately determine soil infiltration rate for a small number of furrows.

In each case, input parameters required for model operation were obtained from the measured field irrigations. Field slope, length and geometry furrow were measured at each site they were illustrated filed parameters under data collection. A siphon tubes was used to measure flow rate. The water lost as tail water was measured by bucket and stopwatch since the lower end of each furrow was open. Stakes were placed at Smeter intervals along the furrow length to measure water advance time, recession time and depth of flow. Gravimetric moisture content determination was conducted at each experimentation site prior to irrigation and after two days of irrigation to measure the plant available soil water replaced by irrigation (root zone soil water deficit). These measurements were used to determine an average soil water deficit for each site, which was used in the subsequent determination of application irrigation efficiency.

**Simulation modeling of furrow irrigation system**

WinSRFR is an integrated software package for analyzing surface irrigation systems. The event analysis tools of WinSRFR were used first to evaluate performance of the irrigation system and estimate its infiltration and hydraulic roughness properties. Among three event analysis procedures currently supported by the Event Analysis World, one of which is Merriam and Keller’s post-irrigation volume balance (PIVB) method were implemented. Using this method infiltration function was estimated from the field- measured geometry, inflow and outflow hydrographs, and advance and recession times. According to WinSRFR is a software package for the hydraulic analysis of surface irrigation systems. Intended users are irrigation specialists, consultants, extension agents, researchers, university level instructors and students, and farmers with moderate to advanced knowledge of surface irrigation hydraulics. The WinSRFR has been extensively used for evaluation and optimization of surface irrigation performance throughout the world. The WinSRFR is coded into four colors worlds with the names Event Analysis World (Irrigation event analysis and parameter estimation functions), Physical Design World (Design functions for optimizing the physical layout of a field), Operations World (Operations functions for optimizing irrigations) and Simulation World (simulation functions for testing and sensitivity analysis). Among the two supported models by WinSRFR such as zero inertia and kinematic wave model were the latter one was used. Because, field slope at three irrigation test plots were steep, so that kinematic wave model gave rescrannable estimation of infiltration parameters for slopes greater than 0.4%.

**Irrigation system evaluation parameters**

Analysis was conducted using WinSRFR model to calculate the parameters of infiltration function, to identify the optimum of application efficiency and analysis to examine the effect of changes in cut-off time and inflow. Performance measurements of a given irrigation systems were analyzed by WinSRFR and many indices have been suggested; according to Aljoumani. Application Efficiency, Storage Efficiency, Application Uniformity, Deep Percolation and Tail Water Ratio are performances measure which are based on volume—balance principles and also according to Nie et al., application efficiency (Es), distribution uniformity (Du), and storage efficiency (Es). According to Burt performance indicators, mainly those Application efficiency, low quarter adequacy, Tail water runoff ratio, Deep percolation ratio and low quarter distribution uniformity were analyzed using event analysis and potential application efficiency low quarter with operational and design folder in WinSRFR 4.1.3.
Results and discussion

Model performance

The best goodness of fit was selected among estimated infiltration function by comparing observed and predicted data between inflow/outflow, advance/recession, and using relative error (RE) observed and predicted performance data, through data comparison tool. The result showed best goodness of fit so that infiltration function was applied for further operational analysis. The infiltration parameters after calibration and the model performance was presented in Table 1 and infiltration function that show infiltrated depth Vs cutoff time also showed by Figure 1.

Table 1 Computed Statistical parameters for evaluation of model performance, estimated and verified Manning's roughness coefficient (n) infiltration parameter's (a, b, and k) using WinSRFR

| Furrow test ID | N   | a  | b (mm/hr) | c (mm) | k mm/hr^a | R^2 | RMSE   | NSE | TL (min) | Re (min) | MBE (%) |
|---------------|-----|----|-----------|--------|------------|-----|---------|-----|----------|----------|--------|
| IR11          | 0.04| 0.26| 50.79     | 0      | 78.141     | 0.97**| 0.98**  | 1.2 | 0.6      | 1.2      | 0.016  |
| IR12          | 0.04| 0.115| 54        | 0      | 44.873     | 0.98 | 0.97    | 0.6 | 0.0016   | 0        | 0      |
| IR21          | 0.04| 0.153| 51.43     | 0      | 66.109     | 0.99 | 0.99    | 1.2 | 0.6      | 0        | 0      |
| IR22          | 0.04| 0.148| 28.93     | 0      | 58.724     | 0.98 | 0.97    | 0.6 | 0.0016   | 0        | 0      |
| IR31          | 0.04| 0.139| 61.07     | 0      | 64.9       | 0.99 | 0.97    | 1.2 | 1.2      | 2        | 2      |
| IR32          | 0.04| 0.094| 57.86     | 0      | 58.602     | 1    | 0.96    | 1.2 | 0.6      | 2        | 2      |

*Relative to Applied Depth.
**Calculated based on time-adjusted runoff values.

Figure 1 Map of the study area.

Infiltration status

Current management of irrigation in test fields showed the variability of infiltration between field to field and from event to event. Both temporal and spatial variability of infiltration function that showed infiltration vs. cutoff time graph for two irrigation events for three fields was shown by Figure 2. Temporal variability of infiltration function for three fields were shown by infiltration curve IR11 and IR12 for field ID IR1, IR 21 and IR22 for field ID IR2 and IR31 and IR32 for field ID IR3. While, spatial variability of infiltration function for 3 fields also shown by curve IR11, IR21 and IR31 for event 1 and IR12, IR22 and IR32.

During each irrigation time each of the field had different infiltration depths with different cutoff time. The results showed that for IR11 infiltration take little time to reach required depth but for...
field two it takes more time to reach require depth of irrigation which leads to lower DP percolation during event two (characterized by under irrigation) than event 1. But, for field 3 infiltration takes nearly the same time reach required depth so that, field 3 achieve comparable results.

**System evaluation**

The concept of including the three terms, i.e. of efficiency, uniformity and adequacy, in reports on irrigation system performance makes the most sense, as it gives an overall picture of what is actually happening, with regards the amount of water applied and the distribution within a field. There also needs to be a balance between an irrigation systems efficiency, uniformity and adequacy, with the economics and suitability under local operating conditions, of attaining the best values for these parameters, being the eventual determining factor.

The calibration and validation of infiltration parameter and manning’s roughness estimation was conducted in event analysis of WinSRFR 4.1.3. Evaluating irrigation system performance the parameters of Table 2, were provided as input data to WinSRFR 4.1.3 simulation model to evaluate observed irrigation performance under event analysis. The simulated irrigation indices of irrigation performance by using simulation analysis were compared with the measured (observed) performance values.

Depending on the purpose of performance evaluation of irrigation system the types of performance indicators has been chosen. Even though, various authors have suggested many performance measures. In this study, the performance of the furrow irrigation system in three fields for two irrigation event was measured in terms of application efficiency (AE %), runoff ratio (RO %), deep percolation ratio (DP %), distribution uniformity of minimum (Du_min) and distribution uniformity of low quarter (Du_lq) by using equation. The results showed that the software simulated the AE, RO, DP, Du_min, Du_lq, Ad_lq and Ad_min with an RE of 0, 10.92, 4.27, 3.94, 2.53, 2.98 and 4.66% respectively. Performance index all of performance indicators simulated by WinSRFR were good but, relatively prediction of runoff by WinSRFR is low.

**Application efficiency**

Application efficiency is primarily affected by the management of the irrigation and may vary significantly between irrigation events. AE is necessary at times to plan for the future, and it is often necessary to judge the performance of an irrigation system in the field. Based on the concept of meeting a target application depth for an irrigation event and how well the irrigation system is able to meet a target depth of application, (SMD taken as target depth) AE were used in this study only to a single irrigation furrow. From results of application efficiency showed that all of the fields, during second irrigation events performed better than first irrigation events. The highest application efficiency of second irrigation event was 65%, 58% and 73% for field IR12, IR22 and IR32 respectively with 65% mean value. But the lowest application efficiency was achieved during first irrigation event on three fields was 58%, 55% and 63% for field IR11, IR21 and IR31 respectively with 58.7% mean AE value. In this study determined application results were better than from the conducted study by Aljoumani, having AE vary between 31% to 52%.

The application efficiencies of typical well-designed and managed furrow irrigation system is 50-70%. Therefore, the results of current operation of furrow irrigation system in case of ETANA SSIS irrigation scheme meet the application efficiencies mentioned by Griffiths having AE range of 55% to 73% with mean AE of 61.8%. Therefore, it is possible to say satisfactory AE were found. The reason for this satisfactory AE was higher inflow rate discharge, steep land.
slope, higher outflow very high advance and recession times, and excess water application as a result of the extended cut-off times.

**Deep percolation**

The result showed that high deep percolation that ranges 1-25% from the inflow volume. For irrigation test field IR11 DP was 25% but, for IR12 DP was 1% for an average inflow discharge of 2l/s and 2.23l/s, cutoff time of 19.8 and 16.7minute and opportunity time 16.8 and 13.8 minute respectively. Even if IR21 has higher inflow discharge, the results implied that DP was mainly affected by cutoff time due to higher opportunity time than inflow discharge in field 1. In case of irrigation test field IR21 DP was 22% but, for IR22 DP was 4% for average inflow discharge of 1.9l/s and 2.15l/s, cutoff time of 22.8 and 19.8minute and opportunity time of 18.6 and 16.8minute respectively. This is due to similar reason as given for filed 1. Finally irrigation test field IR31 DP was 20% and for field IR32 18% for an average inflow discharge of 2.2l/s and 2l/s, cutoff time of 17.4 and 15.6minute and average opportunity time of 14.4 and 12minute respectively. The results implied DP between two irrigation events in field 3 was comparable relative to input data, as inflow discharge, cutoff time and average opportunity time decreases DP was also decreased.

The two principal irrigation water losses in surface irrigation method are run off and deep percolation. All test fields under study has constant filed length, width and soil texture with variable inflow discharge, field slope, required depth of irrigation, cutoff time and spatial and temporal infiltration characteristics. In summary the main variables that affect DP in this study were inflow discharge and cutoff time. Even though, at field 1 and two were DP was mainly affected by cutoff time due to higher opportunity time than inflow discharge. However, at field 3 both inflow and cutoff time directly related to deep percolation.

**Low quarter distribution uniformity**

LQDU of all fields during two irrigation event were greater than 0.89 with mean value of 0.93 the results showed uniform irrigation with high distribution uniformity, which is above Potential field uniformity values for moderately well designed and managed furrow irrigation system as suggested by Griffiths11 which is 0.67–0.87. As mentioned by Ross13 the reason for this Optimum distribution uniformity for a given system occurs when uniform grade is in the direction of irrigation. Typically a constant flow rate is turned into the furrow for the entire irrigation set. Another reason for this was the soil texture for the field under study, which is sandy loam characterized by moderately coarse. As implied by Burt16 distribution uniformity of furrows affected by Opportunity-time differences (down a furrow and between furrows) and different infiltration characteristics for individual furrows and across the field. Therefore, for furrow irrigation system high sediment laden irrigation water generally reduces intake rates, which on coarse textured soils increase advance rates there by improved distribution uniformity for the field.13

**Runoff**

Volume depth or stream flow rate flowing past the end of the field was high. The result of computed and simulated runoff (RO) was shown in table. As shown by table for relative error (RE) of 10.92, which is higher value (poor in prediction) relative to other performance parameters measured by the software. RO observed by the software for field 1 irrigation ID (IR11) was 18% and IR12 was 35.5%, for field 2 irrigation Id (IR21) was 24% and IR22 was 38% and for field 3 irrigation Id (IR31) was 17% and IDR32 was 7% with mean Runoff of 23%.

**Conclusion**

The irrigation performance of furrow irrigation system in case of Etana small scale irrigation scheme is more sensitive to irrigation management on small farms. The field was more susceptible to over-irrigation which exacerbates drainage losses. Optimizing irrigation efficiency and uniformity has been shown possible through changes in irrigation operations parameters: such as changing inflow and cutoff time alone and changing them together. But, the field condition was steeeped slope which result in top soil erosion. Simulation using WinSRFR 4.1.3 provided a quantitative illustration of existing irrigation performance and the effectiveness in optimizing irrigation efficiency through irrigation operation, which can be instrumental in reducing deep drainage losses, thus may reduce water logging and improve water productivity. Therefore, this study, the results showed that WinSRFR 4.1.3 could be successfully used in determined performance indicators. Irrigation status of irrigation system on small farms is sensitive to irrigation management which is more susceptible to over-irrigation which exacerbates drainage losses and deep percolation. The existing irrigation application efficiencies of irrigated fields at ETANA SSIS are poor having a mean value of AE and LQDU are 62% and 0.93. Simulation modeling using WinSRFR 4.1.3 indicated potential of achieving a mean of irrigation to low quarter potential application efficiency up-to 84.3% and 78.3%.

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**Conflicts of interest**

The authors declare that there are no conflicts of interest.

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