



**PERFORMANCE ASSESSMENT OF LARGE SCALE
SPRINKLER IRRIGATION SYSTEM IN CASE OF ARJO-
DIDESSA SUGAR FACTORY, SOUTHWESTERN ETHIOPIA**

MSc. THESIS

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**PERFORMANCE ASSESSMENT OF LARGE SCALE SPRINKLER
IRRIGATION SYSTEM IN CASE OF ARJO-DIDESSA SUGAR
FACTORY, SOUTHWESTERN ETHIOPIA**

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FACULTY OF BIO-SYSTEMS AND WATER RESOURCE ENGINEERING
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November, 2021

DECLARATION

I, the undersigned person, hereby declare that this MSc thesis is my original work and all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, all sources of materials used for this thesis that are not original to this work have been duly acknowledged.

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APPROVAL PAGE

We, the undersigned, thesis advisors and members of the Board of Examiners of the final open defense, we here by approve that we have read and evaluated this thesis by entitled with “Performance Assessment of Large scale Sprinkler Irrigation System in case of Arjo-Didessa Sugar Factory, South-western Ethiopia” and examined the candidate’s oral presentation. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree of Master of Science in Irrigation and Drainage Engineering at Hawassa University, the Graduate Studies Program of the Faculty of Bio-systems and Water Resource Engineering, Department of Water Resource and Irrigation Engineering.

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(Biruk Girma Ayele)

LIST OF ACRONYMS AND ABBREVIATIONS

ADlq	Adequacy of low quarter
AEa	Actual Application Efficiency
ASABE	American Society of Agriculture and Biological Engineers
CU	Coefficient of uniformity
CUC	Christiansen uniformity Coefficient
CWR	Crop water requirement
dg	Actual sprinkler water application depth
Dg	Gross depth of water application in root zone
Dn	Net depth of water application in root zone
DU	Distribution uniformity
DUlq	Distribution uniformity of low quarter
ENMSA	Ethiopia National Meteorology Services Agency
ESC	Ethiopian Sugar Corporation
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
FAO	Food and Agricultural Organization
FC	Field Capacity
GIR	Gross irrigation requirement
GPS	Global positioning system
Ig	Sprinkler water application rate
II	Irrigation interval
Kc	Crop coefficient
m.a.s.l	Meter Above sea level

MAD	Management allowable depletion
NIR	Net irrigation requirement
NRSC	Natural resource conservation service,
OWWDSE	Oromia Water Works Design and Supervision Enterprise
P	Depletion factor
Pa	Average sprinkler pressure
PAE	Potential application efficiency
PAELQ	Potential application efficiency of the low-quarter
Pe	Effective rainfall
Pn	Minimum sprinkler pressure
PWP	Permanent Wilting point
RAW	Readily Available Water
SCU	System coefficient of uniformity
SDU	System distribution uniformity
SMD	Soil moisture deficit
TAW	Total available water
T	Irrigation set time per irrigation
USDA	United state department of Agriculture

TABLE OF CONTENTS

DECLARATION.....	iii
APPROVAL PAGE	iv
ACKNOWLEDGEMENTS.....	v
LIST OF ACRONYMS AND ABBREVIATIONS.....	vi
LIST OF TABLES	xi
LIST OF FIGURES	xii
LIST OF TABLES AND FIGURES IN APPENDICES	xiii
ABSTRACT	xiv
1. INTRODUCTION.....	1
1.1. Background of study	1
1.2. Statement of Problem.....	3
1.3. Objectives.....	4
1.3.1. General Objectives	4
1.3.2. Specific objectives	4
1.4. Research Questions	4
1.5. Significance of study.....	5
1.6. Scope of the Study	5
2. LITERATURE REVIEW.....	6
2.1. Overview of Irrigation System.....	6
2.2. Sprinkler Irrigation System.....	7
2.2.1. Advantages of Sprinkler Irrigation Systems	8
2.2.2. Limitations of Sprinkler Irrigation Systems.....	8
2.3. Estimation of Crop water requirements (CWR) and CROPWAT Model	9
2.3.1. Reference Evapotranspiration (ET _o).....	9
2.3.3. Crop Evapotranspiration (ET _c)	10
2.4. Determining Irrigation Requirement.....	12
2.4.1. Effective Rainfall	12
2.5. Irrigation scheduling	13
2.5.1. Depth of Irrigation (D _n).....	14
2.5.2. Irrigation Interval (II).....	15
2.6. Performance Assessment of Sprinkler Irrigation System	15
2.7. Performance Indicators of Sprinkler Irrigation system	16
2.7.1. Irrigation efficiency.....	17
2.7.2. Adequacy of Irrigation	19

2.7.3. Irrigation Uniformity.....	20
2.7.3.3. Methods of Determination Sprinkler Water Distribution.....	24
2.8. Factor Affecting Actual Water Application Efficiency and uniformity.....	24
2.8.1. Sprinkler Operating Pressure and Precipitation Profile	25
2.8.2. Sprinkler Spacing.....	28
2.8.3 Wind.....	29
2.9. Losses in Sprinkler Irrigation Systems	29
2.10. Gaps Existing In Actual Irrigation Performance.....	30
2.11. Reasons for Performance Assessment	31
2.12. Measures to Improve Performance	33
3. MATERIAL AND METHODS.....	34
3.1. General Description of study Area.....	34
3.2. Material and Tools	36
3.3. Data Collection Methods and Sources	36
3.3.1 Soil Data.....	37
3.3.2. Climate data	38
3.3.3. Description of Catch-cans and Alignment	38
3.3.4. Pressure Measurement	41
3.3.5. Measurement of Sprinkler Discharge.....	41
3.4. Estimation of the crop water requirement.....	42
3.4.1. Reference evapotranspiration (ET _o)	42
3.4.2. Effective rainfall (P _e).....	43
3.4.3. Description of CROPWAT 8.0 Model & Data input	43
3.4.4. Crop Evapotranspiration (ET _c).....	43
3.5. Determining Net irrigation requirement (NIR)	44
3.6. Irrigation Scheduling.....	44
3.6.1. Net depth of water application (D _n).....	45
3.6.2. Gross depth of water application (D _g)	45
3.6.3. Sprinkler operating set time per irrigation (T)	46
3.6.4. Irrigation interval (I)	46
3.7. Sprinkler Irrigation Performance Indicators	46
3.7.1. Sprinkler water application rate (I _g)	46
3.7.2. Sprinkler discharge and pressure variation along lateral.....	47
3.7.3. Coefficient of uniformity (CU)	47
3.7.4. Distribution uniformity (DU).....	47

3.7.5 System uniformity	48
3.7.6. Potential application efficiency (PAE).....	48
3.7.7. Potential Application Efficiency of Low Quarter (PAELQ).....	49
3.7.8. Actual Application efficiency (AEa).....	49
3.7.9. Adequacy Low quarter (ADlq)	50
3.8. Data analysis	50
4. RESULT AND DISCUSSION.....	51
4.1. Design Condition of Irrigation Systems and Water Application Practices	51
4.2. Soil Physical Characteristics and Water Holding Capacity	52
4.3. Crop water requirement (CWR).....	52
4.3.1. Reference Evapotranspiration (ETo).....	52
4.3.2. Crop Evapotranspiration (ETc)	54
4.3.3. Effective Rainfall (Pe).....	54
4.3.4. Net irrigation requirement (NIR)	56
4.4. Irrigation Scheduling.....	56
4.4.1. Depth of Water Application	57
4.4.2. Irrigation Interval (I)	57
4.4.3. Actual Sprinkler Operating set time per Irrigation (T).....	58
4.5. SPRINKLER PERFORMANCE INDICATORS	59
4.5.1. Actual Sprinkler Discharge rate and operating pressure	59
4.5.2. Water application uniformity for overlapping sprinklers (block test).....	61
4.5.3. System uniformity	63
4.5.4. Water application uniformity for single sprinkler test	64
4.5.5. Selecting Sprinkler spacing.....	65
4.5.6. Potential application efficiency (PAE) and PAELQ	66
4.5.7. Actual Application Efficiency (AEa).....	69
4.5.8 Adequacy of irrigation	72
5. CONCLUSION AND RECOMMENDATION	74
5.1. CONCLUSION	74
5.2. RECOMMENDATION	76
References	78
APPENDICES	84

LIST OF TABLES

TABLE.....	PAGE
Table 2.1: FAO Sugarcane Crop coefficient (Kc) value.....	11
Table 2.2: Losses in Spray irrigation system.....	30
Table 3.1: Geographical location of weather monitoring stations.....	38
Table 3.2: Root depth and Kc at different cane ages.....	44
Table 4.1: Soil available water capacity and Bulk density of Study Area.....	52
Table 4.2: Water stored under root zone in mm after hour irrigation.....	52
Table 4.3: Reference evapotranspiration (ETo) of the Study Area for each Month.....	53
Table 4.4: The ETc value of the study area.....	54
Table 4.5: Effective Rainfall (Pe) for each Month of the Study Area.....	55
Table 4.6: The NIR for each growing month and growth stages of sugarcane.....	56
Table 4.7: Net and gross depth of water application of Study Area.....	57
Table 4.8: Irrigation interval for each growing month and growth stages.....	58
Table 4.9: Sprinkler Set Hour for each growing month and growth stages.....	59
Table 4.10: The actual measured values of filed sprinkler system of the Study Area.....	60
Table 4.11: The actual CU and DU of four overlapping sprinklers.....	61
Table 4.12: The measured result of the SCU and SDU.....	63
Table 4.13: The actual CU and DU of the single sprinkler test.....	64
Table 4.14: CU and DU value for different overlapping spacing.....	65
Table 4.15: PAE and PAELQ of study area.....	66
Table 4.16: On-Field storage efficiency of study area.....	69
Table 4.17: The actual application efficiency based on required depth of application.....	70
Table 4.18: The lower quarter adequacy of each test.....	72

LIST OF FIGURES

FIGURE.....	PAGE
Figure 2.1: Spatial distribution of applied water.....	20
Figure 2.2: Effect of pressure on droplet size and wetted diameter.....	26
Figure 2.3: Typical precipitation profiles for operating at different pressures.....	27
Figure 2.4: The effect of wind on a sprinkler pattern.....	29
Figure 3.1: Geographical Location map of study area.....	34
Figure 3.2: Sprinkler type of study area.....	35
Figure 3.3: Photo during soil sample collection with Auger and core samplers.....	38
Figure 3.4: Layout of Catch cans for overlapping sprinklers (Block test).....	39
Figure 3.5: Layout of Catch cans for single sprinkler test.....	40
Figure 3.6: Photo during measuring catch can water volume with graduated cylinder	41
Figure 3.7: Photo during measuring sprinkler water discharge.....	42
Figure 4.1: Average daily value of ETo for each month.....	53
Figure 4.2: Mean monthly variation ETo and Effective rainfall.....	55
Figure 4.3: Factors affect the performance level and in field water application.....	68
Figure 4.4: Poor growing canes due adequacy of water.....	73

LIST OF TABLES AND FIGURES IN APPENDICES

APPENDICES.....	PAGE
Appendix 1: Climate data.....	84
Table 1: Average monthly Rainfall (mm) from Bedelle station.....	84
Table 2: Average monthly Maximum temperature ($^{\circ}\text{C}$).....	84
Table 3: Average monthly Minimum temperature ($^{\circ}\text{C}$).....	85
Table 4: Average monthly Relative Humidity (%).....	85
Table 5: Average monthly Wind speed (m/sec).....	85
Table 6: Average monthly Sunshine Hour (hrs/day).....	86
Appendix 2: Average monthly ETo and Effective rainfall.....	86
Table 7: Monthly climatic data and ETo for each month.....	86
Figure 1: ETo and Effective rainfall from CROPWAT 8.0. Software.....	86
Table 8: Probability analysis of mean monthly dependable rainfall.....	87
Table 9: Effective Rainfall for each Month of the Study Area.....	88
Figure 2: Mean monthly rainfall of study area.....	88
Appendix 3 soil physical characteristics.....	88
Table 10: Soil Particle size distribution and texture classes.....	88
Table 11: Stored depth before and after irrigation in root zone after hour irrigation.....	89
Appendix 4 Discharge and pressure measurement data.....	89
Table 12A: Sprinklers discharge and wetted radius for four overlapping sprinklers.....	89
Table 12B: Measured nozzle pressure and sprinkler discharge along laterals.....	89
Appendix 5: Field measured Catch can data.....	90
Table 13: Catch Cans depth for four overlapping sprinklers (block test).....	90
Table 14A: Catch cans depth for single sprinkler test (Field no 1).....	91
Table 14B: Catch cans depth for single sprinkler test (Field no 2).....	92
Table 15: Overlapped Catch cans depth data for different spacing's.....	93
Appendix 6: Field photos during data collection.....	94

ABSTRACT

An Effective and efficient sprinkler system is combined effect of proper system design, careful operation, and timely maintenance and management, and it depends on its actual performance at field condition. Evaluation of the actual performance of sprinkler irrigation is very important to know the general status of existing system, and for identifying the gaps and applying mitigation measures. The Arjo-Didessa sugar factory is producing sugarcane for about two decades. Sugar cane fields at study area were irrigated irrespective of the soil type, growing month and stage of crop growth with the design application efficiency of 75%. But, now the system is not working with the full design capacity. In irrigation field under and over watering, plant showing yellow color and wilt are observed. However the actual performance of the existing sprinkler system was not clearly understood so far and evaluated yet; so that evaluating the actual sprinkler performance under existing condition was very important. Therefore, this study was conducted to assess the existing sprinkler irrigation performance by measuring the performance indicators of the irrigation as it is normally practiced. This study was started from field observation and referring design document of focus area. Primary and secondary data were used to attain the objective of the study. The soil physical characteristics and the gravimetric water content were determined in the laboratory using collected soil samples from the field. CROPWAT 8.0 model was used to estimate the CWR and effective rainfall (Pe). During the study, 12 field experiments were conducted at two irrigation command areas for hydrant pressure of 3.5 and 4.0 bars, to check infield water application uniformity, for both overlapping and single sprinkler test by installing catch can in grid spacing of 3*3m with three replications. The result shows, measured irrigation interval and sprinkler set hour was vary through growing month and stage. Average sprinkler discharge is 0.295 lit/sec which is below design capacity of 0.54 liter/sec. The mean application rates for 18m x18m sprinkler spacing were 3.27mm/hr. The CU of 72% and 79% obtained at the hydrant pressure of 3.5 and 4.0 respectively. Also DU values obtained from catch can tests data are 62.5% and 69% at respective hydrant pressure, which indicates at poor range and lower than of minimum acceptable range. The values of the system CU and system DU are very closely to the calculated CU and DU values. The catch can data for single sprinkler were overlapped for different spacing's. Acceptable value of CU equal to 78% and 81%; and DU of 72% and 77% at operating pressure 3.5 bar and 4.0 bar respectively obtained at 12m x 18m spacing. The PAE of 74.5% and 80%; and PAELQ of 46.5% and 55.5% were obtained at 3.5 and 4.0bar respectively. The obtained results of the lower quarter adequacy (ADlq) were 0.72 and 0.86 for operating hydrant pressure of 3.5 and 4.0 bar respectively. The current estimated average AEa was 59.5%. Generally, the result of this study shows, the existing system performance is poor. The system has to be improved and revised. So that, the irrigation scheduling based on the actual efficiency was recommended with respect of growing month and stage of growth. The project should use the best combination of the hydrant operating pressure and set time to be successful and work as planned.

Key words: *Performance Assessment, Sprinkler irrigation, irrigation scheduling, Uniformity, application Efficiency, Adequacy of low quarter, Arjo-Didessa*

1. INTRODUCTION

1.1. Background of study

Agriculture is one of the world's most important activities supporting human life. But, agricultural productivity per capita in sub-Saharan Africa has not kept pace with population increase, and the region is now in a worse position nutritionally than it was 30 years ago. Food production has achieved a growth of about 2.5% per year, while population has risen at a rate of over 3% per year. In the past, additional food in Africa came from increase in the area cultivated, but as good land becomes less available, the region will be forced to increase yields (FAO, 1995). For Ethiopia, agriculture is the most important economic sector as it is the main source of population income. Most of the people of the country are engaged in agriculture and it directly supports 85% of the population's livelihoods.

However the agriculture activity in the country still depends largely on rain fed and with very limited areas currently developed under irrigation. As a result the increase in crop production does not match with the population growth of the country (Hailegebriel, 2007). Hence, the irrigation sub-sector has to be given top priority in the overall development plans of the country with the ultimate objective of enhancing agricultural production and sustain crop production and alleviate food insecurity problems (MOA, 2011). Both rain fed and irrigated agriculture will need to be intensified, but irrigated agriculture has a higher potential for intensification. Irrigation development is essential to inspire the economic growth and rural development and it is considered as a foundation of food security and poverty reduction in Ethiopia (Awulachew et. al., 2005).

Ethiopia is one of few African countries endowed with abundant water and land resources with agricultural potential. The country is gifted with sufficient water resources with 12 river basins and 5.3 million ha (Mha) of land that can potentially be used for irrigation. (Awulachew et al., 2007). Considering the whole scenario of need and status of agricultural development in the country, the FDRE has given one of the highest priorities to irrigated Agriculture. The MoA (2011) reported that about 10-12% of the total irrigable land is currently under production in different parts of Ethiopia using traditional and modern irrigation schemes by the government and support of different funding agencies.

The FDRE has launched sugar development program and plan the development of massive irrigation projects for sugar production in different parts of the country, with a clear objective of boosting sugar production to satisfy the domestic sugar demand as well as for any possible export (ESISC, 2012). Accordingly, Arjo-Didessa irrigation is one of the among new biggest sugar development projects in southwestern Ethiopia which has started in 2006. Currently, the project cultivates sugarcane on about 5000 ha of land by diverting Didessa River using surface and sprinkler irrigation, with having future expansion plan of 80,000 ha.

However, due to different environmental and management factors most of these irrigation schemes are not being exploited fully, and irrigation in general is not contributing its share to the overall economic development of the country as required. According to Awulachew et al., (2010a) reports, the irrigation area of the country is 640,000 ha and the actual scheme performance is estimates on average 36% below design capacity, implying a loss of about 230,000ha of irrigated land, leading to only 410,000ha irrigated. This shows that, a gap exists between design and actual performance. The performance of many irrigation systems is far below their potential mainly because of inefficient irrigation water management and inaccurate water distribution due to the lack of a monitoring system for water delivery, poor maintenance and problems associated to input supply and marketing. These problems have greatly reduced their benefits and challenged their overall sustainability.

Therefore, in addition to developing irrigation, the irrigation system has to be improved to attain better efficiency. The development of irrigation and improved agricultural water management has many potential benefits to reduce vulnerability and improve productivity (Seleshi, 2010). Improved irrigation practices are a combined result of proper system design, operation maintenance and management. Adequate and dependable water supply is needed in order to facilitate irrigation water application in accordance with the biological and physiological needs of plants. Poorly designed systems have shorter life span and do not provide the necessary soil- water- nutrient environment for optimum crop growth resulting in poor yield, reduced quality, or high cost per unit of production when compared to well-designed systems (Smajstrla et al, 2002). Thus, improving irrigation system using proper system design with good field water application practice is very important.

The assessment of actual field performances irrigation systems is essentially required during operation to indicate any defects regarding system operation, water distribution and water losses. Solomon, (1979) reported that, the evaluation of the system performance in the field will indicate both the location and magnitude of water losses that are occurring, as well as, how to improve the irrigation system and its operation. Awulachew et al. (2010a) reported that assessing irrigation performance and improving low-performing irrigation system requires incorporating applied research on irrigated agriculture. The present study concentrates on assessment of actual performance of sprinkler irrigation system at Arjo-Didessa sugar project and initiated to understand the main factors or variables affecting the existing sprinkler system. Assessing the actual performance and identification of gaps plays vital role in enhancing and to improve existing system and irrigation sector of the country.

1.2. Statement of Problem

The ability of the irrigation system to apply water uniformly and efficiently to the irrigated area is a major factor influencing the agronomic and economic viability of the production system. According to FAO, (1996), Poor management of available water for irrigation, both at system and farm level has led to a range of problems and further aggravated water availability and has reduced the benefits of irrigation investments.

Arjo-Didessa sprinkler irrigation system is in operation for the last 15 years since 2006. The project after the start of cane plantation activity, it faces problems related to field irrigation practice and management. Many authors wrote that crop water requirements are varies with crop growing stage, month and climate, but the existing project practices uniform/fixed irrigation schedule. A practice of uniform irrigation scheduling without considering the soil type, growing month, and stage of crop growth causes moisture stress and may reduce the expected cane yield per hectare.

Additionally, According to field visit done by walking in existing irrigation project site, Leakage of field pipes connections, breakage of system components, noisy pumps, blocked screens/filters, blocked and broken of sprinklers and pressure gauges and poor service and maintenance also observed. Due to these problems off-target irrigation and ponds, under watering in some fields, some areas gets satisfactory water and over watering in most fields, thus, as a result under developed and non-uniform cane growth, showing yellow

color, wilting and retarding growth are observed. Thus identifying the common problem and improving system performance is very important; this needs the special attention of actual performance assessment by researcher and irrigation professionals.

So far in Arjo-Didessa sugarcane Irrigation project, there was no previously critical research done on the actual performance of the existing sprinkler irrigation system regarding the above stated irrigation problems based on the recommended standard procedures. Therefore, this study was conducted with broad objectives to assess existing practices and estimate field water application performances of Arjo-Didessa sprinkler irrigation system. In this study the level of existing actual sprinkler irrigation performances was evaluated and compared with the targeted potential performance level during design period. The common problems for existed gap between its actual and potential were identified with potential recommendations for improving the performance.

1.3. Objectives

1.3.1. General Objectives

The main objective of this study was to assess the existing sprinkler irrigation system installed in Arjo-Didessa sugar factory irrigation scheme.

1.3.2. Specific objectives

More specifically, this study addressed the following specific objectives:

- ✚ To assess the existing irrigation practices and performance of sprinkler irrigation system
- ✚ To determine in-field water application efficiencies and uniformities of the existing sprinkler irrigation system
- ✚ To identify gaps and the cause of low performance of the existing sprinkler irrigation system

1.4. Research Questions

- ✓ What is the extent of performance of the existing sprinkler irrigation in Arjo-Diddessa sugar factory irrigation system in terms of its potential and existing practices?
- ✓ What is the level of the system in terms of water application uniformity and efficiency?
- ✓ What are the limiting factors which affect potential performances of the system?

1.5. Significance of study

The study was significant for the improvement of irrigation practices of Arjo-Didessa irrigation project and has a great contribution both to the irrigation users and system managers. This document provides useful information on appropriate sprinkler irrigation operation and system design, and improvements for efficient water use. The evaluation of the performances of the irrigation system based on identifying the problems associated with water ineffective use and its remedial solutions will help in planning the project management and overall productivity of the irrigation scheme. The study also provides important guidelines for the other similar sugar development projects on relevant irrigation practicing facts farm areas. Furthermore, this study will be baseline information for the future studies on irrigation system in other similar areas.

1.6. Scope of the Study

The study was focus the assessment of sprinkler irrigation system performance installed at Arjo-Didessa sugar factory and it encompasses evaluating the performance in terms of water application efficiency and uniformity. The study limited on some of different parameters for evaluation of existing irrigation system, parameters like application rate, coefficient of uniformity, distribution uniformity, and potential application efficiency of low quarter. The study includes irrigation scheduling, identification of gaps for efficient resource utilization of sprinkler irrigation system.

2. LITERATURE REVIEW

2.1. Overview of Irrigation System

Irrigation is an artificial application of water to the land, to provide adequate moisture in accordance crop water need for crop production (Solomon, 1990). FAO, (1995) also defined irrigation as, the application of water to agricultural crops by artificial means, designed to permit farming in arid and semi-arid regions and helped to increase agricultural production in developing countries. Irrigation includes the development of the water supply, the conveyance system, the method of application, and the waste water disposal system, along with the necessary management to achieve the intended purpose (USDA, 1984). These therefore underline the importance of irrigation in attaining crop production targets. Thus irrigation development particularly will be an important component of diversification and expansion strategy to strengthen food security in the future.

However, irrigated agriculture can be considered as sustainable if it is every time achieves high productivity without damaging the physical and social environment. If wise utilization and management strategies are not properly implemented; irrigation projects caused serious damage to the environment like salinity and water logging, fertile soil has been removed by flooding and erosion. Thus, the future base of the existing and the coming generation, particularly the land and water resources have been at risk alarmingly (Solomon, 2016). Therefore, the accessibility of irrigation water is not alone significant for reliable and sustainable food security development, poverty reduction and reducing poor crop yield per hectare.

Management activity is a major component of success for any irrigation scheme (Depeweg, 1999). It is important to manage soil moisture to promote desired crop response, minimize irrigation induced erosion, decrease non-point source pollution of surface and groundwater resources, manage salts in the crop root zone and manage air, soil or plant micro-climate (ISUST, 2006). According to U.S Bureau of Reclamation (2005), “Irrigation Water Management” means management of irrigation water on the farm through the act of timing and regulating irrigation water application in a way that will satisfy the water requirement of the crop without washing water, soil and plant nutrients and degrading the soil resource.

According to USDA (1999), irrigation methods are categorized under two broad system types: gravity or surface, and pressurized systems which are characterized by the mode of transport of the water onto the point of application. Surface irrigation is the process of introducing a stream of water at the head of the field and allowing gravity to spread the flow over the surface throughout the field. In a pressure irrigation method, the water is given to soil through a network installation consisting of closed pipes, fittings and other devices properly designed to supply water under pressure from the source to the fields. Pressurized methods further can be categorized as sprinkler irrigation with water delivered through nozzles, and drip irrigation with water delivered through tubes and emitters.

2.2. Sprinkler Irrigation System

In a sprinkler system, water is applied to the soil or crops in the form of spray, somewhat as an “artificial rain” through a pipe network to sprinklers nozzles or jets. As such the sprinkler irrigation is also sometimes known as overhead irrigation (Yoshida et al, 2004). Sprinklers irrigation, broadly categorized into continuous-move systems and set-move system (Keller and Bliesner, 1990). In set systems, the sprinklers are stationary while irrigating, whereas while in case of continuous-move systems, sprinklers move in either straight or circular paths. The major types of continuous-move systems are center-pivots, traveling-gun or boom sprinklers, and linear move (sometimes referred to as lateral move). The set-move system is further sub-divided into portable and periodic-move systems.

The major types of periodic-move systems are hand-move later, end-tow, and side-roll laterals; side-move laterals, with or without trail lines; and gun and boom sprinklers (USDA, 2016). In this study area, the periodic hand-move lateral sprinkler system is used, the risers connected using plastic hose and laterals are moved manually between irrigation sets. Sprinkler head is overhead fully rotated impact type attached with two nozzle size.

In Ethiopia Sprinkler Irrigation is practiced to a limited extent for growing horticultural crops around Ziway, in Tana Beles, Wonji showa irrigation project and for development of large irrigated sugarcane plantation for Fincha’a Sugar Factory and Arjo-Didessa sugar development projects. Now days it has been becoming the major component in supplementing the natural rainfall for food and industrial raw material production and for production of market based agricultural products, such as flower farms owned by private sectors (Negash, 2009).

2.2.1. Advantages of Sprinkler Irrigation Systems

The sprinkler irrigation can be used for all the crops except rice and jute and for all the soils except very heavy soils with very low infiltration rates (Modi, 2000). The most advantages of sprinkler irrigation system were summarized as according to (Keller and Bliesner, 1990; and NRSC, 2016):

- Water savings systems with high application efficiency; Small, continuous streams of water can be used effectively and light, frequent watering can be applied efficiently.
- Uniform application of water is attained and high application efficiency.
- Adaptability to various land topographies, soils with intermixed textures, and the amount of water applied because of the wide ranges of sprinkler discharge available.
- Labour requirements which reduce relative to the system being employed; from hand-moved to fixed systems down to automated systems.
- Surface runoff and erosion can be eliminated
- Achieving other special tasks such as modifying/controlling extreme weather conditions, supplementing erratic rainfall and leaching of salts from saline soils and,
- No land leveling is required, thus land preparation and labour cost is reduced...etc.

2.2.2. Limitations of Sprinkler Irrigation Systems

Sprinkler irrigation has also its own limitation, Relatively high initial costs, compared to surface irrigation methods, windy and excessively dry locations appreciably lower sprinkler irrigation efficiency, wind may distort the sprinkler pattern (it affects the water application uniformity), clogging of sprinklers due to unclean water and entrance of debris, heavy soils with poor intake capacity cannot be irrigated efficiently (Modi, 2000; NRSC, 2016). Irrigation systems are normally designed to satisfy equipment specifications provided in manufacturers' charts. However, information presented in manufacturers' charts is obtained under controlled or still wind conditions and is based on average operating conditions for relatively new equipment. The discharge rates and precipitation rates, and therefore performance, change over time as equipment ages and components wear due to rust (Keller and Bliesner, 1990).

Sprinkler irrigation designs that neglect prevailing field/crop characteristics and environmental factors can lead to poor system performance. Consequently, equipment should be field calibrated regularly to ensure that application rates and uniformity are

consistent with values used during the system design and those given in manufacturers' specifications. Careful design, management and proper practice must be exercised to obtain the high potential performance from sprinkler irrigation and for realizing the benefits of sprinkler irrigation over the system lifetime. Hence, regular evaluation of irrigation systems is of essence to the maintenance of the systems for optimal performance at the designed parameters (Ascough and Kiker, 2002).

The objectives of any irrigation system are to deliver irrigation water in the right amount (size, frequency, and duration), at the right place, at the right moment. But, irrigation system has inherent application limitations that make field calibration critical for efficient use of water resources. Irrigation water management is vital for determining and controlling the volume, frequency, and application rate of irrigation water in a planned and efficient manner. Good sprinkler irrigation requires an understanding of soil-water-plant relationships and that irrigation timing and amount depends on soil water holding capacity, weather, and crop growth progress (Ascough and Kiker, 2002).

2.3. Estimation of Crop water requirements (CWR) and CROPWAT Model

2.3.1. Reference Evapotranspiration (ET_o)

The evapotranspiration rate from a reference surface, not short of water, is called the reference evapotranspiration (ET_o). FAO, (1980) define reference evapotranspiration as, the rate of evapotranspiration from an extended surface of 8 to 15 cm tall green grass cover of uniform height, actively growing, completely shading the ground and not short of water. The only factors affecting ET_o are climatic parameters. Consequently, ET_o is a climatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors (Allen et al., 1998).

There are a number of methods to estimate ET_o. However, the methods vary based on climatic variables required for calculation. Direct measurement in the field is laborious and time consuming. Consequently a large number of estimation methods have been developed. The four most widely known and used are the Blaney-criddle, Radiation, Penman and Pan Evaporation methods. Among them the Penman method recently further refined as modified FAO Penman Monteith method is generally recommended as the sole standard method. It is a method with strong likelihood of correctly predicting ET_o in a

wide range of locations and climates. It also has provision for application in data-short situations and best for mean estimates over short periods of about 10 days (FAO, 1998). The use of older FAO or other reference ET methods is no longer encouraged. The FAO Penman-Monteith method requires radiation, air temperature, air humidity and wind speed data (Allen et al., 1998) as defined equation 2.1;

$$ET_o = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1+0.34u_2)} \dots\dots\dots Eqn (2.1)$$

Where; ETo = reference evapotranspiration [mm day-1], Rn = net radiation at the crop surface [MJ m-2 day-1], G = soil heat flux density [MJ m-2 day-1], T = mean daily air temperature at 2 m height [°C], u2 = wind speed at 2 m height [m s-1], es = saturation vapour pressure [kPa], ea = actual vapour pressure [kPa], es - ea = saturation vapour pressure deficit [kPa], Δ = slope vapour pressure curve [kPa °C-1], and γ = psychrometric constant [kPa °C-1].

2.3.2. CROPWAT Model

CROPWAT 8.0 is a decision support computer program tool based on a number of equations, developed by the Land and Water Development Division of FAO, which is designed to calculate CWR, effective rainfall, irrigation scheduling, and irrigation requirement (IR). The program includes/requires monthly inputs of local climate and rainfall data coupled with general data for various crop features and soil properties to calculate ETo, effective rainfall and allows the development of irrigation schedules for different management conditions and the computation of scheme water supply for different crop patterns (FAO, 2018). The advantage of using the CROPWAT model as a tool for assessing crop water use is that it is simple and easy to use, and its data requirements are less intense than those of other dynamic models such as ARCU, WOFORST and DSSAT. According to Vozhehova., et.al, (2018), the CROPWAT 8.0 software application is an interesting and modern tool for agricultural water management.

2.3.3. Crop Evapotranspiration (ETc)

The ETc differs distinctly from the (ETo) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. FAO (1984) defined crop water requirements as ‘the depth of water needed to meet the water loss through

evapotranspiration of a crop, being disease-free, growing in large fields under non restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment. The values of CWR and Crop Evapotranspiration (ETc) are identical, whereby ETc refers to the amount of water lost through evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss.

In short, the crop water requirement (crop evapotranspiration, ETc) is calculated by multiplying the reference evapotranspiration, ETo, by corresponding crop coefficient, Kc. (Allen et al., 2011).

$$ETc = ETo * Kc \dots\dots\dots (2.2)$$

Usually, the determination of crop coefficient (Kc) involves the knowledge of crop type and date of sowing, length of the total growing season and the durations of initial, crop development, mid-season and late season stages of the crop along with climatic data such as wind speed and humidity. The Kc factor serves as an aggregation of the physical and physiological differences between crops and the reference definition. FAO Irrigation and Drainage Paper No. 24 recommended different Kc value for sugarcane depend on varying relative humidity, crop age and growth stage, as summarized in table 2.1

Table 2.1 Sugarcane Crop coefficient (Kc) value (source FAO, 1992)

Cane age		Growth stage	RH>70%		RH<20%	
12 month	24 month		Light to mod. wind	Strong wind	Light to mod. wind	Strong wind
0-1	0-2.5	Planting to 0.25 full canopy	0.55	0.6	0.4	0.45
1-2	2.5-3.5	0.25-0.5 full canopy	0.8	0.85	0.75	0.8
2-2.5	3.5-4.5	0.5-0.75 full canopy	0.9	0.95	0.95	1.0
2.5-4	4.5-6	0.75 to full canopy	1.0	1.1	1.1	1.2
4-10	6-17	Peak use	1.05	1.15	1.25	1.3
10-11	17-22	Early senescence	0.8	0.85	0.95	1.05
11-12	22-24	ripening	0.6	0.65	0.7	0.75

The Kc concept was introduced by Jensen (1983) and is widely discussed and refined by the FAO in its Bulletin-56 Irrigation and Drainage Paper, (Allen et al., 1998). The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (Kc).

2.4. Determining Irrigation Requirement

2.4.1. Effective Rainfall

In determining irrigation need, the effective rainfall is subtracted from crop evapotranspiration. According to USDA (1967), effective rainfall refers to that portion of rainfall that can be stored in the effective crop root zone and used by plants. It does not include rainfall lost through runoff (RO) and deep percolation (DP). Rainfall for each period will vary from year to year and therefore, rather than using mean rainfall data, a dependable level of rainfall should be selected. FAO (1998) defined dependable rainfall as the amount of rainfall which can be depended upon in 1 out of 4 or 5 years corresponding to a 75% or 80% probability of exceedance and representing a dry year. Monthly dependable rainfall, as well as rainfall in wet, normal and dry years, defined as the rainfall with a probability of exceedance of 20, 50 and 80% respectively, representing a wet, normal and dry year were evaluated. These values are useful for the design of the irrigation system capacity, programming of irrigation supply and simulation of irrigation management conditions (Doorenbos and Pruitt, 1977). The dependable rainfall (80%) is normally used for the calculation of storage reservoir capacity and main irrigation canals.

To calculate rainfall probabilities, a minimum of (15 - 30) year's rainfall record range is required (Doorenbos and Pruitt, 1977). Estimates of the respective rainfall data were obtained by computing and plotting probabilities from the rainfall records using the simple ranking method as described by Doorenbos and Pruitt (1977). CROPWAT version 8.0 is the best model for estimation of effective rainfall from data input of estimated dependable rainfall. To account for the losses due to runoff or percolation, a choice can be made of one of the four methods given in CROPWAT 8.0 (Fixed percentage, Dependable rain, Empirical formula, USDA Soil Conservation Service). The United States Department of Agriculture (USDA) soil conservation service (SCS) method is satisfactory and can be applied for field use after verification in a given situation (FAO, 2009).

2.4.2. Net irrigation requirement

Irrigation requirements (IR) refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements (FAO 2010). If irrigation is the sole source of water supply for the plant, the irrigation requirement will always be greater than the crop water requirement to allow for inefficiencies in the

irrigation system. If the crop receives some of its water from other sources (rainfall, water stored in the ground, underground seepage, etc.), then the irrigation requirement may be considerably less than the crop water requirement

According to the same report, water requirement of sugarcane depends on the agro-ecological conditions, cultivation practices adopted and crop cycle (12-24 months) and it varies from about 1300 mm to 2500 mm evenly distributed over the growing season. Abdel Wahab (2005), reported that the water required by sugarcane increased gradually with plant growth stage, and the quantities of irrigation water required in the crop root zone amounted to 17220 and 20570 m³/ha/season for ratoons and plant cane, respectively. Net irrigation requirement is derived from field balance equation;

$$\text{NIR} = \text{ETc} - (\text{Pe} + \text{Ge} + \text{Wb}) + \text{LR} \dots\dots\dots\text{Eqn. (2.3)}$$

Where, NIR= is net irrigation requirement, ETc= crop evapotranspiration, Pe= effective rainfall (mm), Ge= ground water contribution from water table (mm), Wb= soil water used, and LR= leaching requirement. The contribution from the groundwater table is determined by its depth below the root zone, the capillary properties of the soil and the soil water content in the root zone. Very detailed experiments will be required to determine the groundwater contribution under field conditions (Doorenbos and Pruitt, 1977)

2.5. Irrigation Scheduling

Irrigation scheduling is often defined as, the science of determining “when to irrigate” and “how much” of water to apply. The purpose of irrigation scheduling is to determine the exact amount of water to apply to the field and the exact timing for application. The major objective of irrigation is to produce optimum economic return through increased productivity by maximizing water use efficiency while reducing irrigation costs (Shock, 2003).The amount of water applied is determined by using a criterion to determine irrigation need and a strategy to prescribe how much water to apply in any situation. Hence the importance of irrigation scheduling is that it enables the irrigator to apply the exact amount of water to achieve the goal. This increases irrigation efficiency.

According to Chala., (2018), seasonal and monthly crop water requirement and irrigation water requirement of sugarcane vary from month to month with growth stages, harvesting and first watering month. Applying fixed amount of irrigation water at a fixed frequency

throughout the growing season to soils having different water holding capacities possibly lower water use efficiency and decline yield and make irrigation scheduling (depth of application, irrigation period and irrigation interval) more complex in terms of practicability and probably incur additional cost. Proper irrigation scheduling as per soil water holding capacity, crop water demand based on growth stages, especially, during critical stages of water requirement of sugarcane crop, is important for efficient use of available water and improved yield.

2.5.1. Depth of Irrigation (Dn)

Depth of irrigation application is the depth of water that can be stored within the root zone between field capacity and the allowable level the soil water can be depleted for a given crop, soil and climate. It is the fraction of TAW that a crop can extract from the root zone without suffering water stress and it is equal to the readily available soil water over the root zone (James, 1988). The moisture deficit (d) in the effective root zone is found out by determining the field capacity moisture contents and bulk densities of each layers of the soil. Total available water (TAW) is the amount of water that a crop can extract from its root zone, and its magnitude depends on the type of soil and the rooting depth. To determine the total available water (TAW, mm) in each soil profile, considering one value of bulk density for each of the soil types. The following equation was used for this purpose (Walker and Skogerboe, 1987; Allen et al, 1998):

$$TAW = 10 \sum_{i=1}^n (FC_i - PWP_i) * \rho_i * Drzi \dots \dots \dots \text{Eqn. (2.4)}$$

$$D_n = RAW = TAW * P \dots \dots \dots \text{Eqn. (2.5)}$$

Where: TAW: Total available water (mm), FC_i = Moisture content of soil horizon i at field capacity (%); PWP_i = Moisture content of soil horizon i at wilting point (%); ρ_i = bulk density of the soil horizon i (g/cm³), Drzi: Depth of soil horizon i (cm) and, n = number of layers in the root zone. Where, D_n = Net depth of application in (mm) RAW = the readily available soil water in the root zone [mm], and P is allowable depletion factor (%).

Previous studies of Habib (2004) and Solomon (2010) has considered the maximum rooting depth of 1.0 meter for Metahara sugar estate to calculate water application depths in each soil types of the estate. Similarly, in their study the maximum rooting depth of 1m and the optimum factor of depletions for sugarcane was in between 0.50 to 0.65 used

which was also proposed by Booker Tate (2009) for Metahara sugar estate soils, and in agreement with recommended 0.55 by Rao (1990) and 0.65 by FAO (1979)

2.5.2. Irrigation Interval (II)

Sugarcane is one of the most water demanding crops after rice. It is frequently criticized for its high water consumption. Frequency and depth of irrigation should vary with growth periods of the cane (Michel, 2008; FAO, 2010). Irrigation interval is defined as the frequency of applying water to a particular crop at a certain growth stage and is expressed in days. According to Mishra and Ahmed (1990), irrigation interval is calculated by:

$$II = \frac{AMD \text{ or } Dn}{ETc} \dots \dots \dots \text{Eqn (2.6)}$$

Where, II is irrigation interval in days, AMD = allowable moisture depletion which is similar to net depth of application or readily available moisture (mm); ETc = daily water use or CWR, mm/day,

$$\text{set time} = \frac{Dg}{Ig} \dots \dots \dots \text{Eqn (2.7)}$$

Where; Set time in hour, Dg is gross application depth (mm), Ig is sprinkler application rate (mm/hr). Dg is calculated as a ratio of net depth of application to sprinkler actual application efficiency.

2.6. Performance Assessment of Sprinkler Irrigation System

Aberenethy (1986) describes the sprinkler irrigation performance as the degree to which a system achieves its objectives; the effectiveness of the physical system and operation decisions to deliver irrigation water from a water source. Maheshwari, (1993a) also defined the performance of a system as its efficiency, understood as the relation between actual results versus the expected results of the system (inputs and outputs). An efficient sprinkler system is a combined result of proper system design, careful operation, and timely maintenance, and depends on its actual performance at field condition. Thus, actual on-farm irrigation systems and operations need to be measured to determine the potential performance of the systems as designed and the actual performance that is obtained with present management (Merriam et al., 1983).

According to USDA, (2016), the sprinkler irrigation system is designed based on the expected potential performance, before installation, based on an analysis of a proposed

system layout and configuration, the calculated design performance also presupposes correct operating parameters and maintenance of the system. In contrast, the actual performance is measured in the field on an existing sprinkler system based on the current actual operating condition, for the purpose of comparisons and the identification of changes that could be made to improve the system performance. The two major approaches to performance evaluation consider how well service is being delivered and the outcomes of irrigation in terms of efficiency and productivity of resource use. This helps to identify why a scheme is performing in a particular way, which in turn imply means of improvement (Clemmens and Molden, 2007).

According to Molden et al., (1998) performance is assessed for a variety of reasons: determining the elements which cause trouble to the system, to assess the general health of a system, to better understand determinants of performance, to understand cost effectiveness and financial viability of the system, to compare the performance of a system with others or with the same system over time, to improve system operations and management. Bos et al., (2005) also describes the purpose of performance evaluation is to achieve an efficient and effective use of resources by providing relevant feedback to the scheme management at all levels, and to ensure that the system functions as described in the design report and whether the system was installed according to plan. Performance evaluation result provides the information required for design, model validation, and then suggest improvements to the operation of the system and management practices. It assists the system management or decision makers in determining whether performance is satisfactory and, if not, which corrective actions need to be taken in order to improve the situation (Julaia, 2009).

2.7. Performance Indicators of Sprinkler Irrigation system

The monitoring of the performance of sprinkler irrigation systems requires the measurement of system variables and the calculation of performance indicators. To assess the performance it is important to confirm the indicators selected in respect to the objectives established for that irrigation system. A good indicator tells a manager what current performance of the system is, and, in combination with other indicators, may help to identify the correct course of action to improve performance within that system (Clemmens and Molden, 2007). According to Merriem et.al (1999), there are three performance parameters which are important when reporting on the evaluation of an

irrigation system. These are adequacy of irrigation, irrigation efficiency and application uniformity. All of these parameters are discussed in the following sections.

2.7.1. Irrigation efficiency

The principal objective of evaluating sprinkler irrigation systems is to identify management practices and systems that can be effectively implemented to improve the irrigation efficiency. Wolters and Bos (1989) state that; efficiency is generally defined as the dimensionless ratio of output divided by input. Fairweather et al., (2003) concur with this definition and cite Barret Purcell and Associates (1999) as correctly pointing out that efficiency is in fact a dimensionless term obtained by dividing values which have the same units. However, in the context of irrigation there is much confusion with respect to the definition of efficiency.

This is due to the fact that efficiency can mean different things to different people. There are publications which document the evolution of efficiency terms and performance concepts used in the irrigation industry (Wolters and Bos, 1989; Fairweather et al., 2003; Ascough, 2004) and a wealth of publications reviewing efficiency terms which researchers believe are relevant within the field of irrigation (Heerman et al., 1990; Clemmens et al., 1995; Burt et al., 1997; Pereira, 1999; Purcell and Curry, 2003; Page Bloomer and Associates, 2006).

The “confusion” surrounding the efficiency terms has lead to some countries and international institutions, to attempt to clarify and standardize the relevant terms used. One of the most comprehensive initial attempts was carried out by the American Society of Civil Engineering (ASCE) Task Committee on Defining Irrigation Efficiency and Uniformity, which published a variety of papers on the subject, clarifying common points of confusion and proposing methods where by the accuracy of numerical values of the performance indicators can be assessed (Burt et al., 1997). This committee favored the irrigation water balance approach, which determines the fate of the various fractions of the total irrigation water applied, by defining terms such as consumptive and non-consumptive use, beneficial and non-beneficial use and also reasonable.

Although there are variant definitions of irrigation efficiency, they can be grouped into three main categories: irrigation efficiency, application efficiency and distribution

efficiency (Landwise Inc., 2006). The International Commission on Irrigation and Drainage (ICID) is currently drafting a paper titled “Efficient Irrigation; inefficient communication; flawed recommendations”, which also seeks to propose a framework on consistent terminology and definitions (ICID, 2006).

Burt et al., (1997) stated that efficiency terms are, in principal, difficult to evaluate rapidly and require a detailed inventory and quantification of the ultimate destinations and uses of applied irrigation water that was applied. In order to overcome this difficulty, single event efficiency is described which enables the performance of an irrigation system in the field to be assessed by how efficiently the system satisfies a perceived need.

According to Landwise Inc, (2006), irrigation efficiency relates to the fraction of water applied to a field that is really utilized beneficially by the crop. The measurement of ‘beneficial use’, however, is only attainable on long term basis rather than a single event. So in defining ‘beneficial use’ the boundary area is very critical. This single event efficiency is known as the Application Efficiency (AE), which is based on the concept of meeting a target irrigation depth for that event, as interpreted by Burt et al., (1997). The Burt et al., (1997) equation is defined in Equation 2.8.

$$AE = \frac{\text{average depth of irrigation water contributing to TARGET}}{\text{Average depth of irrigation water applied}} \times 100 \dots \text{Eqn (2.8)}$$

The application efficiency provides a general indication of how well an irrigation system performs its primary task of delivering water from the conveyance system to the crop. Samir M., (2003) stated that, Irrigation efficiency is influenced by the system design and management, which can be divided into two, I) water losses which are predominately affected by management; and II) Water lost in the form of non-uniform distribution over the field, which is predominately affected by system design.; A non-uniform distribution not only can deprive portions of the crop of needed water, but, furthermore, can over-irrigate portions of a field, leading to water-logging, plant injury, salinization, and transport of chemicals to the ground water (Solomon 1983). Thus, how well the applied water is used, is the important issue of how uniformly this water is distributed to the crop or the soil.

Total irrigation efficiency should be evaluated in terms of the movement of water from its source to the root zone of the irrigated crop. Sprinkler irrigation industry indicates that

10% to 25% of the irrigation water leaving the sprinkler is lost between the sprinkler nozzle and the root zones (Kohl, Kohl, and Deboer, 1987). This loss is attributed to a combination of wind drift and spray evaporation, which together account for the application efficiency.

It must be noted that the potential application efficiency(AE) for sub-surface drip can be quite difficult to determine using standard evaluation methodology; however, studies have shown that on average, AE values of over 80% can be regularly attained. This can be attributed to the fact that water can be applied by the system, to a specific point for a specific period of time and therefore only applies water when needed (Magwenzi, 2000).

2.7.2. Adequacy of Irrigation

Adequacy (AD) is the ratio of delivered amount of water to the required amount (Cuenca, 1989).The fraction of the field that receives more water than the net irrigation requirement is said to be over irrigated. The remaining fraction of the field is under-irrigated. The depth of applied water in excess of the net irrigation requirement goes to deep percolation.

For a single irrigation event it is appropriate to include a parameter which determines how well the required depth of water has been satisfied. In many cases managers and researchers are interested in the low-quarter depth just equaling the required depth, this is termed the low-quarter adequacy (ADlq), and is given by (Burt et al., 1997):

$$ADlq = \frac{dlq}{dreq} X100 \dots \dots \dots Eqn (2.9)$$

Where: dlq: low-quarter distribution uniformity, Dreq:-is the required depth for all beneficial uses [mm]. Ascough (2004) states that with this definition, if ADlq < 1 indicates under-irrigation, and an ADlq > 1 indicates over-irrigation.

Another form of interpretation of adequacy is the graphical concept and can be defined as the percentage of the field that is fully irrigated. Figure 1 illustrates the concept (English, 2000; King *et al.*, 2000; Magwenzi, 2000). The shape and slope of Figure 2.1 is determined by the uniformity of applied water. The more uniform the application the more level of the curve. As more water is applied more of the curve will be above the irrigation requirement

line, and so the adequacy will be higher. This format can be used to examine the relationship between adequacy, efficiency and uniformity (English, 2000).

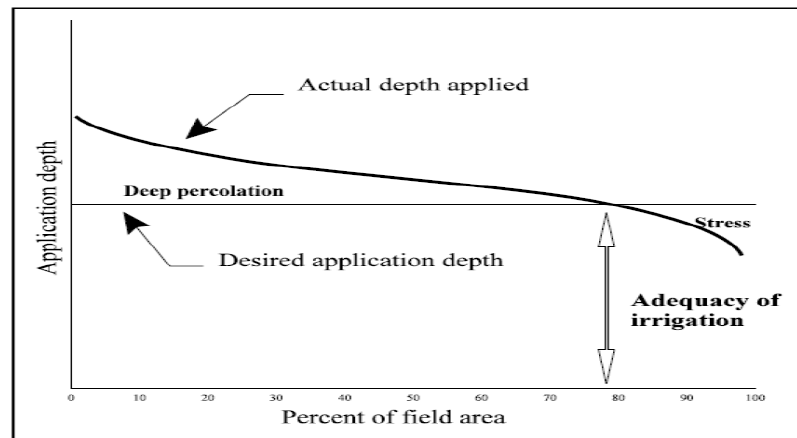


Figure 2.1 Spatial distribution of applied water (English, 2000)

Megersa (2006) stated that on his research title of evaluating the adequacy performance of the dragline sprinkler irrigation system at Finchaa Sugarcane Plantation, the adequacy of irrigation performance was measured actually at field condition considering three operating hydrant pressures (4.0, 4.5 and 5.0 bars) and two sprinkler nozzle sizes (2.4mm x 4.4mm and 2.4mm x 4.8mm). The authors has concluded that the dragline sprinkler irrigation system was used excess irrigation water application more than the crop net irrigation requirement and soil moisture deficit, especially for the 2.4mm x 4.8mm nozzles sprinkler at all pressure ranges considered, this consequence leaching of soluble nutrients and rise of groundwater. The later might lead to drainage problems, which requires the construction of expensive drainage.

According to Solomon, (1990), inadequate water results in high soil moisture tension, plant stress and reduced crop yields, whilst excess water may also reduce crop yield through mechanisms such as leaching of plant nutrient s, increased disease incidence or hindered growth of commercially valuable parts of crops.

2.7.3. Irrigation Uniformity

Irrigation uniformity is how evenly water is distributed to different areas of the field. Solomon (1992) wrote that irrigation uniformity actually refers to the variation, or non-uniformity in the amounts of water applied to locations within the irrigated area. Therefore,

(Kelley, 2004 as cited in Osei, 2009) asserts that irrigation uniformity is a concept that all areas within an irrigated field received the same amount of water.

Keller and Bleisner (2000) noted that the uniformity of sprinkler irrigation is a central design goal. Since no irrigation system can apply water precisely to the entire field, thus it becomes necessary to estimate the uniformity of water application in order to assess the system performance. According to (Dalton and Raine, 1999); an important component of the evaluation of in-field irrigation system performance is the assessment of irrigation uniformity. Irrigation uniformity is thus an important management factor necessary for achieving high irrigation efficiency. It has been found that raising the irrigation uniformity from 70% to 90% allows half as much area to be irrigated adequately with a given volume of water. As a result, irrigation uniformity can be a good indication of potential irrigation efficiency, and is easier to quantify and measure (Baum et al., 2005). The two most common method of expressing quantitative measures of Irrigation Uniformity are the coefficient of uniformity (CU) and distribution uniformity (DU).

2.7.3.1. Christiansen's Uniformity Coefficient (CUC)

Irrigation systems should apply water in the most efficient way possible to prevent unnecessary losses and water wastage. In order to achieve this, the uniformity coefficient with which the irrigation system applies water will have to be high (Burt et al., 1997). Coefficient of uniformity is a measure of non-uniformity of water application for a given sprinkler head, nozzle type, operating pressure and sprinkler spacing combination. It is measurable index of the degree of irrigation uniformity obtainable for any size of sprinkler under given conditions (Solomon, 1992).

Specific quantitative study of sprinkler irrigation uniformity started with the work of Christiansen in 1942. Dalton and Raine (1999) found that a wide range of irrigation uniformity coefficients are used when evaluating performance of irrigation systems and that one of the basic measures of any irrigation system's performance is Christiansen's uniformity coefficient (CU). The CUC is computed from field observations of the depths of water caught in open cans placed at regular intervals within a sprinkled area. This coefficient measures the average deviation from the mean application depth. Hence, for a perfectly uniform application the CU is 100%, which is impossible to achieve on a field scale due to equipment deficiencies and limiting environmental factors.

The mathematical relationship for CU as proposed by Christiansen (1942) is;

$$CU = \left(1.0 - \frac{\sum_{i=1}^n |x_i - \bar{x}|}{n\bar{x}} \right) * 100 \dots \dots \dots \text{Eqn (2.10)}$$

Where, x_i = depth of water in catch can, mm, \bar{x} = mean depth caught in mm, and n = number of sample (catch can).

2.7.3.2. Distribution Uniformity (DU)

Distribution uniformity is usually defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002). This uniformity measure is also called low-quarter distribution uniformity and it is often used to quantify irrigation uniformity of surface systems (King *et al*, 2000). The DU coefficient takes into account the variation of can readings from the mean but concentrates on the lowest 25% of readings. According to Pereira et al., (2002), the DU of an irrigation system depends both on the system characteristics and on managerial decisions. It gives an indication of the magnitude of the uneven distribution and can be defined as the percent of average application amount in the lowest quarter of the field. In order to determine whether the system is operating at acceptable efficiency, DU (of low quarter) will be calculated. Merriam and Keller (1978) defined distribution uniformity coefficient:

$$DU = \left(\frac{x_{avlq}}{x_{av}} \right) * 100 \dots \dots \dots \text{Eqn (2.11)}$$

Where, x_{avlq} is average irrigation depth applied to the driest or lowest quarter of all the can readings, and x_{av} is the average depth applied across the all the can readings.

Wilson and Zoldoske, (1997) stated that the disadvantage of the DU coefficient is that it treats under-watering as the critical element but does not indicate how big or severe the dry spot really is.

There are various research works conducted by different researchers on uniformity of sprinkler irrigation. According to those studies sprinkler uniformity is generally affected by the combination of wind speed/direction, operating pressure and sprinkler spacing, in the case of set-move sprinkler system. According to Wu and Gitlin (1983), uniformity coefficient is a design criterion for sprinkler irrigation and is affected mainly by the spacing of laterals, the lateral move and the local prevailing wind speed. A desired value of

uniformity coefficient is achieved with a well-designed irrigation system where the sprinklers operating pressure and discharge rate are maintained at the manufacturer's recommendations.

King *et al.*, 2000 wrote that, CU values of 80-90% is attainable for set-move systems which are properly designed and maintained, operating under moderate wind speeds less than 16km/h. It has been found that CU values as low as 60% can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions. Smith (1995) as in Dalton and Raine (1999) also indicated that the uniformity of application is acceptable for CU values greater than 84%.

Keller and Bliesner.,(2000) state that, DU of 85% or greater is considered excellent, 80% is considered very good, 75% is considered good, 70% is considered fair, and 65% or less is considered poor and unacceptable (It is generally accepted that sprinkler systems should have a minimum DU of 75%. In general CU of at least 85% is recommended for delicate and shallow-rooted crops such as potatoes and most other vegetables, whilst values between 75% and 83% is acceptable for deep-rooted crops like alfalfa, corn, cotton and sugar beets. In cases where chemicals are applied through the irrigation water, the CU should be at least 80%. According to (Huck 2000 as cited in Osei, 2009), any sprinkler irrigation system with distribution uniformity (DU) of 85%, in the field, is excellent and acceptable. This means that even the best sprinkler irrigation system may begin with some 15% inefficiency.

Dereje (2012) conducted a study on the title evaluation of the in-field performance of dragline sprinkler irrigation at WSSF. The study outcome shows the value of CU under different combinations was found to be ranges from 59% to 86% for single sprinklers and 71.7% to 87% for overlap sprinklers, and also the DU was found to be 43% to 78% and 56% to 82% for single and overlap tests, respectively. The author has concluded that the system was below designed capacity and to improve the system performance it should be maintained the best combination of the operating pressure and nozzle sizes.

Fikadu (2016) conducted a study on the title of evaluated the dragline sprinkler irrigation system at Beles Sugar Development Project. The study result has shown that the average result of DU and CU were obtained at 3 and 2.5 bars at existing sprinkler spacing of 18m by 18m was 53% and 63%, respectively. The study has concluded that the dragline

sprinkler irrigation was not working full designed capacity and the actual application uniformity was out of the acceptable range which current operating hydrant pressure is obtained less than 4.0 bars.

Montero et al (2002) stated that low values of CU are usually indicators of a faulty combination of factors such as nozzle sizes, working pressure and spacing of Sprinklers. Keller and Bliesner (1990) linked the performance of sprinkler irrigation systems to the sprinkler physical characteristics (i.e. jet angle, number and shape of nozzles and mode of operation), nozzle size and pressure.

2.7.3.3. Methods of Determination Sprinkler Water Distribution

The procedures for determining water distribution uniformity of sprinkler uniformity are:

- Applying the catch can grid to the existing irrigation system according to Merriam and Keller (1978) as in Keller and Bliesner (1990)
- Placing a catch can grid around a single sprinkler head in no-wind conditions and establishing the corresponding overlapping for any sprinkler spacing (Solomon, 1979 as in Montero *et al*, 2002)
- Reducing the catch cans grid to a single-leg in a radial pattern, in no-wind and with high relative humidity conditions. The application rate can be calculated by rotating the radial pattern around the sprinkler (Vories and von Bernuth, 1986 as in Montero *et al*, 2002).

2.8. Factor Affecting Actual Water Application Efficiency and uniformity

Pitts (2001) noted that a highly uniform application of water does not ensure high efficiency since water can be uniformly under or over-applied. However, in order to achieve good crop yields, both a highly efficient system and uniform application of water are required. Baum et al., (2005) also explained that irrigation can be uniform and inefficient; however, irrigation cannot be non-uniform and efficient. Thus, the first requirement for the efficient operation of an irrigation system is the uniform application of water. Irrigation uniformity is generally affected by the sprinkler characteristics and layout, operating pressure, management and environmental conditions (Dalton and Raine, 1999). According to Solomon, (1992), Sprinkler irrigation water distribution uniformity is affected significantly by:

- Equipment and design factors such as sprinkler characteristics (that is number of Nozzles, size and shape), operating pressure and sprinkler spacing
- Environmental factors such as humidity and more importantly wind condition and
- Management factors such as length of irrigation time, time of day irrigation is Performed, practicing of offsetting laterals (alternate sets) and irrigating blocks of several adjacent laterals at once.

The delivery of the water to the soil/plant through the air introduces some degree of uncertainty as wind and other atmospheric conditions, such as temperature and relative humidity affect the water application efficiency. Furthermore, variation in rotational speed of sprinklers, differences in discharges and irregularity of the trajectory angle caused by riser straightness contribute to the non-uniform application problem. The presence of such bottlenecks leads to under- or over-irrigation on the same field. Non-uniform application also leads to surface redistribution and eventually leaching of nutrients on over-irrigated areas whilst under-irrigated portions end up as dead spots, unable to support plant growth and also create non-uniform crop stands,(Keller and Bliesner, 1990, 2009).

Water distribution uniformity of sprinkler is mainly affected by: Equipment and design factors such as sprinkler characteristics (that is number of Nozzles, size and shape) operating pressure and sprinkler spacing, Environmental factors such as humidity and more importantly wind condition and Management factors such as length of irrigation time, time of day irrigation is Performed, practicing of offsetting laterals (alternate sets) and irrigating blocks of several adjacent laterals at once (Solomon, 1992 as cited in Osei, 2009).

2.8.1. Sprinkler Operating Pressure and Precipitation Profile

The pressure of the irrigation system is the maximum water pressure required for normal operation and it includes the friction losses in the piping network from the control station to the distal end of the system, the difference in elevation and the pressure required at the emitter/sprinkler. Operating pressure used in this work refers to the pressure measured at the emitter, in this case the sprinklers. Sprinkler irrigation systems can be classified by the operating pressure as follows (Phocaides, 2000):

- ✓ Low pressure systems, where the pressure required are 200-350 kPa;
- ✓ Medium pressure, where the pressure required is 350-500 kPa;
- ✓ High pressure, where the pressure required exceeds 500 kPa.

The operating pressure of sprinklers has significant impact on irrigation uniformity and the overall performance of the irrigation systems. The optimum operating pressure of impact sprinklers, with standard straight bore nozzle is 310.5 kPa to 414 kPa (45 to 60 psi). Armstrong *et al* (2001) give the common operating pressure range for overhead impact sprinklers as 240 – 400 kPa. Under low pressures less than 276 kPa (40 psi), the water jet leaving the nozzle does not break up adequately and this results in concentrated water application. Conversely, pressures above 483 kPa (70 psi) break the jet excessively (misting) resulting in concentrated water application near the sprinklers (King *et al*, 2000). This also creates fine mist in the sprinkling zone resulting in excessive wind drift and evaporation. The operating pressure controls the wetted diameter and the mean water droplet size (Kranz *et al*, 2005) as depicted in Figure 2.2.

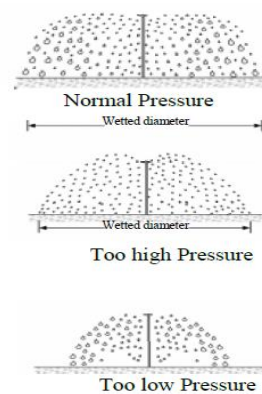


Figure 2.2 Effect of pressure on droplet size and wetted diameter (Kranz *et al*, 2005)

To achieve acceptable uniformity, the pressure variation along a lateral is not to exceed 20% of the design pressure. Excessive pressure variation, however, is prevalent on undulating or sloping topographies and this problem is best rectified with the use of pressure compensating nozzles or pressure regulators. With rocketing energy cost, the tendency has been to reduce the operating pressure so as to make savings on fuel. To achieve this, special nozzles (with non - circular orifices) which use mechanical means to provide extra breakup of the water jet at low pressures are utilized. Such nozzles operate at pressures that are 1 bar lower than the traditional nozzles (Solomon, 1990).

The extent of uniformity achievable by a set irrigation system is greatly affected by the water distribution pattern. Each type of sprinkler has its characteristic precipitation profile which varies with nozzle size and operating pressure. Figure 2.3 gives Relative effects of

Different Pressure on Precipitation Profiles for a Typical Double Nozzle Sprinkler (Keller and Bliesner, 1990)

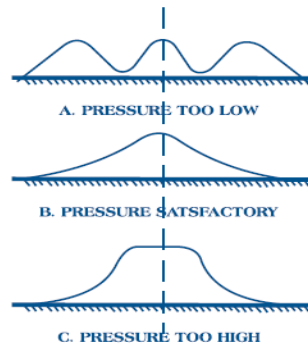


Figure 2.3:

Figure 2.3 typical precipitation profiles for sprinklers operating at different pressures.

A depicts a sprinkler operating at too low a pressure. When the sprinkler operates at too low pressure, the droplet size is large. Under such conditions, the water from the nozzle would then concentrate in a form of a ring a distance away from the sprinkler resulting in a poor precipitation profile. At satisfactory/optimum pressure range the precipitation is symmetrical around the sprinkler as shown in Figure 2.3B. When the pressure is too high (Figure 2.3C), the water from the nozzle breaks into very fine droplets, the fineness of the droplets makes them susceptible to wind movement, settling around the sprinkler in no wind conditions. Under wind conditions, the distribution pattern is easily distorted (Keller and Bliesner, 1990).

2.8.1.1. Operating Pressure Measurement

Operating Pressure is the maximum water pressure required for normal operation and it includes the friction losses in the piping network from the control station to the distal end of the system, the difference in elevation and the pressure required at the sprinkler. According to King *et al* (2000), a Pitot tube attached to a pressure gauge can be used to check a pressure regulator's operation. There are three categories of pressure measurement, namely, absolute pressure, gauge pressure and differential pressure. Moreover, there are two types of fluid systems, which are static and dynamic systems. In dynamic systems, typical of flow through a nozzle, pressure is defined using three terms: static pressure, dynamic pressure and total pressure. The Pitot tube measures the total pressure, which is the sum of the static and dynamic pressures. The total pressure is obtained when the

flowing fluid decelerates to zero in an isentropic (frictionless) process. Hence the energy of the fluid is converted to pressure in the Pitot tube and the magnitude is registered by the pressure gauge attached to the tube (Heeley, 2005).

2.8.2. Sprinkler Spacing

According to Phocaidis, (2000), there are three main types of sprinkler spacing patterns and a number of variations to adapt these patterns to special situations. These spacing are the square, rectangular and triangular patterns. The square pattern is suitable for irrigating square- shaped areas. The limitation of this pattern is the diagonal distance between sprinklers in the corners and this is usually susceptible to wind effects. To minimize wind effects, closer spacing is recommended depending on the severity of the wind. The rectangular sprinkler spacing has sprinkler positions forming a rectangle with the shorter side of the rectangle across the wind and the longer side with the wind, so as to obtain a good coverage. This pattern has the advantage of fighting windy situations and it is suitable for areas with defined straight boundaries and corners. In the triangular pattern, sprinklers are arranged in equilateral triangle formats so that the distance from each other is equal. This pattern allows for lengthy spacing and therefore requires fewer sprinklers compared to the square spacing, for a specified area. Furthermore, two of the above patterns can also be combined on the same site to achieve optimum sprinkler coverage.

Phocaidis (2007) stated that, for good uniformity the sprinkler overlap pattern should be corresponded to 65% of the sprinkler coverage diameter under light to moderate wind conditions in square or rectangular patterns.

According to FAO, (2001), the selection of the correct sprinkler spacing depends on how the best fit spacing with a certain pressure and nozzle size can provide the water at an application rate that does neither cause runoff nor damage the crop and at the best possible uniformity under the prevailing wind conditions. The selected sprinkler should fully satisfy the irrigation water requirements and the irrigation frequency. According to USDA, (2016), the basic criterion governing the selection of spacing for any given sprinkler nozzle-pressure and wind combination is the desired distribution uniformity. Higher values of CU generally require closer nozzle or lateral spacing, higher operating pressures, or both, which in turn require higher investment and perhaps operating costs.

2.8.3 Wind

The performance of sprinkler irrigation systems is greatly affected by both the direction and magnitude of the prevailing wind. Wind is the chief modifier that reduces the diameter of throw and changes the profiles of sprinklers. Wind speed in combination with sprinkler spacing has significant impact on the uniformity of sprinkler irrigation systems. The problem is pronounced especially when wind speed exceeds 8 km/h. The changes in wind speed and direction, however, tend to increase the cumulative irrigation uniformity calculated over 26 multiple irrigation events.

Another phenomenon associated with the wind condition is “wind skips”, which occurs when there is a large difference in wind speed and/or direction between adjacent irrigation sets. This creates temporary dry zones adjacent to the sprinkler laterals on the upwind side. It is, however, not cumulative and successive irrigations/moves correct this effect (King et al, 2000). Notwithstanding these limiting effects, Merkley and Allen (2004) wrote that occasionally, wind can help improve uniformity as the randomness of wind turbulence and gusts contribute to smoothing out the distribution pattern/profile.

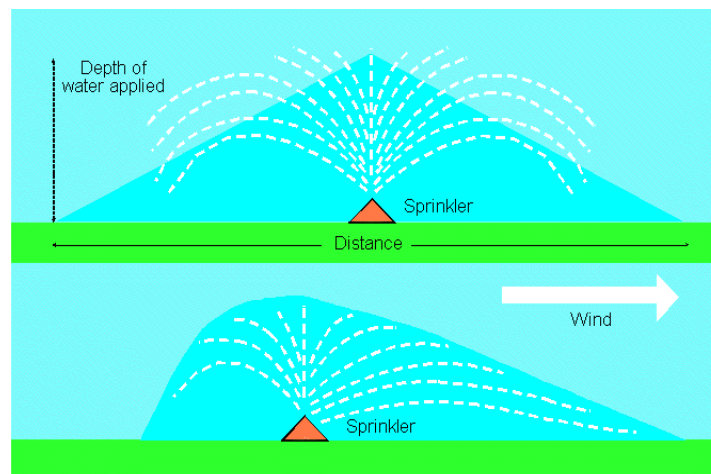


Figure 2.4: The effect of wind on a sprinkler pattern. Top: Sprinkler working under ideal conditions. Bottom: The same sprinkler under windy conditions (Source: Calder, 2005)

2.9. Losses in Sprinkler Irrigation Systems

There are much inefficiency associated with sprinkler irrigation systems including leakages in pipes, evaporation, wind drift, canopy interception, surface runoff and uneven/excessive application depths. These losses and their typical values are presented in Table 2.2.

Table 2.2. Losses in Spray irrigation system (Source; Davoren, 1995)

Loss component	Range	Typical values
Leaking pipes	0-10%	0-1%
Evaporation in the air	0-10%	<3%
Wind drift	0-20%	<5%
Interception	0-10%	<5%
Surface runoff	0-10%	<2%
Uneven/excessive application depth and rates	5-80%	5-30%

It is therefore clear from Table 2.2 that, the greatest losses in sprinkler irrigation is as a result of uneven application, i.e. uniformity of application. Keller and Bliesner (1990) wrote that other losses encountered on field scale included evaporation from wet soil surfaces, transpiration from unwanted vegetation and field border losses. Thus studying the uniformity of a system is of vital importance to the effectiveness and efficiency of a sprinkler irrigation system.

2.10. Gaps Existing In Actual Irrigation Performance

Several authors have reported that; actual performance of sprinkler irrigation is affected by design, operation and management gaps (Solomon, 1979; Kincaid et al. 1996). According to Odi (1995), the factors that account for under performance of irrigation system include: Poor system management and service provision, Poor understanding of farmer priorities and inadequate markets for produce, Lack of clear and sustainable water rights accorded to users, at an individual or group level, Lack of clear and recognized responsibilities and authority vested in the managing organizations, Lack of transparent accountability; and supporting incentives for the managing entities. According to research made at Beles sugar development project by Abshiro and Singh, (2016), the performance of sprinkler irrigation is affected by management problems.

Generally, Douglas and Juan, (1999) summarize the four potential kinds of performance gaps that can occur with irrigation systems.

The first is a technological performance gap. This is when the infrastructure of an irrigation system lacks the capacity to deliver a given hydraulic performance standard. The normal solution to technology performance gaps is to change the type, design or condition of physical infrastructure.

The second kind of performance gap is when a difference arises between how management procedures are supposed to be implemented and how they are actually implemented, such as how irrigators adjust pump gates, maintain hydrant valve, checking leaky of main pipe and report information. This can be called a gap in implementation performance. A problem of this kind generally requires changes in procedures, supervision or training.

The third kind of performance gap is a difference between management targets and actual achievements. Examples of management targets are the size of area served by irrigation in a given season, cropping intensity, irrigation efficiency, water delivery schedules and water fee collection rates. This can be called a gap in achievement. Such problems are generally addressed either by changing the objectives (especially simplifying them) or increasing the capacity of management to achieve them, such as through increasing the resources available or reforming organizations.

The fourth type of performance problem concerns impacts of management. This is a difference between what people think should be the ultimate effects of irrigation and what actually results. These are gaps in impact performance and include such measures as agricultural and economic profitability of irrigated agriculture, productivity per unit of water, and environmental problems such as water logging and salinity. If management procedures are being followed and targets are being achieved, but ultimate impacts are not as intended, then the problem is not that the managing organization has performed badly, since these effects are generally beyond its direct control. The problem is that the objectives of the organization do not produce the desired impacts. This is more a problem of policy than management.

2.11. Reasons for Performance Assessment

There are several cases for carrying out performance assessment of irrigation scheme (Walker, 1987)

- When we know something is wrong and we wish to find out what is causing it
- When we want, as part of management, to know how we are doing and can improve it
- When a researcher, using the case study approach, seeks to understand the detailed workings of an irrigation scheme in order to draw generalized inferences.

The need to develop comprehensive methodologies to evaluate the performance of irrigation schemes has long been recognized. The concluding remarks of a workshop on irrigation water management held at the International Rice Research Institute (IRRI) in 1979 stated that: "What is most needed is an established methodology to determine the efficiency of an irrigation system in physical, economic, and social terms as well as in terms of water use and to show how the efficiency can be improved..." (IRRI, 1980)

Bhuiyan (1981) states that: "There is a need for more research work to develop appropriate system evaluation criteria that could be used for systematic but rapid identification of irrigation systems weaknesses and strengths, and also for the better evaluation of management improvement efforts."

Against this background, there have been several attempts over the past three decades to address this problem. The interest in the subject of 'irrigation performance' further gained momentum in the 1980s, and has presently become one of the top issues of discussion in irrigation circles. This is evident in the many national and international activities undertaken on the subject in the past decades. In 1983, FAO organized an Expert Consultation on Irrigation System Performance in an early effort to develop guidelines and methodologies for assessing irrigation systems performance and for identifying their problems and solutions. In June 1989, the International Commission on Irrigation and Drainage (ICID) widened the task of its Working Group on 'Irrigation Efficiencies' to 'Irrigation Performance Assessment.' This marked a move away from viewing performance as purely technical (i.e. losses in canals) to broader issues.

The bottleneck in irrigation water management of the sugarcane irrigation projects has got special attention by irrigation professionals in recent times. Without the knowledge and information of the actual field performance of the irrigation system, all attempts made to alleviate the water management problems of irrigation project remains incomplete and fruitless. Thus, assessment of actual irrigation performance is an essential component of the general sugar development projects of Ethiopia. Improving the existing irrigation systems performance is more preferable than developing new irrigation due to investment in irrigation has failed to produce the expected result in many countries.

There are a few research works done on assessment of sprinkler irrigation performance on sugar projects in Ethiopia. The results obtained through irrigation system evaluation by

different researchers, institutions, and/or organizations, will not always be easily comparable. This may be due to the subtle differences in evaluation methodology, interpretation of performance parameters and calculations.

The main reason of these study are to assess the actual performance of the sprinkler system as it is currently practice, in terms of water application practices in accordance to crop water need, by considering three performance indicators; water application efficiency, irrigation adequacy and water application uniformity. The selected indicators are the most important parameters to evaluate the actual performance and indicate existing gaps in terms of design, management and system maintenance. Therefore, these stated literatures is very crucial to improve the actual performance of sprinkler irrigation system installed at Arjo-Diddessa sugar Development Project and also uses as a benchmark for further studies.

2.12. Measures to Improve Performance

To improve the performance of sprinkler systems the following measures should be available (Samir M. Ismail, 2003)

- Know the application rate and average depth applied.
- Avoid over irrigating. Over irrigation means applying water in excess of the soil moisture depletion in the parts of the field receiving the least amount of water. Reduce over irrigation by decreasing the set time.
- Irrigate during low wind periods (wind speed less than 15 km/h). Sprinkler uniformity is greatly reduced at wind speeds greater than 10-15 km/h.
- Offset lateral locations to improve seasonal uniformity. In offsetting, the lateral locations of the current irrigation are midway between the lateral locations of the previous irrigation.
- Use the same nozzle size throughout the irrigation system. Mixing nozzle sizes results in non-uniform application rates.
- Repair leaks in the irrigation systems and replace or repair malfunctioning nozzles.
- Prevent crop interference by using properly sized risers.
- Maintain adequate pressure by cleaning the suction sump and screen, adjusting the pump impeller, repairing or replacing a worn impeller, or reducing the number of laterals.

3. MATERIAL AND METHODS

3.1. General Description of study Area

The study was conducted at Arjo-Diddessa Sugar Factory irrigation project which is found southwestern Ethiopia between East Wollega, Buno-Beddelle and Jimma zones of Oromia regional state. Geographically the area is located between Latitude $8^{\circ}-30'-00''$ to $8^{\circ}-40'-00''$ N and longitudes between $36^{\circ}-22'-00''$ to $36^{\circ}-43'-00''$ E. The altitude range of the sub basin is 1300 to 2280 m.a.s.l. The sugar factory is found at a distance of 395 kilometers distance in the Addis Ababa- Nekemte-Bedelle route or at 540 kilometers distance in the Addis Ababa-Jimma-Bedelle-Nekemte route. The Factory was previously owned by Al-Habesha Plc, a Pakistani company. Sugar Corporation bought the Sugar Factory from the Pakistani AL- Habasha Sugar Mills PLC in 2012/2013.

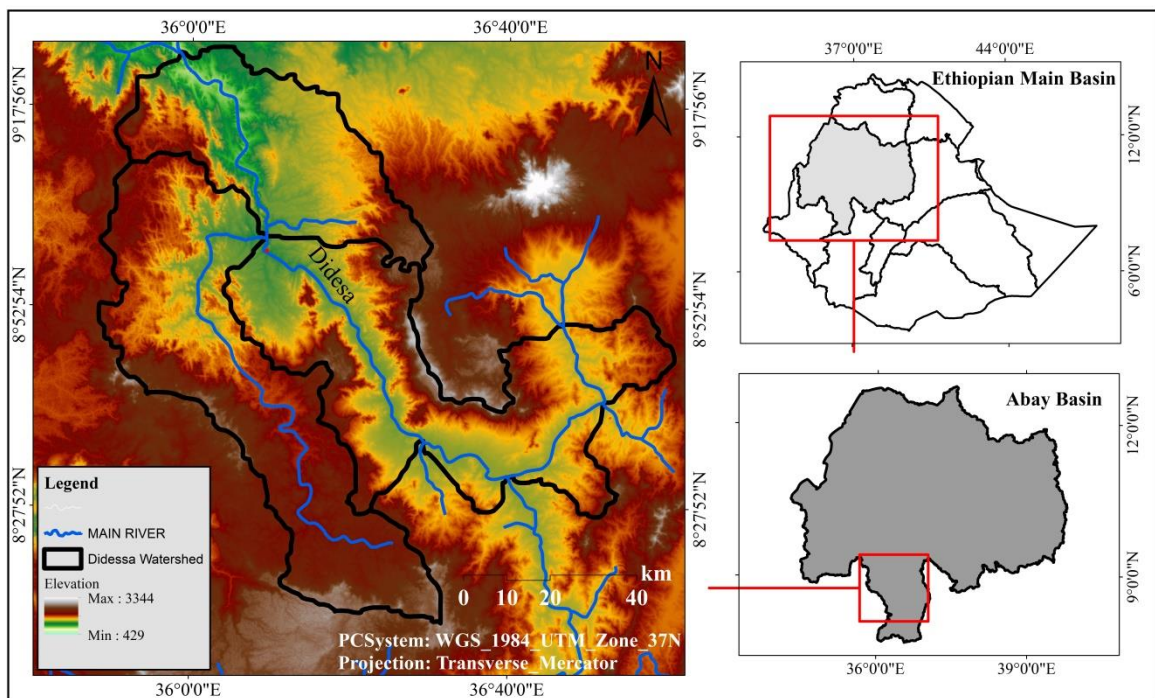


Figure 3.1. Geographical Location map of study area (generated from Arc GIS)

The climatic condition of the majority area of the irrigation project area can be conveniently categorized into moist kola agro-climatic zone or it is known for being hot with heavy rainfall (OWWDSE, 2012). The representative related meteorological station for the project area based on the monthly climatic data for the 1996-2018 period observed at Bedelle meteorological station, The high rainy season of the area which is called kiremt, mostly concentrated in May to September period every year, with virtual drought from

November through March. The mean annual rainfall of the area ranges between 1445 mm to 2357mm, with total annual average rainfall of 1933mm. The mean monthly maximum and minimum temperature are range from 22⁰C to 29⁰C and 11⁰C to 14⁰C respectively. The total annual mean maximum and minimum temperature are 25.8⁰C and 12.8⁰C respectively. The hottest season is happened from January to April, whereas the coldest season happens during June to November. Wind speed of study area is categorized under low; it ranges from 1.62 km/hr to 3.72km/hr, with mean annual of 2.34 km/hr. The low wind speed condition of the area makes it suitable and optimum condition for the operation of sprinkler irrigation. The mean daily sunshine hours vary from 3.7 hr/day in July to 8.7 hr/day in December. The average monthly relative humidity is varies from 59% to 83%, with mean annual of 70%. The soil types of the study area are ranges from clay loam to heavy clay textured soils. More than 75% of extensive soils of the current irrigation practice of the project are Vertisols (Heavy clay soil) that has very low permeability. The climatic condition and the soil properties of the area make it suitable for sugarcane development. There is an irrigable command area of 80,000 hectare. Currently, the sugarcane is cultivated in more than 5000 hectares of land, with the planned additional expansion in the future. The factory receives water from Diddessa River for irrigating sugarcane which is the major tributary of Abay River. The major tributaries of the Didessa River are the Wama entering from the east, the Dabana from the west, and the Anger from the east. Didessa catchment is situated in the southwest part of Blue Nile River Basin (OWWDSE, 2013).



Figure 3.2. photo of sprinkler type of study area

The present sprinkler irrigation system practice uses a drag-line/Hose-Move sprinkler system of irrigation. The whole sprinkler irrigation system supplied water from the main

canal with the aid of pump and deliver water to the fields through a network of supply mains, Branch mains, Sub Mains, Mani Folds, Laterals, Drag Hoses and Sprinklers. The lengths of the lateral lines were 90 m, whereas the spacing between the sprinklers was 18m x 18m. The sprinkler assembly comprises 36 m length and 25 mm diameter plastic hose connected to a galvanized steel tripod with 4 meter high riser valve and a brass sprinkler. The sprinkler heads used for this study were of the full circle rotating impact sprinkler design capacity of 1.95 m³ /hr.

3.2. Material and Tools

The materials used to collect data were Global positioning system (GPS) used for altitude, longitude and latitude reading, soil Auger hole, core sampler, soil plastic pack, tag number, catch cans, four sprinklers, graduated cylinder, stopwatch, tape meter, water bucket/container, flexible plastic water hose (4m) which connects the hydrant and the sprinklers, hydrant pressure gauge with Pitot tube, hammer, sticks for catch can handling and other related accessory materials. Some of Computer tools are also used. ARC GIS is used to delineate the map of study area. Microsoft office Excel is used to calculate and analyze measured field data. CROPWAT 8.0 software was used to calculate crop water requirement.

3.3. Data Collection Methods and Sources

In order to assess the performance of sprinkler irrigation system at Arjo-Didessa sugar factory, primary and secondary data source were collected and different performance parameters were evaluated. Necessary Sample sizes were taken based on standard recommendation as required to minimize errors and to represent the whole existing field condition. Other relevant information related to general irrigation practices of the area were gathered by referring the feasibility study and design document, field report and by physical contact with Technical responsible persons such as Irrigation and Plantation Staff and from field observation of respective sites. Infield sprinkler water application performance tests were done at two selective command areas (for 3.5bar and 4.0bar hydrant pressure) and sprinkler performance indicators were measured. The assessment contained: i) Crop water requirement and Irrigation requirement with respect to growing month and stage ii) Irrigation schedule (interval & setting hour) iii) Sprinkler discharge and operating pressure iv) water application rate v) water application efficiency and uniformity, v) Adequacy of Irrigation.

3.3.1 Soil Data

Totally 45 representative soil samples were taken at a depth of 0-30 and 30-60cm using auger hole and core samplers. Each soil sample was taken by plastic bag. The samples are taken at different area considering the lowest, medium and highest spot of the fields. According to Walworth., (2006), the actual number of sub-samples depends on field size and uniformity. No less than 5 sub-samples should be taken from a sampled area, and 15 to 25 are preferable. It is possible to take more samples as required to minimize errors. Booker Tate (2009) recommended the top 60 cm as an effective rooting depth was appropriate to estimate soil moisture deficit for the irrigation timing of sugarcane. This was to protect the sugarcane from moisture stress in its effective root area. Soil samples were tasted for soil texture, bulk density, field capacity (FC) and wilting point (PWP) at Bedelle Research Center, Soil Laboratory Section. Laboratorial procedures and recommendation manuals of Kamara and Haque (1991) and Sahlemedhin and Taye (2000) were used.

To determine soil texture, determined in the laboratory using Sieve analysis and textural triangle. Bulk density of the study area was determined using undisturbed soil samples collected from five pits at different intervals starting from surface to a depth of 60 cm based on sugarcane root abundance with core sampler's volume of 100 cm³ each. The samples were placed in an oven and dried at 105°C for 24 hr. After drying, the soil and container were again weighed. The dry weight of the soil was divided by the sample volume to determine the dry bulk density. Moisture contents at field capacity and wilting point were determined in laboratory using disturbed soil samples collected from five sampling points at different intervals. Soil samples were soaked in water for one day and a pressure of 1/3 (FC) and 15 bars (PWP) were exerted in the laboratory using pressure plate apparatus until no further change in soil moisture content was observed.

For this study the Soil samples before and after irrigation were collected at the depth of 0 to 30cm and 30 to 60cm 0.3 to 0.6 m from selected sprinkler irrigation fields. The gravimetric water content was determined in the laboratory and the difference in water content between before and after irrigation was determined and it indicates the amount of water stored in the effective root depth. Soil moisture deficit (SMD) for each site was determined using gravimetric soil moisture content between field capacity and existing moisture multiplied by soil bulk density and depth of the soil layer within root zone.



Figure 3.3 Photo during soil sample collection with Auger and core samplers

3.3.2. Climate data

Monthly average of twenty three (23) years (1996-2018) rainfall data and 15 years (2005-2019) of maximum and minimum temperature, sunshine hour, relative humidity, and wind speed data were collected to estimate the Reference Evapotranspiration and Effective rainfall of the study area. The climatic data were collected from Ethiopian National Metrology Service Agency (ENMSA) of Bedelle, Arjo and didessa station and given in tin appendix 1 (Table 1 to 6). The criterions for the selection of the meteorological data will be based on the availability of data, the data quality and possibly whether the station is within the watershed or not. Therefore, data from Bedelle metrology station was chosen and used for this study, because of the greater data accuracy and availability than the other two stations. Geographical locations of weather stations are listed in table 3.1 below.

Table 3.1. Geographical location of weather monitoring stations

No	Weather monitoring Station	Zones	Lat. (dd)	Long. (dd)	Altitude (m.a.s.l)
1	Arjo	East Wollega	8.75	36.5	2565
2	Bedelle	Bunno-Bedelle	8.45	36.35	2011
3	Didessa	East Wollega	9.35	36.1	1310

3.3.3. Description of Catch-cans and Alignment

The number of catch-cans placed in the test depended on the system being tested and the spacing of the sprinkler. According to Cuenca (1989) for sprinkler spacing 18m by 18m a minimum of 24 Catch-cans for overlapping uniformity test are recommended. Also the Irrigated Crop Management Centre (2002) recommended at least 30 catch-cans, of minimum height of 100mm and minimum diameter of 80mm, for the evaluation of sprinkler irrigation uniformity. For the purpose of evaluating sprinklers, the typical catch-

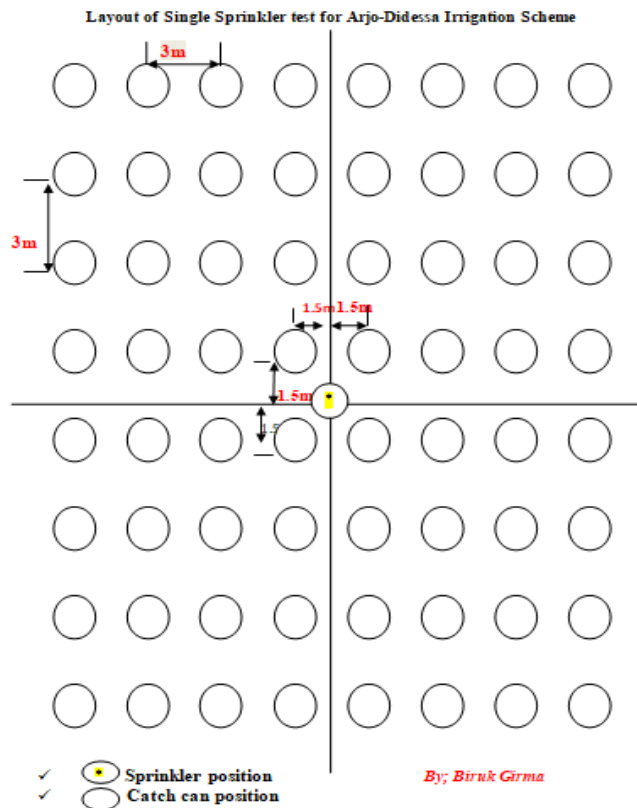


Figure 3.5: Layout of Catch cans for single sprinkler test

The run time for both single and four sprinklers were 2 hours. Evaporation loss was measured by installing four catch can at the edge of each test layouts having water to the test area for similar catch can running time of 2 hours, then the depth recorded before catch can data for entire field taken and after taking data of catch can at the same time reading taken for installed catch can which serve as a pan and finally the difference was taken as lost as suggested by Abshiro and Singh (2018). An average value of 4.3% loss is recorded during all tests. The catch can water volume was measured with a graduated cylinder and recorded, starting with the outermost part of the wetted pattern and ending with the central part, as suggested by Osei (2009).

According to Markley and Allen, (2004), catch can tests represent a specific wind and pressure situation and must be repeated to obtain information for other pressure or wind conditions. For this study, the data were collected with three replications (morning, mid-day, and afternoon/late day) for 3.5 and 4.0 bar operating pressure. Totally twelve (12) field experiments were conducted for both overlapping and single sprinkler test of water

distribution uniformity. Markley and Allen, (2004) also says, Catch can data is often overlapped for various sprinklers and lateral spacing's to evaluate uniformities for design and management purposes. Thus, for this study, to evaluate uniformities for design and management purposes, actual single sprinkler data were overlapped with different four sprinkler spacing (i.e.12mx18m, 12mx12m, 18mx12m and 9mx12m) and tested to analyze the effect of spacing and wind. The overlapped catch can data were simulated from the single sprinkler catch can data as suggested by Osie., (2009).



Figure 3.6 Photo during measuring catch can water volume with graduated cylinder

3.3.4. Pressure Measurement

The actual operating hydrant pressure which delivers water for the sprinklers, was measured using pressure gauge. The nozzle operating pressure during the test was measured using pressure gauge with Pitot tube. Pitot tube was inserted into the nozzle to obtain the nozzle pressure. Measurements were taken for all sprinklers in the block test zone. All pressure measurements were taken before the catch cans were overturned to the start collection of precipitations and sprinklers discharge record. To observe actual pressure variations along lateral, nozzle operating pressure was recorded from the first lateral to the last end of hydrant positions.

3.3.5. Measurement of Sprinkler Discharge

The actual sprinkler discharge rate was measured at field condition on two fields for two hydrant pressure (3.5 & 4.0 bar) with four replicates. Totally eight (8) tests was carried out across the lateral pipes to measure discharge of sprinkler by connecting flexible plastic hose to the top parts of the riser or on each of sprinkler nozzles and allowing the water to fill a known volume of bucket (5 liters) for a measured period of time. The time taken to

fill the container was recorded by stop watch. The discharge from the two nozzles were collected separately and finally added together. Because, those two different nozzle size diameters (2.4 mm and 4.4 mm) are attached and operated on one sprinkler riser. To see the actual sprinkler discharge variation across lateral, discharge records were taken with the same aid from the first lateral end to last end of hydrant positions. The sprinkler discharge measurements were taken before the catch- cans were overturned to the start collection of precipitations. The actual sprinkler discharge rate which was measured from volume of bucket used divided by time taken to fill, is estimated by the following equation 3.1 (Abshiro and Singh., 2016).

$$q = \frac{v}{t} \dots \dots \dots \text{Eqn (3.1)}$$

Where; q is the sprinkler discharge rate at tested field (l/s), v is volume of water collected in bucket from nozzle in liters (l), t is time taken to fill the bucket in second (s). Discharges were determined for all the sprinkler heads in operation and the averages obtained were used to represent discharge of sprinklers used for the block test.



Figure 3.7 Photo during measuring sprinkler water discharge

3.4. Estimation of the crop water requirement

3.4.1. Reference evapotranspiration (ET_o)

Fifteen (15) years from 2005 to 2019 of average monthly minimum and maximum temperature, sunshine hour, relative humidity, and wind speed were used for estimation of reference evapotranspiration (ET_o). The ET_o of study area with respect of their month was estimated from average monthly climate data input using FAO CROPWAT 8.0 software model based on FAO Penman- Monteith method equation (Allen et., 1998).

3.4.2. Effective rainfall (Pe)

The effective rainfall (mm) of the study area for each month was computed by inserting 80% dependable rainfall data input into FAO CROPWAT 8.0 Software, using USDA Soil Conservation Service method (USDA., 1997). The estimation of 80% dependable rainfall of study area was done based on procedures of Doorenbos and Pruitt (1977) using 23 years of monthly average rainfall data of study area.

3.4.3. Description of CROPWAT 8.0 Model & Data input

CROPWAT 8.0 model which is developed by FAO, Land and Water Division, (2018) were used to estimate Reference Evapotranspiration and effective rainfall of this study. The model requires Rainfall data (mm) and climate data of monthly maximum and minimum temperature (°C), wind speed (km/h), mean relative humidity (%), and sunshine hours (h) This model also contains the coordinates and altitude of the location of study area (Clarke., et. al, 2001). To calculate CWR, IRs for different crops for a range of climatological stations at least 15 years of recent climate data is needed (FAO, Land and Water Division, 2018). For this study required rainfall data and climate data of ranging 1996 to 2019 were gathered from the Bedelle Meteorological Station, which is a climatic database to be used in association with the CROPWAT program and which allows the calculation of ETo and effective rainfall of study area. The CROPWAT version 8 calculates effective rainfall according to United States Department of Agriculture (USDA) soil conservation (S.C.) method ((USDA.,1997), and daily reference evapotranspiration (ETo) from weather data according to the equation of FAO-PM (Allen et al., 1998) as presented in Equation 2.1.

3.4.4. Crop Evapotranspiration (ETc)

The sugarcane water requirement (ETc) is describes the water consumed by crop from planting up to harvesting season. The ETc of the study area was determined by multiplying ETo of the crop with corresponding sugarcane crop coefficient (Kc) for each month and growing stage using equation 3.2

$$ETc = ETo * Kc \dots \dots \dots \text{Eqn. (3.2).}$$

Where, ETo (mm/day), Kc is crop coefficient dimensionless. The crop coefficients based on FAO standards from FAO 56 are used as estimates of sugarcane crop coefficients (Kc) of study area. The Kc values for sugarcane was varying during initial, development, mid, and final growth phases. The irrigation water demand and crop water requirement were

determined based on the growing stage and length of the growing period. The growth stages of sugarcane of the study area were obtained from field information and can be classified by four age groups for irrigation purpose.

According to CROPWAT 8.0 software default data, the sugarcane root depth may go up to 1.5 m, but in Ethiopian sugar estates the maximum is considered to be 90cm and effective root depth of 60cm. The Kc values and rooting depth data corresponding to cropping stages were obtained from previous survey data made at Metahara sugar estate by Solomon (2010) and Habib (2001); relatively because the same cane varieties grown, and cane management practices done in Ethiopian sugar estates (Abshiro and Singh., 2016; Tadesse G. S.,2015), in this study the same root depth and crop coefficient values were used as maximum rooting depths at given cane ages as shown in table 3.2.

Table 3.2: Root depth and Kc at different cane ages (Habib, 2001 and Solomon, 2010)

Cane age (months)	Root depth (cm)	Crop coefficient (kc)
0-3	30	0.55
3-6	45	0.9
6-15	60	1.05
Above 15	90	0.7

3.5. Determining Net irrigation requirement (NIR)

Net irrigation requirement is the depth of water, which is exclusive of other water sources, such as effective precipitation, ground water contribution. The actual NIR of the study area was estimated for the respective months and crop stages, using the method outlined by (Habib, 2001).

$$NIR = ETc - Pe - Gw \dots\dots\dots Eqn. (3.3)$$

Where, NIR in mm/day, Pe is effective rainfall (mm), Gw is ground water contribution (In our case, the value of Gw is zero, because there is not a detail survey study take place in this study area). Thus, the NIR of the study area was estimated on daily bases by considering the monthly effective rainfall. For crops age less than 3 months, the NIR was made equals to crop water requirement (ETc) to provide more frequent irrigation water requirement as suggested by Tadesse G. S.,(2015)

3.6. Irrigation Scheduling

Irrigation scheduling is the science of determining the exact amount of water to apply to the field and the right time of application, for the purpose of increasing water use

efficiency and to minimize crop water stress (Broner., 2005). The parameters were used to develop sugarcane irrigation scheduling with respect to growing month, growth age and the soil type of study area were discussed below:

3.6.1. Net depth of water application (Dn)

Net depth of water applied in (mm) for the study area was estimated using the formula:

$$Dn = TAW * P * Dr * \rho_i \dots\dots\dots Eqn. (3.4).$$

Where, TAW = (FC – PWP) is Total available water; FC is moisture content of the soil at filed capacity (%), and PWP is moisture content of the soil at permanent wilting point (%), ρ_i is the soil bulk density (gm/cm³), Dr is maximum effective root depth (m) differ for different growth stage, and P is moisture depletion factor (%).

Previous studies of Habib (2004) and Solomon (2010) has considered the maximum rooting depth of 1.0 meter for Metahara sugar estate to calculate water application depths in each soil types of the estate. Similarly, in their study the maximum rooting depth of 1m and the optimum factor of depletions for sugarcane was in between 0.50 to 0.65 was used which was also proposed by Booker Tate (2009) for Metahara sugar estate soils, and are in agreement with recommended 0.55 by Rao (1990) and 0.65 by FAO (1979). Booker Tate (2009) recommended, considering the maximum sugarcane rooting depth of 90cm or 90% concentration, effective rooting depth at top 60 cm was appropriate to estimate soil moisture deficit for irrigation timing of sugarcane. This was to protect the crop from moistures stress in its effective root area. Thus, 60% soil moisture depletion factor was used for this study.

3.6.2. Gross depth of water application (Dg)

The gross depth of irrigation water applied of the study area was estimated using equation 3.5 according to (Merriam and Keller, 1978)

$$Dg = \frac{\text{net depth of water application (mm)}}{\text{sprinkler actual application efficiency}} \dots\dots\dots Eqn (3.5)$$

The actual application efficiency was determined based on gross sprinkler depth application as currently practiced using equation 3.17

3.6.3. Sprinkler operating set time per irrigation (T)

The sprinkler set time is the specified time duration to apply the required depth of water for set of sprinkler. It is total operating time (hour) to complete one irrigation cycle or depth. The actual sprinkler set time for the study area was determined using the equation 3.6

$$T = \frac{Dg}{I_g} \quad \text{OR} \quad T = \frac{Dn * sl * sm}{q * 3600 * E_a} \dots \dots \dots \text{Eqn (3.6)}$$

Where, Dg is the gross depth of water application (mm), I_g average sprinkler application rate (mm/hr), dn is net depth of application (mm), Sl*Sm sprinkler spacing (m*m), q average sprinkler discharge (l/sec) and E_a sprinkler actual application efficiency (%)

3.6.4. Irrigation interval (I)

Irrigation interval is the frequency of applying irrigation water. The actual irrigation interval of the study area was determined for each month, growth stages, and soil type using the equation 3.7:

$$I(\text{days}) = \frac{\text{net depth of application (mm)}}{\text{Crop water requirement} \left(\frac{\text{mm}}{\text{day}} \right)} \dots \dots \dots \text{Eqn (3.7)}$$

To consider the wet seasons which have enough effective rainfall to meet the crop water requirement and to avoid over water application, the net irrigation water requirement was used in terms of crop water requirement (ET_C) to estimate the irrigation interval of the study area (Abshiro and Singh., 2016).

3.7. Sprinkler Irrigation Performance Indicators

Data collected and recorded from various source and observation were used to estimate the sprinkler irrigation performance indicators. The following indicators were used for the assessment of the systems performance: Uniformity coefficient (UC), Distribution uniformity (DU), system uniformity (SU), the potential application efficiency of low quarter (PAELQ), Application efficiency (AE_a), and Adequacy (AD_{lq}); as defined by Merriam and Keller, 1978 and ASAE Standards (2000).

3.7.1. Sprinkler water application rate (I_g)

The sprinkler water application rate (I_g) in mm/hr was computed using the equation 3.8 (Huffman et al., 2011)

$$I_g = \frac{q * 3600}{S_m * S_l}, \dots \dots \dots \text{Eqn (3.8)}$$

Where; q is Average sprinkler discharge during the test (lit/s), Sm is the sprinkler spacing (m), and Sl is the lateral spacing (m). For this study the spacing of 18*18m was used as currently practiced by project.

3.7.2. Sprinkler discharge and pressure variation along lateral

The Sprinkler discharge and pressure variation across lateral of the current irrigation system of the study area was estimated as the ratio deduction of the maximum and minimum to average sprinkler flow rate and hydrant valve operating pressure respectively using equation 3.9 and 3.10. (Merkley and Allen., 2004)

$$= \frac{(Maximum - Minimum Sprinkler flow rate)}{Average Sprinkler flow rate} \times 100 \dots \dots \dots Eqn (3.9)$$

$$= \frac{(Maximum - Minimum hydrant valve pressure along lateral)}{Average hydrant valve pressure along lateral} \times 100 \dots \dots \dots Eqn (3.10)$$

3.7.3. Coefficient of uniformity (CU)

Christiansen’s uniformity coefficient is the most popular uniformity coefficient used by researchers on the global scale. It is a measure of non-uniformity of water application for a given sprinkler head, nozzle type, operating pressure and sprinkler spacing combination. It is thus an index of irrigation uniformity. The depth of water in catch can in mm was obtained by dividing the measured volume of water in catch cans by cross sectional area of the catch cans. The coefficient of uniformity for each field was computed using equation 3.11 as proposed by Christiansen (1942)

$$CU = \left(1.0 - \frac{\sum_{n=1}^n |di - d|}{d * n} \right) * 100 \dots \dots \dots Eqn (3.11)$$

Where: CU = Coefficient of uniformity in percent (%), di = depth of water collected in individual catch cans during irrigation, mm, d = mean water depth of water collected in all catch-cans, mm and n = total number of catch cans.

3.7.4. Distribution uniformity (DU)

Distribution uniformity is usually defined as a ratio of the smallest accumulated depths in the distribution to the average depths of the whole distribution (Ascough and Kiker, 2002). The DU takes into account the variation of can readings from the mean but concentrates on the lowest 25% of readings. This uniformity measure is also called low-quarter distribution uniformity (DUlq) and was calculated from lowest quarter fraction, Dlq. The lowest

quarter fraction, Dlq , has been used by the United States Department of Agriculture (USDA) since the 1940s' and has proved to be useful in irrigated agriculture. $DUlq$ and dlq is calculated by the following equation 3.12 and 3.13 (Burt *et al.*, 1997).

$$DUlq = \frac{Dlq}{Da} * 100 \dots \dots \dots Eqn (3.12)$$

Where: $DUlq$ is low quarter distribution uniformity in percent (%), Dlq is average low quarter (1/4 depth) catch can readings; in mm, Da is average depth of all catch can readings in mm

$$Dlq = \frac{\text{sum of smallest quarter depth can reading}}{\text{quarter number of catch can}} \dots \dots \dots Eqn (3.13)$$

3.7.5 System uniformity

In order to account for the pressure variation in the system in performance assessment two additional coefficients were determined. These are: the system coefficient uniformity (SCU) and the system distribution uniformity (SDU). These system uniformity coefficients of study area were calculated using the following equations 3.14 & 3.15(Merkley and Allen, 2004).

$$\text{System } CU \approx CU \left[\frac{1}{2} \left(1 + \sqrt{\frac{Pn}{Pa}} \right) \right] \dots \dots \dots Eqn (3.14)$$

$$\text{System } DU \approx DU \left[\frac{1}{4} \left(1 + 3 \sqrt{\frac{Pn}{Pa}} \right) \right] \dots \dots \dots Eqn (3.15)$$

Where, p_n is the minimum sprinkler pressure in the whole field, p_a is the average sprinkler pressure in the entire system over the field area.

3.7.6. Potential application efficiency (PAE)

In system evaluation, the PAE was calculated by dividing the average depth of water reaching the ground by the average depth of application supplied by the system, or it is the ratio of the mean water depth observation in the catch-can supplied to the farm to the mean water depth discharged from sprinkler due to irrigation to (Keller and Blisner, 1990).

$$PAE = \frac{\text{Average water depth observed from catch can (mm)}}{\text{Average water depth discharged from sprinkler(mm)}} * 100 \dots \dots \dots Eqn (3.16)$$

3.7.7. Potential Application Efficiency of Low Quarter (PAELQ)

The PAELQ were determined in order to evaluate how effectively the system can utilize the applied water and what the total losses may be. It is, therefore, a measure of the best management practice and should be thought of as the full potential of the system. PAELQ is calculated by (Jensen, 1983);

$$\text{PAELQ} = \frac{\text{Average of low quarter depth received (dlq)}}{\text{Average depth of water applied at nozzle (AR)}} \times 100 \dots \dots \text{Eqn (3.17)}$$

3.7.8. Actual Application efficiency (AEa)

Application efficiency is determined in order to evaluate how much of the applied water is stored in the soil and available for consumptive use. It refers to the amount of water needed for crop production compared with the amount applied to the field and depends on system design and management (Merriam and Keller, 1978). For this study two technical performance parameters of actual water application Efficiencies were used to determine the current irrigation management system; which are on-field storage efficiency based actual storage of water due to irrigation, and on-field application efficiency based on required depth in effective root zone of crop stages.

➤ On-field storage efficiency (Es)

The on-field storage efficiency (Es) is a comparison between the amount of water applied and the amount retained in the root zone; which is determined as the ratio of average water stored in the root zone or moisture retained due to irrigation (ds) to average depth of water applied (dg) equation 3.18: (Zerihun et al., 1997)

$$E_s = \frac{\text{Average of water stored in root zone (ds)}}{\text{Average depth of water applied (dg)}} \times 100 \dots \dots \text{Eqn (3.18)}$$

➤ On-field actual application efficiency (AEa)

On-field actual application efficiency (AEa) of the current irrigation management system was determined as the ratio of average net irrigation depth needed in effective root zone or soil moisture deficit which is equal the soil management allowable depletion to average depth of water applied (dg): (Merriam et al., 1983).

$$\text{AEa} = \frac{\text{net depth of application needed in root zone (dn)}}{\text{Average depth of water applied (dg)}} \times 100 \dots \dots \text{Eqn (3.19)}$$

$$dg = \frac{3600 * q * Tt}{Sm * sl} \dots \dots \dots Eqn (3.20)$$

Where dn & dg is in mm, q is the measured sprinkler discharge (lit/sec), Tt is irrigation run time (hours) for this study 22 hours (as currently practiced)

The soil samples were collected before and after irrigation using auger hole at the depth of 0.3 to 0.6 m from selected fields of the two sprinkler irrigation methods. After determining the average depth of water actually applied from sprinkler into the fields; The gravimetric water content was determined in the laboratory and the difference in water content between before and after irrigation was determined and it indicates the amount of water stored in the effective root depth (ds), and the results were used to analyze on field water storage efficiency (Es). Soil water deficit (SMD) or the depth of water needed (dn) represents the depth of water the irrigation system should supply; which mean the required infiltration depth. Gravimetric method has also used to determine an average SMD for each site of study area using soil moisture content between field capacity and existing moisture multiplied by soil bulk density and depth of the soil layer within root zone, which was used in the subsequent determination of on-field actual application efficiency (AEa).

3.7.9. Adequacy Low quarter (ADlq)

The adequacy performance of irrigation was determined from the measured low quarter distribution uniformity of each hydrant pressure and amount of water required to be stored in crop root zone using equation 3.21 as defined by (Burt et al., 1997):

$$ADlq = \frac{dlq (mm)}{dreq(mm)} \times 100 \dots \dots \dots Eqn (3.21)$$

3.8. Data analysis

Data analysis is done using computer program Microsoft Office Excel and CROPWAT 8.0; to analyze collected field data and to estimate ETo and effective rainfall of study area. The actual system performance was determined using equations outlined in this chapter and important sprinkler irrigation performance indicators. The actual result values is then compared with potential capacity during design period and with the recommended standards (*Merriam and Keller, 1978 and ASAE Standards (2000), Merkley and Allen, 2004 Keller and Bliesner, (1990) & FAO standards were used*)

4. RESULT AND DISCUSSION

4.1. Design Condition of Irrigation Systems and Water Application Practices

The present sprinkler irrigation system practice uses a Hose-Move rotated impact sprinkler system of irrigation. The sprinkler heads used were full circle rotating impact with two nozzle diameter type of having 4.4mm (Main) and 2.4mm (Auxiliary) sizes attached on single sprinkler. According to Feasibility study and Design document (2007), the existing system is designed to operate at 4.21 bar hydrant operating pressure with discharging rate through two nozzles to give application rate of 1.95 m³/hr (or 0.54l/sec) with application efficiency of 75%. But, now most of fields are working below these operating pressures, which means the required discharge is not achieved as per design. The laterals were designed with actual length of 90m with sprinkler spacing of 18*18m. But in some observed fields the existing spacing in practice was less or more than this value. These can cause non uniformity of water application in most fields and over application of water in some fields. Finally, the system is not working as per design capacity.

The project practices uniform/fixed 22 hour set time and 10 days irrigation interval according to Feasibility and Design Study document (2007), irrespective of the soil type, growth stage, and growing month. A practice of uniform irrigation scheduling without considering the soil type, growing month, and stage of crop growth causes moisture stress to the crop. In addition, excess water may be applied in 22 hours than be absorbed by the soil profile thus leading to wastage, which reduces the application efficiency. Finally, these practices may cause poor cane growth and performance which intern reduced the expected yield per hectare.

The operation service, care and maintenance of the irrigation systems were clearly put in the Feasibility study and Design document (2007). But, in practice now, the operation, care and maintenance of the existing system have its gap. During field visiting, very old worn and corrode system components and needs replacement, runoff sedimentation and vegetable/weed matters covers field components, pipe breakage and leakage through pipes are observed. Lack of regular checkup, immediate irrigation maintenance and correction for any system defects are also observed Thus, the effects of all these combined gaps creates the system to poor, and malfunction, increasing cost of maintenance, and finally reduces the system irrigation efficiency.

4.2. Soil Physical Characteristics and Water Holding Capacity

Average measured values of soil physical characteristics and percentage of available water at 0-30cm and 30-60cm depth of study area were given in Table 4.1. Detail measured value of soil physical parameters for each test were given in appendix 3 (Table 10 & table 11)

Table 4.1: Soil available water capacity and Bulk density of Study Area

Si.No	PARAMETERS								
	FC, %			PWP, %			TAW (%)	Bulk density g/cm ³	Texture class
	Soil Depth (cm)			Soil depth (cm)					
	0-30	30-60	Avg.	0-30	30-60	Avg			
1	40.5	42	41.25	28	31	29.5	11.75	1.31	Clay
2	42.1	43.3	42.7	32.5	34.4	33.45	9.25	1.2	Clay
3	37	40.2	38.6	26.9	30.7	28.8	9.8	1.41	Clay
4	39.4	41.5	40.45	28.6	31.7	30.15	10.3	1.28	Clay
5	43	43.2	43.1	34.2	34.7	34.45	8.65	1.15	Clay
Avg	40.4	42.4	41.22	30.04	32.5	31.27	9.95	1.27	Clay
TAW (mm/m)							126.36		

Based on this result table 4.1, the soil textural type was namely clay type which was categorized under vertisols. According to soil profile observation and information gathered from plantation department Vertisols covers more than 75% of the Project command area. The bulk density values vary from 1.15 g/cm³ to 1.41 g/cm³ and average value is 1.27 g/cm³, shows that the actual field soils were black clay soils. The volumetric total available water (TAW) ranges from 8.65% to 11.75%. The water holding capacity of the soils is 126.36 mm per meter soil depth. The gravimetric water content was determined in the laboratory and the difference in water content between before and after irrigation was determined and it indicates the amount of water stored in the effective root depth. The average amounts of water stored determined were 46.31mm as given in table 4.2 below.

Table 4.2. Water stored under root zone in mm after hour irrigation

Fields	Stored depth (mm)			
	Depth of soil layer(cm)			Total depth in 22 hour
	0-30	30-60	Total	
Field 1	1.31	0.7	2.01	44.22mm
Field 2	1.43	0.77	2.2	48.4mm
Average	1.37	0.735	2.105	46.31mm

4.3. Crop water requirement (CWR)

4.3.1. Reference Evapotranspiration (ET_o)

The estimated value of Reference Evapotranspiration (ET_o) for each month of study area using CROPWAT 8.0 model based on FAO Penman-Monteith method equation, were given in Table 4.3

Table 4.3. Reference evapotranspiration (ETo) of the Study Area for each Month.

Months	Min temp (°C)	Max temp (°C)	Humidity (%)	Wind speed m/sec	Sunshine hours (hr)	Radiation MJ/m ² /day	ETo mm/day
January	11.8	27.3	59	0.6	8.3	20.0	3.54
February	12.9	28.7	59	0.6	7.7	20.2	3.89
March	13.7	28.7	56	0.9	7.7	21.2	4.36
April	14.0	28.0	64	1.0	7.3	20.7	4.31
May	13.6	26.9	70	1.0	7.3	20.2	4.11
June	13.0	23.6	79	0.8	5.1	16.6	3.23
July	12.9	22.3	83	0.6	3.7	14.6	2.80
August	12.8	22.9	82	0.5	4.1	15.5	2.95
September	12.5	23.8	83	0.5	5.5	17.8	3.28
October	12.5	25.7	70	0.5	8.0	20.8	3.78
November	12.0	25.6	71	0.4	8.4	20.2	3.54
December	11.8	26.7	67	0.5	8.7	20.0	3.52

According to result of table 4.3 an average monthly maximum temperature for the study area ranges from 22.3°C to 28.7°C. The highest values were obtained at February and March. Monthly average minimum temperatures varied from 11.8 °C in December and January to 13.6°C and 14 °C in May and April respectively. The humidity is ranges from 56 % to 83%, the highest is in September in the wet season. Wind speed varied from 0.4-1.0 m/sec. Sunshine hours varied from 3.7 hours in July to 8.7 hours in December. The ETo of study area increased from January and reached the maximum in March then it decreased in June to reach the minimum in August and July every year. The actual ETo values were varied from 2.8 mm/day in July to 4.36mm/day in March. Thus, the maximum ETo was in March whereas the minimum ETo was in July. The average daily ETo is 3.62mm/day. The graphical representation of monthly ETo are shown in figure 4.1.

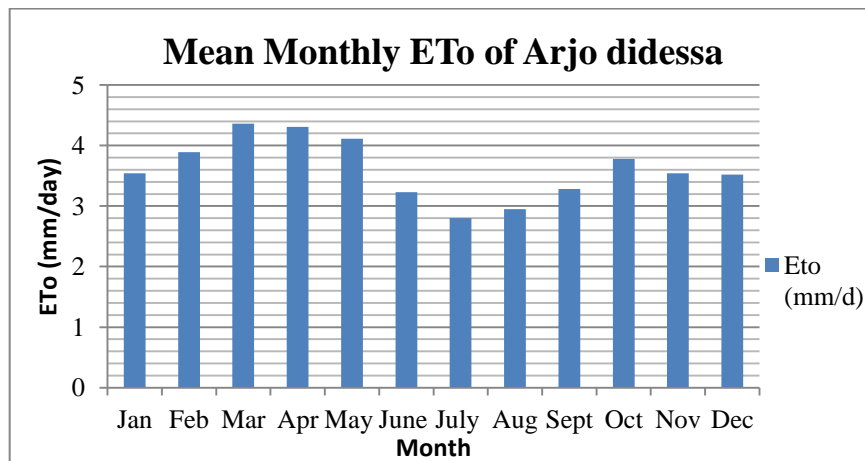


Fig 4.1. Average daily value of ETo for each month

4.3.2. Crop Evapotranspiration (ETc)

The actual sugarcane water requirement of study area estimated using equation 3.2 for each growing months and growth stages and the values are given in table 4.4 below.

Table 4.4: The ETc value for each growing month and growth stages of the study area

Growing Month/stage	ETc (mm/day)			
	Crop growing stages (Months)			
	(0-3)	(3-6)	(6-15)	(Above 15)
January	1.95	3.2	3.75	2.5
February	2.15	3.51	4.1	2.75
March	2.4	3.95	4.6	3.01
April	2.38	3.9	4.55	3.02
May	2.3	3.7	4.35	2.9
June	1.8	2.91	3.4	2.26
July	1.54	2.52	2.94	1.96
August	1.63	2.66	3.1	2.07
September	1.81	2.96	3.5	2.3
October	2.1	3.41	4	2.65
November	1.95	3.2	3.75	2.5
December	1.94	3.17	3.7	2.47

Table 4.4 shows that, The minimum average monthly sugarcane water requirements of the study area started with low value 1.54 mm/d and 1.63 mm/d during the initial stage (0-3 month) in July and August, due to the minimum evapotranspiration in these months and the lowest crop coefficient in these stages, then increased to a peak requirement of 4.6 mm/d and 4.55mm/d in growth stage (6-15 month) in the March and April, which is due to, the highest evapotranspiration in these months and the highest crop coefficient in the growth stages of 6-15 months. According to this study, the average cane water requirements mm per day for the growing age of 0-3, 3-6, 6-15, and above 15 months were 2.0, 3.26, 3.82, and 2.54 mm/day respectively. Thus the maximum water requirement is in 6-15 months of cane age.

4.3.3. Effective Rainfall (Pe)

The effective rainfall of the study area estimated, using CROPWAT 8.0 model USDA, SCS method from the 80% dependable rainfall for each month were given in Table 4.5 below. The 80% dependable rainfall computed from 23 years rainfall data with its procedures is given in (appendix 2; Table 8).

Table 4.5 : Effective Rainfall (Pe) for each Month of the Study Area

Month	80% Dependable rainfall (mm)	Pe (mm/month)	Pe (mm/day)
January	1.3	1.3	0.04
February	2.6	2.6	0.09
March	28.9	27.6	0.89
April	65	58.2	1.94
May	120	97.0	3.12
June	224.4	143.8	4.79
July	278	152.8	4.92
August	235	146.6	4.72
September	246	149.2	4.97
October	69.3	61.6	1.98
November	21.1	20.4	0.68
December	2.6	2.6	0.08
Total	1294.2	863.7	28.22

According to table 4.5, the average monthly Pe values varied from 0.04 mm/day in January to 4.97 mm/day in September. Average monthly effective rainfall exceeds crop water requirement in the wet season from June to September, indicating no need for irrigation in this season, because the average monthly Pe in this wet season can fulfill more than the need of crop requirement. Thus, surface drainage is needed to remove the excess water from the field, especially in water-logged fields. Other than these wet seasons, irrigation water is needed to meet the crop requirement. Thus, the study supports the design document that no need of irrigation water from June to September months. The daily ETo and Pe variation on a monthly basis are shown in Figure 4.2.

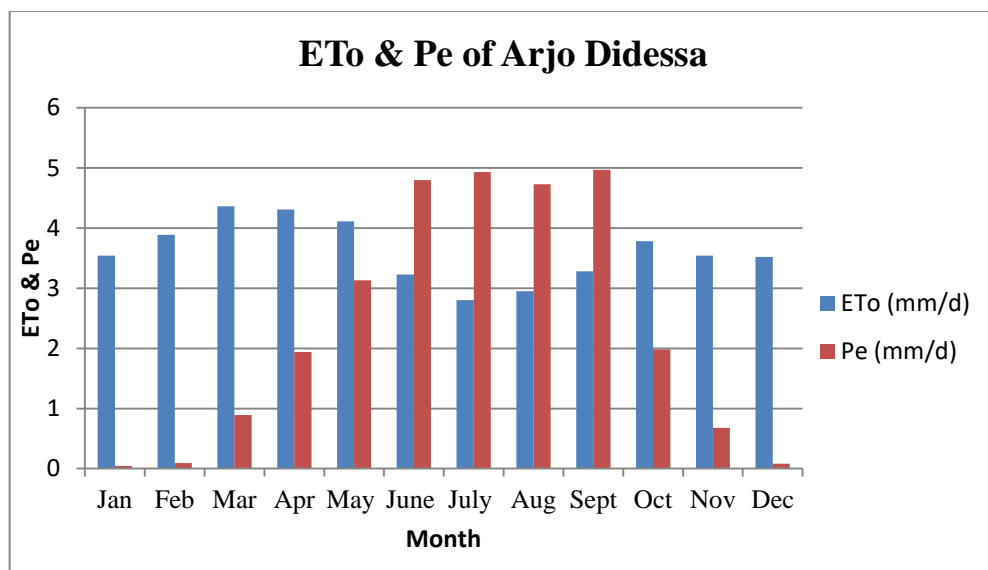


Figure 4.2. Mean monthly variation ETo and Effective rainfall

4.3.4. Net irrigation requirement (NIR)

Net irrigation requirement (NIR) of study area estimated for each growing month and growing stage using equation 3.3 were given in Table 4.6:

Table 4.6: The NIR for each growing month and growth stages of sugarcane

Growing Month/stage	NIR (mm/day)			
	Crop growing stages (Months)			
	(0 -3)	(3 -6)	(6 – 15)	(Above 15)
January	1.95	3.16	3.71	2.46
February	2.15	3.42	4.01	2.66
March	2.4	3.06	3.71	2.12
April	2.38	1.96	2.61	1.08
May	2.3	0.58	1.23	*
June	1.8	*	*	*
July	1.54	*	*	*
August	1.63	*	*	*
September	1.81	*	*	*
October	2.1	1.43	2.02	0.67
November	1.95	2.52	3.07	1.82
December	1.94	3.09	3.62	2.39

According to table 4.6, the NIR of study area varies from 0.58 mm/day in 3 to 6 months cane age in May to 4.01 mm/day in 6 to 15 months age of cane in February. The asterisk sign (*) in table 4.5 shows that no need for irrigation water in the wet season from June to September for 3-6, 6-15 cane ages and May to September for cane above 15 month ages, due to the value of effective rainfall was greater than the sugarcane water requirement. For crops age less than 3 months, the net irrigation requirement was intentionally made equals to crop water requirement (ETc) to provide more frequent irrigation water requirement (Tadesse and Guchie..., 2017). That is the reason for taking the net irrigation requirement equals with crop water requirement (ETc) for crops age less than 3 months. In contrary, the full irrigation water is needed in dry seasons from January to May and from October to December.

4.4. Irrigation Scheduling

Water application depth and interval in days are the important elements in irrigation scheduling. However, there was a problem in irrigation schemes applying the required depth of water at the proper time to optimize crop yield. The irrigation interval in Arjo-Didessa irrigation scheme is fixed and uniform schedule, the interval is 10 days with 22 hour set time. The irrigation interval was similar for different crop growing month and stage. Furthermore, irrigation schedule is very important to achieve the maximum crop

yield and water productivity. As a result, it needs to fix the most suitable and practicable interval which is constant at each growth stages month. Additionally, plant water requirement is highly dependent and varies on the growing stages, i.e. plant water demand at initial stage is not equal to the plant water demand at development stage. As a result it is better grouped the depth and interval based on growing stages. Furthermore, it helps to minimize the confusion gaps on irrigation scheduling. For this study, the estimated irrigation scheduling for the clay (vertisols) soils with respect to cane growing month and stage were discussed in the following next sub topics.

4.4.1. Depth of Water Application

The net depth (Dn) and gross depth (Dg) of application was estimated for the clay soil of the study area using equation 3.4 and equation 3.5 respectively and the results of for each growth stages are given in Table 4.7:

Table 4.7: Net and gross depth of water application of Study Area

Parameters	Sugarcane Stage of growth (month)			
	0 - 3	3 - 6	6 - 15	Above 15
Root depth (Dr) in (cm)	30	45	60	90
Moisture depletion factor (p) in %	60	60	60	60
Total available water, in mm/m	126.36	126.36	126.36	126.36
Net depth of application (Dn), in mm	22.7	34.11	45.48	68.23
Gross Depth of Application (Dg), mm	38.15	57.32	76.43	114.6

The result of Dn summarized in table 4.7 shows that net depth of water application is increased with the stage of canes and effective rooting depth of canes. According to this table the net depth of application is vary from age to age, which are range from 22.7 mm to 68.23 mm. Crops with age above 15 months need more water depth of application. Gross depth of application is estimated based on the current actual sprinkler application efficiency and sprinkler operating set time as currently practiced by project.

4.4.2. Irrigation Interval (I)

The actual irrigation interval of the study area estimated using equation 3.7 for clay soil and each growing months and cane stages are given in Table 4.8. As shown in the table 4.8, the average monthly irrigation interval varied from 10 to 28 days through all growing months and stages. Currently the project practices fixed irrigation interval of 10 days irrespective of sugarcane growing month, stage of growth and soil type, which was according feasibility study document.

Table 4.8: Irrigation interval for each growing month and growth stages

Growing Month	Irrigation interval (I), days			
	0 to 3 months	3 to 6 months	6 to 15 months	> 15 months
January	12	11	12	28
February	11	10	11	26
March	10	11	12	*
April	10	18	17	*
May	10		*	*
June	13	*	*	*
July	15	*	*	*
August	14	*	*	*
September	13	*	*	*
October	11	24	23	*
November	12	14	15	*
December	12	11	13	28

According to the result in table 4.8, the irrigation interval varied with respect of growing month and stage as shown in the table 4.8. The irrigation interval of study area varied from month to month for the same growing stage due to the monthly climatic variations, and also it varied from stage to stage for the same growing month due to variation of crop coefficient and effective root depth across different age. As practical field experience and the crop age of behavior, the first growth stage (0-3 month) of irrigation interval should be reasonable to take as a week interval because the cane needs considerable amount of water frequently at its initial growth stage (Abshiro and singh., 2016; Tadesse and Guchie..., 2017). It needs to check soil moisture status with nearby apparatus such as, augur test and others soil moisture sensors. For the rest of growth stages irrigation intervals have to be applying according to its growing month and growth age of the crop as the stated irrigation interval in Table 4.8.

4.4.3. Actual Sprinkler Operating set time per Irrigation (T)

The actual sprinkler operating time of the study area estimated using equation 3.6 for each month of growing stage under existing operating condition were given in Table 4.9. Currently the project followed uniform/fixed 22 irrigation set hour irrespective of cane stage of growth and the soil according to feasibility study and design document (2007) with a design application efficiency of 75%. There is no information which shows weather the soil physical properties of the project area are considered or not. A practice of uniform irrigation scheduling without considering the soil type, growing month, and stage of crop growth causes moisture stress.

Table 4.9: Sprinkler Set Hour for each growing month and growth stages

Growing Month	Sprinkler set hour (T), hours			
	0 to 3 months	3 to 6 months	6 to 15 months	> 15 months
January	11.6	17.5	23.3	35
February	11.6	17.5	23.3	35
March	11.6	17.5	23.3	35
April	11.6	17.5	23.3	35
May	11.6	17.5	23.3	*
June	11.6	*	*	*
July	11.6	*	*	*
August	11.6	*	*	*
September	11.6	*	*	*
October	11.6	17.5	23.3	35
November	11.6	17.5	23.3	35
December	11.6	17.5	23.3	35

According to Table 4.9, the sprinkler set hour for the growth age of 0-3, 3-6, 6-15, and >15 month is 11.6, 17.5, 23.3 and 35 hours respectively. The asterisk sign (*) shows that no need of irrigation as stated in table 4.6. Finally the result of this study shows the irrigation interval and sprinkler set hour is varying with the growing month and growth stage of crops, which is dependent on soil physical properties and actual sprinkler application efficiency. Therefore, it is important to practice/fix a proper irrigation schedule with respect to soil types, cane growth month, growing stage and actual application efficiency of the study area. The above shown set hour was developed based on actual sprinkler application efficiency of 59.5% estimated as currently practiced by project, considering different growth stage and the soil physical properties as given in table 4.17. Thus, the stated sprinkler set hour will be updated when the system is working under full capacity.

4.5. SPRINKLER PERFORMANCE INDICATORS

4.5.1. Actual Sprinkler Discharge rate and operating pressure

The actual infield measured volumetric discharge rate, sprinkler water application rate, wetted radius and operating pressure were given in table 4.10. The infield measured data were given in appendix 4 (table 12A and 12B). According to feasibility study and design document of study area (2007), the sprinkler system is designed to work at a hydrant pressure of 4.21bar with sprinkler discharge of 1.95m³/hr or 0.54 lit/sec and wetted radius 15.0m. Currently, the existing system is working below design capacity. The actual measured average sprinkler discharge and wetted radius was 1.06 m³/hr and 12.8m respectively. The actual operating pressure is varying from field to field (ranges from 3.0

to 4.0 bars) which is working below the design operating pressure of 4.21bar. The impact of low pressure on water application rate is high.

Table 4.10: The actual measured values of filed sprinkler system of the Study Area

Parameters	Fields	
	Field no 1	Field no 2
Hydrant pressure (bar)	3.5	4.0
Nozzle diameter (mm)	2.4*4.4	2.4*4.4
Average discharge, q, (lit/sec)	0.28 (1.01m ³ /sec)	0.31(1.12m ³ /sec)
Wetted radius (m)	12.2	13.4
Max. pressure along lateral, (bar)	3.5 bar	4.0 bar
Min. pressure along lateral, (bar)	2.95	3.5
Avg. pressure along lateral, (bar)	3.23	3.75
Max. Discharge along lateral, (lit/sec)	0.30	0.34
Min. discharge along lateral, (lit/sec)	0.26	0.3
Avg. Discharge along lateral, (lit/sec)	0.272	0.319
Sprinkler application rate, Ig, (mm/hr)	3.11	3.44
Pressure variation along lateral (%)	17%	14%
Discharge variation along lateral (%)	15%	13%

As shown in table 4.10, the actual sprinkler application rate of 1.01m³/sec and 1.12m³/sec were obtained at 3.5 and 4.0 bar operating pressure respectively. This indicates the rate of sprinkler water application increased as sprinkler pressure increased and vice versa. As a result, the sprinkler discharge rate and the operating hydrant pressure has a positive correlation with each other. The actual sprinkler discharge variation along laterals is 15% & 13% and the pressure variation along laterals is 17% &14%. Merkley and Allen, 2004 recommended, the acceptable range of sprinkler discharge and pressure variations shall not be above 10% and 20% respectively. Thus, the actual obtained discharge variation is above and out of the acceptable range, and the pressure variation is within the accepted range.

In this study area, the common problems cause operating pressure and water application rate is the loss of water in conveyance and insufficient flow capacity from the intake; due to pump and pipe wear, breakage and leakage of field pipes, passage of dust through the pipe system due to lack sufficient filters and the filling of off take filter with unnecessary large debris and dust and nozzle clogging. This all factors have an impact on discharge rate and operating pressure. Thus, the existing system needs a special attention on care, maintenance and regular checkup for water delivery system components and operation.

4.5.2. Water application uniformity for overlapping sprinklers (block test)

The actual coefficient of uniformity (CU) and Distribution Uniformity (DU) of the four overlapped sprinklers were calculated using equation 3.11 & 3.12 from measured field catch can data in two command area for 3.5 and 4.0 bar operating pressure and the result is given in table 4.11. The individual catch-can data were given in appendix 5 (Table 13).

Table 4.11 : The actual CU and DU of four overlapping sprinklers

Field Number/name	Hydrant pressure (bar)	Replications	dav (mm)	Dlq (mm)	CU (%)	DU (%)
Field 1	3.5	Morning	2.5	1.56	69	62
		Mid-day	2.16	1.4	74	65
		Afternoon	2.29	1.4	72	60
Average			2.32	1.45	72%	62.5%
Field 2	4.0	Morning	2.9	1.93	76	67
		Mid-day	2.7	2.0	83	74
		Afternoon	2.75	1.8	78	66
Average			2.78	1.91	79%	69%

Where; dav=average depth of water in all catch-can, Dlq = average depth low quarter

Table 4.11 shows The average CU at 3.5 bar is 72% (varied from 69% to 74%) and 79% (varied from 76% to 83%) were obtained at 3.5 & 4.0 bar hydrant pressure respectively and similarly average DU of 62.5% (varied from 60% to 65%) and 69% (varied from 66% to 74%) obtained at 3.5 & 4.0 bar. The uniformity is varying in morning, mid-day and afternoon at the same hydrant pressure and sprinkler discharge due to the slight wind and evaporation effect.

According to Merkley and Allen (2004), $CU > 78\%$ and $DU > 65\%$ is considered as the minimum acceptable performance level for economic system design. According this, recommendations, the CU and DU values of this study, obtained at 3.5 bar operating hydrant pressure were falls below the minimum acceptable range, whereas the CU and DU values obtained at 4.0 bar operating hydrant pressure falls within the recommended minimum range ($CU > 78\%$ and $DU > 65\%$). Osei., (2009) says that, CU values of 80-90% is attainable for set - move systems which are properly designed and maintained, operating under moderate wind speeds less than 16km/h. It has been found that CU values as low as 60% can occur with systems on undulating topography, with worn or plugged nozzles, and/or under windy conditions. Keller and Bliesner., (2000) stated that, a DU of 85% or greater is considered excellent, 80% is considered very good, 75% is considered good, 70% is considered fair, and 65% or less is considered poor and unacceptable. It is generally

accepted that sprinkler systems should have a minimum DU of 75%. Therefore, the uniformity of this study was in the range of fair to poor at the both 3.5 and 4.0 operating hydrant, which indicate the low performance levels according to, the above recommended ranges. Montero et, al, (2002) stated that low value of CU are usually indicators of a faulty combination of factors such as nozzle size, working pressure and spacing of sprinklers.

According to Merkley and Allen, (2004), Operating pressure in combination with sprinkler spacing and wind speed/direction affects sprinkler water application uniformity and overall system performance in the case of set -move sprinkler system. If the pressure is too low, the result is that the water jet does not break up and all the water tends to fall in one area towards the outside of the wetted circle. If the pressure is too high then the distribution will also be poor. A fine spray develops which falls close to the sprinkler. Spray from sprinklers is easily blown about by even a gentle breeze and this can seriously reduce uniformity. To reduce the effects of wind the sprinklers can be positioned more closely together. According to Phocaidis (2007), for good uniformity the sprinkler overlap pattern should be corresponded to 65% of the sprinkler coverage diameter under light to moderate wind conditions in square or rectangular patterns.

Merkley and Allen, (2004) also stated, operating pressure and application rate has significant impact on uniformity. The application rate depends on the size of sprinkler nozzles, operating pressure and the distance between sprinklers. Sprinklers will only work well at the right operating pressure recommended by the manufacturer; optimum water droplet distribution is achieved only under correct pressure. If the pressure is above or below recommended by the manufacturer then the distribution will be affected. In Arjo-Didessa irrigation project sprinkler spacing and sprinkler nozzle size are similar throughout the system, but the existing operating pressure is varying from field to field (ranges from 3.0 to 4.0 bars) which is below design capacity of 4.21bar.

Therefore, the existing system is working far below design operating pressure and discharge capacity due to poor field management practices, such as transport of unnecessary dust material in the pipes and nozzle clogging due to lack of sufficient screen filters, leakage through pipes, Pipe friction losses due to pumps and pipes wear which increases friction. This all factors have an impact on application rate and operating pressure, they reduce the energy of water flowing in pipes and so operating pressure at the

sprinkler reduces, which in turn lowers the desired uniformity level. As field observation of this study, the care and maintenance for existing system is very poor. Therefore, in order to achieve desired water application uniformity, the system has to be functional with the full design capacity. This is improved by immediate irrigation maintenance, regular checkup and correction for any of existing field water delivery components and system operation.

4.5.3. System uniformity

In order to account the pressure variation, the system uniformity coefficients (SCU) and the system distribution uniformity coefficients (SDU) was calculated from the uniformity of actual individual tests (using Eqn3.14 & 3.15), based on the average pressure (Pa) and minimum pressure (Pn) across the lateral. The results are indicated in table 4.12.

Table 4.12 The measured result of the SCU and SDU

Field Number/name	Hydrant pressure (bar)	Pn, bar	Pa, bar	Replications	CU (%)	DU (%)	SCU (%)	SDU (%)
Field 1	3.5	2.95	3.23	Morning	69	62	67.5	60
				Mid-day	74	65	72.5	63
				Afternoon	72	60	70.5	58
				Average	72	62.5	70.5%	60.5%
Field 2	4.0	3.5	3.75	Morning	76	67	75	65.5
				Mid-day	83	74	81.5	72
				Afternoon	78	66	77	64.5
				Average	79	69	78%	67.5%

Pn = minimum sprinkler pressure at whole field, Pa = average sprinkler pressure of entire system

According to table 4.12, the average SCU of 70.5% & 78% and average SDU of 60.5% & 67.5% were obtained at respective operating pressure of 3.5 bar & 4.0 bar respectively. The result shows, System uniformity is less than the actual application uniformity (CU and DU) obtained from individual tests. According Keller and Bliesner, (1990) the system uniformity is less than actual uniformity, due to the pressure and discharge variations throughout the irrigated field during the operation time. Merkle and Allen (2004) also stated that, the uniformity is usually less when the entire sprinkler system is considered, because there tends to be greater pressure variation in whole system than at any given lateral position. If Pn is equal to Pa, there is no pressure variation and then System uniformity and actual uniformity is equal. In this study, the values of the SCU and SDU are very closely less to the calculated actual CU and DU values of individual tests, this

indicate that the pressure variations within the systems are small. As discussed previously the measured pressure variation is within the recommended acceptable range of 20% as suggested by Merkley and Allen, (2004)

4.5.4. Water application uniformity for single sprinkler test

The actual CU and DU of single sprinkler test is made by placing 64 catch cans in a 3x3m square grid position around the sprinkler. The same equations as for block test were used and actual results were given in table 4.13. The infield individual catch can data were given in appendix 5 (Table 14A, and 14B).

Table 4.13: The actual CU and DU of the single sprinkler test

Field Number/name	Hydrant pressure (bar)	Replications	dav (mm)	Dlq (mm)	CU (%)	DU (%)
Field 1	3.5	Morning	1.55	0.8	61	51
		Mid-day	1.48	0.7	65	46
		Afternoon	1.6	0.8	63	50
Average			1.54	0.76	63%	49%
Field 2	4.0	Morning	1.46	0.8	65	55
		Mid-day	1.54	0.77	70	50
		Afternoon	1.52	0.87	66	57
Average			1.51	0.82	67%	54%

Table 4.13 shows, the actual average CU of 63% and 67%, and whereas actual average DU of 49% and 54% were obtained at operating pressure of 3.5 and 4.0 bars respectively. According to field test, the actual application uniformity of a single sprinkler is different from time to time for the same hydrant pressure and sprinkler discharge due to wind and evaporation effect. The wetting pattern from a single rotary sprinkler is not very uniform. For good uniformity several sprinklers must be operated close together so that their patterns overlap. The result shows, the actual uniformity of single sprinkler working alone is very less than the uniformity of four overlapped sprinklers working together. This shows that the better acceptable actual application uniformity is achieved when sprinklers are overlapped together to reduce the wind effect.

However as discussed above the existing overlapped sprinkler uniformity with 18mx18m of design spacing is also not satisfactory with existing operating pressure, which ranges from fair to poor. According to Merkley and Allen, (2004), uniformity is mainly a function of design and subsequent system maintenance. Therefore, in addition to system

maintenance, evaluation of system design and management is also very important. As suggested by Merkley and Allen, (2004) and Osie, (2009), the sprinkler catch can data is often overlapped for various sprinklers and lateral spacing's to evaluate uniformities for design and management purposes. Thus, in this study different four spacing types were tested from single sprinkler catch can data as discussed in next sub-topic. The result is very important to suggest proper spacing pattern which gives acceptable uniformity level with combination of existing operating pressure.

4.5.5. Selecting Sprinkler spacing

As state in the above, different overlapped spacing of 12m*18m, 12m*12m, 18m*12m, and 9m*12m were tested, with their respective hydrant bar operating pressure. The overlapped catch can data were simulated from the measured actual single sprinkler catch can data using spreadsheet program which was similar as suggested by Merkley and Allen, (2004) and Osie, (2009). The measured CU and DU of these different spacing's were given in table 4.14. The actual overlapped catch can data of stated spacing types were given in appendix 5 (Table15)

Table 4.14: CU and DU value for different overlapping spacing of single sprinkler

Spacing	At 3.5 hydrant bar pressure		At 4.0 hydrant bar pressure	
	CU (%)	DU (%)	CU (%)	DU (%)
12*18m	78	72	81	77
12*12m	84	81	86	83
18*12m	75	70	80	74
9*12m	85	82	88	85

As shown in table 4.14, the CU and DU value of the 12*18m, 12*12m, 18*12 and 9*12 m spacing's for both of hydrant operating pressure was greater than the existing design overlapping sprinkler spacing of 18*18m. Specially, the values for 12*18m, 12*12m, and 9*12 m spacing's are in acceptable recommended range of uniformity level at both operating pressures. According to USDA, (2016), the basic criterion governing the selection of spacing for any given sprinkler nozzle-pressure and wind combination is the desired distribution uniformity. Higher values of CU generally require closer nozzle or lateral spacing, higher operating pressures, or both, which in turn require higher investment and perhaps operating costs. Thus, some balance is required. Therefore, keeping in view of economy, wider spacing of 12mx18m is recommended for existing system operation of

study area, to have very good water distribution with CU of 78% and 81% and DU of 72% and 77% at stated respective operating pressure under existing wind condition of the area. Phocaides (2007) stated that, in order to obtain good distribution uniformity by overlapping, the sprinkler spacing (Sm) should not exceed 65% of the sprinkler diameter coverage under light to moderate wind conditions in the square and rectangular patterns.

4.5.6. Potential application efficiency (PAE) and PAELQ

Potential application efficiency is the relationship between the water collected by the catch-cans and water discharged by the sprinkler. The difference between the actual discharge and the water collected is attributed to evaporation and wind drift losses during the irrigation event, mainly as a result of environmental conditions. The potential application efficiencies (PAE) and potential application of low quarter (PAELQ) values which determined from the surface uniformity of catch cans depth data measurements using equation 3.16 & 3.17 were tabulated in table 4.15 below.

Table 4.15 PAE and PAELQ of study area

Field no	Hydrant Pressure (bar)	Ig, mm	Replication	dav (mm)	Dlq (mm)	PAE, %	PAELQ, %
Field no 1	3.5	3.11	Morning	2.5	1.56	80.5	50
			Mid-day	2.16	1.4	69.5%	45
			Afternoon	2.29	1.4	73.5	44.5
			Average	2.32	1.45	74.5%	46.5%
Field no2	4,0	3.44	Morning	2.9	1.93	83.5	56
			Mid-day	2.7	2.0	78	58
			Afternoon	2.75	1.8	79.5	52
			Average	2.78	1.91	80%	55.5%

As shown in table 4.15.PAE based on the mean depth of catch can varies from 69.5% to 83.5%, whereas obtained PEALQ value varies from 44.5% to 58%, on both operating hydrant pressure. The minimum PAE and PAELQ value was obtained at 3.5 bars. This result was taken without considering the evaporation losses from catch cans during the experiment. The average PAE of 74.5% & 80% and average PAELQ of 46.5% & 55.5% were obtained at 3.5 and 4.0 bar hydrant pressure respectively.

PAE is the relationship between the water collected by the catch cans and actual water discharged from the sprinkler, and the difference between them is attributed to evaporation and wind drift losses during the irrigation event. As shown in table, PAE increases with

increasing operating pressure. But, according to Merkley and Allen, (2004), if operating pressure is too high and above the recommended condition, wind drift and evaporation loss also high due to the fineness of sprinkler water application and PAE decreases due to increasing pressure. Thus the PAE influenced by environmental condition and droplet size, in which optimum droplet size is obtained at correct operating pressure. PAE also varies during morning, midday and afternoon at same hydrant operating pressure due to environmental conditions at the time of irrigation. According to result evaporation and wind effect is high at mid-day and slightly at late day. The mean air temperature during the test is high at midday, but the wind condition ranges from 1.5 km/hr to 3.65km/hr, which is categorized under light condition, thus the impact of wind very small.

Merkley and Allen, (2004) stated that, it is not enough to have uniform application if the average depth is not enough to fill the root zone to field capacity. Similarly, it is not enough to have a correct average application depth if the uniformity is poor. We can design a sprinkler system that is capable of providing good application uniformity, but depth of application is a function of set time (in periodic-move system). Thus, uniformity is mainly a function of design and subsequent system maintenance, but application depth is a function of management. Thus, it is important to evaluate the potential efficiencies of the lower quarter (PAELQ) which include the concept of uniformity and adequacy of irrigation as proposed by USDA. It is a measure of how effectively the system can utilize the applied water and low values indicate design or management problems.

It is, therefore, PAELQ is a measure of the best management practice and should be thought of as the full potential of the system (Jensen, 1983). According to Keller and Bliesner, (1990) recommendations, the PAELQ should be greater than 60% for typical potential application efficiencies for well-designed and managed irrigation systems. But, the values of PAELQ obtained for this study are less than the recommendation value for both hydrant pressures. This indicates as the water losses increased and the application efficiency was lowered, which are mainly affected by system design and management factors, such as; time of irrigation, non-uniform distribution, lack of system maintenance.

Operating pressure and discharge rate of sprinklers has significant impact on irrigation water application efficiency and the overall performance of the irrigation system. In the existing system, the design operating pressure is affected by system pipe leakage and

insufficient flow capacity due to lack of system maintenance. A number of the components are affected by sedimentation, weed growth, flooding, and erosion. In rainy season any soil particle or sedimentation, and any large matters are easily passed to the pipe system due to lack of sufficient filter. This causes the pipe breakage and low flow rate at different fields up to the hydrant and nozzle clogging. Sprinkler nozzle wear and clogging causes the operating pressure and application rate capacity. Additionally, problems such as, noisy pumps, lack of sustainable and regular power supply for operation of pumps, lack of faults, lack of recording information and correction for any system failure (such as: location, timing of failure, failure types, cause of failures), lack of pressure gauges instruments for daily checkup of operating pressure are observed. This indicates the existing operation management regarding system care and regular irrigation maintenance has its gap.



Figure 4.3 Factors affect the performance level and in field water application

The effects of all these combined gaps increases the water loss, non-uniformity of water application in most fields and over application of water in some fields, and final reduces the system irrigation efficiency. Therefore regular checkup of the system, care, maintenance, is very important for efficient operation of the system. Regular maintenance provides the opportunity for inspection and minor repairs to prevent potential system failure. To achieve the acceptable application efficiency, it is better to apply Preventive maintenance program as recommended in Design document and to work with design operating pressure. Additionally, to obtain good water application performance with existing operating pressure, it is better to use 12mx18m of sprinkler spacing as discussed in sprinkler spacing topics. The effect of sprinkler nozzle characteristics (i.e size, number, and diameter) on system efficiency is not investigated in this study, but it is important to aware that mismatched nozzle size with pressure and sprinkler spacing has also an impact on water application efficiency.

4.5.7. Actual Application Efficiency (AEa)

Application efficiency refers to the amount of water needed for crop production compared with the amount applied to the field and depends on system uniformity and management. It is the ratio of the amount of irrigation water beneficially used to the amount of applied water. It can be defined as the ratio of the depth of water used by the plant to the depth of water applied to the field (Zerihun et al., 1997).

➤ On-Field storage Efficiency (Es)

The application efficiency measured based the fraction of water that actually stored in root zone, can be obtained at field condition by current management system was determined based on the average depth of water applied (dg) and actually stored in the effective root depth (ds) using equation 3.18. The dg was measured using equation 3.20. The average result of Es was given in table 4.16.

Table 4.16; On-Field storage efficiency of study area

Fields	Hydrant pressure (bar)	Depth of applied water (dg), in mm	Depth of water stored (ds), in mm	Es (%)
Field 1	3.5	68.45mm	44.22mm	64.6
Field 2	4.0	75.8mm	48.4mm	63.8
Average				64.2%

The AE relates the actual storage of water in root zone to meet the crop water need in relation to the water applied to the field. Thus, to compute Es it is necessary to identify the amount of water stored in the root zone. Actual stored water was determined by taking soil sample before and after irrigation. Gravimetric method has used to determine an average soil water deficit for each site, which was used in the subsequent determination of irrigation efficiency. Finally, application efficiency would obtain from the percent ratio of depth of water added and stored in crop root zone to the depth of water applied to a field.

The actual application efficiency, Es, was obtained for this study was 64.6% and 63.8% for hydrant pressure of 3.5, and 4.0 bars respectively. The result shows, the application efficiency decreases with increasing operating pressure because the fineness of droplet increases with pressure as a result evaporation and wind drift loss increases from water sprayed and the application efficiency lowered. Actual Application efficiency refers to the amount of water applied that is stored in the crop root zone and depends on system uniformity and management (Merriam et al., 1983). It was determined in order to evaluate

how well the system can apply water and it is a measure of management losses. According to Keller and Blisner, (1990), the irrigation efficiency for pressurized irrigation system should be greater than 85%. Therefore the measured actual irrigation efficiency does not meet this recommendation.

It is important to note here that the application efficiency, which is the ratio of depth of stored to depth of water applied; indicates that the fraction of water applied at the sprinkler nozzle which effectively stored in the effective root zone, and is equal to the storage efficiency. Which means it is not consider the actual water required SMD by the crop in effective root zone.

➤ **On-field Actual Water Application Efficiency (AEa)**

According Merklely and Allen, (2004) application efficiency is mainly influenced by actual sprinkler depth of application, which is a function of set time and management. For this study, the actual application efficiency which is a measure of current management was measured at field condition by considering net depth of irrigation application needed or SMD in each effective rooting depth of growing stage of sugarcane with amount of water applied to the field which is measured for a given operating pressures, sprinkler spacing of 18mx18m and 22 hours irrigation set time as currently practiced by project. AEa was measure using 3.19 and the average result estimated for each growing stage was given in table 4.17.

Table 4.17: The actual application efficiency based on required depth of application

Field No	Hydrant pressure, bar	Ig, mm	dg, in mm	Actual application efficiency (AEa), %				Avg.
				Net depth of application needed Dn (mm) for Stage of growth				
				0 - 3	3 - 6	6 - 15	>15	
				22.7	34.11	45.48	68.23	
Field 1	3.5	3.11	68.45	33%	50%	66.5%	99.5%	62.5%
Field 2	4.0	3.44	75.8	30%	45%	60%	90%	56.5%
Total average								59.5%

Where; dg = actual gross application depth from sprinkler

As shown in the table 4.17, the existing AE varied through crop growing stages, due to the variation of required depth of application with respect to effective rooting depth of different crop stage. The average AE of overlapping sprinklers measured for all growing stage were 62.5% and 56.5% at 3.5 and 4.0bar operating pressure respectively. It varied

with crop growing stage and it also varied with the different operating pressure of the similar growing stage. As shown in the table the AEA value for all growing stage was less than 100%, which means the actual sprinkler depth of application is more than the needed depth of application.

The existing system was designed to apply water at 10 days irrigation interval for 22 hour set time irrespective of the soil type and growth stage with application efficiency of 75%. However, according to this study the average actual application efficiency of the overlapping sprinklers estimated by considering different effective root depth with their respective of growing age was 59.5%, which is below design application efficiency. As shown in table over application and more water loss is observed in 0-3 month & 3-6 month crop growing stage due to excess water may be applied in 22 hrs than required depth in those crop stages and absorbed by the soil profile thus leading to wastage, and in addition, under water applications were obtained in some of crops above 15 month fields when considering other unavoidable losses and environmental factors. This causes poor cane growth and which in turn reduces the expected crop yield.

Finally, the result of this study clearly indicates, the existing actual water application performance is poor due to system design and management problems. The irrigation set hour with actual sprinkler operating pressure has a significant impact on existing actual application efficiency such as applying uniform irrigation scheduling irrespective of soil characteristics, growing stage and month. A practice of uniform scheduling (depth and interval) through all growing stages created a problem of over irrigation (deep percolation loss) at initial and development stage, and under irrigated during mid and late growing stages (water stress). The reason is that, water uptake capacity of the crop is directly related to the root development and vegetative development stages. Consequently it leads to low water productivity and low crop production results. Thus, it is better to fix irrigation scheduling of sugarcane by considering net depth of application needed in effective root zone of each growing stage and based on actual water application efficiency, to achieve better irrigation water management and crop production. As a result application efficiency of 59.5% was used to develop irrigation set hour for this study based on the existing actual operating condition.

The actual application efficiency (AEa) does not give any indication of the level of adequacy of the irrigation system and with the exaggerated under irrigation it may be 100%. In other words, AEa only indicates the fraction of applied water stored in the root zone that is potentially accessible for evapotranspiration. Since, the above potential and actual efficiencies do not indicate the level of adequacy, it is important to evaluate the efficiencies, which include the concept of uniformity and adequacy of irrigation

4.5.8 Adequacy of irrigation

The effectiveness use of a given sprinkler system can be determined from how much of the applied water is stored in the soil and available for consumptive use and how uniformly it is applied. Irrigation adequacy is generally defined as providing a satisfactory irrigation depth in the field or is the percentage of a field that receives a sufficient amount of water to maintain quantity and quality of crop production at profitable level; it depends on system uniformity and management (Cuenca, 1989; James, 1993). It is possible to attain a very high AE in a field by under irrigating. A parameter, complementary to AE, indicating the degree to which the target or required depth is met should be included in any list of pertinent performance measures. Adequate watering takes into account the water added to the effective root zone, but does not raise the soil water content to or above the target level. For a single irrigation event it is pertinent to include a parameter which determines how well the required depth of water has been satisfied. In many cases managers and researchers are interested in the low-quarter depth just equaling the required depth, this is termed the low-quarter adequacy (ADlq). For this study the adequacy performance of irrigation was determined from the measured low quarter distribution uniformity of each hydrant pressure and amount of water required to be stored in crop root zone using equation 3.21 as defined by Burt et al., (1997) and the result were given in table 4.18

Table 4.18; the lower quarter adequacy of each test

Field no	Hydrant pressure (bar)	Depth of stored	Dlq	ADlq
Field 1	3.5	2.01	1.56	0.78
			1.4	0.7
			1.4	0.7
Average				0.72
Field 2	4.0	2.2	1.93	0.87
			2.0	0.90
			1.8	0.82
Average				0.86
Total average				0.79

The results of average lower quarter adequacy were 0.72% and 0.79 for the respective operating hydrant pressure of 3.5 and 4.0 bar. The values vary from 0.7 to 0.90 for all experiments at all operating pressures. Ascough (2004) states with this definition, $ADlq < 1.0$ implies under irrigation, whereas $ADlq > 1.0$ implies over irrigation. Therefore as shown in Table 4.17, the $ADlq$ value of all tests are less than 100%, according this definition the existing system is completely under irrigated, which means none of the irrigated areas received the depth of water it required or the current irrigation practices cannot meet crop water requirement in well. The adequacy level of the irrigation system is very low at all operating hydrant pressure. This indicates that there was water stress at all hydrant pressure considered.

Arjo-Didessa irrigation systems were designed to apply, on average, 132.4 mm of water every 10 days of irrigation interval for 22 hours, but the actually measured applied water depth ranges from 64.78mm to 82.11 mm of water at 22 hour of application time. Average actual application depth is 72.11mm. This indicates that the system is under irrigated compared to design irrigation. This means the amount water applied to the field is not sufficient or the irrigation area cannot receive the required depth of water. Figure 4.9 shows the difference in growth height, non-uniform growth, poor stand and yellowing of planted cane observed at the study area due to water stress.



Figure 4.4. Poor growing canes due adequacy of water

5. CONCLUSION AND RECOMMENDATION

5.1. CONCLUSION

The Assessment of Arjo-Didessa irrigation system performance has a great importance and vital to know its status, gaps and the influencing factors. This study was undertaken to assess the actual sprinkler irrigation performance of Arjo-Didessa Sugar project based on the current operating condition and to comparing with its potential performance during design period and with standard sprinkler system recommendations. The study identifies the common gaps existed in actual operating condition and has made opportunities for improvements of existing system performance. The primary and secondary data were collected. The Infield water application performance test was conducted in two fields for 3.5 bar & 4.0 bar operating pressure and important sprinkler performance indicators were measured.

According to design document of study area, the existing sprinkler system is designed to operate at 4.21 hydrant pressure, 1.95m³/hr discharge rate and to apply water at 10days of irrigation interval and 22hrs set time with application efficiency of 75%. However, the actual maximum operating pressure is 4.0bar and average measured sprinkler discharge rate is 1.06 m³/hr. The actual Sprinkler discharge variation across laterals was above and out of the range accepted value of 10% and whereas the pressure variation is within the accepted range value of 20%. The existing operating pressure and discharge rate is working below design capacity due to lack of sufficient flow capacity through the system influenced by lack of regular system maintenance such as nozzle clogging, leakage of pipes and breakage of field components in existing system The irrigation interval estimated based on required depth of application in different rooting depth varies from 10 to 28 days through all growing month and growing stage. Actual Irrigation set hour of existing system estimated based on AEa was varying from 11.6 to 35 hours through all growing stage.

PAE of 74.5% and 80% and PAELQ of 46.5% and 55.5% were obtained at 3.5 and 4.0 bar respectively PAE increases with increasing operating pressure, it also varies during morning, midday and afternoon at same hydrant operating pressure due to environmental conditions at the time of irrigation. The mean air temperature during the test is high at midday, thus the effect of evaporation is high at mid-day and slightly at late day, but the wind condition during the entire test was categorized under light condition, so the wind

impact is very small. The values of PAELQ obtained for this study is less than the recommendation value of >60%, which indicates not sufficient, for typical potential application efficiencies for well-designed and managed irrigation systems.

For overlapping sprinkler test, average CU of 72% and 79% and average DU of 62.5% and 69% were obtained at 3.5 & 4.0 bar hydrant pressure. The obtained result is in the range of poor to fair at both successive hydrant pressures. The values of System uniformities are very closely less to the calculated actual values of individual tests, this indicate that the pressure variations is within the systems are small. The result of single sprinkler uniformity test is far below than the overlapping test, which indicates better acceptable actual application uniformity is achieved when sprinklers are overlapped together to reduce the wind effect. The dominant factors affecting water application uniformity is the existing operating pressure and discharge rate is working below design capacity due to poor system maintenance and field management problems.

According to Merkley and Allen, (2004), uniformity is mainly a function of design and subsequent system maintenance. Operating pressure with combination of sprinkler spacing has a significant impact on uniformity. To assess the design and management of existing practices, four types of spacing were tested from single sprinkler catch can data with existing operating pressure as suggested by Merkley and Allen, (2004) and Osie, (2009). Therefore, keeping in view of economy, wider spacing of 12mx18m is recommended for existing system operation of study area, to have very good water distribution with CU of 78% and 81% and DU of 72% and 77% at stated respective operating pressure under existing wind condition of the area. In general the result of this study shows the application uniformity of sprinklers is increasing with increasing operating pressure and decreasing sprinklers spacing.

The average AEa of the overlapping sprinklers estimated by considering depth of application in different crop growing stage was 59.5%, which is below design application efficiency. The existing AEa varied through crop growing stages, due to the variation of required depth of application with respect to effective rooting depth of different crop stage. Thus, the set hour, also vary with the amount of required depth through growth stages at existing sprinkler application rate. Thus, AEa is influenced by depth of application, which is a function of set time and management. Finally, the existing actual water application

performance is poor due to system design and management problems such as applying uniform irrigation set hour for all crop growing stage. The results of average lower quarter adequacy were 0.72% and 0.79 for the respective operating hydrant pressure of 3.5 and 4.0 bar. According Ascough (2004) the existing system is completely under irrigated, which means none of the irrigated areas received the depth of water it required or the current irrigation practices cannot meet crop water requirement in well.

Generally, the result of this study indicates, the existing actual performance is at poor level and not working as expecting potential performance during design period. The existing gaps are interrelated each other and in general categorized into design, management and system maintenance problems. The numbers of functional components initially installed has been becoming nonfunctional due to system maintenance and management problems. Additionally, due to the frequent power supply interruption, all existing electric pumps disturbs proper functioning of the pumps to affect amount of water delivery for irrigation, which does have negative implication on the performance of the irrigation systems.

Nasab et al., (2007) in their evaluation of sprinkler systems in Iran, concluded that the main problems of sprinkler irrigation systems are deficient design and implementation, low distribution uniformity, low water pressure, deficient distribution of pressure, insufficient lengths of lateral pipelines in addition to poor quality equipment and deficient management and maintenance processes. These problems are similarly observed in Arjo-Didessa Sprinkler irrigation system. Therefore, the result of this study has made opportunities for government and existing management in identifying the suitable improvement approaches for existing system performances.

5.2. RECOMMENDATION

Generally, based on the assessment done and the study result evaluation, the following recommendations were forwarded:

- ✓ It is better to follow irrigation interval and sprinkler set hour based on the growing month, and stage of growth and current measured actual application efficiency.
- ✓ In order to attain the acceptable water application uniformity range, the system has to be work either with full design capacity or needs some design modification with existing operating pressure. Sprinkler spacing of, 12 x 18 m is suggested with current operating condition.

- ✓ Regular checkup, service, care, maintenance of the system must be adopted. The project has to fix common cleaning day for the whole system. The pressure measurement devices should be available in numbers to check the daily operating pressure. The operating pressure should be checked against design pressure and corrected accordingly.
- ✓ Proper awareness, training and instruction must be given for the experts, operators and irrigators how to operate the system.
- ✓ Sustainable and alternative power source shall be taken as an option to increase pumps running time. All the electric pumps should be repaired to achieve the desired capacity.
- ✓ Furthermore, this study paper focused the performance assessment at existing operating condition by considering the operating pressure and the sprinkler spacing parameters on water application performance. Further detail studies are required by considering the effect of existing nozzle characteristics (size & number), riser height on water application performance and additionally, experimental investigations are required on quality of equipment, pump efficiency, pipe diameter and network.

Finally, as all we know currently the Grand Ethiopian Renaissance Dam (GERD) is on construction on Nile River. Roughly a quarter of the total flow of Nile River as measured at the Sudan border originates from Didessa sub-basin (Sima, 2011; Awulachew et al., 2008). However, the flow of Didessa River is reduced due to the combination effects of climate change and upstream water development for irrigation including Arjo-Didessa sugarcane irrigation project (Shaka, 2008). Currently the project is practicing both surface and sprinkler irrigation. Thus the author would like to recommend for the factory to practice water saving irrigation system i.e sprinkler irrigation, considering long term economic benefit.

References

- Abdel Wahab, D.M., (2005). Effect of irrigation at different soil moisture levels on yield and yield components of sugarcane. University of Khartoum Journal of Agricultural Science 13 (2), 276.
- Abernethy C. (1986). Performance measurement in canal water management Journal of International Irrigation Management Institute ODI, 86 (2d), p 1-25.
- Abernethy, C. (1989), Performance criteria for irrigation systems. In: Proceedings on International Conference on Irrigation Theory and Practice, University of Southampton, UK., 12-15.
- Abshiro FK, Singh P (2018) performance evaluation of infield sprinkler irrigation system under existing condition in Beles sugar development project, Ethiopia, Irrigat Drainage Sys Eng, an open access journal Volume 7 • Issue 2 • 1000213 ISSN: 2168-9768
- Allen RG, Pereira LS, Raes D, Smith M (1998). Crop evapotranspiration. Guidelines for computing crop water requirements. FAO Irrigation and Drainage. Paper No. 56. FAO, Rome
- Allen, R.G., Pereira, L.S., Howell, T.A., Jensen, M.E. (2011). Evapotranspiration information reporting: I. Factors governing measurement accuracy. Agricultural Water Management, Vol.98 (6):899-920..
- Aminul, Haque M. (2005). Estimating Monthly and Yearly Dependable Rainfall for Different Climatic Zones of the World. Songklanakar J. Sci. Technol., 2005, 27(3): 667-673.
- Arjo-Didessa Irrigation project, feasibility study Irrigation and drainage, main report WWD & SE and ITC of India, may, 2007
- ASABE, R. (1998). Standards, 45th ed. 1998.S436.1. Test procedure for determining the uniformity of water distribution of center pivot, corner pivot and moving lateral irrigation machines equipped with spray or sprinkler nozzles. ASAE, St Joseph, USA.
- Ascough GW, Kiker GA. (2002). The effect of irrigation uniformity on irrigation water requirements, Water SA, 28(2): 235-242.
- Awulachew S. B., Teklu, E. and Regassa, E. N. (2010b), Irrigation Potential in Ethiopia; Constraints and Opportunities for Enhancing the System, International Water Management Institute
- Awulachew S.B., Merrey, D.J., Kamara, A.B., Van Koppen, B., Penning, de Vries F. Boelee, E. and Makombe, G. (2005), Experiences and opportunities for promoting small scale/micro irrigation and rainwater harvesting for food security in Ethiopia, IWMI, (Working paper 98). Colombo, Sri Lanka.
- Awulachew S. B., Lambisso R. Asfaw, G. Yilma A.D. and Moges S.A. (2010a), Characterizing, Assessing of performance and causes of underperformance of irrigation in Ethiopia, Ethiopian Journal Development Research
- Baum, M., Dukes, MD and Miller, GL. (2005). Analysis of residential irrigation distribution uniformity. *Journal of Irrigation and Drainage Engineering* 131(4):336-341.
- Booker Tate Limited, (2009). Re-evaluation of Plantation Soil at Metahara Sugar Factory, Final Report. Ethiopian Sugar Industry Support Center Share Company, Research and Training Services. Wonji.
- Bos, M.G., Burton, M.A, and Molden, D. J. (2005). Irrigation and drainage performance assessment practical guidelines ISBN 0-85199-967-0 (alk. paper)
- Burt, C. M., Clemmens, A. J., Strelkoff, T. S., Solomon, K. H., Bliesner, R. D., Hardy, L. A., Howell, T. A. & Eisenhauer, D. E. (1997). Irrigation performance measures: efficiency and uniformity, *Journal of irrigation and drainage engineering*, 123(6), 423-442.

- Ceunca, H. R. (1989). Irrigation system design, Engineering approach. Prentice Hall. Englewood Cliffs and New Jersey.
- Chala Daba Geleta., (2018), Effect of first watering month on water requirement of sugarcane using CROPWAT Model in Finchaa Valley, Ethiopia Department of Water Resources and Irrigation Management, Wollega University, Nekemte, Ethiopia. Received 31 October, 2018; Accepted 27 December, 2018.
- Christiansen JE. (1942). Irrigation by Sprinkling. California Agriculture Experiment Station Bulletin No. 670.
- Clarke, D.; Smith, M.; El-Askari, K.(2001) CropWat for Windows: User Guide; University of Southampton: Southampton, UK, 2001
- Clemmens A & Molden D (2007), Water uses and productivity of irrigation systems. Irrigation Science, 25, 247-261
- Crawford T. D. Himelrick, D. G. Sibley J. L. & Pitts J. A. (2001), Effect of runner plantlet size on performance of strawberry plug plants. Small Fruits Review, 1, 15-21.
- Cuenca, R. (1989). Irrigation system design: an engineering approach prentice hall, Inc. NJ. 552PP.
- Dalton P. Raine S. & Broadfoot K. (2001), Best management practices for maximizing whole farm irrigation efficiency in the Australian cotton industry. Final report to the Cotton Research and Development Corporation, National Centre for Engineering in Agriculture Report, 179707
- Dalton, P. And Raine, S., (1999). Measures of Irrigation Performance and Water Use Efficiency, Department of Environmental and Resource Management, Australia. Accessed on 17th August 2007.
- Depeweg, H. (1999). Off-Farm Conveyance and Distribution Systems. *Land and Water Engineering. CIGR Handbook of Agricultural Engineering*. Volume I. America Society of Agricultural Engineers (ASAE). USA.
- Dinka MO. (2004), evaluating the field water application performance of sprinkler irrigation system at Finchaa Sugar Estate, MSc Thesis submitted to ArbaMinch University, Ethiopia.
- ESC, (2012), Ethiopian Sugar Corporation projects profile. www.etsugar.gov.et/corp. Posted on Jun17, Sunday @ 11:58 pm.
- FAO (1989), Guideline for Designing and Evaluating Surface Irrigation Systems, Irrigation and Drainage Paper, No. 45. FAO, Rome
- FAO (1990) Irrigation and Drainage paper No 56, Crop Evapotranspiration, guidelines to determine Crop Water Requirements.
- FAO (1995). *Irrigation in Africa in Figures*. Water Report No.7. FAO, Rome.
- FAO (1996), Irrigation Scheduling: From theory to practice, Water Reports, 8. FAO, Rome.
- FAO (1999), Poverty reduction and irrigated agriculture Food and Agriculture Organization of the United Nations: IPTRID: Issues Paper No.1, Rome, Italy.
- FAO (2010). Water development and management unit crop water information: sugarcane. www.fao.org/nr/water/cropinfo-sugarcane.htm. (Accessed on July, 2015).
- FAO (2014), Building a common vision for sustainable food and agriculture principles and approaches. Food and Agriculture Organization of The United Nations. Rome, 2014
- FAO (2001) Irrigation Manual, Planning, Development Monitoring and Evaluation of Irrigated Agriculture with Farmer Participation Volume III Module 8, FAO, Sub-Regional Office for East and Southern Africa (SAFR) Harare, 2001, ISBN 0-7974-2318-4

- FAO, (2018). CROPWAT Software Available online: <http://www.fao.org/landwater/databases-and-software/cropwat/en/> (accessed on 20 August 2018)
- FAO. (1984). Crop water requirements. By: J. Doorenbos and W.O. Pruitt. FAO Irrigation and Drainage Paper 24. Rome, Italy.
- Griffiths, B. (2006). In-field evaluation of irrigation system performance. Thesis submitted to University of KwaZulu-Natal for MscEng Degree. Pp36
- Habib D. (2001). Evaluation of irrigation water application practices at Fincha Sugarcane Plantation. Ethiopian Sugar Industry Support Center Share Company, Research and Training Services. Wonji
- Hachum, A. (2006). Performance Evaluation of Sprinkler Irrigation Systems: Symposium on Irrigation Modernization, International Program for Technology and Research in Irrigation and Drainage, Syria. Accessed on 28th June 2007 from <http://dotproject.fao.org/Syria/hachum.pdf>, 1-24
- Hailegebriel S. (2007). Irrigation potential evaluation and Crop suitability analysis using GIS and Remote Sensing technique in Beles sub basin. MSc. in Geographic Information Systems and remotesensing. Addis Ababa University, Addis Ababa
- Heeley, D. (2005). Understanding Pressure and Pressure Measurement, Application Note, Free scale Semiconductor Inc., USA. Accessed on 28th August 2007.
- Huck, M. (2004). Irrigation Uniformity, Turf grass Information Center, USA. Accessed on 27July2007fromhttp://turf.msu.edu/docs/74th_Conference/Huck_Water_Irrigation.pdf, pp.1-4
- Huffman, R. L., et al (2011), Soil and water conservation Sixth Edition: Published by ASABE. 403-433.
- Broner (2005). Irrigation Scheduling. Colorado State University Extension. No. 4.708.
- Irrigated Crop Management Centre, (2002), Evaluating Sprinkler System, Primary Industries and Resources, Australia. Accessed on 3rd August, 2007 from <http://www.pir.sa.gov.au/factsheets//408600.pdf>, 1- 2
- J. doorenbos and W. O. Pruitt., (1977), guidelines for predicting crop water requirement, FAO Irrigation and drainage paper food and agriculture organization of the united nations Rome 1977
- Jacobson, W. L. (1952). Sprinkler Irrigation Research in Canada. Journal, American Society of Agricultural Engineers, Vol. 33,pp. 497-498.
- James L. Walworth (2006), Soil Sampling and Analysis, The University of Arizona Cooperative Extension. College of Agriculture and Life Sciences, *State Soil Specialist AZ1412. Revised 10/11*
- Jensen, M.E. (1983). Design and operation of farm irrigation system, ASAE. In ASAE Monograph series, No.3 Michigan.
- Julaia, C. de S. (2009). Performance assessment of water distribution in large scale irrigation: Case study of Chokwe Irrigation System in Mozambique. Thesis (MSc). Delft, The Netherlands: UNESCO-IHE.
- Kamara CS, Haque I (1991). Soil Physics Manual. Working Document No.B12 Soil science & Plant Nutrition Section: International Livestock Center for Africa. Addis Abeba, Ethiopia
- Keller, J. & Bliesner, R. (2000). Splinker and trickle irrigation. Avi Book, New York.
- Keller, J. and Bliesner, R.D. (1990). Sprinkle and Trickle Irrigation, Van Nostrand Reinhold, New York, 3-5, 86-96

- Kincaid, D., Solomon, K. & Oliphant, J. (1996). Drop size distributions for irrigation sprinklers. *Transactions of the ASAE*, 39, 839-845.
- King, B. A., Stark, J. C. and Kincaid, D. C., (2000). Irrigation Uniformity, University of Idaho, USA Accessed on 28th June 2007 from <http://info.ag.uidaho.edu/pdf/BUL/BUL0824.pdf>, 1-11
- Kranz, B., Yonts, D. and Martin, D. (2005). Operating Characteristics of Center Pivot Sprinklers, University of Nebraska- Lincoln Extension, USA. Accessed on 27th March 2007 from www.ianrpubs.unl.edu/epublic/live/g1532/build/g1532.pdf, 1- 4
- Landwise Inc., (2006). Evaluating Irrigation Efficiency, Hawkes Bay Regional Council, New Zealand. Accessed on 28th June 2007
- Lincoln Environmental, (2000). Designing Effective and Efficient Irrigation Systems, Ministry of Agriculture and Forestry, NewZealand. Accessed on 12th December 2007 from <http://www.maf.govt.nz/mafnet/ruralnz/sustainableresourceuse/irrigation/designing-irrigation-systems/finalwater09checked.pdf>, 1-30
- Locascio, B. & Delpuglia, S. (1989). Yield response of eggplant as affected by irrigation scheduling and plant density. In: *Symposium on Scheduling of Irrigation for Vegetable Crops under Field Condition 278*, 1989. 587-594.
- Luis S. P. (1999), Higher Performance through Combined Improvements in Irrigation Methods and Scheduling: a discussion *Agricultural Water Management*, 40 (3): 153169.
- Makanjuola, M. B.(2018) estimating dependable rainfall for improved crop production in idofian, nigeria *GSJ: Volume 6, Issue 4, April2018*, Online: ISSN 2320-9186
- Merkley GP and Allen RG (2004), *Sprinkler and Trickle Irrigation; Lecture; Notes*. Biological and Irrigation Engineering Department, Utah State University, Logan, Utah. .
- Merriam, J. L. and Keller, J. (1978). *Farm Irrigation System Evaluation: A Guide for Management*. Agricultural and Irrigation Engineering Department, Utah State University, Logan, USA
- Merriam, J.L., M.N. Shearer and C.M. Burt, (1983). Evaluating irrigation systems and practices. In *Design and operation of farm irrigation systems* (Ed. M. E. Jensen), ASAE Monograph 3. American Society of Agricultural Engineers, St. Joseph, Michigan.
- Michael, A.M., (2008). *Irrigation: Theory and Practice*. Second edition. Vikas Publishing House Pvt. Ltd, Delhi. P. 554-577
- Mishra, R.D., M. Ahmed, (1990). *Manual on Irrigation Agronomy*. Oxford and IBH Publishing Co. Pvt. Ltd. New Delhi, Bombay, Calcutta.
- MODI, P .N., (2000). *Irrigation Water Recourses and Water Power Engineering*. Standard Book fourth edition. Rajinder Kumar Jain. 1705-A, Nai Sarak, Delhi-110006.
- Molden D.J., and Gates, T.L. (1990). Performance measure of irrigation water delivery systems,
- Molden D. Sakthivadivel, R., Perry, C.J., Fraiture, C.D. and Kloezen, W.H. (1998). *Indicators for Comparing Performance of Irrigated Agricultural Systems*, Vol. Research Report 20 Colombo, Sri Lanka: International Water Management Institute
- Montero, J. Tarjuelo, J.M. and Ortega, J.F. (2002). *Heterogeneity Analysis of the Irrigation in Fields with Medium Size Sprinklers*, CIGR, USA.
- Nasab, S. B., Baradarane-Hezave, F. & Behzad,M., (2007) *Technical Evaluation of Sprinkler Irrigation Systems in Arak, Iran*. *Journal of Applied Sciences*, 7, 3338-3341. 2007.
- NRCS, (2016), natural resource conservation service, Part 623 National Engineering Handbook, sprinkler irrigation, 210–VI–NEH, Amendment 80, August 2016

- Odi (1995), Recent trends in Irrigation Management: Changing Directions for the public Sector, Natural Resource Perspectives; London: UK..
- Osei FK (2009), Evaluation of sprinkler irrigation system for improved maize seed production for farmers in Ghana. MSc Thesis submitted to the Department of Agricultural Engineering, Kwame Nkrumah University of Science and Technology, March 2009.
- OWWDSE, (2013). Arjo-Didessa Irrigation Project Meteorological and Hydrological Aspects. Addis Ababa.
- OWWDSE, (2013). Arjo-Didessa Sugarcane Development Irrigation Project, Detail Design of Dam and Appurtenant Structures. Addis Ababa.
- Patil P, Kulkarni U, Desai BL, Benagi VI, Naragund VB. (2012). Fuzzy logic based irrigation control system using wireless sensor network for precision agriculture. Proceedings AIPA 2012, India.
- Pereira, L. S., Oweis, T. & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, 57, 175-206.
- Phocaides, A., (2007), Handbook on Pressurized Irrigation Techniques, FAO, USA. Accessed on 6th <http://www.fao.org/waicent/faoinfo/agricult/aglw/ies>, 101-112 th August 2007.
- Raine SR, Foley JP. (2002). Comparing application systems for cotton irrigation - What are the pros and cons. Field to Fashion, 11th Australian Cotton Conference. Australian Cotton Growers Research Association, Brisbane, Australia
- Sahlemedhin S, Taye B (2000). Procedures for Soil and Plant Analysis. National Soil Research Center. Ethiopian Agricultural Research Organization. Technical Report No. 74. Addis Abeba Ethiopia.
- Samir M. Ismail., (2003) field evaluation of sprinkler irrigation systems managed by wuus in bustan 3, Technical Report · April 2003 *B.A.D.P. – Bustan Agricultural Development Project, Ministry Of Agriculture And Land Reclamation, Egypt European Commission No SEM/02/220/039 & SEM/03/220/042*
- Seleshi B. (2010), Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. International Water Management Institute.
- Smajstrla, A. G., Zazueta, F. S., Haman, D. Z. (2002). Potential Impacts of Improper Irrigation System Design, University of Florida, USA. Accessed on 4th October 2007 from <http://edis.ifas.ufl.edu/AE027.1>
- Solomon K. (1979): Variability of sprinkler coefficient of uniformity test results. *Transactions the ASAE*, 22: 1078-10
- Solomon M. (2010). Evaluation of irrigation scheduling and field application of hydro flume furrow irrigation at Metehara Sugar Estate. MSc. in Irrigation Engineering. Arba Minch University, Arba Minch.
- Solomon W.T, (2016) performance evaluation of irrigation schemes: a case study of jari and aloma small-scale irrigation schemes, tehuledere district, M.Sc thesis Arba Minch University, Ethiopia, February 2016
- Solomon, K. H. (1992). Sprinkler Head Testing makes Dollar and Sense, Center for Irrigation Technology, USA.
- Solomon, K.H., (1990). Sprinkler Irrigation Uniformity, Center for Irrigation Technology, USA. Accessed on 11th May 2007 from cati.csufresno.edu/CIT/rese/90/900803/index.html
- Tadesse G. Sh. and Guchie G (2017) Determining the Optimum Decision Variables and Rescheduling the Irrigation System of Tendaho Sugar Estate, Ethiopia

- Tadesse G.S., (2015) Performance evaluation of field water application at Tendaho sugar project, Ethiopia, Msc thesis Submitted to Arba Minch university institute of technology September, 2015, Arba minch, Ethiopia
- Teklu, Y. and Hammer, K. (2006). Farmers' perception and genetic erosion of tetraploid wheats landraces in Ethiopia. *Genetic Res. and Crop Evolution*, 53: 1099-1113
- Tsegaye M. L., (2019), Comparison of dragline and center pivot sprinkler irrigation methods using performance indicators: the case of Wonji/shoa sugar factory, Ethiopia, Msc Thesis Addis Ababa science and technology university, June, 2019
- United States Department of Agriculture (USDA), (1997). *Natural Resources Conservation National Engineering Handbook, Irrigation Guide*, Natural Resource Conservation Service, Washington DC, 754 p.
- USDA, NRCS, (2016), Part 623 National Engineering Handbook, Chapter 11 Sprinkler Irrigation (210-VI-NEH, Amendment 80, August 2016
- Vozhehova R. A., Lavrynenko Y. O., Kokovikhin S. V., Lykhovyd P. V., Biliaieva I. M., Drobitko A. V., Nesterchuk V. V. 2018. Assessment of the CROPWAT 8.0 software reliability for evapotranspiration and crop water requirements calculations. *Journal of Water and Land Development*. No. 39 p. 147–152. DOI: 10.2478/jwld-2018-0070.
- Walker WR, Skogerboe GV (1987). *Surface irrigation. Theory and practice*. Prentice Hall, Inc. Englewood Cliffs, New Jersey, USA 386 p.
- Wil, N. M. Van der Krogt. (1994). OMIS: A model package for irrigation system management. *Water Reports 2*. FAO, Rome.
- Wu Pai-i and H.M. Gitlin (1983), *Sprinkler Irrigation Design for Uniformity on Slopes Trans. ASAE*. 26
- Yoshida, K., Tanji, H., Somura, H., Toda, O., Higuchi, K. (2004), *Evaluation of Irrigation Efficiency at KM6 Project Site, Laos*, Water Resources Research Center, Japan.

APPENDICES

Appendix 1: climate data

Table 1: Average monthly Rainfall (mm) from Bedelle station.

Year/ month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	48.3	33.5	210	103	296	205	298	197	237	50	44.6	13
1997	52.7	1.8	49.8	142	328.6	307	221	304	232	309	40.1	2.4
1998	13.1	14.6	87	57	203	332	310.4	327	291	245	58.5	0.9
1999	28	2.9	13	208	401	408	339	235	324	318	8.1	39
2000	10.8	0.6	13.9	123	222	371	212	273	286	242	29.3	7.8
2001	0.3	33	87	69	323	353	297	343	380	223	30.2	27
2002	15.6	3.8	62.6	38	120	298	374	202	253	34	2.8	46
2003	7.1	66	83.9	131	36.9	320	278	270	197	33	13.2	9.6
2004	6.3	2.6	46.3	81	248	407	308	279	293	168	62.1	15
2005	15	2.2	122	65	117	278	363	408	486	138	83	0
2006	0.2	39	90.6	75	230	399	391	340	364	230	104	95
2007	14.6	69.3	78.7	135	174	352	320	308	386	58	21.1	1.4
2008	41.2	27	3.8	223	381	201.8	402	297	228	150	32.7	12
2009	19	42.2	28.9	163	115.4	337	350	366	341	226.2	29.1	24
2010	1.3	8.9	6.4	98	365	385	401	364	317	243	74.3	13
2011	0	36.3	71.2	49	110.2	306	297.7	232.3	284.6	103.1	75.3	8.1
2012	14.4	43	60.6	94.8	243	296.4	311	329	296	69.3	48	13.7
2013	6	39	74	178	312	346	250.7	299.8	291	194	31.9	16
2014	4.8	61	63.7	147.2	290	338	351	387	309.7	144.7	73	2.6
2015	12	16.2	49	119	316	322.7	374	331.2	301	156	69.6	11
2016	3.5	0.9	59.9	80.5	304.1	218.8	258	352	246	150	4.3	19.5
2017	0	50.1	43.8	106.7	245.7	224.4	362.4	312.8	311	153.3	40.4	9
2018	6.4	63.5	88	43.8	274.3	220.2	286.4	230	314	220.3	40.3	9.7

Table 2: Average monthly Maximum temperature (°C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	29.1	29.3	28.3	28.2	27.1	23.2	22.9	23.4	23.3	25.4	26.6	27.0
2006	28.1	29.0	26.0	27.7	27.3	22.7	22.3	22.3	23.0	24.6	26.0	26.3
2007	24.2	28.4	28.0	28.4	26.2	22.0	22.3	21.7	22.6	25.0	24.3	26.3
2008	24.8	26.8	28.0	27.0	26.8	23.0	21.5	22.6	23.1	25.6	25.2	26.5
2009	28.1	29.1	27.2	28.5	27.5	25.1	23.0	24.5	23.5	26.5	26.3	27.5
2010	27.2	27.0	28.5	28.1	26.7	22.9	21.6	21.8	24.1	26.0	24.8	26.1
2011	26.2	29.1	28.2	27.0	27.9	24.0	22.1	24.0	23.8	26.2	26.5	27.0
2012	28.1	28.7	28.8	28.4	27.5	23.7	21.5	22.0	23.2	25.3	24.6	26.5
2013	25.6	28.5	29.0	27.4	26.5	24.8	23.5	23.8	24.5	26.2	25.3	26.7
2014	28.8	29.1	29.3	28.0	26.5	22.1	21.2	22.0	23.4	25.1	24.8	24.5
2015	26.4	29.3	30.3	28.6	27.5	24.0	21.2	22.5	23.8	25.8	26.5	27.8
2016	27.3	29.4	29.4	28.1	25.6	23.5	22.2	23.0	24.1	26.7	26.6	27.3
2017	29.2	28.6	30.2	28.7	26.0	25.4	22.5	23.5	25.0	25.9	26.0	27.1
2018	27.5	28.5	29.5	27.6	27.0	24.0	22.8	23.1	25.1	25.9	25.6	27.6
2019	28.4	29.2	29.4	27.8	27.3	23.6	23.1	22.8	23.8	25.4	25.4	26.3

Table 3: Average monthly Minimum temperature (°C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	12.9	13.5	14.5	14.7	14.45	14.3	13.9	14.2	13.4	13.0	13.3	13.0
2006	11.5	13.4	13.6	14.1	14.34	13.1	12.7	12.4	12.7	12.0	12.0	10.9
2007	11.7	13.1	13.8	13.67	12.3	12.8	13.0	12.78	12.3	11.9	11.2	12.1
2008	11.3	12.5	13.3	14.7	12.9	13.8	12.5	12.2	11.6	12.4	11.3	12.3
2009	11.2	10.8	12.1	11.9	12.4	11.2	11.6	11.0	10.9	11.1	10.7	11.0
2010	11.9	12.9	12.7	14.4	13.9	13.6	13.5	12.5	12.5	11.9	12.0	11.0
2011	11.5	12.1	12.0	13.7	13.1	12.3	13.0	13.5	13.4	12.5	12.0	11.22
2012	11.9	13.6	14.1	13.0	13.8	12.1	12.7	12.3	12.1	12.1	13.2	13.0
2013	12.8	13.0	14.7	14.7	14.6	14.2	13.9	14.4	13.5	13.3	13.0	13.2
2014	11.8	13.1	13	13.9	13.7	13	12.2	12.2	12	13.1	11.0	11.0
2015	11.6	13.3	15.5	14.2	13.9	13.4	12.5	13.3	12.6	12.5	11.6	12.0
2016	11.6	12.5	15.2	15.3	14.0	13.7	13.9	13.6	13	12.8	11.0	11.5
2017	11.9	13.2	14.4	14.0	14.0	12.7	13.0	13.0	13.1	13.0	11.8	11.0
2018	11.3	13.3	12.4	13.4	13.3	13.1	13.2	13.0	12.4	13.2	12.6	12.3
2019	11.7	13.4	14.1	14.0	13.8	12.1	12.2	11.8	12.3	12.3	12.9	12.2

Table 4: Average monthly Relative Humidity (%)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	56	50	43	58	70	71	80	85	83	65.8	73	71
2006	51.8	59	50	55	70	76	84	86	80	72	68.9	67.3
2007	58	42	56	65	72.5	73	83	73	73	70	75	66
2008	62	66	59	63	60	72	81	79	80	64	61	65
2009	54	53.3	60	67	65	78	75	74	89	72	70.5	64
2010	60	54	50	61	72	76	74	75	88	70	72	65.8
2011	55	57	54	66.2	60	76	80	78	83	73	63	72
2012	68	58	49	65	70	71	75	87	82	70	66.4	61
2013	60.8	55	51	55	62	78	84.3	75	87	66	73	63
2014	65.5	58	60	59	65	88	86	81	89.8	65.4	71.5	65.3
2015	55.9	63	51	70	63	89	80	89	81	70	72	60
2016	67.8	63.4	64.2	58.1	74.6	85.6	89.5	87	82.5	65.7	54.7	66.4
2017	61	69	64	72	88	84	90	87	85	68	75	70
2018	68.2	70.1	63	69.7	78.1	88	88.1	89.6	83.6	79.5	78	72.3
2019	49.8	67.7	68	76.6	81	87.7	89.4	90.3	87.6	82.1	83.4	78

Table 5: Average monthly Wind speed (m/sec)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	0.42	0.6	0.8	1.0	1.05	0.8	0.7	0.6	0.45	0.5	0.44	0.48
2006	0.6	0.6	1.1	1.05	0.95	0.7	0.55	0.56	0.5	0.55	0.56	0.5
2007	0.54	0.7	0.9	1.1	1.0	0.8	0.6	0.5	0.45	0.6	0.5	0.5
2008	0.6	0.62	1.0	1.18	0.9	0.7	0.6	0.6	0.6	0.5	0.26	0.45
2009	0.55	0.55	0.88	1.18	1.1	0.6	0.48	0.5	0.4	0.5	0.49	0.5
2010	0.5	0.7	0.9	1.2	0.9	0.8	0.7	0.4	0.4	0.4	0.44	0.4
2011	0.5	0.42	0.7	1.0	1.0	0.9	0.5	0.55	0.5	0.45	0.5	0.5
2012	0.6	0.7	1.0	0.95	0.8	0.78	0.5	0.5	0.5	0.4	0.6	0.3
2013	0.53	0.5	0.8	0.9	0.9	0.6	0.6	0.45	0.8	0.53	0.7	0.7
2014	0.47	0.9	0.8	0.95	1.03	0.6	0.5	0.5	0.6	0.5	0.3	0.5
2015	0.5	0.7	0.9	1.0	0.96	0.6	0.6	0.4	0.47	0.45	0.3	0.5
2016	0.52	0.64	0.85	1.1	1.0	1.0	0.55	0.34	0.55	0.5	0.35	0.45
2017	0.7	0.5	1.0	0.9	0.9	0.8	0.5	0.5	0.5	0.5	0.4	0.3
2018	0.62	0.6	0.9	1.0	1.1	0.92	0.53	0.45	0.48	0.6	0.4	0.64
2019	0.58	0.75	0.97	1.0	1.05	0.9	0.6	0.4	0.51	0.5	0.53	0.5

Table 6: Average monthly Sunshine Hour (hrs/day)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	7.3	7.9	8.2	7.0	8.4	5.5	3.4	4.6	5.2	8.1	8.7	8.1
2006	7.8	8.2	6.5	7.4	8.2	5.1	3.7	3.5	6.0	8.3	7.6	8.17
2007	8.0	8.4	6.9	8.3	8.0	6.0	4.1	5.0	5.7	8.2	9.2	9.4
2008	7.2	8.1	8.6	8.4	7.1	4.3	3.8	4.8	7.0	7.6	7.9	7.4
2009	9.1	7.3	7.5	7.4	5.9	4.9	3.6	4.7	6.1	8.3	8.3	8.2
2010	9.5	8.0	6.0	7.1	6.3	4.7	3.5	4.0	6.0	7.6	8.2	7.8
2011	8.0	6.9	6.8	6.5	8.3	4.2	3.9	3.6	5.1	7.3	8.6	7.9
2012	8.1	7.2	8.8	6.8	8.5	6.1	3.6	3.5	4.9	7.4	9.4	9.5
2013	7.5	7.7	8.2	7.0	7.9	5.5	3.5	3.4	5.1	8.4	8.0	9.1
2014	8.4	7.0	7.8	6.2	7.1	4.1	4.0	3.2	5.4	7.8	9.0	8.9
2015	7.6	8.1	8.0	7.7	6.4	6.2	4.3	4.9	5.0	8.2	8.2	8.3
2016	7.9	8.8	7.6	6.3	5.1	5.5	3.2	5.1	6.0	8.3	9.4	10.0
2017	10.3	7.6	7.7	8.0	6.0	6.3	3.3	4.0	5.6	7.8	8.8	9.7
2018	8.5	6.6	8.0	8.1	8.0	4.0	3.6	3.9	5.5	8.6	7.9	9.3
2019	10.0	8.25	8.8	7.7	8.3	4.6	3.9	3.5	4.2	8.1	6.7	8.8

Appendix 2: Average monthly ETo and Effective rainfall

Table 7: Monthly climatic data and ETo for each month

Country; Ethiopia		Station; Bedele		Altitude 2011m.a.s.l,		lat; 8.45 ⁰ N;		Long 36.35 ⁰ E	
Months	Min temp (°C)	Max temp (°C)	Humidity (%)	Wind speed m/sec	Sunshine hours (hr)	Radiation MJ/m ² /day	ETo mm/day		
January	11.8	27.3	59	0.6	8.3	20.0	3.54		
February	12.9	28.7	59	0.6	7.7	20.2	3.89		
March	13.7	28.7	56	0.9	7.7	21.2	4.36		
April	14.0	28.0	64	1.0	7.3	20.7	4.31		
May	13.6	26.9	70	1.0	7.3	20.2	4.11		
June	13.0	23.6	79	0.8	5.1	16.6	3.23		
July	12.9	22.3	83	0.6	3.7	14.6	2.80		
August	12.8	22.9	82	0.5	4.1	15.5	2.95		
September	12.5	23.8	83	0.5	5.5	17.8	3.28		
October	12.5	25.7	70	0.5	8.0	20.8	3.78		
November	12.0	25.6	71	0.4	8.4	20.2	3.54		
December	11.8	26.7	67	0.5	8.7	20.0	3.52		
Average	12.8	25.8	70%	0.7	6.8	19.0	3.62		

Figure 1: ETo and Effective rainfall from CROPWAT 8.0. Software

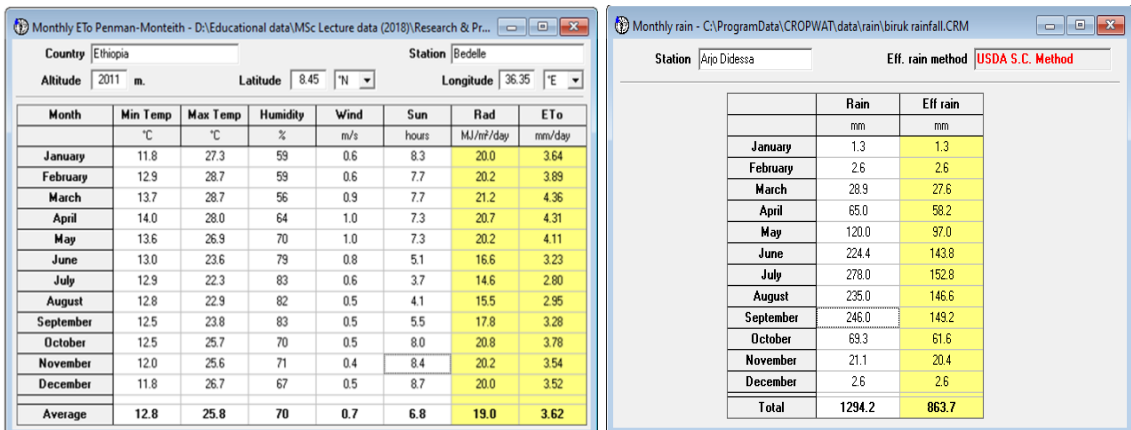


Table 8: Probability analysis of mean monthly dependable rainfall

Rank	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Prob(%) M/(N+1)
1	52.7	69.3	210	223	401	408	402	408	486	318	104	95	4.2%
2	48.3	66	122	208	381	407	401	387	386	309	83	46	8.5%
3	41.2	63.5	90.6	178	365	399	391	366	380	245	75.3	39	12.5%
4	28	61	88	163	328.6	385	374	364	364	243	74.3	27	17%
5	19	50.1	87	147.2	323	371	374	352	341	242	73	24	21%
6	15.6	43	87	142	316	353	363	343	324	230	69.6	19.5	25%
7	15	42.2	83.9	135	312	352	362.4	340	317	226.2	62.1	16	29%
8	14.6	39	78.7	131	304.1	346	351	331.2	314	223	58.5	15	33%
9	14.4	39	74	123	296	338	350	329	311	220.3	48	13.7	37.5%
10	13.1	36.3	71.2	119	290	337	339	327	309.7	194	44.6	13	42%
11	12	33.5	63.7	106.7	274.3	332	320	312.8	301	168	40.4	13	46%
12	10.8	33	62.6	103	248	322.7	311	308	293	156	40.3	12	50%
13	7.1	27	60.6	98	245.7	320	310.4	304	291	153.3	40.1	11	54%
14	6.4	16.2	59.9	94.8	243	307	308	299.8	291	150	32.7	9.7	58.5%
15	6.3	14.6	49.8	81	230	306	298	297	289	150	31.9	9.6	62.5%
16	6	8.9	49	80.5	222	298	297.7	279	286	144.7	30.2	9	67%
17	4.8	3.8	46.3	75	203	296.4	297	273	284.6	138	29.3	8.1	71%
18	3.5	2.9	43.8	69	174	278	286.4	270	253	103.1	29.1	7.8	75%
19	1.3	2.6	28.9	65	120	224.4	278	235	246	69.3	21.1	2.6	80%
20	0.3	2.2	13.9	57	117	220.2	258	232.3	237	58	13.2	2.4	84%
21	0.2	1.8	13	49	115.4	218.8	250.7	230	232	50	8.1	1.4	87.5%
22	0	0.9	6.4	43.8	110.2	205	221	202	228	34	4.3	0.9	92%
23	0	0.6	3.8	38	36.9	201.8	212	197	197	33	2.8	0	96%

The procedures to calculate 80% dependable rainfall and effective rainfall above are summarized as follows (Doorenbos and Pruitt.,1977).

1. The probability of exceedence (P) of 80% was used to calculate the return period (Tr)

$$P=1/Tr ; Tr=1/p = 1/0.8=1.25$$

2. The rank of rainfall with 80% probability of exceedence was calculated and the corresponding monthly values were taken as dependable rainfall.

$$Tr = (N+1)/M; N= \text{no of events (23 years)} M= (N+1)/Tr , M=\text{rank } m=(n+1)/Tr$$

$$m= (23+1)/1.25= 19.2 \text{ take 19 as shown above.}$$

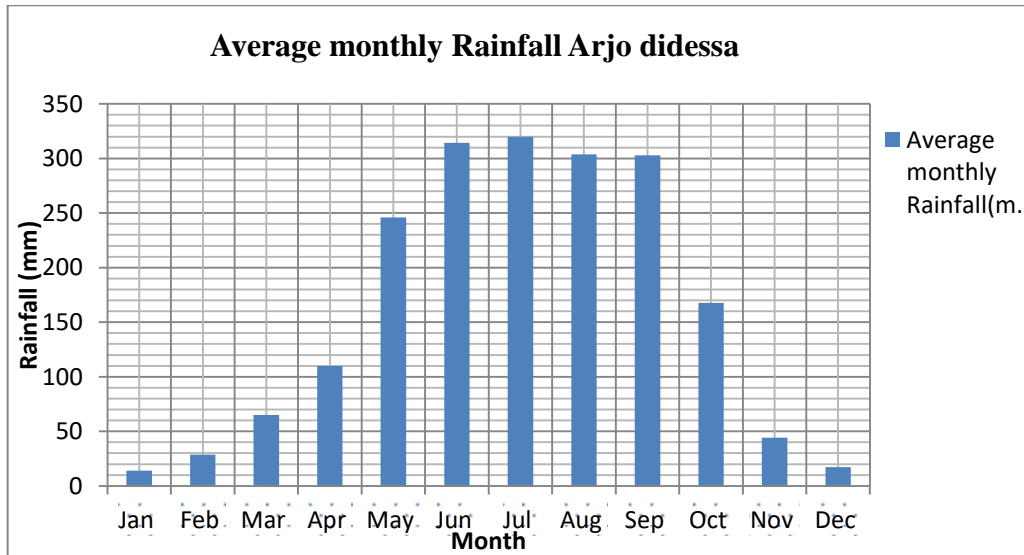
$$\text{OR, Simply calculated Prob (80\%)} = M/(N+1) = 19/(23+1) = 0.7916 = 0.8.$$

Therefore the 19th order is taken as 80% dependable rainfall to calculate the monthly effective rainfall using CROPWAT 8.0 Model

Table 9: Effective Rainfall for each Month of the Study Area

Station; Bedele		Method: USDA S.C.S Method	
Month	80% Dependable rainfall (mm)	Effective rainfall (mm per month)	Effective rainfall (mm per day)
January	1.3	1.3	0.042
February	2.6	2.6	0.093
March	28.9	27.6	0.89
April	65	58.2	1.94
May	120	97.0	3.13
June	224.4	143.8	4.8
July	278	152.8	4.93
August	235	146.6	4.73
September	246	149.2	4.97
October	69.3	61.6	1.98
November	21.1	20.4	0.68
December	2.6	2.6	0.084
Total	1294.2	863.7	28.27

Figure 2: Mean monthly rainfall of study area



Appendix 3: Soil physical characteristics

Table 10: Soil Particle size distribution and texture classes

Field number	Soil textural distribution and bulk density									
	Soil sample depth (0-30cm)					Soil sample depth (30-60cm)				
	Sand	Silt	clay	Texture class	Bulk density g/cm ³	Sand	Silt	clay	Texture class	Bulk density g/cm ³
1	19	30	51	Clay	1.32	22	23	55	Clay	1.3
2	27	18	55	Clay	1.22	19	22	59	Clay	1.18
3	39	17	44	Clay	1.42	38	11	51	Clay	1.4
4	22	30	48	Clay	1.3	18	28	54	Clay	1.26
5	15	26	59	Clay	1.19	10	30	60	Clay	1.11
Average	24.4	24.2	51.4	Clay	1.29	21.4	22.8	55.8	Clay	1.25

Table 11: Stored depth before and after irrigation in root zone after hour irrigation

Fields	Before irrigation (mm)			After irrigation depth			Stored depth (mm)		
	Depth of soil layer(cm)			Depth of soil layer(cm)			Depth of soil layer(cm)		
	0-30	30-60	Total	0-30	30-60	Total	0-30	30-60	Total
Field 1	2.9	3.15	6.05	4.21	3.85	8.06	1.31	0.7	2.01
Field 2	3.8	4.1	7.9	5.23	4.87	10.1	1.43	0.77	2.2
Average	3.35	3.625	6.975	4.72	4.36	9.08	1.37	0.735	2.105

Appendix 4: Discharge and pressure measurement data

Table 12A: Sprinklers discharge and wetted radius for four overlapping sprinklers

Sprinkler no	Field no 1 (3.5hydrant pressure)		Field no 2 (4.0 hydrant pressure)	
	Sprinkler discharge lt/sec	Wetted radius (m)	Sprinkler discharge lt/sec	Wetted radius (m)
1	0.27	11.8	0.34	13.7
2	0.30	13.0	0.30	13.1
3	0.285	12.5	0.305	13.3
4	0.265	11.5	0.30	13.5
Average	0.28	12.2	0.31	13.4

Table 12B: Measured nozzle pressure and sprinkler discharge along laterals

Field no 1			Field no 2		
Sprinkler no	Nozzle pressure in bar	Sprinkler discharge along lateral lit/sec	Sprinkler no	Nozzle pressure in bar	Sprinkler discharge along lateral lit/sec
1	3.5	0.3	1	4.0	0.34
2	3.4	0.28	2	3.8	0.33
3	3.2	0.265	3	3.7	0.32
4	3.35	0.27	4	3.8	0.31
5	3.0	0.26	5	3.9	0.33
6	3.3	0.27	6	3.65	0.31
7	2.95	0.26	7	3.85	0.33
8	3.3	0.28	8	3.6	0.3
9	3.1	0.265	9	3.5	0.31
10	3.2	0.27	10	3.7	0.31
Average	3.23	0.272	Average	3.75	0.319
Max	3.5	0.3	Max	4	0.34
Min	2.95	0.26	Min	3.5	0.3

Appendix 5: Measured Catch can data

Table 13: Individual Catch Cans depth for four overlapping sprinklers (block test)

Catch can No	Catch can depth (ml)					
	Field no 1 (3.5bar)			Field no 2 (4bar)		
	Morning	Mid-day	Afternoon	Morning	Mid-day	Afternoon
1	43	40.5	36	61	50.5	51.5
2	40.5	26	43	48.5	56	80
3	77.5	29.5	27	61.5	36	43
4	90	83	84.5	93.5	74	56
5	43.5	34.5	32.5	72	47.5	74
6	84	53	61.5	32.5	54	56
7	18	39.5	32.5	88	52	74
8	43	30.5	38	58.5	45	39.5
9	27	35	34	48.5	65	59.5
10	47	49.5	62	66.5	56	33
11	32.5	27	29	52.5	48.5	61
12	76.5	30.5	93.5	63	48.5	34
13	92	41.5	37	50.5	98	49.5
14	74	45	59.5	29	39.5	35
15	30	75.5	48	56	54	54
16	40.5	38	19	40.5	43	52
17	34	45	54	83	58.5	90
18	28.5	43	41	75.5	41.5	54
19	43	23.5	58.5	48.5	34	27
20	45	34.5	41.5	52	51.5	63
21	81	62	43	92	72	45
22	45	20	39.5	39.5	56	56
23	66.5	57	47.5	36	60	61
24	41.5	56.5	36	81	53	95.5
25	36	37	50.5	38	33	42.5
26	40	33	23.5	43	47	38
27	44	70	66.5	47	59	50.5
28	58.5	47	48	68.5	48.5	48.5
29	41.5	32.5	46.5	51.5	50.5	74
30	44	45	26	52	76.5	57.5
31	41.5	54	47	43.5	61	62
32	35	37	25	48.5	56	44
33	58.5	38.5	75	74	76	52
34	70.5	52	57.5	45	50.5	59.5
35	44	34	41.5	77	40	32.5
36	43.5	55	40.5	56	52	72
Sum	1800.5	1555	1645.5	2073.5	1944	1976.5
Mean (d)	50.0	43.2	45.7	57.6	54	54.9
Sum di-d 	557.5	403.2	457.3	502.1	336	435.3
Dlq	31.2	28.0	27.6	38.55	39.9	36
CU	69%	74%	72%	76%	83%	78%
DU	62%	65%	60%	67%	74%	66%

Table14A: Catch cans depth for single sprinkler test (Field no 1)

Catch can depth (ml)							
Field no 1 (3.5bar)							
Catch can No	Morning	Mid-day	Afternoon	Catch can No	Morning	Mid-day	Afternoon
1	26	29	19	39	24.5	5	11
2	11	8.5	16.5	40	12.5	26	6.5
3	7.5	13	17	41	9	15	9
4	22	13	18	42	11	5	23
5	30	20	14	43	19.5	26	14
6	10.5	12	26.5	44	8	6.5	23
7	11	21	5	45	25	26	9.5
8	9	6	26	46	14	20	12
9	11.5	20.5	15	47	8.5	14	20
10	29	15	26	48	12.5	19.5	6.5
11	9.5	8	22	49	7	13	25
12	13	14.5	13.5	50	18	16	8.5
13	13	16	9	51	9	20	21
14	20	7	11.5	52	15	13	7
15	12	18.5	29	53	11.5	9	24.5
16	6	14	19.5	54	24	18	15
17	18	7.5	13	55	20	19	9
18	23	11	17	56	31	14.5	14.5
19	9.5	6	20	57	8	6	19.5
20	12	15	12	58	12	22	8
21	13	23	10	59	25	31	25
22	10	12.5	18	60	11	10.5	14
23	25	8	26	61	7.5	11	8.5
24	12	11	11	62	9	5.5	11
25	16	19.5	7.5	63	23	15	7
26	7	7	22	64	14	11.5	18
27	22	25	31	Sum	992	947	1024
28	16.5	14	10.5	Mean (d)	15.5	14.8	16
29	15	8.5	11	Sum di-d	384	330	378
30	18	12.5	9	Dlq	7.95	6.81	8.0
31	14	5.5	15	CU	61%	65%	63%
32	30	16	11.5	DU	51%	46%	50%
33	5	19	24				
34	26	16.5	20				
35	8	17	32				
36	26	18	8				
37	22	14	13				
38	13.5	26.5	25				

Table 14B: Catch cans depth for single sprinkler test (Field no 2)

Field no 2 (4bar)							
Catch can depth (ml)							
Catch can No	Morning	Mid-day	Afternoon	Catch can No	Morning	Mid-day	Afternoon
1	16	23	12.5	39	8	18	9.5
2	9.5	6	11	40	11	6	9
3	18.5	15	10	41	20	13	18.5
4	14	22	34.5	42	7	10	12
5	7.5	12.5	14	43	27	27	20
6	11	19	16.5	44	13.5	6	9
7	10	8	11	45	10	25	11
8	15	14	13.5	46	12	5.5	12.5
9	23	14.5	12.5	47	9.5	9.5	11.5
10	12.5	18	7.5	48	11	15.5	10
11	19	8.5	10.5	49	6.5	21	28
12	13	8	24	50	26	18	19
13	6	15	13	51	11	15	12
14	22	16.5	16.5	52	8	5	11.5
15	33	17	15	53	28.5	23	21
16	10.5	16	6.5	54	7.5	9	8.5
17	11	16	19.5	55	21	19	28
18	7	15	14	56	20	18	36
19	15	8.5	21	57	11	14	9.5
20	11.5	12	14.5	58	19.5	10	10
21	30	14	15	59	13	21	18.5
22	8.5	7.5	8	60	12	18	11
23	13	12	17	61	10.5	15.5	8
24	13	20	13	62	11.5	27	26
25	20	13.5	18.5	63	9	29	23
26	12	14	6	64	18	16	12
27	21	22.5	14.5	Sum	934.5	986	976
28	6	17	10	Mean (d)	14.6	15.4	15.25
29	20.5	8	17	Sum di-d	326	298	334.5
30	15	15	9.5	Dlq	8.0	7.65	8.7
31	8	7	10.5	CU	65%	70%	66%
32	14.5	16	8.5	DU	55%	50%	57%
33	19	18.5	16				
34	16.5	20	28				
35	12	13	16				
36	18	24	20				
37	14	26	26				
38	26.5	19.5	20				

Table 15: Overlapped Catch cans depth data for different spacing's.

	Catch can depth (ml)							
	Field no 1 (3.5bar)				Field no 1 (4bar)			
	spacing's (mxm)				spacing's (mxm)			
	12X18	12X12	18X12	9X12	12X18	12X12	18X12	9X12
1	18	31	21	34	26.5	28	19	36.5
2	25	26.5	34	46	22	32.5	25	42.5
3	19	44	25	36	39	42	23.5	34
4	18	30.5	42	46	36.5	30	26	32
5	23.5	29.5	34	48	27	29.5	32	34.5
6	18.5	42	36.5	34.5	31	39	20	43
7	36	26	21	30	24	26	32	31.5
8	21	36.5	37	31	33	24	40.5	36.5
9	33	45	20	48	41	39	23	48
10	28.5	32	20	33.5	26	28	28	43
11	22	32	34.5	37	37	27	37	32.5
12	30.5	42	38	38	40	32.5	21.5	39
13	18.5	40	23		38	39	36	
14	37	29	39		26	27	34.5	
15	17	32	24.5		35	32	28	
16	41	30	21.5		26	28.5	32	
17	20.5		32		36		24	
18	24		24		20		29.5	
19	25		36		24		21	
20	28		21		27		19	
21	23		25		23		40.5	
22	30		24		32		21	
23	22.5		38		25		25	
24	18		37		26		22	
Sum	597.5	548	708	462	720	504	660	453
Mean (d)	24.9	34.25	29.5	38.5	30	31.5	27.5	37.75
Sum di-d 	130.1	87.8	168	68	136	71	135	53.5
Dlq	18.0	27.75	20.75	31.5	23	26	20.25	32
CU	78%	84%	75%	85%	81%	86%	80%	88%
DU	72%	81%	70%	82%	77%	83%	74%	85%

Appendix 6: Field photos during data collection



