PERFORMANCE EVALUATION AND IMPROVEMENT MEASURES OF WATER PRODUCTIVITY FOR MSANGE IRRIGATION SCHEME IN TANZANIA

A DISSERTATION

Submitted in Partial fulfillment of the requirements for award of the Degree of

MASTER OF TECHNOLOGY

In

IRRIGATION WATER MANAGEMENT

By

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DECLARATION

I hereby declare and certify that the Dissertation entitled "**Performance Evaluation and Improvement Measures of Water Productivity for Msange Irrigation Scheme in Tanzania"** is an authentic and genuine record of my own capacity. It is submitted in partial fulfillment for the award of the degree of **Master of Technology** with specialization in Irrigation Water Management**,** submitted to the Department of **Water Resources Development and Management**, **Indian Institute of Technology Roorkee, India** under the Supervision and Guidance of **Dr. M.L. Kansal,** Professor, WRD&M Department, Indian Institute of Technology Roorkee (Uttarakhand), India. This report is entitled to acceptance as it has not been presented anywhere for the same purpose by any person.

Date: 03.05.2018
Place: Roorkee

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CERTIFICATION

This is to certify that the above statement made by the Candidate is correct to the best of my knowledge and belief.

(Dr. M.L. Kansal)

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ABSTRACT

Performance evaluation is an activity that supports planning and implementation procedure of irrigation projects. The motivation behind performance is to accomplish an effective and viable utilization of resources by giving important criticism to the scheme management. Therefore, the objective of the study is to evaluate the performance of Msange irrigation scheme at Singida District in Tanzania employing a various performance indicators. The scheme has a command area of 10 ha served by drip irrigation system benefiting about 58 farmers. To accomplish the set objectives both field and secondary data were collected such as discharge measurements, soil samples, irrigation application, delivered volume of water to the field, meteorological data, cropping pattern, yields, crop prices, irrigation cost, irrigated land, cost of production and O&M costs. Water supply, agricultural outputs, economic performance and environmental quality indicators were evaluated in this study. To facilitate the assessment three main crops were evaluated, for this case maize, onion and tomatoes. The specific indicators for water supply performance are RWS and RIS and WDC. The results for RWS, RIS and WDC were found to be 0.93, 0.92 and 1.79 respectively. The analysis of agricultural outputs, outputs per irrigated cropped land and command area were found as 2,179.41 and 2,799.50 US$/ha respectively, and the corresponding outputs per unit irrigation supply and water consumed was 0.51 and 0.46 US$/m^3 respectively. The results from economic performance on BCR and O&M fraction depicted the value of 1.01 for BCR and 0.65 for O&M fraction. This indicates that Msange irrigation project is worthy undertaking for supporting farmers' livelihood. To evaluate environmental quality, SQI was used by integrating chemical and physical parameters. The soil type from the study area is silt loam with an overall SQI of 0.57 making the soil to be rated as medium quality.

In conclusion, the determined overall performance index of Msange irrigation scheme is 69 % which show a satisfactory performance, rated as medium to high performance. However with this index, improvement is needed to further increase performance and water productivity so that more benefits are obtained. Among the measures to improve performance and water productivity include proper irrigation scheduling, correct estimation of water demand, regulating water delivery, optimizing irrigation water, improving agronomic practices and soil quality management.

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ACRONYMS AND ABBREVIATIONS

AHP	Analytic Hierarchy process
AVRDC	Asian Vegetable Research and Development Center
AWC	Available water capacity
BCR	Benefit-Cost Ratio
BD	Bulk density
CEC	Cation exchange capacity
CIID	Copenhagen Institute of Interaction design
CWU	Consumptive water use
EC	Electrical conductivity
ET	Evapotranspiration
ETc	Crop evapotransipiration
ETo	Reference evapotranspiration
FAO	Food and Agriculture Organization
FC	Field capacity
IARI	Indian Agricultural Research Institute
ICID	International Commission on Irrigation and Drainage
IR	Irrigation requirements
Kc	Crop coefficient
MACL	Mzalendo Associates Company Limited
MT	Metric Tone
NMRP	National Maize Research Program
NIH	National Institute of Hydrology
NRCS	Natural Resources Conservation Services
OC	Organic carbon
OCA	Output per unit Command area

OCP	Output per unit cropped area
OIS	Output per unit irrigation supply
O&M	Operation and maintenance
OMF	Operation and Maintenance fraction
OPVs	Open pollinated varieties
OPI	Overall performance index
OWC	Output per unit water consumed
PC	Principal Component
PCA	Principal Component analysis
PD	Particle density
RIS	Relative irrigation supply
RWS	Relative water supply
SFA	Scoring function approach
SPAW	Soil-Plant-Air and Water
STFR	Soil testing and fertilizer recommendation meter
SQI	Soil quality index
UNDP	United Nation Development Programme
URT	United Republic of Tanzania
US$	United States Dollars
USAID	United States Agency for International Development
USDA	United States Department of Agriculture
WDC	Water delivery capacity
%	Percentage

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Performance evaluation in irrigation system is characterized as the deliberate perception, documentation and understanding of irrigation activities with the target to make improvement (Bos et al. 2005). It refers as the undertaking that serves the preparation and excursion procedures. A definitive motivation behind performance is to accomplish an effective and viable utilization of assets by giving important criticism to the scheme management.

The performance all in all is ought to be judged not just by utilizing potential area created regarding irrigated area yet in addition by estimating increased agriculture through predominant agronomic practices, decision on cropping in connection to soil condition, available water and use of other supportive inputs.

In Tanzania, the concept of productivity isn't surely known and the work of assessing its performance is insufficient (Mahoo et al., 2007). In most irrigation systems there are no any endeavors to mainstream the evaluation concerning water. For example water supply, numerous irrigation schemes water is acquired on permits characterizing volume per time taken, yet reallocations and installments by individual clients are estimated by irrigated area. Moreover, the measure of water given to individual growers isn't much to volume but through allocated hours of water access as per frequencies of irrigation chosen by irrigation organization (Tarimo et al., 2004). Really, there is small consideration given to convey water for irrigation from rivers and underground.

Generally, irrigation system efficiency includes economic benefits and environmental success accomplished by utilizing land resources to agricultural production. Along these lines, to accomplish this objective the evaluation should be conducted in the field, crop and system level to ascertain good water management.

1.2 RESEARCH GAPS

Significant of water utilize segment in Tanzania is irrigation systems, although it have been performing defectively because of poor practices and water losses. The water losses have become potential risk for environmental degradation and profitable asset and vital infrastructures. However, it guarantee as engine of agricultural development, irrigation projects regularly perform far below their potential (Small and Svendsen, 1992). Numerous developing countries have made gigantic investments in irrigation infrastructure in past century, by understanding its significance for food production (Goratiwar and Smout, 2005). This venture, together with enhanced plant production technologies, for example, utilization of manures, chemicals and so forth, has empowered numerous nations to gaining food security. Nevertheless, there is similarly a perception that numerous irrigation schemes don't perform up to desires or accomplish their objectives. Other than that, no much work done in assessing performance to give impressive information in selecting better performance practices under present situation.

Performance evaluation is a useful practice to measure achievements of irrigation project for the sake of addressing challenges such as increased water demand of growing population, the competition from allocating water from high priority non-agricultural and technical sector (Molden et al., 1998). It is significant to follow new procedures and ways to deal with existing management practices to irrigation performance. In acknowledgment to both the assurance and hazards related with irrigation activity, assessing performance now is fundamental significance not exclusively to identify where the issue exists, yet to suggest options feasible in improving the system performance of irrigation (Yusuf and Tena, 2006).

Subsequently, performance assessment is a vital significance not exclusively identify issues but in addition assist to suggest options leading to successful performance of the system. As indicated by Mchelle (2011) more studies should be carried to compare situations before and after construction or rehabilitation of farmers managed irrigation scheme. Henceforth, it is important to assess outputs from irrigated agriculture. With the view to diminish loss and increase productivity in irrigation systems, performance evaluation ought to be conducted to check health condition of the systems (Molden et al., 1998). This must be done using reliably chosen indicators from different criteria which portray whether the system perform well or badly as per the set objectives.

1.3 OBJECTIVES

The objective of the study is to evaluate the performance and to suggest measures for improving productivity of water for Msange irrigation scheme. The specific objectives were:

i) To assess water availability for Msange during crop growing season;
ii) To assess existing productivity of water at Msange irrigation scheme;
iii) To evaluate supply of water, outputs from agriculture, and economic and environmental quality;
iv) To suggest measures for improving water productivity in Msange irrigation scheme

1.4 ORGANIZATION OF THESIS

This thesis presents five chapters. The highlights of each are described hereunder.

Chapter 1: Introduction

This chapter narrates what the dissertation is about; explaining the research gaps and justifying its relevance. It covers background, research gaps, study objectives, organization of chapters and procedures to achieve objectives.

Chapter 2: Literature Review

The chapter describes important definitions in the selected field, discusses previous studies and performance evaluation concepts such as evaluation processes, irrigation systems, productivity and various formulas.

Chapter 3: Methodology of study

The chapter describes and highlights the methodologies adopted during evaluation process. The framework for assessment is based on goal-oriented approach by evaluating different systems. It justifies data analysis and determination of appropriate values of indicators.

Chapter 4: Results and Discussion

The chapter highlights and discusses the findings of the study based on water supply, agricultural outputs, and economic aspect and environmental indicators. It includes also tables and figures to illustrate results and facts analyzed.

Chapter 5: Conclusion and Recommendations

The conclusion chapter summaries the work and provides recommendations on the performance for best management practice as a management monitoring tool. Likewise, recommendations are given for further study to improving performance of irrigation system.

1.5 EVALUATION PROCEDURES

Performance evaluation involves planning activity, field survey, detailed survey, analysis, suggestions and recommendations. The following procedures are proposed for completion of performance evaluation:

i) To identify factors this may have effects on water management in the scheme.
ii) To conduct field visit/survey and observation to familiarize with the study area
iii) To select suitable performance evaluation indicators related to the system of irrigation and socio-economic conditions.
iv) To calculate the various parameters including performance indicator values.
v) To assess and evaluate the irrigation performance by analyzing the indicators values.
vi) To analyze the various improvement alternatives and suggest the most suitable ways for increasing water productivity and overall performance of the scheme

Various factors which influence use of water for irrigation involves irrigation system, soil type, prevailing climatic condition, command area, types of crops, cropping pattern, management practices, economic conditions and farmers' knowledge. Other information is collected through interview with farmers regarding operation and management and general aspects.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Irrigation is a practices used to stabilize food production among farmers who are engaged in agriculture, characterized as the application of water for plant to grow by means of artificial methods. Irrigation is necessary for production of crops and used to secure crops during dry spell or water scarcity. Irrigation is of major imperative in numerous countries regarding food production and supply, incomes generation, and investments for community development. Due to inadequate management of water most projects have low performance from system to farm level.

2.2 IRRIGATION SYSTEMS

Irrigation system in a country is of real significance regarding farming for food supplies,wages creation, public investment and expenditure (Small and Svendsen, 1990). The motivation behind irrigation is the increasing productivity for the nation or its food supplies. Small and Svendsen (1990) described irrigation as human mediation to alter the spatial or temporal water distribution from regular channel or aquifers. System of irrigation is then characterized as an institutional arrangement and physical components to obtain water from natural source facilitate and control movement of from source such as river, spring to the soil. The main irrigation components include allocation, distribution and application. Consequently, supply of water for growth of crop represents an output from irrigation system.

Several options of water supply to the farm include surface irrigation system and pressure irrigation systems. The options for irrigation by surface or gravity include basins, borders, check and furrow irrigations. Meanwhile, drip, sprinkler and lateral move system form part of pressurized systems. Nowadays, micro-irrigation systems are adopted due to their economical water use and enhanced yield compared to surface systems of irrigation.

Table 1 Potential efficiencies of various irrigation systems application (Ali, 2011)

Type of irrigation system	**Range of attainable efficiency** (%)
Surface irrigation:	
Border	75 - 85
Basin	80 – 90
Furrow	65 – 80
Sprinkler irrigation:	
Solid set/permanent	75 – 85
Hand move or portable	75 – 85
Center pivot and linear move	75 – 90
Traveling gun	65 – 75
Trickle irrigation:	
Point source emitters	80 - 90
Line source	75 – 85

2.3 IRRIGATION WATER MANAGEMENT

Irrigation water management means the timing and application of water in a manner that fulfill water need of crop without loss, soil degradation, nutrients depletion and debasing soil resources (Molden et al., 1998; Sakthivadivel et al., 1999). This brings up the concept of water productivity. Water productivity is characterized as the measure of yield produced per unit of utilized water in the production for a given conditions (Tuong et al., 2000; Bastiaansen et al., 2003; Igbadun et al., 2006). Therefore, management of irrigation water focus on practices that promote water use efficient to have more water for use (Mateos et al., 2010).

2.3.1 Crop water requirement

As discussed by ICID-CIID (2000) crop water need is the sum of water required by crops in a particular climate for ET requirement at all stages. Reddi and Reddy (2002) depicts crop water requirement as the amount of water required for typical development and yield provided either by precipitation or irrigation or by both. Crop ET and water requirements seems the same; crop ET refers to the amount of water that is lost through ET and crop water requirement measures the total water needs to be supplied (Allen et al. 1998). Therefore during evaluation, irrigation efficiency should be considered.

Water is essential to meet requirements for metabolism, evaporation and transpiration and consequently considered as consumptive use. At the point when metabolic needs are viewed as irrelevant, ET is consequently considered as equivalent to consumptive use. Different losses like seepage and runoff occur during conveyance and application of water. Requirement of water is a demand though the supply comprises of contribution from irrigation water, effective precipitation and soil profile contribution including that from shallow water table.

When describing irrigation requirements, net irrigation requirement and gross irrigation requirement are referred. Net irrigation requirement is required to bring the soil moisture content in the root zone depth to field capacity. Gross irrigation requirement is the aggregate of net irrigation requirement and different water losses.

Table 2 Approximate values of water need for various crops (FAO, 2018)

S/No.	**Crop**	**Water requirement** (mm)	**S/No.**	**Crop**	**Water requirement** (mm)
1.	Alfalfa	800 – 1600	11.	Peanut	500 – 700
2.	Banana	1200 – 2200	12.	Pepper	600 – 900
3.	Wheat	450 – 650	13.	Potato	500 – 700
4.	Bean	300 – 500	14.	Rice (paddy)	450 – 700
5.	Cabbage	350 – 500	15.	Sorghum	450 – 650
6.	Citrus	900 – 1200	16.	Soybean	450 – 700
7.	Cotton	700 – 1300	17.	Sugar beet	550 – 750
8.	Maize	500 – 800	18.	Sugarcane	1500 – 2500
9.	Mellon	400 – 600	19.	Sunflower	600 – 1000
10.	Onion	350 – 550	20.	Tomato	400 – 800

2.3.2 Irrigation scheduling

Irrigation scheduling determines when to irrigate and how much water to apply in the farm. Good schedule should apply correct amount of water at the right time, meanwhile optimizing production and minimize adverse effect of environmental (Shah et al., 2015). To generate efficient irrigation scheduling, knowledge of water, soil, water requirements, and potential yield under water stressed conditions is a prerequisite (Zegbe et al., 2003). Basically there are two approaches to irrigation scheduling techniques, crop monitoring and soil measurements (Hoffman et al., 1990). Information of initial soil available water to plant is required during estimation of the next irrigation for efficient irrigation before water stress condition can affect plants. Enhanced irrigation schedule can decrease irrigation costs and improve plant quality.

2.3.3 Crop water productivity

Water resources to help rain-fed and irrigation at present are under pressure, influencing the efficiency with which water is transformed to food, water productivity as another basic scenario in food production (Bessembinder et al., 2005; Passioura, 2006). Water productivity has been characterized as the measure of output (yield) per seasonal water supply assigned for production (Molden et al. 1998; Tuong et al., 2000; Bastiaanssen et al., 2003). Water productivity can be characterized concerning the distinctive sectors of production that utilizes water; agriculture, fishery, forestry, domestic and industry. Water productivity is expressed as kg/m^3 and furthermore can be characterized in monetary value from yield per water volume in equivalent currency, for example US$/m^3 (Kadigi et al., 2004). In this way, the concept of crop per drop is essential for Tanzania as agriculture is the main economic sector.

Improving water productivity based on physical or economic value is one of the critical processes towards encountering future water shortage (Molden et al., 2003). Increasing water productivity to get higher yield or incentive for each water drop used can assume a key part in alleviating water scarcity (Molden et al., 2001; UNDP, 2006). Worldwide projections demonstrate that increments in water productivity and extension of irrigated areas are required to represent half of the long-term increase in worldwide water prerequisites for food supply that will assure security of food of the projected 2050 population (Tropp et al., 2006).

2.3.4 Soil quality management

Quality of soil is an important and integral aspect that reflects the soil health, characterized as a continued capacity of soil to function as a living system within ecosystem and land use boundaries (USDA-NRCS, 2012; Doran et al. 1996; Doran and Zeiss, 2000). Soil quality refers to the capacity of soil to function within natural and managed ecosystem boundaries (Doran and Parking, 1994). Therefore, to reduce soil degradation and maintain better soil quality need to adopt appropriate soil management measures. Depending on various uses of land, soil quality is improved via organic matter, increased nutrient content and reduced erosion processes (Kashuk et al., 2010); however, soil quality can be degraded by use of fertilizers, pesticides, intensive tillage and increased erosion processes (Lal et al., 2004).

Soil quality is considered to have dynamic and inherent quality characteristics (Kalu et al., 2015). Inherent soil characteristics are related to the soils natural type and composition. Moreover, dynamic characteristics refer to soil characteristics that change as a result of soil use and management by human (Karlen et al., 2003; Nair, 2016). Dynamic soil characteristics describe how well soils perform ecological functions essential to people and environment. Soil properties at 0-15 cm depth are more dynamic and they are indicative of dynamic characteristics whereas properties at control depth 0 to 100 cm represent inherent soil quality (Vasu, 2016).

The impacts of agriculture on soil when quantified are crucial for monitoring, assessing and understanding management effects (Karlen et al., 2011; 2013). Soil quality ideas offer an approach that cannot be measured directly but incorporate different soil attributes called indicators (Nortcliff, 2002; Ditzler and Tugel, 2002). The indicators can be characterized to have biological, physical and chemical properties. In evaluating soil quality, there is no universal list of indicators appropriate for all places and ecosystem functions due to different soil and site characteristics, and prevailing climatic conditions (Arshad and Coen, 1992; Seybold, et al., 1998). The selected indicators ought to be sensitive to management practices, (Doran and Parkin, 1996) and not be site specific to a soil type so as to be utilized for monitoring soil quality (Brogan et al., 2002). Ideally, soil quality should be ease to measure, able to reflect changes, sensitive to variations and accessible to many users (Shukla et al., 2006).

Soil quality knowledge is important for decision making on sustainable land use (Sakbaeva et al., 2012); however, individual soil parameter is adequate for the evaluating quality of soil (Andrews et al., 2004). A powerful tool uses the idea of SQI, which depends on combining soil parameters that best reflect the condition of soil quality differentiated to individual parameters (Andrews et al., 2004; Amacher et al., 2007). SQI can be an essential tool for farm managers and policy makers to reduce degradation through the adaptation of appropriate intervention.

As an example, Andrews et al., (2002) developed indices based on additive, weighted additive and decision support for vegetable production. In the study, it was concluded that few quality indicators, when aggregated as non-linear scored index can enough give data expected to choice of the best soil management. Glover et al. (2000) highlighted that developed SQI can provide a better methodology for evaluating the overall effects of various orchard production practices on soil quality.

To decide SQI, there are main three steps involved; selection of indicators, scoring the chosen indicators in light of linear or non-linear relationships, and aggregating scores. The aggregation techniques utilized in literature is simple additive technique as described by Amacher et al. (2007) and Mukherjee and Lal, 2014. In this strategy, indicators are given thresholds from literatures and expert opinion. The individual values are then totalized to get a total index (∑SQI). The scaled SQI of the given soil is dictated by the equation:

$$SQI_{SA} = \frac{\sum SQI - SQI_{\min}}{SQI_{\max} - SQI_{\min}} \qquad [1]$$

where; SQI_{SA}, the scaled SQI; ∑SQI, the total index of individual indicators; SQI_{max} and SQI_{min}, the maximum & minimum SQI value from the total data set.

Most studies have been using weighted additive technique for aggregation (Karlen and Stott, 1994; Masto et al., 2008, 2007). In weighted additive technique, soil quality assessment tools should be flexible regarding selection of soil attributes (Weinhold et al., 2009) and indicators measured for particular management goals. In this strategy, the transformed soil quality data are given weights either by EO or PCA. The weights given to indicators utilizing expert opinion strategy relies on relative significance in determining soil function. Total weights for all soil function have to be 1. The strategy utilizes selected soil indicators and aggregated according to Karlen and Stott, 1994.

$$SQI_{WA} = \sum_{i=1}^{n} W_i \times S_i \qquad [2]$$

where; SQI_{WA}, the weighted soil quality index; S_i, indicator score; n, number of indicators included; and W_i, the weights of individual soil quality indicators.

Another method for combining indicators is by utilizing PCA analysis. In PCA soil indicators are combined utilizing weighted additive index (Karlen et al., 1994). The weights of each indicators in light of PCA is figured by as the variance of dataset explained by every PC divided by the total cumulated variance explained by all PCs with eigenvalues > 1. Once the indicators are weighted, values are combined into a SQI utilizing equation (Sanchez-Navarro et al., 2015; Tesfahunegn, 2014):

$$SQI_{PCA} = \frac{\sum \left(W_i \times S_i \right)}{\sum w} \quad [3]$$

where; SQI_{PCA}, PCA soil quality index; W_i, weight of chosen indicator; S_i, the score of i^{th} indicator; and w, the loading coefficients.

2.4 PERFORMANCE EVALUATION

2.4.1 Irrigation system performance

Performance is a measure of how close an irrigation event is to reference irrigation (Ali, 2011) and evaluation is a procedure of benchmarking standard value of something. Therefore, performance evaluation in general definition is the analysis of a system or management in light of estimations taken under field conditions and practices regularly utilized and contrasting the same with an ideal condition.

As indicated by Lenton (1986) irrigation performance depict the level to which an irrigation system accomplished its established objectives. Abernethy (1989) characterized performance as a measure of its levels of accomplishment as much as one or a few parameters which are selected as of the system's objectives. However, water management performance can be described as the level to which the resources in the irrigation schemes are ready for allotment to various farmers during preparation and operation stages.

As per Molden et al. (1998) performance is evaluated for various reasons which include to enhance system operation, assess progress against objectives, evaluate effects of interventions, analyze requirements, and better comprehend determinants of performance and to contrast it with other system or similar system.

Performance assessment is tied in to ensuring that all undertakings continue easily as arranged towards accomplishing those objectives and that system supervisors are cautioned effortlessly to potential dangers to crop and production system performances and respond to maintain a strategic distance from the situation. The principle part of performance assessment are to guarantee the cropping intensity targets met, for precise supply demand coordinating, water savings and to caution potential crisis event.

2.4.2 Selection of performance indicators

Performance assessment comprises of field works, analysis, and suggestions. The accompanying steps to complete an assessment include; (i) recognize all variables influencing water use, (ii) select suitable indicators on irrigation method, irrigation system, and financial condition, (iii) measure and compute the indicator values, (iv) assess performance by examining/contrasting the indicator values with the perfect one, (v) analyze improvement measures utilizing technical and monetary criteria, make comparison of options, and recommend/embrace the most proper one.

Performance is estimated using indicators for which information are collected. The investigation of indicators at that point advises on the level of performance. Performance indicators are acquainted here with regards to their place in the performance review. The linkage between the criteria against which performance is to be estimated and indicators that are to be utilized to measure accomplishment of those criteria is vital. Performance indicators are named either as external or internal indicators (Jisha and Balamurugan, 2017). The distinction amongst internal and external indicators is that internal indicators are utilized just for the performance review within a system and they are data intensive while external indicators relate out to the input and are not very data intensive. Internal indicators involve technical or field performance by estimating how close an irrigation event is near optimal. The analysis of field data permits quantitative meaning of the irrigation system.

External performance indicators assess irrigation system in view of relative correlation of supreme values, instead of being referenced to standard or target. Numerous indicators utilized for external performance assessment can be computed from secondary data instead of primary data. External indicators are grouped based on agriculture, water use performance, physical performance and economic performance. Small and Svendsen (1992) saw it as agricultural performance, economic performance and social system performance.

As per Bos et al. (1994) performance indicators to be utilized must have logical premise, that is an indicator must be derived from an analytically and measurably experienced key model it alludes to, quantifiable and must have reference to an objective value. The selected indicators must be related to the current technology and type of management and must be convenience and cost adequacy and ought to give unbiased information.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter describes approaches for performance evaluation. Consequent chapters connected to this just contribute to the different stages involved during implementation of performance evaluation program. The approach serves to characterize why the performance evaluation is required, what information is required, what techniques for analysis of data provided. Without an appropriate approach the performance evaluation program may neglect to gather all the essential information, and may not give the required data and comprehension.

This study involved assessment of inputs and output factors to suggest whether performing well or not in regard to the purpose is. To attain the evaluation process, data and information were collected through interview, field survey and visual observations. Criteria for selection based on irrigation method, agronomic practice, availability of secondary data and presence of planted crops during assessment. The interview aimed at collecting relevant information/data for the calculation of performance evaluation indicators, like productivity, environment sustainability, land size, cropping pattern and satisfaction level of water supply services.

3.2 DESCRIPTION OF STUDY AREA

The study was carried out at one of the smallholder irrigation scheme at Singida district in Tanzania served by one borehole at Msange village. Singida District Council (SDC) is one among the six Districts councils of Singida. The Council has an aggregate territory of 5,053 Km^2 partitioned into land for agriculture covering 3,214 Km^2, grazing area 1,306 Km^2 while forestry, bushes, water bodies, hills and rocks covering 533 Km^2. The major socio-economic activities are farming and livestock keeping. Different other activities include bee-keeping, fishing, mining, business and cottage industries.

Msange irrigation scheme is having a potential area for irrigation of 1,400 ha is located 45 km from Singida town to Latitude 04^{0}37’30” S and Longitude 35^{0}02’56” E, 1602 m above sea level. The area receives unimodal rainfall during winter from November/December to April while the remaining months are dry. The mean annual rainfall ranges from 600 to 800 mm, meanwhile annual temperature range between 12^0C and 30^0C. Major crops growing are maize, onion, tomatoes and a variety of leafy vegetables. The command area at the scheme is 10 ha served by drip system.

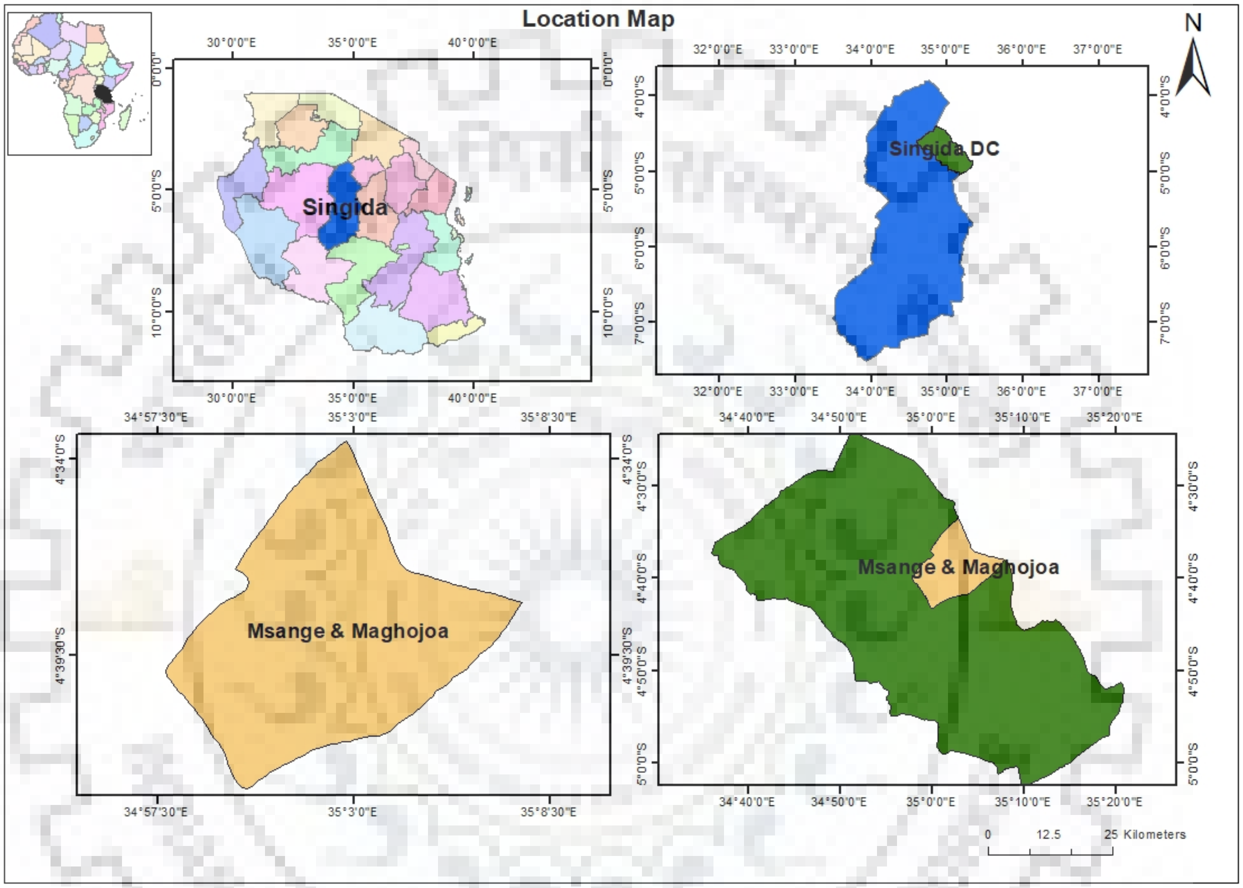


Figure 1 Location of study area

Onion (Oryza sativum) can be grouped according to various characteristics upon the Color, planting season, length of day and growth habit (MACL, 2015). Choice of variety to plant onions is preferred for specific uses, for example, in making salads red onions and spring onion are used. Dry bulb onions are the important onion spice. Types of onions grown in Tanzania are Red Creole, Red Tropicana, Bombay Red and Texas Grano.

In general, the country produces about 189,604 MT of onion per year ranking it at 12th amongst onion producing countries in Africa and 49th Worldwide (FAO, 2013).

Figure 2 Farmers maintaining onion field at Msange

Low yields of onion are a common experience in Tanzania. FAO (2013) statistics show that the average yield of onion in the country is about 10.06 t/ha while the World's average estimated at 19.31 t/ha. One factor to low yields is the use of poor varieties and poor agronomic practices.

Maize (Zea mays) is another major food crop produced in Tanzania. Over the past 20 years, maize varieties were developed and releases by National Maize Research Program (NMRP), and others released by various seed companies that operate in the country (Luzi-Kihupi et al., 2015). According to Lyimo (2005) and Moshi et al. (1997), the most preferred OPVs varieties are Staha, Staha-St, Kilima, Kilima-St, Katumani, TMV-1, ICW, and UCA due to their high yielding.

Tomato (Lycopersicum esculentum) production in Tanzania is more produced than other vegetables and the average yield is 2.2 – 3.3 t/ha (UTR, 2003) less to world average of 27.5 t/ha (FAO, 2005). According to Minja et al. (2011), the low productivity is caused by the increased stresses, for example salinity, drought, soil infertility, diseases and poor crop management. Various improved tomato varieties are grown, but not tolerant to infection and are low yielding with a short shelf life (AVRDC, 2006). AVRDC released two high-yielding varieties in 1997, Tanya and Tengeru 97 that are less susceptible to pests and diseases compared to former varieties, such as Money Maker, Roma and Marglobe.

3.3 DATA COLLECTION AND ANALYSIS

The collected data encompasses primary data from the field and secondary data. Field visits, discussion with farmers, direct observation, literature review, and laboratory testing were the method used during analysis. The field data include flow measurements, irrigation practices, system capacity, and amount of water delivered, O&M cost and water requirements. The secondary data include yields, crop prices, cropping pattern, production costs, revenue, crop type and meteorological data.

3.3.1 Meteorological data

Climatic data during 2012 to 2016 were collected from Singida Meteorological station in Tanzania and averaged for calculation of effective rainfall and water demand. The data collected were temperature, relative humidity, sunshine hours, wind speed, and precipitation.

Figure 3 Discussion with leaders of Msange Irrigators organization during field visit

3.3.2 Flow and field measurements

Measurement of flows through the on-farm conveyance system ensures optimal water deliveries to the field, as determined by irrigation scheduling methods. Determining when and amount to apply is an important part of irrigation management process. Many devices are available to measure pipeline or open channel flows such as weirs, flumes, and water meters.

Selection of plots for evaluation concentrated at plots with crops planted during time of analysis. The evaluated crops were maize, onion and tomatoes. To determine water supplied by farmers to field, flow into the plots was estimated during cropping season June to November, 2017. The estimation based on readings recorded by farmers using water meter installed at the main line.

3.3.3 Pump flow rate

The estimation of pump capacity relied on the flow measurements against time recorded using water meter. From the recorded values an average value was utilized to depict the capacity.

3.3.4 Crop water requirements

Analysis of water demand for crops and irrigation requirements was done using CROPWAT model. CROPWAT is computer software which uses FAO Penman-Monteith method to determine ETo, ETc and irrigation scheduling (Smith, 1992). It is a useful tool to engineers, scientists, researchers for determination of ET and irrigation schemes management.. The inputs to CROPWAT are the meteorological data.

The data inputs to CROPWAT include climate/ETo, rain, crop type, soil and cropping pattern. To calculate crop water requirement, irrigation schedules and water supply the output modules CWR, schedules and scheme are used (Allen et al., 1998).

3.3.5 Operation and maintenance cost

The O&M cost was obtained from extension staff and leaders of irrigators' organization. The maintenance cost was difficult to get and hence 10% of the operation cost was taken.

3.3.6 Gross value of production

The value of production was calculated for the selected crops in the scheme; maize, onion and tomatoes from collected yield and crop price.

3.4 SOIL SAMPLING AND ANALYSIS

3.4.1 Physical and chemical soil parameters

Soil samples at a depth of 0 - 15 cm were taken from study area in Tanzania and transported to the laboratory for analysis in India. Laboratory analyses were meant for analyzing chemical and physical parameters which presents the quality of the soil. The analyses were done at NIH Institute Roorkee in India. Soil quality analysis is necessary due to its affects on crop productivity and nutrient uptakes by plants.

During processing, samples were firstly air-dried and the clods carefully crushed by hand and slightly by mortar. The soil then was passed to sieve of sizes 2, 1.4, 0.85, 0.425, 0.25, 0.215 and 0.075 mm. Samples were shaken for 30 minutes by sieve shaker which resulted in the separation of aggregate sizes 4.75-2, 2-1.4, 1.4-0.85, 0.85-0.425, 0.425-0.25, 0.25- 0.215, 0.215-0.075 and less than 0.075. Furthermore, separation continued using wet sieving and for finer particles by Mastersizer separation which yielded up to 0.00132 mm particle sizes.

Figure 4 Determination of particle size by sieve analysis and Mastersizer separation

Figure 5 Digital STFR meter and testing tube rack

Table 3 Soil texture classification

S/N	**Soil texture**	**Particle size diameter** (mm)
1.	Gravel	>2
2.	Coarse and medium sand	2.0 – 0.1
3.	Very fine sand	0.1 – 0.05
4.	Silt	0.05 – 0.002
5.	Coarse clay	0.002 – 0.0002
6.	Fine clay	<0.0002

The clay and sand proportions were used to determine soil water characteristics important in estimation of available water in the soil using SPAW (Soil-Plant-Air-Water) model. The input of the model has textural triangle which provides values. The inputs are the sand and clay contents (%). The outputs are soil type, wilting point, field capacity, saturation, available water, hydraulic conductivity and bulk density.

Table 4 Methods for soil physical parameters estimation

Parameter	**Method of extraction or estimation**
Bulk density (g/cm^3)	Estimated from sand and clay proportions using SPAW model
Porosity (%)	Porosity was calculated as 1 – Bulk density/Particle density
AWC (%)	Calculated by subtracting wilting point from field capacity
Sand, silt and clay (%)	Determined from dry and wet sieving and Mastersizer separation

Table 5 Methods for soil chemical parameters estimation

Parameter	**Method of extraction or estimation**
Organic carbon (%)	OC was measured after color development by oxidizing soil with strong acid (Conc. H_2SO_4)
Available P (kg/ha)	A 1:20 soil/PHX extract was shaken for 30 minutes and available phosphorus determined by STFR meter after color development.
Available K (kg/ha)	A 1:5 soil/PSX extract was shaken for 30 minutes and available potassium measured by STFR meter after color development.
Available S (mg/kg)	Identical extraction method as used for potassium. The concentration of sulphur was measured by STFR meter after color development.
Available Zn & Fe (mg/kg)	Extracted from 1:5 soil/ZNX extract; shaken for 30 minutes and filtered. Zinc and Iron were measured by STFR meter after color development.
Available Mn (mg/kg)	Extracted from 1:5 soil/MNX extract, shaken for 30 minutes and filtered. During color development the extract was kept into boiling water and measured by STFR meter.
Available B (mg/kg)	Extracted from 1:2 soil/BX extract, shaken for 30 minutes and double filtered. After color development Boron was measured by STFR meter.
Soil pH	Measured in a 1:5 soil/water suspension with pH meter and read from STFR meter. Std pH 7.0 & pH 4.0 was used to calibrate the instrument.
EC (dS/m)	Measures in a 1:5 soil/water suspensions by EC probe and read from STFR meter. Std EC 0.407 dS/m was used to calibrate the instrument.
Available N (kg/ha)	Calculated from the relation of measured OC and pH values. If pH < 6, OC value is multiplied by 93.4; pH 6 – 8, the OC is multiplied by 210; and pH > 8, OC is multiplied by 278 (Gopi, 2017)
CEC (cmol+/kg)	Calculated as CEC=1.6 OC – 0.02 pH (Rashid and Seilsepour, 2009)

Plant nutrients were analyzed using digital STFR meter, a method described by Indian Agricultural Research Institute. The instrument quantitatively estimates available concentrations in the soil. The available nutrients were extracted with an extracting reagents through color developed in the extract with another reagent. The intensity of color shows proportional amount of nutrients extracted and measured by the meter.

Table 6 Critical limits for the availability of basic chemical properties

	Soil pH (1:5)	**EC** (dS/m)	**CEC** (cmol+/kg)
Very high	>8.5	>2.0	>40
High	6.6 – 8.5	0.8 – 2.0	25 - 40
Medium	5.6 – 6.5	0.4 – 0.8	15 - 24
Low	4.6 – 5.5	0.15 – 0.4	10 - 15
Very low	< 4.5	< 0.15	< 10

Source: Motsara and Roy (2008); Thiagalingam (2000); Horneck et al. (2011)

Table 7 Critical limits for macronutrients availability

Availability	**OC** (%)	**N** (kg/ ha)	**P** (kg/ha)	**K** (kg/ha)
Very high	>1	>350	>50	>600
High	0.75 - 1	250 – 350	25 – 50	280 – 600
Medium	0.5 – 0.75	150 – 250	10 – 25	120 – 280
Low	0.2 - 0.5	50 – 150	5 – 10	100 – 120
Very low	<0.2	< 50	< 5	< 100

Source: Motsara and Roy (2008); Thiagalingam (2000); Horneck et al. (2011)

Table 8 Critical limits of sulphur and micronutrients availability

Availability	**S** (mg/kg)	**Zn** (mg/kg)	**Fe** (mg/kg)	**B** (mg/kg)	**Mn** (mg/kg)
Very low	<5	< 0.3	< 2	<0.2	<0.5
Low	5 – 15	0.3 – 0.8	2 – 10	0.2 – 0.5	0.5 – 1.2
Medium	15 – 50	0.8 – 5	10 – 50	0.5 – 1	1.2 – 3.5
High	50 – 150	5 – 15	50 – 70	1 – 2	3.5 – 6
Very high	>150	>15	>70	>2	>6

Source: Motsara and Roy (2008); Thiagalingam (2000); Horneck et al. (2011)

3.4.2 Development of scoring functions

Scores are based on measured values for each indicator derived either by linear or non-linear function upon the user. The present study recommends and identifies the non-linear scoring models. To develop scoring function, standard deviations and mean were calculated as a cumulative normal distribution function. The scoring function approach (SFA) relies on the assumption of a representative dataset covering the full range of soil parameters with given threshold values. It converts measured value to a unit less score from 0 to 1. This approach can be adapted to by adjusting scoring functions to fit different conditions like soils, climate and management.

The development of scoring functions involves the following steps:

i) *Identifying soil indicator*. The selection of soil quality indicators is based on EO or PCA. The indicators should respond to management practices related to one or more management objective, such as land productivity and environmental quality. Eighteen (18) soil parameters were identified under the proposed strategy as indicated in Table 9 and 10.

ii) *Identifying available datasets*. Dataset to include into the scoring functions can be original/collected data or existing datasets from previous studies.

iii) *Establish soil indicator and score relationship*. This is done by plotting the relationship between a soil indicator and a score to determine the type of the relationship, such as more is better, less is better or optimum. Curve expert 1.4 software is used to develop a type curve..

iv) *Identify baseline and optimal values.* To establish baselines values on which scores are derived. The baseline value of soil indicator is obtained when the score is at 0.5 and optimum value obtained at a point when the score is maximum at 1. Below and above the baseline values the soil indicator is considered as having constraints.

v) *Validation of scoring function.* Scoring functions are used to determine scores using data not used to estimate baseline parameter values. A number of validation methods, including EO on outcomes, comparison with measured potential goals (such as yield or soil loss) or comparing with published data. Further, validation is accomplished as other users implement the proposed strategy using scoring functions and report their results.

Table 9 Threshold values and scoring functions for physical soil parameters

No.	Indicator	Scoring	Threshold	Reference
1	Sand (%)	Optimum	0 - 60	Tesfahunegn, 2014
2	Silt (%)	More is better	0 – 38	Tesfahunegn, 2014
3	Clay (%)	More is better	0 – 30	Masto et al., 2008
4	BD (g/cm^3)	Less is better	0.8 – 2	Gelaw et al., 2015
5	Porosity (%)	Optimum	20 – 80	Gelaw et al., 2015
6	AWC (%)	More is better	10 – 58	Tesfahunegn, 2014

Table 10 Threshold values and scoring functions for chemical soil parameters

No.	Indicator	Scoring	Threshold	Reference
1	pH (1:5)	Optimum	3 – 9	Fernandes et al.1999
2	OC (%)	More is better	0 – 1	Thiagalingam, 2000
3	EC (dS/m)	Less is better	0 – 2	Glover et al., 2000
4	CEC (cmol/kg)	More is better	0 – 30	Gelaw et al., 2015
5	N (kg/ha)	More is better	0 – 400	Masto et al., 2008
6	P (kg/ha)	Optimum	0 – 50	Masto et al., 2008
7	K (kg/ha)	More is better	0 – 400	Masto et al., 2008
8	S (mg/kg)	Optimum	0 – 150	Motsara and Roy, 2008
9	Zn (mg/kg)	Optimum	2 – 20	Tesfahunegn, 2014
10	Fe (mg/kg)	Optimum	10 – 50	Tesfahunegn, 2014
11	B (mg/kg)	Less is better	0.2 – 2	Thiagalingam, 2000
12	Mn (mg/kg)	Less is better	0.5 – 14	Thiagalingam, 2000

To describe scoring functions, three types are detailed in the development; more is better, less is better and optimum and selection of what type to use relies on indicators to be used. “More is better” scoring curve relies on the principle that higher the measured value of the indicator, the higher the score until the maximum score of 1 is attained. Value exceeding this maximum score is assigned a score of 1. Examples of this include AWC, available N and K. The scoring function for these indicators is given as:

$$Y = \frac{1}{1 + e^{-3.9(\frac{x-\mu}{\sigma})}} \qquad [4]$$

where; Y, Indicator score; x, measured value; μ and σ, the mean and standard deviation respectively

There are few indicators for which lower values are associated with better soil functioning and a danger of harmfulness from overburden levels. These types of indicators are scored using “less is better” scoring function. Example of this group is the bulk density, the developed scoring function in these indicators are determined and given as:

$$V = \frac{1}{1 + e^{3.9(\frac{x-\mu}{\sigma})}} \qquad [5]$$

where; V, Indicator score; x, measured value; μ and σ, the mean and standard deviation respectively.

Optimum scoring function combines more is better and less is better. In this, the scoring curve ascends with increasing measured value until a maximum point is reached, and starts declining to the lower end of the optimum range. At the optimum point the score is always 1; values exceeding this point follow a scoring curve with a negative slope which decreases with further increase in measures values. Good examples are soil pH and sand. The developed scoring function for these indicators is determined and given as:

$$S = e^{-3(\frac{x-\mu}{\sigma})2} \qquad [6]$$

where; S, Indicator score; x, measured value; μ and σ, the mean and standard deviation respectively.

Scores are quantified in termed of very low (0 – 0.2), low (0.2 – 0.4), medium (0.4 – 0.6), high (0.6 – 0.8) or very high (0.8 – 1) depending on the values as suggested by Moebius-Clune et al. (2016).

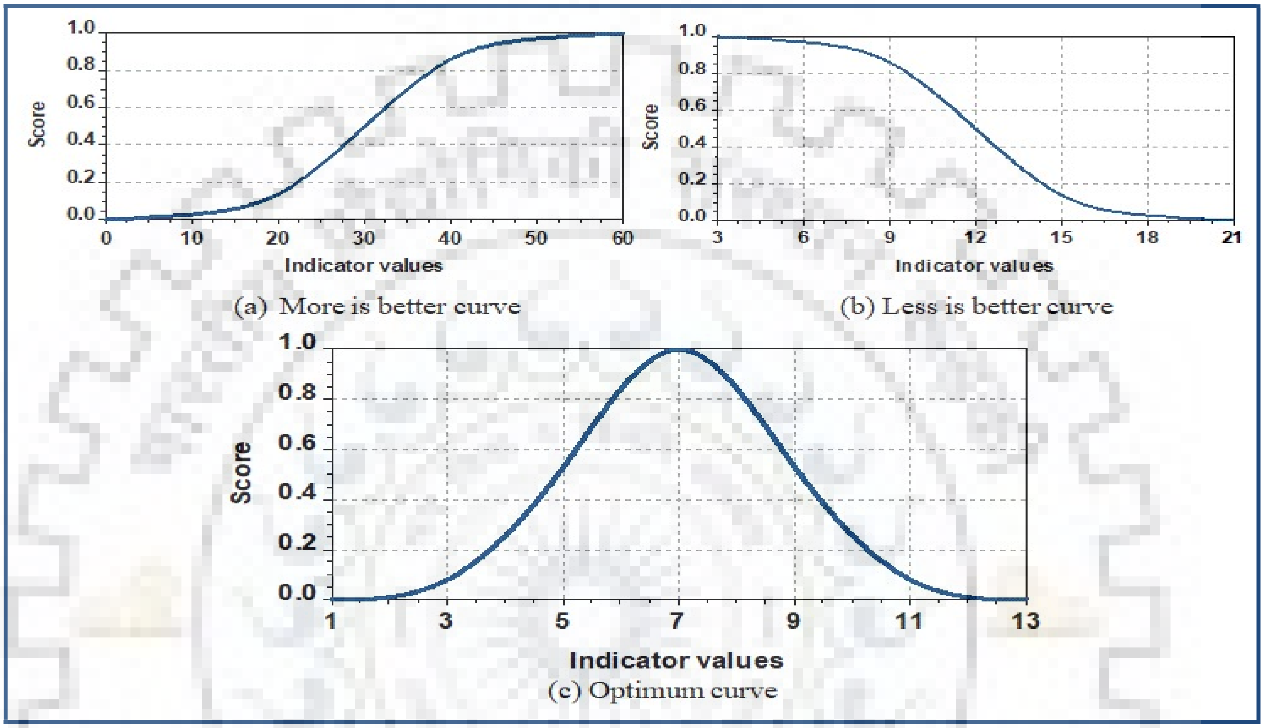


Figure 6 Types of scoring function curves

3.4.3 Determination of Soil Quality Index (SQI)

Soil quality assessment tools need to be flexible in terms of indicator selection to be measured suitable for specific management (Weinhold et al., 2009). The determination of SQI value involved three main steps; selection and measuring of soil indicators, transformation of indicator values into dimension less value from 0 to 1, and aggregation of scores into index. Selection and measurement of total dataset indicators included 18 indicators of which 6 were physical parameters and 12 chemicals parameters. Depending on environmental and agronomic conditions, each indicator was scored using either “more is better”, “less is better” or “optimum function.

Once the scores have been quantified, the SQI is calculated as an additive index of individual scores (Moebius-Clune et al., 2016; Masto et al., 2008). The quantitative interpretation of SQI value follows the ratings of that of individual score as suggested by Moebius-Clune et al. (2016); 1.0 being the highest score and 0 the least conceivable scores. Lower score values of indicator signifies less functioning of soil processes compared to crop productivity. The formula for the proposed additive SQI is given by equation:

$$SQI_A = \frac{1}{N}\left(\sum_{i=1}^{n} S_i\right) \qquad [7]$$

where; SQI_A, soil quality index; N, total number of indicators; and $S_{i,}$ the normalized score.

3.5 CROP WATER DEMAND AND IRRIGATION REQUIREMENTS

The net water requirements and irrigation requirements was calculated for each crop using data collected from the field from June to November, 2017. CROPWAT computer program was used to compute the water requirements for maize, onion and tomato in all the growing stages based and dependable rainfall for estimation of effective rainfall (Smith, 1992). The input data included soil type, planting date, climate data and cropping pattern. The meteorological data was taken from Singida Meteorological station. The crop ETc is calculated as:

$$\mathrm{ET_c = K_c \times ET_o} \qquad [8]$$

where; ETo, Reference evapotranspiration; Kc, Crop factor; and ETc, the Crop ET/crop water demand at any growing stage. The ETo is defined and calculated using the Penman-Monteith equation (Allen et al., 2005).

$$\mathrm{ET_o} = \frac{0.408\,\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\left(\frac{900}{\mathrm{T} + 273}\right)\mathrm{U_2}(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34\,\mathrm{U_2})} \qquad [9]$$

where; ETo, reference ET (mm/day); R_n, Net radiation at crop surface (MJ $m^{-1}day^{-1}$); G, Soil heat flow density ($MJm^{-1}day^{-1}$); T, Average daily air temperature at 2 m height (^0C); U2, Wind speed at 2 m height (m/s); e_s, Saturated vapor pressure (kPa); e_a, Actual vapor pressure (kPa); e_s- e_a, Saturation vapor pressure deficit (kPa); Δ, Slope vapor pressure curve (kPa^0C^{-1}); and γ, Psychometric constant (kPa $^0C^{-1}$).

Table 11 Major crop parameters at Msange irrigation scheme (FAO, 2018)

Crop type	Parameter	Growth stage				
		Initial	Crop dev.	Mid	Late	Total
Maize	Length, days	20	22	28	20	90
	Kc values	0.3	0.8	1.2	0.5	0.5
	Depletion fraction, p	0.5	0.5	0.5	0.8	0.8
	Yield response, Ky	0.4	0.4	1.3	0.5	0.5
	Root depth, m	0.3	-	1.0	-	-
Onion	Length, days	10	35	55	20	120
	Kc values	0.7	0.75	1.05	0.75	0.75
	Depletion fraction, p	0.3	0.3	0.3	0.3	0.3
	Yield response, Ky	0.45	0.45	0.8	0.3	1.1
	Root depth, m	0.3	-	0.6	-	-
Tomato	Length, days	20	30	30	20	100
	Kc values	0.6	0.75	1.15	0.8	0.8
	Depletion fraction, p	0.3	0.3	0.4	0.5	0.3
	Yield response, Ky	0.4	1.1	0.8	0.4	1.05
	Root depth, m	0.25	-	1.0	-	-

3.6 ESTIMATION OF WATER SUPPLY AND WATER PRODUCTIVITY

It is vital for farmers to know the availability of irrigation water into their irrigation system management practices. Both surface and ground water can be utilized to supply water. An evaluation of available irrigation water during the growing season is basic to decide the type and amount of crops that can be developed in a specific time of the season.

In Msange available water to the farm from the source is transported to fields under pressure through networks of pipelines which include main line, manifold and drip lines. Pressure for the drip systems is through pumping using pump coupled with diesel engine. Water productivity as physical (kg/m^3) and in economic term (US\$/m^3) were determined (Igbadun et al. 2006).

$$W_{EP} = \frac{Y_a}{CWU} \qquad [10]$$

$$W_{EC} = \frac{Y \times P}{CWU} \qquad [11]$$

where: W_{EP}, Physical water productivity (kg/m^3); W_{EC}, water productivity in economic term (US\$/m^3); CWU, Consumptive water use (m^3/ha); and Ya, actual yield (kg/ha); P, crop price (US\$/kg)

Table 12 Range of yield and water productivity for maize, onion and tomatoes (FAO, 2018)

Crop	**Yield** (t/ha)	**Water productivity** (kg/m^3)
Maize	6 – 9	0.8 - 1.6
Onion	35 – 45	8 - 10
Tomatoes	45 – 65	10 - 12

3.7 PERFORMANCE EVALUATION FRAMEWORK

Several approaches and methodologies have been described and used for evaluation of irrigation systems in irrigated agriculture (Bos et al., 1994; Murray-Rust and Snellen, 1993; Small and Svendsen, 1992). The two mostly used approaches are; the goal-oriented approach and the natural system approach. Goal-oriented approach measures the performance related to the level to which a system attains its goals, meanwhile the natural system approach measures the system as the ability to obtain inputs rather than output or impacts.

The goal oriented approach was adopted as described by (Small and Svendsen 1992) and then modified by (Bos et al. 1994) and in this study. Bos et al. (1994) highlighted the necessity that data collected form part of the normal task of operating and maintaining irrigation system in the framework. Small and Svendsen (1992) conceptualized through a nested means-ends framework by forming components of broader agricultural, economic and social systems by considering performance measures on the process, output and impact. In this context the outputs from one system becomes the inputs to next system level.

Table 13 Description of nested irrigation systems framework (Small and Svendsen, 1992)

System	**Explanation**	**Input (means)**	**Output (ends)**
Irrigation system	Function of water delivery from source to farmer's field	Infrastructure and facilities operation	Supplied water to crops
Irrigated agriculture system	Farmers use supplied water and other inputs to produce crops.	Supply of water to crops	Agricultural production
Agricultural economic system	Includes values of crops or incomes generated from irrigation activities.	Agricultural production	Generated incomes
Socioeconomic system	Concern with entire set of economic activities done by farmers that in turn form part of the national development	Generated incomes	Socioeconomic and irrigation infrastructure development

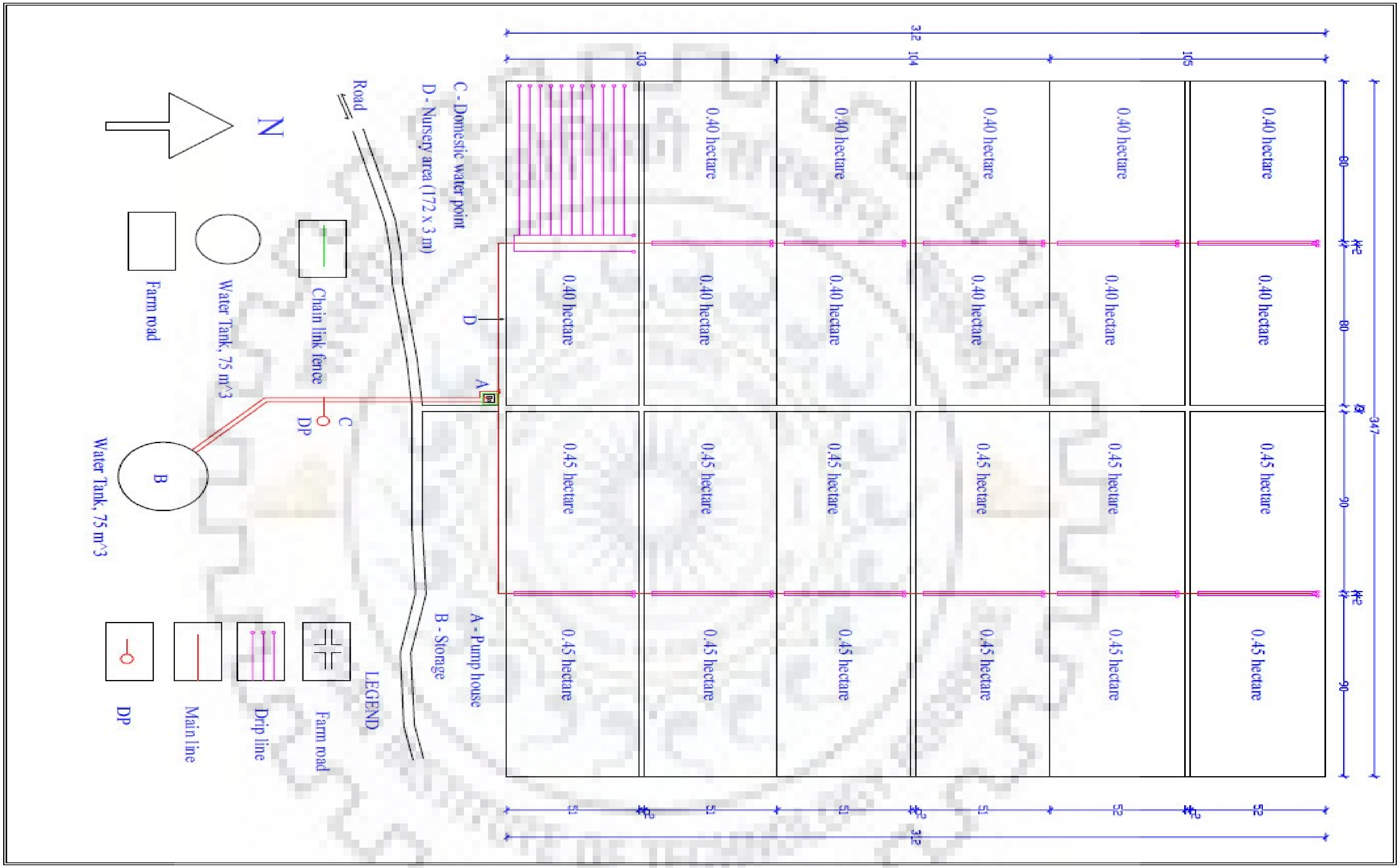


Figure 7 Layout of Msange irrigation system

3.7.1 Selection of performance indicators

Nested means-ends-framework for indicator selection described under this concept are categorized based on three criteria which are water supply, agricultural production and economic performance and environmental quality. Water supply describes the allocation and transportation of water from the source to the field. Agricultural outputs normally address the direct impact of water and land inputs from production. Meanwhile, economic performance and environmental quality views the impact of both operational and agricultural inputs on the economic viability and sustainability of irrigated land. Under each criterion indicators was selected to assess the performance of Msange irrigation scheme (Goratiwar and Smout, 2005; Bos et al., 1994; Kloezen and Carlos, 1998; Small and Svendsen, 1992).

3.7.2 Determination of indicators value

Performance is measured through the use of indicators, for which data are collected. The analysis of the indicators then informs us on the level of performance (Bos et al. 2005). To achieve the study objectives, performance indicator values were determined to evaluate the scheme The weights for each criterion and performance indicators were assigned using AHP (Saaty, 2008).

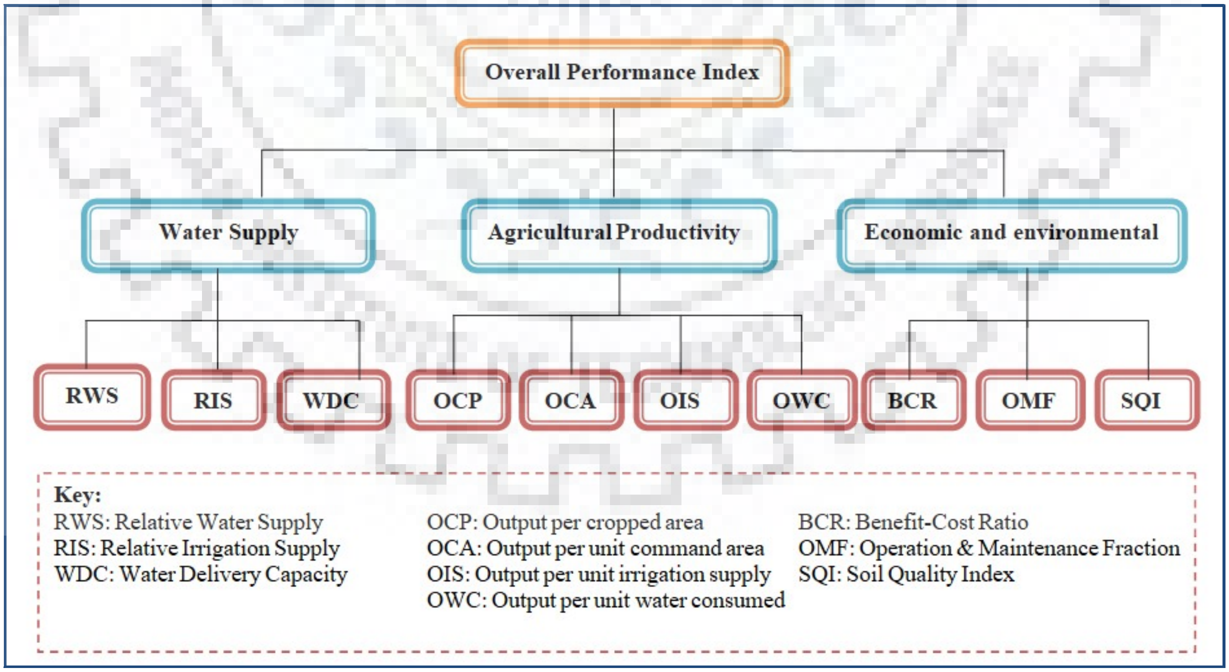


Figure 8 Hierarchy for overall performance evaluation

3.7.3 Determination of water supply indicators

Water supply was assessed based on RWS, RIS and WDC. The water demand is based on criteria such as evaporation demand for each crops or cropping pattern, soil moisture and water lost through seepage and percolation, rainfall.

Relative water supply (RWS): RWS relates water supply to irrigation demand and indicates the condition of water availability or scarcity and how tightly supply and demand is matched. The value greater than 1 indicates that the supply is enough to meet crop demand (Jisha and Balamurugan 2017). The value of RWS was determined using equation (Perry, 1996):

$$\mathrm{RWS} = \frac{\mathrm{TWS}}{\mathrm{TCWD}} \qquad [12]$$

where; RWS, Relative water supply; TWS, Total water supply (Irrigation + Rainfall); and TCWD is Total crop water demand at field level.

Relative irrigation supply (RIS): This indicator relates irrigation supply to irrigation demand, total crop demand less effective rainfall. If required water is met the value of RIS is unity while the value > 1 indicates that the irrigation supply is enough to meet crop demand ((Jisha and Balamurugan, 2017); also is an indication that excess irrigation water is supplied and value < 1 would show that the crop are not getting enough water (Molden et al. 1998). RIS > RWS values are a sign that major water supplied in the area is from irrigation. RIS was determined using equation (Perry, 1996):

$$\mathrm{RIS} = \frac{\mathrm{IWS}}{\mathrm{IWD}} \qquad [13]$$

where; RIS, Relative irrigation supply; IWS, Irrigation water supply; and IWD, Irrigation water demand.

Water delivery capacity (WDC): This illustrate if the design is somehow a constraint to cope with the actual crop demand at the peak period or not. To meet demand at peak period without limitation, WDC must be greater than 1. WDC < 1 indicate the difficulties for the system to meet the water requirements at the peak period. The value is calculated (Molden et al. 1998) as:

$$\mathrm{WDC} = \frac{\mathrm{SWD}}{\mathrm{PCD}} \qquad [14]$$

where; WDC, Water delivery capacity; SWD, system water delivery capacity; and PCD, Peak consumptive demand (l/s)

3.7.4 Determination of agricultural indicators

The specific indicators adopted to assess agricultural outputs were; OCP, OCA, OIS and OWC. These are ratio based performance indicators which measure production in tons, yield in tons/ha and water productivity in kg/m^3. Local prices were considered during determination of agricultural outputs.

Output per cropped area (OCP): OCP quantifies value of agricultural production per unit of area harvested during analysis. This indicator is not affected by irrigation intensity; however it can also indirectly indicate the level of water availability. In addition to water availability, soil type and fertility, land suitability, crop variety and agricultural inputs do have significant impact on the output under land productivity. The indicator is calculated using the equation (Molden et al. 1998; Malano et al. 2004):

$$\mathrm{OCP} = \frac{\mathrm{GVP}}{\mathrm{ICA}} \qquad [15]$$

where; OCP, Output per cropped area; GPV, Gross production value measured at local price; and ICA, Irrigation cropped area during time of analysis

Output per unit command area (OCA): The OCA means production per unit of command area which can be irrigated. Small values of this indicator can also imply, although not necessarily less intensive irrigation and vice versa. It is important where land is a constraining resource for production (Molden et al. 1998). The value of OCA is estimated as:

$$\mathrm{OCA} = \frac{\mathrm{GVP}}{\mathrm{CA}} \qquad [16]$$

where; OCA, Output per unit command area; GPV, the Gross production value; and CA, command area

Output per unit irrigation supply (OIS): This indicator relates the yields to amount of water diverted into a specific field. It provides information on water use in the farm. The indicator is important to water managers and farmers; water managers are usually dealing with water use and farmers want to realize maximum returns from their investment. OIS is expressed in kg/m^3 otherwise in terms of market value calculated using equation (Molden et al. 1998):

$$\text{OIS} = \frac{\text{GVP}}{\text{DIS}} \qquad [17]$$

where; OIS, Output per unit irrigation supply; GVP, Gross value of production; and DIS, Diverted irrigation supply

Output per unit water consumed (OWC): The indicator focuses only on crop ET; water evaporated from the soil and transpired by crops and therefore focusing on crop behavior. It excludes water that is used for leaching of salts or drained away through deep percolation or surface flow. It is calculated using the equation (Molden et al. 1998):

$$\text{OWC} = \frac{\text{GVP}}{\text{VWC}} \qquad [18]$$

where; OWC, Output per unit water consumed; GPV, Gross production value; and VWC, Volume of water consumed by crop ET (the actual ET of each crops)

Table 14 Cropping calendar for Msange at the time of evaluation

S.N	Crop	Command (ha)	Area irrigated (ha)	Planting date	Harvesting date	Area (%)
1.	Maize	2	2.03	05-June	02-September	40
2.	Onion	5	1.62	10-July	06-November	32
3.	Tomato	2	1.42	01-August	08-November	28

3.7.5 Determination of economic and environmental indicators

Indicators used to assess economic viability were BCR and O&M fraction (OMF) and the quality of soil was assessed using SQI. BCR is the ratio of benefit obtained from unit land to production costs for that land. For multiple crops or yearly calculation, different crops should be converted to the equivalent of each crop. BCR was determined using the equation (Solomon, 1988):

$$\text{BCR} = \frac{\text{B}}{\text{C}} \qquad [19]$$

where; BCR, irrigation benefit/cost ratio; B, total seasonal monetary benefit or income obtained from 1 hectare land (US\$); C, seasonal cost of production for that land (US\$). When BCR < 1, means that costs of production exceeds the benefits and the project should not proceed. At BCR equals to 1, costs equals to benefits means the project should be allowed to proceed but with little viability. And when BCR > 1, benefits exceed the costs and the project should be allowed to proceed.

O&M Fraction quantifies the effectiveness of the irrigation organization with respect to the actual water delivery and the maintenance of the canal or pipes lines and related structures, the OMF are used. This indicator deals with the salaries involved with the actual operation plus maintenance cost and minor investments. This indicator can be estimated using the following equation (Bos, 1993):

$$OMF = \frac{OM}{TOB} \qquad [20]$$

where; OMF, Operation and maintenance fraction; OM, the Cost of operation and maintenance; and TOB is Total organization budget for sustainable MO&M.

Environmental quality performance was meant by determining SQI by aggregating soil physical and chemical indicators as described under subsection 3.4.3.

Table 15 Data required for performance assessment of Msange irrigation scheme

Performance indicator	Data set requirement
Water supply performance	
Relative water supply	Measured water inflow, rainfall and water demand
Relative irrigation supply	Measured water inflow, irrigation demand, crop water demand and rainfall
Water delivery capacity	Pump discharge and crop irrigation requirements
Agricultural productivity	
Output per unit cropped area	Yield of each crop, crop price & irrigated crop area
Output per unit command area	Yield of each crop, crop price and command area
Output per unit irrigation supply	Yield of each crop, crop price, total measured water inflow and crop area
Output per unit water consumed	Yield of each crop, crop market price, actual crop ET and crop area
Economic & environmental viability	
Benefit-Cost ratio	Production costs, operation costs, benefit and expenditure on production
O&M fraction	Cost of O&M and total O&M budget
Soil quality index	Values of physical and chemical indicators

3.7.6 Overall performance

When all the indicators have been measured or estimated, they were aggregated into a single index value known as overall performance index (OPI). The estimated values of each indicator were normalized into score as follows.

$$\text{Score} = \frac{X}{X_t} \qquad [21]$$

where: X, measured value of indicator; and Xt, target value of indicator

Table 16 Threshold values of the performance indicators

Performance indicator	Good	Reference
Relative water supply	≥1[-]	(Molden et al. 1998)
Relative irrigation supply	≥1[-]	Molden et al., 2008
Water delivery capacity	>1[-]	(Molden et al. 1998)
Output per cropped area	4,445 $/ha	USAID, 2014
Outputs per command area	>4,445 $/ha	USAID, 2014
Outputs per irrigation supply	0.6 - 1.6 $\$/m^3$	(Molden et al. 1998)
Outputs per water consumed	0.6 - 1.6 $\$/m^3$	(Molden et al. 1998)
Benefit-Cost ratio	≥1	Solomoni, 1988
O&M fraction	≤1	(Bos, 1993)
Soil quality index	1	(Masto et al. 2008)

Table 17 Determination of the overall performance

Indicator	Score	Weights	Weighted score	Criteria score	Weights
(1)	(2)	(3)	(4)=(2) x (3)	(5)	(6)
RWS	S1	W1	$F_1 = S1.W1$	Water Supply (S) $S = F_1+F_2+F_3$	*Ws*
RIS	S2	W2	$F_2 = S2.W2$		
WDC	S3	W3	$F_3 = S3.W3$		
OCP	S4	W4	$F_4 = S4.W4$	Agricultural productivity (A) $A = F_4+F_5+F_6+F_7$	*Wa*
OCA	S5	W5	$F_5 = S5.W5$		
OIS	S6	W6	$F_6 = S6.W6$		
OWC	S7	W7	$F_7 = S7.W7$		
SQI	S8	W8	$F_8 = S8.W8$	Economic & environmental (E) $E = F_8+F_9+F_{10}$	*We*
BCR	S9	W9	$F_9 = S9.W9$		
OMF	S10	W10	$F_{10} = S10.W10$		

Finally, the OPI was calculated as:

$$OPI = W_s * S + W_a * A + W_e * E \qquad [22]$$

where; OPI, the overall performance index; Ws, Wa and We, weights for water supply performance, agricultural performance and economic & environmental performance indicators; S, A, E, are the score for water supply, agricultural and economic & environmental indicators

Table 18 General rating for overall performance index (Modified from CCME, 2007)

Class range	Value of OPI (%)	Performance rating
1	90 - 100	Excellent performance
2	70 - 90	High performance
3	50 - 70	Medium performance
4	30 - 50	Low performance
5	0 - 30	Very low performance

3.8 MEASURES FOR IMPROVING WATER PRODUCTIVITY

Water productivity as discussed implies how most effectively one can improve crop yield from lesser water. Therefore, productive techniques or options must be selected and put into practice. Some of these options include improving capacity building of farmers, spatially optimizing water application and use, and monitoring water delivery. Cultural practices such as conservation tillage, planting population, improved crop varieties, infection control and crop rotation influence crop water productivity. Therefore, measures at Msange irrigation scheme focuses on raising outputs from production with the purpose of improving productivity of water. Table 19 highlights some of the techniques which can be adopted for productive use of water.

Table 19 Selected techniques for improving water productivity

Technique	Description of selected option
Use of deficit irrigation	Water productivity can be increased by reducing depth of irrigation, increasing interval of successive irrigation and refill only some part of the root
Increasing soil fertility	In areas with low soil quality it is recommended to use fertilizers or manure in increasing yield
Soaking of seed before sowing	Soaking seeds in water before sowing causes earlier growth and maturity and increase seed yield
Application of organic manure	Management of organic matter is one of the major factors to increase soil moisture responsible for crop production and improve the structure of the soil
Sub-soiling and soil tillage	Tillage breaks soil surface which leads to improve water storage in the soil by increasing infiltration

Technique	Description of selected option
Precise irrigation	The use of precise technology of irrigation reduces water loss. Methods like micro-irrigation and sprinkler irrigation can promote productivity of water
Crops selection	Selection of crops can be done based on climate condition. In water scarcity selecting low water demand crop will save water for additional area
Selection of high valued crops	Selecting proper crops is significant in increasing economic return which promote high yield per water utilized

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The performance of Msange was assessed by considering the various parameters and the performance indicators. The results in this chapter are organized under the following subheadings; soil quality assessment, crop water requirement, water use and water productivity, performance evaluation indicators, and measures for improving performance and water productivity.

4.2 SOIL QUALITY ASSESSMENT

The results from laboratory analysis to evaluate the SQ of the study area indicate that the type of soil is silt loam with constraints due to high salinity level, low organic matter and available nitrogen, ferrous and phosphorus. In this study, eighteen parameters were selected to evaluate soil quality.

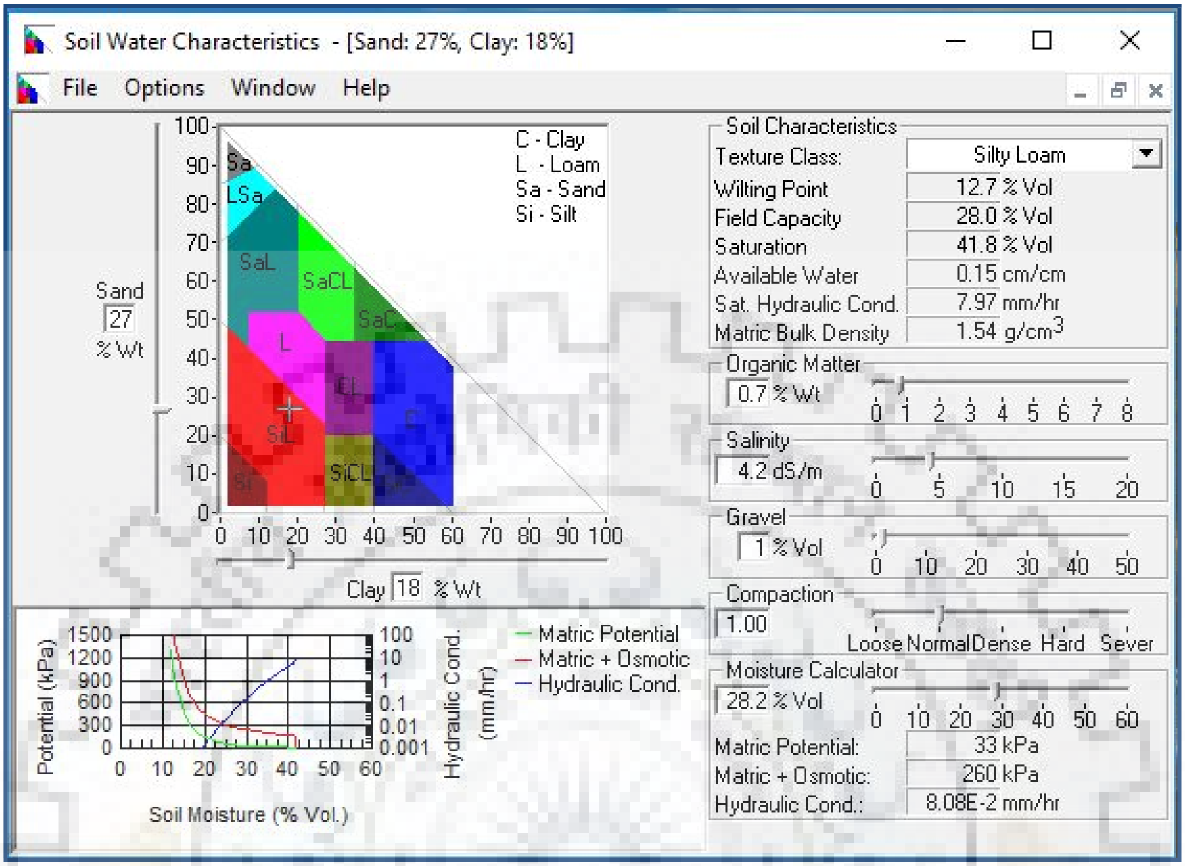
4.2.1 Soil physical parameters

The identified soil type is silt loam. Soil analysis was done at the NIH Roorkee using sieve shaker (grain > 0.075 mm) and Master Sizer E- system (fine grain < 0.075 mm).

Other physical parameters of the soil were determined using SPAW (Soil-Plant-Air-Water) model in which utilizes proportions of sand and clay as inputs. The AWC of 15.3% was determined by subtracting wilting point from field capacity as percentage by volume. The porosity determined was 41.89% in a very good range of suitability for plant to grow well.

Table 20 Results of physical soil parameters

Depth (cm)	**FC** (%)	**WP (%)**	**BD** (g/cc)	**Sand** (%)	**Clay** (%)	**Silt** (%)	**Soil type**
0 - 15	28.0	12.7	1.54	27.21	18.10	54.21	Silt loam



Soil Water Characteristics - [Sand: 27%, Clay: 18%]

Sand 27 % Wt

Clay 18 % Wt

Soil Characteristics

Texture Class: Silty Loam

Wilting Point 12.7 % Vol

Field Capacity 28.0 % Vol

Saturation 41.8 % Vol

Available Water 0.15 cm/cm

Sat. Hydraulic Cond. 7.97 mm/hr

Matric Bulk Density 1.54 g/cm^3

Organic Matter 0.7 % Wt

Salinity 4.2 dS/m

Gravel 1 % Vol

Compaction 1.00

Moisture Calculator 28.2 % Vol

Matric Potential: 33 kPa

Matric + Osmotic: 260 kPa

Hydraulic Cond.: 8.08E-2 mm/hr

Figure 9 Soil water characteristics

4.2.2 Soil chemical parameters

The parameters determined were OC, available P, K, S, B, Zn and Mn, soil pH, CEC and EC. The measured values were rated as very high, high, medium, low or very low. Soil pH is a major characteristic that affects the quality of plant growth. The pH value determined was 6.79 under the category of high suitability for most vegetable crops, slightly acid. A soil with pH 6.0 - 7.0 requires no special cultural practices to improve plant growth. However, soil modification is often necessary for pH above 7.5 (Tarkalson et al., 2006). Maintaining a proper pH is important to avoid nutrient deficiencies and toxicities in vegetables like maize (5.5 – 7.5), onion (6.0 – 7.0) and tomatoes (5.5 – 7.5).

Another important parameter is the electrical conductivity. EC was estimated at 4.25 dS/m in the category of low suitable range for agriculture. The highly suitable class for agriculture activity is in the range for EC<1 dS/m. The CEC value of 13.25 cmol+/kg was determined from the equation proposed by Rashidi and Seilsepour (2009) which is under low suitability region. Low CEC may be associated with low levels of total phosphorus and potassium, however high CEC may be associated with high pH at least up to 8.5.

OC was found as 0.3884% which indicates that the soil has low suitability. Although isn't a plant nutrient, concentrations below 0.5% will indicate problems on soil structure, low nutrient holding capacity and AWC (Thiagalingam, 2000). OC suitable for crop should at least be in the level of 0.75%. From measured content of OC, available nitrogen was estimated at 81.564 kg/ha categorized as low suitability by considering bulk density. The required amount of available N in the soil should at least be more than 250 kg/ha. Nitrogen has effect on growth and flowering and fruiting of crops.

The determined phosphorus content indicated inadequate amount for crop to grow. The phosphorus content was 16.5 kg/ha classified as medium suitability. For most crops the adequate level for phosphorus is more than 25 kg/ha and low suitability < 10 kg/ha. The available K in the sampled soil was 752.9 kg/ha in the category of very high suitability. Potassium is important for efficient water relationships in the plant, both for controlling water content in cells and water movement through tissues. Low suitable values range below 120 kg/ha.

Sulphur is another attribute which was determines. The value determined was 187.64 mg/kg which is highly suitable. Sulfur support nodule development in legumes and fortifies seed formation. It assumes a key role in chlorophyll formation. Available Zn is a basic part of numerous enzymes including some plant development hormones. It has a role in protein synthesis, seed maturing and plant height development. The determined zinc concentration was 12.6 mg/kg under the category of high and sufficient. The low suitability values lies in the category below 0.8 mg/kg.

Available iron is important for proper functioning of chlorophyll. The iron in the tested soil was 9.34 mg/kg which is not sufficient in the low category. At least iron concentration should range from 10 - 70 mg/kg, more than that iron has toxicity effects.

For the specific role for germination, chlorophyll formation and maturity manganese is of vital important which was measured. Manganese was 3.18 mg/kg which is sufficient for crop to grow well. The highly suitable range for manganese is between 2 – 50 mg/kg and above that toxicity effect to crops develops. The deficient symptoms of lack of manganese occur when it is below 2 mg/kg.

Another parameter of important for manufacture of sugar is boron. Boron also helps carbohydrates in crops and in the development of shoots and roots. The boron was determined as 0.917 mg/kg which lies in the category of medium level but sufficient for crop to grow. The sufficient range is from 0.85 - 2 mg/kg against its optimum value.

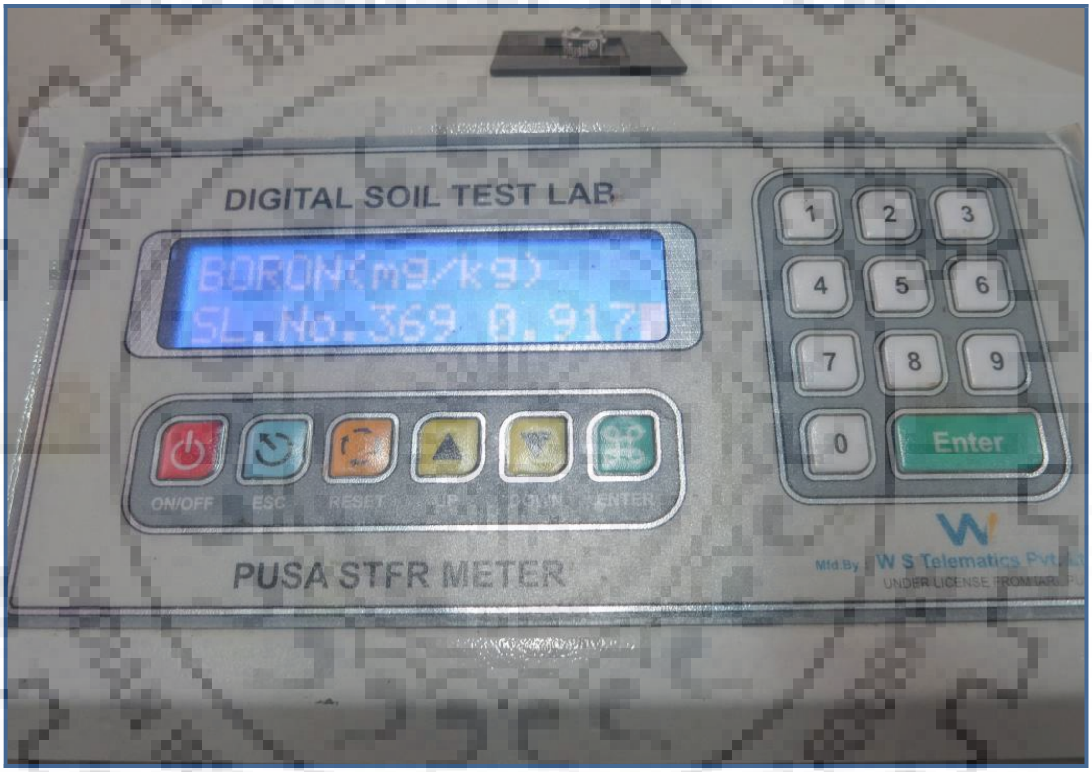


Figure 10 Result of measured value for Boron on digital STFR meter

4.2.3 Soil Quality index

Total of 18 soil indicators were analyzed to assess quality of soil with 6 physical soil parameter and 12 chemical parameters. The results from laboratory analysis and interpretation of scores for soil quality parameters are shown in Table 21 and 22.

Table 21 Physical parameters of the soil in the study area

Indicator	**Sand** (%)	**Clay** (%)	**Silt** (%)	**BD,** (g/cm^3)	**Porosity** (%)	**AWC** (%)
Value	27.21	18.10	54.21	1.54	41.89	15.30
Score	0.95	0.75	1.00	0.22	0.64	0.01
Rating	Very high	High	Very high	Low	High	Very low

Table 22 Chemical parameters of soil in the study area

Indicator	**pH (1:5)**	**CEC** (cmol/kg)	**EC** (dS/m)	**OC** (%)	**N** (kg/ha)	**P** (kg/ha)
Value	6.79	13.25	4.25	0.3884	81.564	16.50
Score	0.99	0.35	0.00	0.22	0.04	0.46
Rating	Very high	Low	Very low	Low	Very low	Medium

Indicator	**K** (kg/ha)	**S** (mg/kg)	**Zn** (mg/kg)	**Fe** (mg/kg)	**B** (mg/kg)	**Mn** (mg/kg)
Value	752.9	187.64	12.6	9.34	0.917	3.18
Score	1.00	1.00	0.82	0.05	0.75	0.96
Rating	Very high	Very high	Very high	Very low	High	Very high

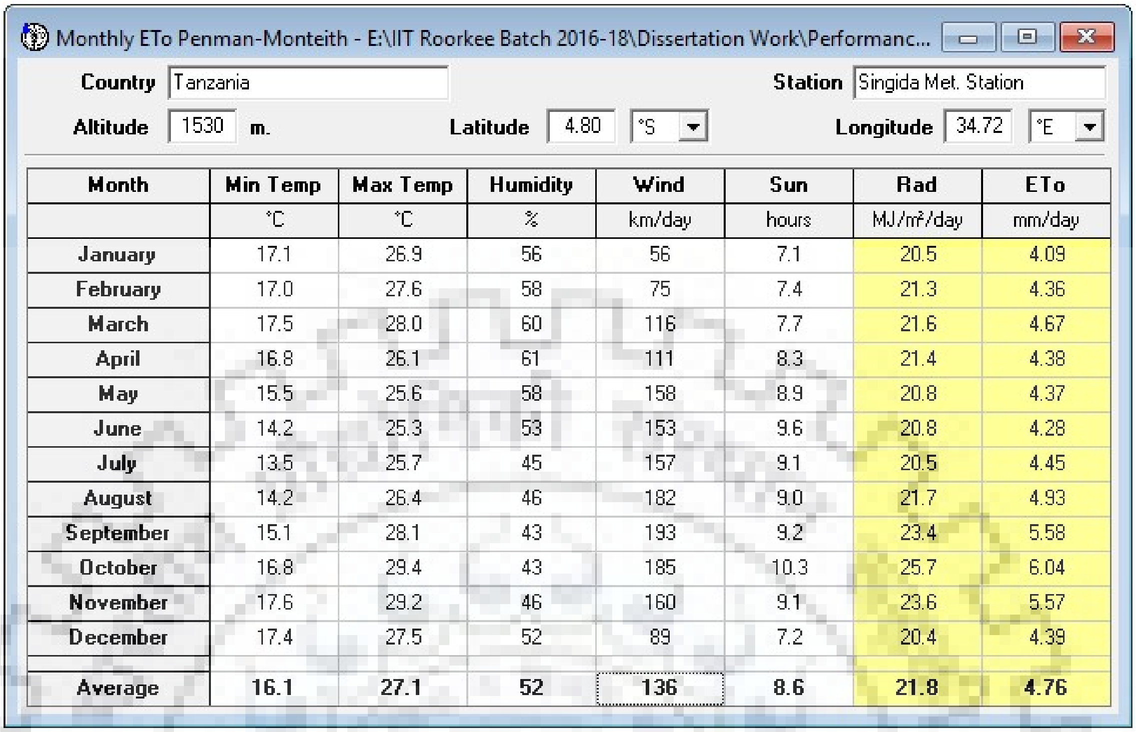
The soil indicators after scoring were combined for index calculations. Hence, the result shows that the SQI of the study area is 0.57 of silt loam soil in the medium quality. This value assumes that improvement is needed to further improve soil fertility.

4.3 CROP WATER REQUIREMENTS

Irrigation demand was estimated using CROPWAT model incorporating climatic and crop data. The total seasonal crop water demand and irrigation requirements were determined as a sum of the water requirements for each of the crops as presented in Table 23.

Table 23 Seasonal crop water demand (ET) and Irrigation requirements (IR) for Msange

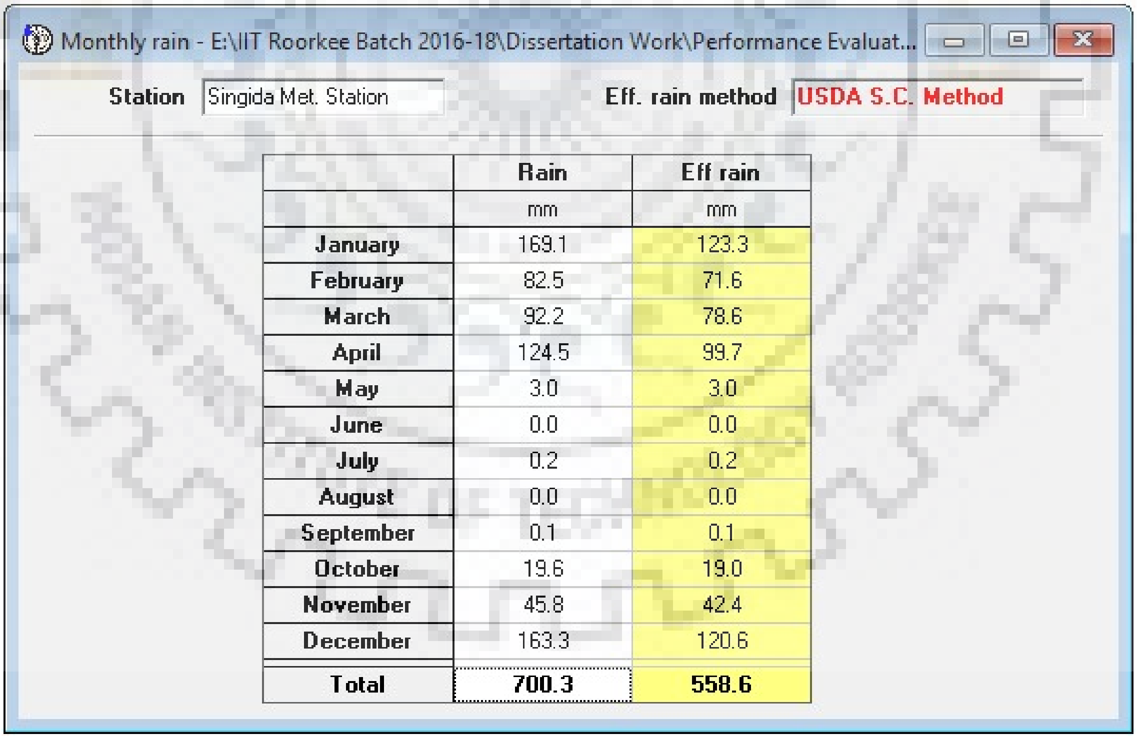
Crop	**Area** (ha)	**ET** (mm/season)	**Effective rain** (mm/season)	**IR** (mm/season)
Maize	2.03	340.3	0.2	340.1
Onion	1.62	611.8	25.3	586.5
Tomato	1.42	519.3	27.1	492.2
Total	**5.07**	**1471.4**	**52.6**	**1422.1**



Country: Tanzania
Station: Singida Met. Station
Altitude: 1530 m.
Latitude: 4.80 °S
Longitude: 34.72 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	17.1	26.9	56	56	7.1	20.5	4.09
February	17.0	27.6	58	75	7.4	21.3	4.36
March	17.5	28.0	60	116	7.7	21.6	4.67
April	16.8	26.1	61	111	8.3	21.4	4.38
May	15.5	25.6	58	158	8.9	20.8	4.37
June	14.2	25.3	53	153	9.6	20.8	4.28
July	13.5	25.7	45	157	9.1	20.5	4.45
August	14.2	26.4	46	182	9.0	21.7	4.93
September	15.1	28.1	43	193	9.2	23.4	5.58
October	16.8	29.4	43	185	10.3	25.7	6.04
November	17.6	29.2	46	160	9.1	23.6	5.57
December	17.4	27.5	52	89	7.2	20.4	4.39
Average	**16.1**	**27.1**	**52**	**136**	**8.6**	**21.8**	**4.76**

Figure 11 Monthly ETo of the study area



Station: Singida Met. Station
Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	169.1	123.3
February	82.5	71.6
March	92.2	78.6
April	124.5	99.7
May	3.0	3.0
June	0.0	0.0
July	0.2	0.2
August	0.0	0.0
September	0.1	0.1
October	19.6	19.0
November	45.8	42.4
December	163.3	120.6
Total	**700.3**	**558.6**

Figure 12 Estimation of effective rainfall

Table 24 Daily crop water requirements of maize from 5 June to 2 September, 2017

Month	Decade	Stage	Kc value	ETc	ETc	Eff. rain	Irrig. Reg.
				mm/day	mm/dec	mm/dec	mm/dec
June	1	Initial	0.30	1.29	7.8	0.1	7.7
June	2	Dev.	0.30	1.28	12.8	0.0	12.8
June	3	Dev.	0.39	1.67	16.7	0.0	16.7
July	1	Dev.	0.77	3.37	33.7	0.0	33.7
July	2	Mid.	1.13	5.04	50.4	0.1	50.3
July	3	Mid.	1.19	5.50	60.5	0.0	60.5
August	1	Mid.	1.19	5.69	56.9	0.0	56.9
August	2	Mid.	1.09	5.40	54.0	0.0	54.0
August	3	Late	0.74	3.81	42.0	0.0	42.0
September	1	Late	0.52	2.76	5.5	0.0	5.5
Total					**340.3**	**0.2**	**340.1**

Table 25 Daily crop water requirements of Onion from 10 July to 6 November, 2017

Month	Decade	Stage	Kc value	ETc	ETc	Eff. rain	Irrig. Reg.
				mm/day	mm/dec	mm/dec	mm/dec
July	1	Initial	0.70	3.08	3.1	0.0	3.1
July	2	Initial	0.70	3.12	31.2	0.1	31.1
July	3	Dev	0.77	3.55	39.1	0.0	39.1
August	1	Dev	0.88	4.18	41.8	0.0	41.8
August	2	Dev	0.98	4.82	48.2	0.0	48.2
August	3	Mid	1.05	5.40	59.4	0.1	59.3
September	1	Mid.	1.05	5.64	56.4	0.0	56.4
September	2	Mid.	1.05	5.87	58.7	0.0	58.7
September	3	Mid.	1.05	6.03	60.3	0.2	60.1
October	1	Late	1.05	6.27	62.7	4.1	58.6
October	2	Late	1.04	6.41	64.1	6.1	58.0
October	3	Late	0.91	5.44	59.9	8.8	51.1
November	1	Late	0.78	4.49	26.9	5.9	21.0
Total					**611.8**	**25.3**	**586.5**

Table 26 Daily crop water requirements of Tomato crop from 1 August to 8 November, 2017

Month	Decade	Stage	Kc value	ETc	ETc	Eff. rain	Irrig. Reg.
				mm/day	mm/dec	mm/dec	mm/dec
August	1	Initial	0.60	2.86	28.6	0.0	28.6
August	2	Initial	0.60	2.96	29.6	0.0	29.6
August	3	Dev.	0.71	3.66	40.2	0.0	40.2
September	1	Dev.	0.90	4.85	48.5	0.0	48.5
September	2	Mid.	1.09	6.06	60.6	0.0	60.6
September	3	Mid.	1.15	6.61	66.1	0.2	65.9
October	1	Mid.	1.15	6.86	68.6	4.1	64.5
October	2	Late	1.15	7.07	70.7	6.1	64.6
October	3	Late	1.03	6.11	67.2	8.8	58.4
November	1	Late	0.86	4.90	39.2	7.9	31.3
Total					**519.3**	**27.1**	**492.2**

4.4 WATER USE AND WATER PRODUCTIVITY

4.4.1 Irrigation water supply

Seasonal irrigation supplies were determined based on the current pumping capacity estimated at 12.9 m^3 per hour or 3.59 l/s as presented in Table 27. The peak consumptive use during the growing season was 2.01 l/s. From the analysis, the irrigation depth during the growing season at Msange was estimated at 362.8 mm, 516 mm and 430 mm for maize, onion and tomatoes respectively which is equivalent to 21,830.29 m^3 supply volume as indicated in Table 28.

Table 27 Estimation of current irrigation flow at Msange irrigation scheme

Date	**Flow record,** units*			**Time** (hrs)	**Discharge** (m^3/hr)	**Flow rate** (l/s)
	Start	**End**	**Volume**			
6 Sept	22430	22468	38	3.05	12.46	3.46
9 Sept	22549	22589	40	3.00	13.34	3.71
Average			**39**	**3.03**	**12.90**	**3.59**

*Measure of volume of water recorded by water meter; 1 unit is equivalent to 1 m^3

Table 28 Determination of irrigation water supply at Msange irrigation scheme

Crop	**Area** (ha)	**Irrigation event**				**Volume**	
		Interval (day)	**Hours**/ha	**Duration** (day)	**# Irrig.**	**m^3**	**mm**
Maize	2.03	4	12.5	90	23	7365.1	362.8
Onion	1.62	3	10	120	40	8359.2	516.0
Tomato	1.42	3	10	100	33	6106.0	430.0

During the assessment of water management there were problems noted which influence performance. Such causes include poor irrigation schedule at the scheme level, low water prices to meet O&M costs, weak irrigation organization responsible for irrigation water management, poor cropping pattern, untimely pest and disease control, small fragments of cultivated land and improper field leveling. Also inaccurate records on water usage, excessive water application and frequent irrigation. The charges incurred on pumping water are about US$ 1.33/hr (1 US$ = 2245.64 Tshs) for a diesel engine operated well. As almost 12.5 hrs are required to irrigate one hectare of maize, and 10 hrs are required to irrigate one hectare of onion and tomatoes, therefore, cost of pumped water with a diesel engine becomes US$16.63/ha for maize, and that for a onion and tomatoes is US$13.30 per hectare. Hence, water cost has a direct impact on net return and where increasing cost of diesel becomes a big problem.

4.4.2 Assessing water productivity

The average yields and water productivity of the three crops was estimated as shown in Table 29. Due to relatively low yields and high application of water, the water productivity of all crops in the command area was very low. The physical water productivity of maize, onion, and tomatoes were estimated at 0.9, 2.03 and 2.32 kg/m^3 for maize, onion and tomatoes respectively. Therefore, the water productivity of these crops can be increased substantially by improving the water management practices in order to enhance food security and economic return.

Table 29 Actual crop yield and water productivity of maize, onion and tomato

Crop	**Crop price** (US$/kg)	**Yield** (t/ha)	**Water use** (mm)	**W_{EP}** (kg/m^3)	**W_{EC}** (US$/m^3)
Maize	0.23	3.251	362.8	0.90	0.21
Onion	0.36	10.5	516.0	2.03	0.73
Tomato	0.24	10	430.0	2.32	0.56

Small land holding is a major issue affecting the water availability. Average farm size was found to be between 0.1 ha and 0.4 ha at Msange. As the small farmers are relatively poor and illiterate therefore, they do not have resources for proper inputs. They normally grow onion as cash crop and a mix of vegetables. A number of farmers have fragmented piece of lands, even on different field plots which creates problems in managing land during irrigation season.

Onion and tomatoes are normally grown in nursery and later on transplanted to beds. Farmers prepare beds which are not uniform and level, this practice encourages water loss during application. Also cultivation is done each season resulting in loss of water and fertility, and subsequently requiring more time of irrigation during the next irrigation. Therefore, for efficient use of water the field plots have to be kept level to avoid unnecessary water loss.

4.5 PERFORMANCE EVALUATION INDICATORS

The performance of Msange irrigation scheme was evaluated using three sets of external indicators; water supply, agricultural productivity, and economic and environmental quality indicators. After analysis and calculation of various performance indicators, the indicators were aggregated to arrive at one composite index called overall performance index (OPI). By considering different contributions, different weights were assigned to various indicators using AHP approach. The indicator values were normalized into score based on target values.

4.5.1Water supply performance indicators

Three types of indicators were used to evaluate water supply performance. The indicators are RWS, RIS, and WDC indicator. Water for the crop and net irrigation requirement were determined for each irrigated crop for the cropping season June to December 2017.

***Relative water supply*:** The value of this indicator during evaluation season for maize, onion and tomato crops were found as 1.07, 0.88 and 0.88 respectively, meanwhile the overall value of relative water supply was found as 0.93. The value of less than 1 indicates that total water supply was not enough to meet the crop demand.

Table 30 Relative water supply for Msange Irrigation Scheme

Crop	ET potential	Irrigation	Total rainfall	Irrigation +rainfall	RWS
	mm/season	mm/season	mm/season	mm/season	
Maize	340.3	362.8	0.2	363.0	1.07
Onion	611.8	516.0	25.3	541.3	0.88
Tomato	519.3	430.0	27.1	457.1	0.88

***Relative irrigation supply*:** The value of RIS indicator during evaluation season for maize, onion and tomato crops were found as 1.07, 0.88 and 0.87 respectively, meanwhile the relative irrigation supply value for the scheme was found as 0.92. The value of RIS less than 1 show that the crops are not getting enough water (Molden et al., 1998).

Table 31 Relative irrigation supply for Msange Irrigation Scheme

Crop	ET Potential mm/season	Irrigation mm/season	Eff. rainfall mm/season	ET Pot- eff. rain mm/season	RIS
Maize	340.3	362.8	0.2	340.1	1.07
Onion	611.8	516.0	25.3	586.5	0.88
Tomato	519.3	430.0	27.1	492.2	0.87

During evaluation it was recognized that farmers perceive that excess irrigation water application would result in increased yield; however, to actual sense improved yield is the result of good farm management practice.

Water delivery capacity**:** The average pumping discharge for the scheme was estimated at 3.59 l/s. From the computation of the CROPWAT model the peak irrigation requirement was 0.66 l/s per hectare which occurred in October. The peak demand calculated for that month was obtained by multiplying the peak irrigation requirement by the cropped area for that month which was found as 2.01 l/s. Water delivery capacity ratio was calculated by dividing the estimated average pumping discharge to the scheme peak irrigation demand for the cropping season. Therefore, WDC value obtained was 1.79. The result revealed that the system capacity has lesser constraint to meet crop water demands. Since water delivery capacity value is greater than unity there may not be difficulties in meeting short-term peak demands.

Table 32 Water supply for Msange irrigation scheme

Month	June	July	August	September	October	November
Precipitation deficit:						
1.Maize	37.3	145.8	154.3	5.5	0.0	0.0
2.Onion	0.0	73.2	149.0	174.8	166.8	21.7
3.Tomato	0.0	0.0	98.4	174.9	187.4	29.4
Net scheme irrig.req:						
In mm/day	0.5	2.6	4.4	3.6	3.4	0.5
In mm/month	14.9	81.8	137.0	107.1	105.9	15.2
In l/s/ha	0.06	0.31	0.51	0.41	0.40	0.06
Irrigated area:						
(% of irrigated area)	40	72	100	100	60	60
Irrigation req. for actual area (l/s/ha)	0.14	0.42	0.51	0.41	**0.66**	0.10

4.5.2 Agricultural productivity performance indicators

There are four types of indicators used during evaluation of Msange irrigation scheme; OCP, OCA, OIS, and OWC. The values of these indicators were estimated based on equation proposed by Molden et al. (1998). In this evaluation three main crops were taken into account. The evaluated irrigated area was 5.07 ha from a command area of 9 ha.

***Output per cropped area*:** The output per cropped area for Msange irrigation scheme was computed considering yield of maize, onion and tomatoes as 3.25 t/ha, 10.5 t/ha and 10 t/ha. According to the analysis from data collected from the scheme the total output per cropped area is US$ 2,179.41 per ha, the value for individual crops are US$ 747.78, 3,780 and 2,400 per ha for maize, onion and tomato respectively. The value for maize is very low indicating that there is a need for improving productivity by reducing operation cost during production and providing proper supportive price for the produce.

Table 33 Details of irrigated area, productivity and price rates

Crop	**Area,** ha	**Production**		**Productivity** (Kg/ha)	**Price*** (US$/kg)
		Tons	Kg		
Maize	2.03	6.60	6,600	3,251	0.23
Onion	1.62	17.01	17,010	10,500	0.36
Tomato	1.42	14.2	14,200	10,000	0.24

*Exchange rate, US dollar 1 = Tanzanian Shs.2245.64 (rate as on 13-Jan-2018)

***Output per unit command area*:** The output per unit command area in US$ per ha for Msange irrigation scheme was determine considering yield of maize, onion and tomato as 3.25 tons/ha, 10.5 tons/ha and 10 tons/ha. The total value of outputs per unit command area for Msange was found as US$ 2,799.50 per ha. The reason for the variation for different crops is due to the difference in cropped area of the command area. This indicates that there is an urgent need to develop command area so as increase production.

***Output per unit irrigation supply*:** The total amount of water pumped during the crop growth period was estimated based on the output per second of the pump and total number of days taken by crops to mature. Msange irrigation scheme is operated by a pump coupled with diesel engine at the rate of 12.9 m^3 per hour. Hence, the irrigation supply was estimated at 7365.09, 8359.2, 6106.0 m^3 for maize, onion and tomato respectively during the growing season. From these values, the output per irrigation supply during growing season for maize, onion and tomato was found as US$ 0.21, 0.73 and 0.56 per m^3 respectively. Hence, the total output per irrigation supply for Msange was found to be US$ 0.51 per m^3.

***Output per water consumed*:** The value of output per water consumed was computed considering crop demand for maize, onion and tomato of 7167.93, 9566.1 and 7541.62 m^3 respectively. The result shows a value of OWC for maize, onion and tomato as US$ 0.21, 0.64 and 0.45 per m^3 respectively. Therefore, the output per water consumed for Msange irrigation scheme was US$ 0.46 per m^3. This reveals that production value per unit of water consumed for onion is little better that for maize and tomato.

4.5.3 Economic performance and environmental quality indicators

There are three indicators which have been evaluated at Msange irrigation scheme; irrigation Benefit-Cost Ratio, O&M fraction, and SQI.

Benefit Cost Ratio: BCR was estimated based on the yield or income generated from unit land and the irrigation cost per unit of irrigated area for the same land.

Table 34 Cost of irrigation at Msange irrigation scheme

Item	**Irrigation cost** (US$/ha)	**Maize**	**Onion**	**Tomato**
1.	Capital cost with drip	256.84	592.70	430.17
2.	Maintenance cost, 10% of capital cost	25.68	59.27	43.12
3.	Labor cost	171.96	671.30	211.97
4.	Energy cost being fuel & lubricants	272.80	387.95	323.07
	Total	**727.28**	**1711.22**	**1008.33**

Fuel cost was estimated based on monthly pumping hours per hectare from the month of June to November and lubrication oil cost taken as 10% of the fuel cost. Total hours of pumping per season were estimated at 571, 648 and 473 for maize, onion and tomato respectively. According to the operator of the pump, the fuel consumption rate was 1 liter/hour. The diesel cost on average during the growing season was taken as 1,980 Tsh/liter (www.ewura.go.tz).

Table 35 Benefit-Cost ratio analysis for Msange irrigation scheme

Crop	**Area** (ha)	**Total cost** (US$/ha)	**Gross benefit** (US$/ha)	**Net benefit** (US$/ha)	**BCR**
Maize	2.03	727.28	747.78	20.50	0.03
Onion	1.62	1,711.22	3,780	2,068.78	1.21
Tomato	1.42	1,008.33	2,400	1,391.67	1.38
Total	**5.07**	**3,446.83**	**6,927.78**	**3,480.95**	**1.01**

The BCR was estimated considering production cost of maize, onion and tomato as US$ 727.28, 1711.22 and 1008.33 per ha respectively. The results show a value of BCR for maize, onion and tomato as 0.03, 1.21 and 1.38 respectively, meanwhile the overall BCR for the scheme was found as 1.01. The value of BCR greater than 1 indicates that the present benefits obtained is more than the present value of irrigation costs. Hence, production at the scheme is economically viable and more benefits are generated from onion and tomato crop; however, no benefits generated from maize.

O&M Fraction: OMF relates annual O&M budget as proposed by the irrigation agency in the command area to the actual released fund to cater operation and maintenance (O&M) activities during the growing season. The O&M items included salaries of O&M personnel, facilities operation and maintenance, minor works, per-diem and transport and administrative costs.

Table 36 Operation and maintenance (O&M) costs at Msange irrigation scheme

O&M item	**Maize** (US$/ha)		**Onion** (US$/ha)		**Tomato** (US$/ha)	
	Budget	**expense**	**Budget**	**expense**	**Budget**	**expense**
Operation costs	1,192.95	676.80	2,476.91	1616.68	1,148.13	935.84
Maintenance costs	119.28	50.48	247.68	94.54	114.82	72.49
Total	**1,312.23**	**727.28**	**2,724.59**	**1711.22**	**1,262.95**	**1008.33**

The estimated O&M fraction based on operation and maintenance costs of maize, onion and tomato were 0.55, 0.63 and 0.80 respectively, meanwhile the overall OMF value for the scheme was found as 0.65. The result shows a value of OMF less than 1 indicating that not all the budgeted fund were released and used during production.

Table 37 O&M fraction for Msange irrigation scheme

Crop	**Area** (ha)	**O&M expenses** (US$)	**O&M budget** (US$)	**OMF**
Maize	2.03	727.28	1,312.23	0.55
Onion	1.62	1,711.22	2,724.59	0.63
Tomato	1.42	1,008.33	1,262.95	0.80
Total	**5.07**	**3,446.83**	**5,299.77**	**0.65**

4.5.4 Overall performance index (OPI)

After calculation and analysis of individual various performance indicators, the indicators were aggregated to arrive at one composite index for each category of performance criteria; water supply, agricultural productivity, and economic-environmental performance indicators. By considering different contributions, various indicators were assigned different weights for each of the indicators and performance criteria using AHP approach.

In order to combine the various indicators, each indicator was normalized dividing the value to the threshold value technique by transforming the measured values into scores of common scale of dimensionless values. The scores for the indicators were used to calculate the overall performance index (OPI).

Table 38 Overall performance index of Msange irrigation scheme

Performance indicator	**Units**	**Value**	**Score**	**Weights**	**Weighted score**
Water supply performance:				**0.30**	**0.93**
Relative water supply	Ratio	0.93	0.93	0.63	0.58
Relative irrigation supply	Ratio	0.92	0.92	0.26	0.24
Water delivery capacity	Ratio	1.79	1.00	0.11	0.11
Agricultural productivity:				**0.40**	**0.52**
Output per cropped area	US$ ha^{-1}	2,179.41	0.49	0.26	0.13
Outputs per command area	US$ ha^{-1}	2,799.50	0.63	0.51	0.32
Outputs per irrigation supply	US$ m^{-3}	0.51	0.32	0.15	0.05
Outputs per water consumed	US$ m^{-3}	0.46	0.29	0.08	0.02
Economic-environmental:				**0.30**	**0.68**
Benefit-Cost ratio	Ratio	1.01	1.00	0.23	0.23
O&M fraction	Ratio	0.65	0.65	0.12	0.08
Soil quality index	Fraction	0.57	0.57	0.65	0.37
Overall system performance = (0.3*0.93 + 0.4*0.52 + 0.3*0.68) x 100					**69 %**

The results from above Table 38 depicts the overall system performance is satisfactory having an overall performance index of 69 % indicating medium performance.

4.6 MEASURES FOR IMPROVING PERFORMANCE AND WATER PRODUCTIVITY

As highlighted by Joneydi (2012) strategies to reduce the pressure that irrigation system has been subjective and various management practices are available. Therefore, the productive measures for improving performance of irrigation system include better use of drip irrigation systems, improved farmers management practice, monitoring of soil quality, decide cropping pattern based on consumption and market demands, use of disease tolerant varieties and minimize unnecessary application of water.

Table 39 Identified problems by evaluation at Msange irrigation scheme

S/N	Identified problems	Suggestion for performance improvement
1.	Irrigation water loss	Control over irrigation schedule
2.	Water application efficiency if low	Minimize on-farm water loss
		Estimate correct amount of crop water demand
		Apply correct flow rate based on irrigation scheduling
		Level the land with appropriate slope
		Improve water holding capacity of the soil
3.	Unsatisfactory irrigated area	Generate irrigation schedule which will lead to properly use and application water
4.	Low irrigation intensity	Reduce all possible losses
		Schedule crops and arrange crop rotations
5.	Low crop productivity	Ensure proper irrigation
		Ensure proper inputs management
		Ensure cultural management practices such as proper plant population, weeding, crop pesticide and insecticide application if needed
6.	Low water productivity	Minimize water losses and optimize irrigation scheduling properly
		Ensure other crop management aspects
7.	Low irrigation BCR for maize	Minimizing irrigation cost by proper scheduling
		Maximize production by proper management and selecting suitable crop variety

In the Msange irrigation scheme water productivity was determined on the basis of available data during the study. The results show that there was a reduction in water productivity compared to the range of optimum values (Molden et al., 2010; FAO, 2018) and hence improvement is required for efficient use of water. For the evaluated Msange irrigation scheme physical water productivity of tomato was found to be 2.32 kg/m^3 followed by onion 2.03 kg/m^3 and comparatively lower water productivity recorded for maize at 0.90 kg/m^3. These values are still very low and improvement is needed to make sure that the potential outputs are achieved.

Water productivity at the field can be improved by increasing the total output per unit water used, reducing the unproductive water outflows and use of effective rainfall. However, this can be achieved either by reducing water losses that occur during water delivery at time of irrigation or increasing the economic produce of the crop. Hence, the measures to improving water productivity involve such practices as regulating water deliveries, optimizing irrigation water, growing crops in favor of climate advantages, improving agronomic practices and soil quality management.

4.6.1 Improving water deliveries

The best approach here is to recognize optimal level of water and nutrient contributions to guarantee most extreme return from utilized resources. For the greater part of the farmers the work would be to limit the irrigation by controlling water conveyance and delivery to the field, which would help acquire highest water productivity in economic terms. Thus, it might be important for the farmers to increase area under irrigation to keep up the net returns.

In developing seasonal net irrigation requirement for maize, onion and tomatoes at Msange ETo and climatic data from Singida station were used under AquaCrop model. AquaCrop simulates potential yields of crops as a component of water use (Steduto et al., 2012). AquaCrop model was simulated by setting field management parameters at no water stress, unlimited soil fertility, no soil salinity stress and no weed infestation to get net irrigation.

Table 40 Crop development characteristics for simulation under AquaCrop model

Crop calendar	Maize	Onion	Tomatoes
Time from sowing to emergence/recovery, days	7	7	4
Duration to maximum root depth, days	55	60	50
Time from sowing to start senescence, days	70	100	80
Time from sowing to maturity, days	90	120	100
Time from sowing to flowering, days	50	45	32
Duration of flowering/start yield formation, days	13	45	42

AquaCrop was run for the selected crops and from each crop irrigation needs was determined under net irrigation water requirement mode. Then, together with the output from irrigation schedule the timing and depth of irrigation scheduling were determined.

Different runs were used to compare ETc of the three crops and their irrigation needs. In Msange irrigation scheme with 700 mm annual rainfall, simulated ETc values of 417.6, 648 and 559.4 mm for maize, onion and tomatoes were obtained. The potential yield and corresponding net irrigation requirements are shown in Table 41.

Table 41 Summary for Net irrigation requirement and potential yield

Evaluated crop	**Yield** (t/ha)	**Net irrigation requirement** (mm)
Maize	9.791	340
Onion	14.103	545
Tomato	10.888	450

4.6.2 Optimize irrigation water

There isn't much observational proof to propose that more noteworthy reliability of water prompts more prominent water productivity. With more prominent reliability and adequacy of irrigation, farmers would have the capacity to embrace great agronomic practices and modify supplement utilize. Improved reliability of irrigation would likewise enable farmers to advance the irrigation application in each irrigation occasion and give satisfactory number of watering including watering at critical stages of plant development under stress. This would not only increase the yield, but also reduce unnecessary losses. Many farmers at Msange irrigation scheme, normally over irrigate because of lack of appropriate knowledge about irrigation scheduling, and with the expectation to get more yield, though more water applications result in low water productivity.

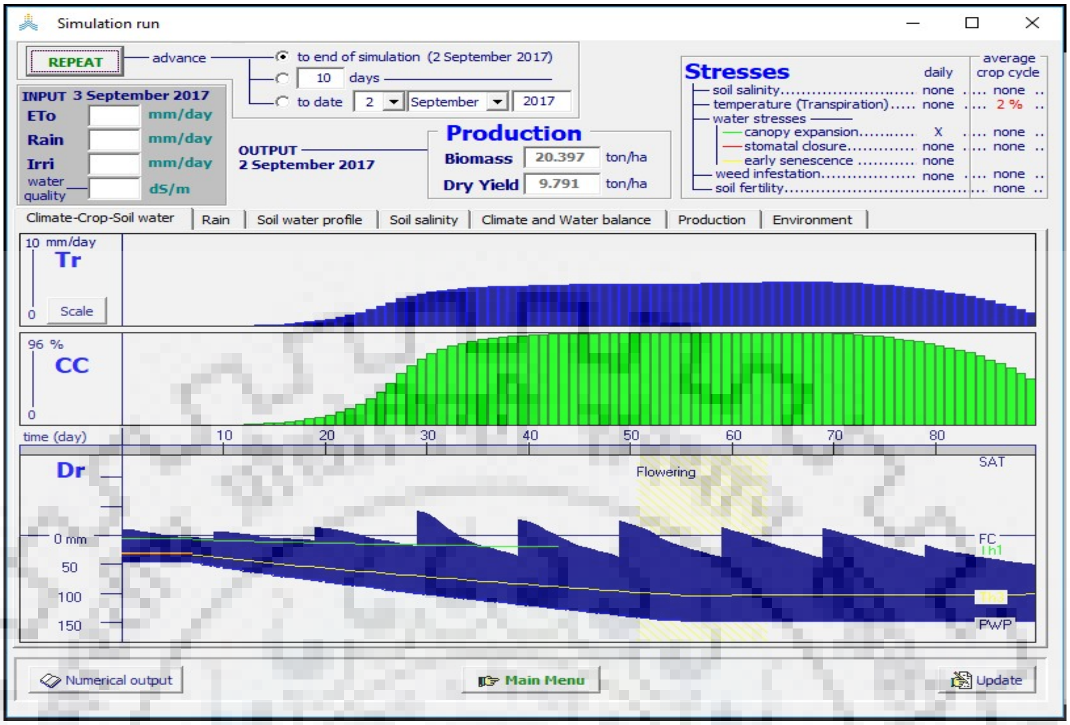
In many cases, the depth of each application is much less than the optimum demand determined by the capacity of the field with uncertainty of water supply. Farmers should avoid excessive irrigation and decrease ET depletion. Greater irrigation application may also increase fertilizer leaching, and which will also reduce nutrient use efficiency in the farm.

Table 42 Generated irrigation schedule for maize at Msange irrigation scheme

Irrigation event	Day on growing cycle	Net irrigation (mm)
1	1	10
2	10	10
3	20	20
4	30	60
5	40	60
6	50	60
7	60	50
8	70	50
9	80	20

Table 43 Generated irrigation schedule for onion at Msange irrigation scheme

Irrigation event	Day on growing cycle	Net irrigation (mm)
1	5	15
2	15	15
3	20	15
4	25	25
5	30	25
6	35	25
7	40	25
8	45	25
9	50	25
10	55	30
11	60	30
12	65	30
13	70	30
14	75	30
15	80	30
16	85	30
17	90	30
18	95	30
19	100	30
20	105	25
21	110	25


Simulation run

REPEAT advance
○● to end of simulation (2 September 2017)
○ 10 days
○ to date 2 September 2017

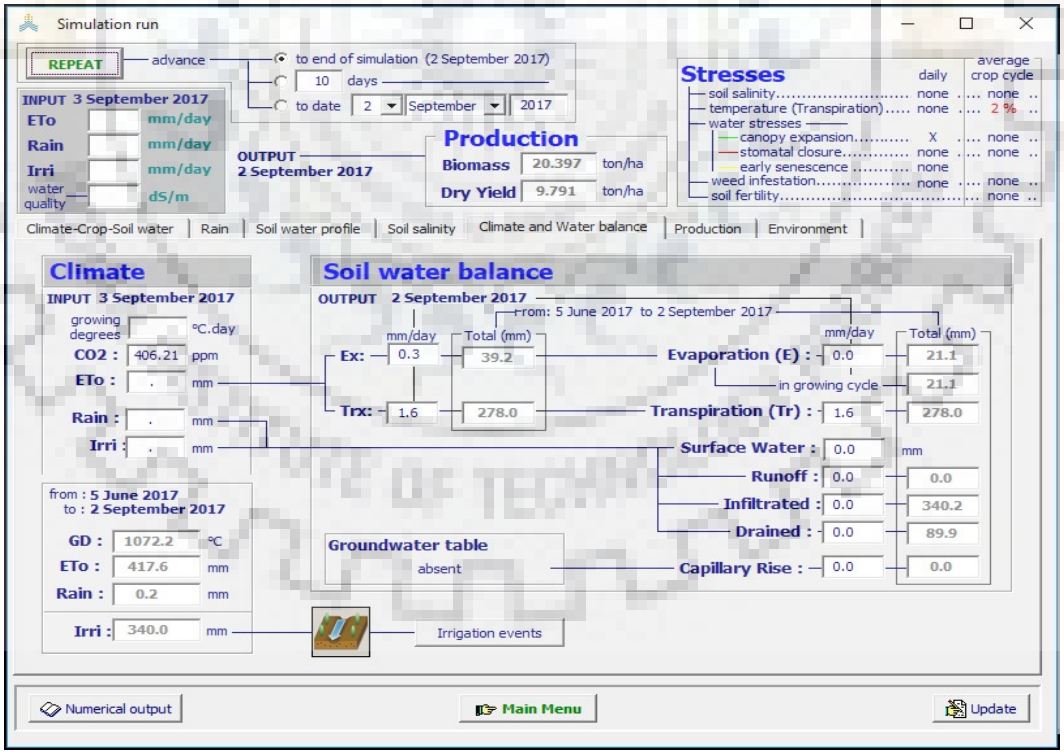
INPUT 3 September 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 2 September 2017

Production
Biomass 20.397 ton/ha
Dry Yield 9.791 ton/ha

Stresses — daily — average crop cycle
soil salinity........................ none .... none ..
temperature (Transpiration)..... none .... 2 % ..
water stresses
canopy expansion........... X .... none ..
stomatal closure............. none .... none ..
early senescence .... none
weed infestation.................. none .... none ..
soil fertility....................................... none ..

Figure 13 AquaCrop simulations results for canopy cover of maize


Simulation run

REPEAT advance
○● to end of simulation (2 September 2017)
○ 10 days
○ to date 2 September 2017

INPUT 3 September 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 2 September 2017

Production
Biomass 20.397 ton/ha
Dry Yield 9.791 ton/ha

Stresses — daily — average crop cycle
soil salinity........................ none .... none ..
temperature (Transpiration)..... none .... 2 % ..
water stresses
canopy expansion........... X .... none ..
stomatal closure............. none .... none ..
early senescence .... none
weed infestation.................. none .... none ..
soil fertility....................................... none ..

Climate
INPUT 3 September 2017
growing degrees °C.day
CO2 : 406.21 ppm
ETo : . mm
Rain : . mm
Irri : . mm

from : 5 June 2017
to : 2 September 2017
GD : 1072.2 °C
ETo : 417.6 mm
Rain : 0.2 mm
Irri : 340.0 mm

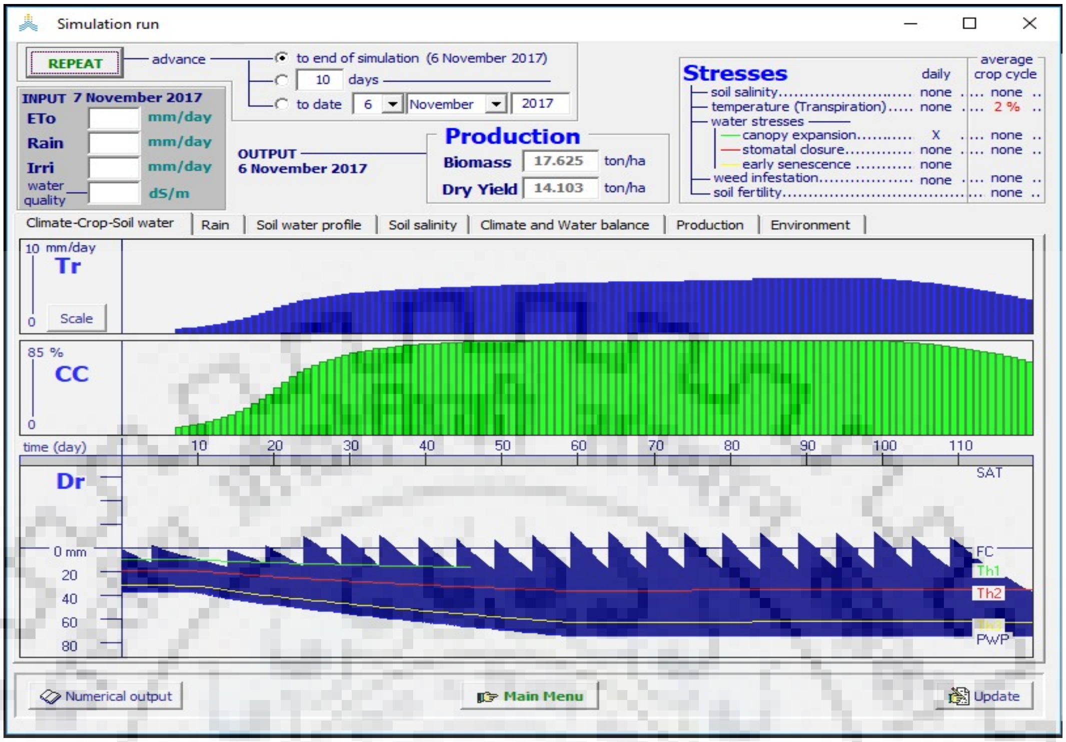
Soil water balance
OUTPUT 2 September 2017
from: 5 June 2017 to 2 September 2017

	mm/day	Total (mm)
Ex:	0.3	39.2
Trx:	1.6	278.0

	mm/day	Total (mm)
Evaporation (E) :	0.0	21.1
in growing cycle		21.1
Transpiration (Tr) :	1.6	278.0
Surface Water :	0.0 mm	
Runoff :	0.0	0.0
Infiltrated :	0.0	340.2
Drained :	0.0	89.9
Capillary Rise :	0.0	0.0

Groundwater table
absent

Figure 14 AquaCrop simulations results of irrigation requirements for maize



● to end of simulation (6 November 2017)
○ 10 days
○ to date 6 November 2017

INPUT 7 November 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

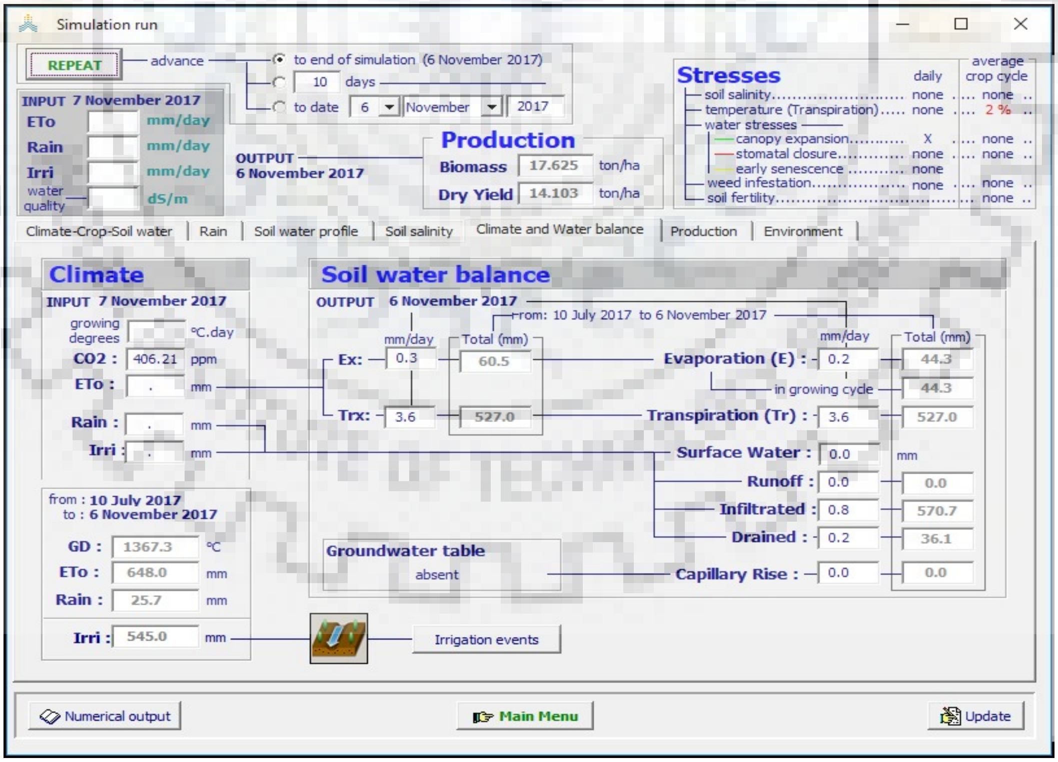
OUTPUT 6 November 2017

Production
Biomass 17.625 ton/ha
Dry Yield 14.103 ton/ha

Stresses

	daily	average crop cycle
soil salinity	none	none
temperature (Transpiration)	none	2 %
water stresses		
canopy expansion	X	none
stomatal closure	none	none
early senescence	none	
weed infestation	none	none
soil fertility		none

Figure 15 AquaCrop simulations results for canopy cover of onion



● to end of simulation (6 November 2017)
○ 10 days
○ to date 6 November 2017

INPUT 7 November 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 6 November 2017

Production
Biomass 17.625 ton/ha
Dry Yield 14.103 ton/ha

Stresses

	daily	average crop cycle
soil salinity	none	none
temperature (Transpiration)	none	2 %
water stresses		
canopy expansion	X	none
stomatal closure	none	none
early senescence	none	
weed infestation	none	none
soil fertility		none

Climate

INPUT 7 November 2017
growing degrees °C.day
CO2 : 406.21 ppm
ETo : . mm
Rain : . mm
Irri : . mm

from : 10 July 2017
to : 6 November 2017
GD : 1367.3 °C
ETo : 648.0 mm
Rain : 25.7 mm
Irri : 545.0 mm

Soil water balance

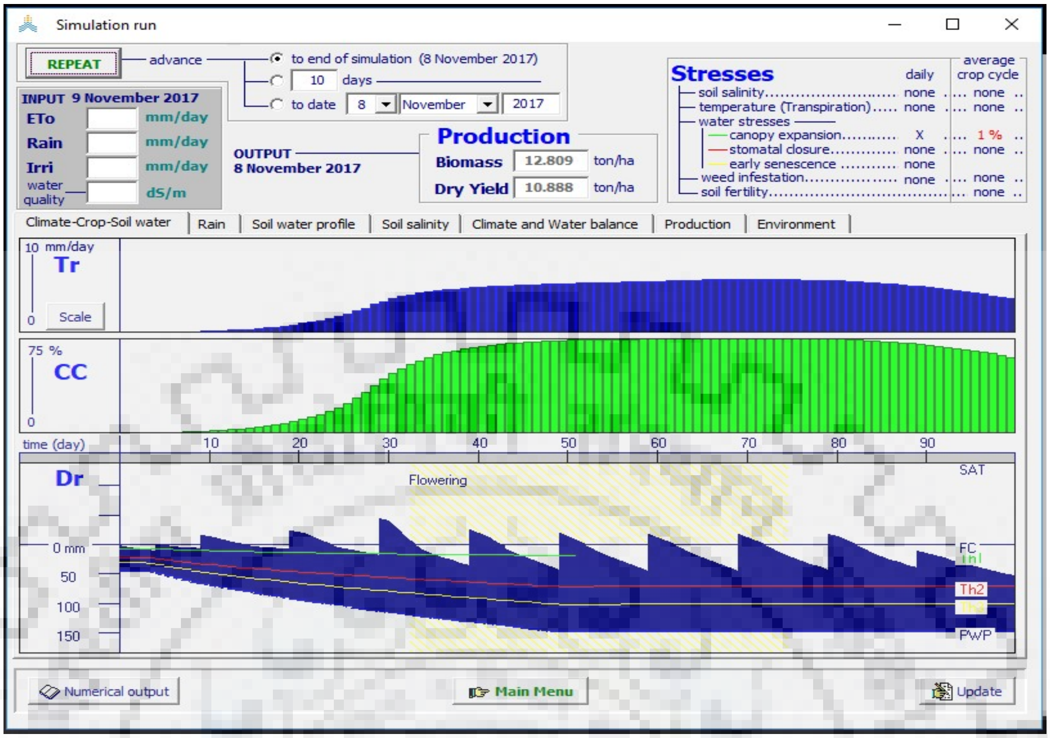
OUTPUT 6 November 2017
from: 10 July 2017 to 6 November 2017

	mm/day	Total (mm)
Ex:	0.3	60.5
Trx:	3.6	527.0

	mm/day	Total (mm)
Evaporation (E) :	0.2	44.3
in growing cycle		44.3
Transpiration (Tr) :	3.6	527.0
Surface Water :	0.0	mm
Runoff :	0.0	0.0
Infiltrated :	0.8	570.7
Drained :	0.2	36.1
Capillary Rise :	0.0	0.0

Groundwater table
absent

Figure 16 AquaCrop simulations results of irrigation requirements for onion


Simulation run

REPEAT — advance — ● to end of simulation (8 November 2017) ○ 10 days ○ to date 8 November 2017

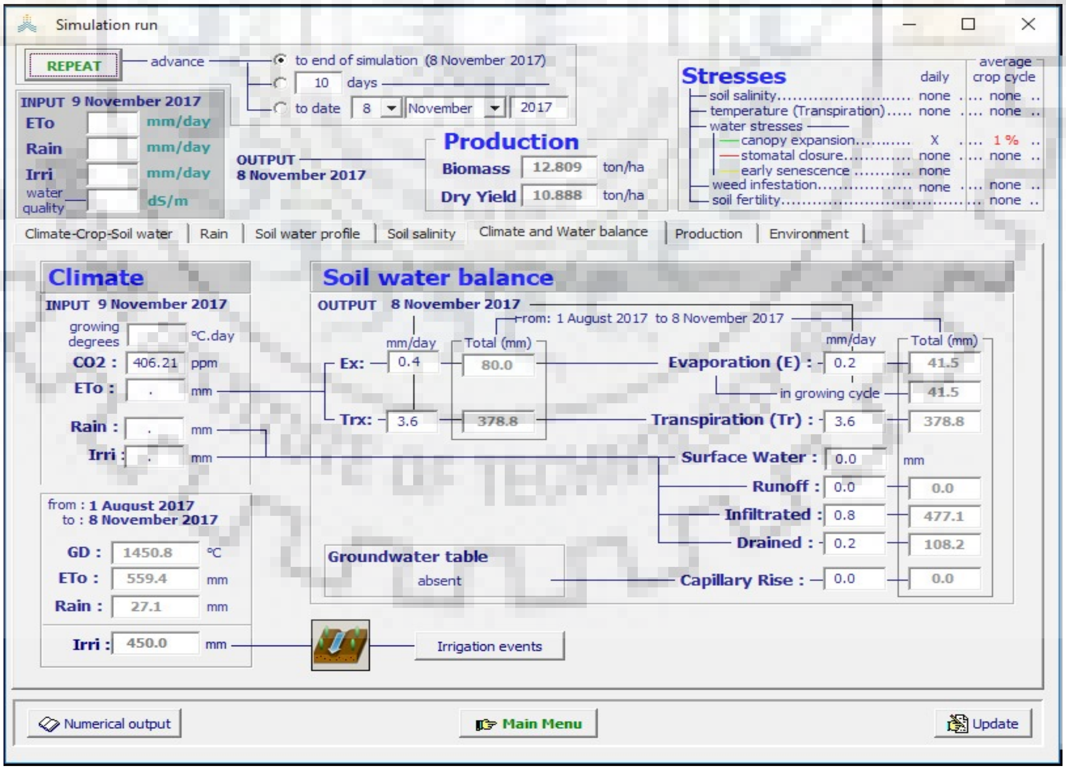
INPUT 9 November 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 8 November 2017

Production
Biomass 12.809 ton/ha
Dry Yield 10.888 ton/ha

Stresses — daily — average crop cycle
soil salinity — none — none
temperature (Transpiration) — none — none
water stresses
canopy expansion — X — 1 %
stomatal closure — none — none
early senescence — none
weed infestation — none — none
soil fertility — none

Figure 17 AquaCrop simulations results for canopy cover of tomato


Simulation run

REPEAT — advance — ● to end of simulation (8 November 2017) ○ 10 days ○ to date 8 November 2017

INPUT 9 November 2017
ETo mm/day
Rain mm/day
Irri mm/day
water quality dS/m

OUTPUT 8 November 2017

Production
Biomass 12.809 ton/ha
Dry Yield 10.888 ton/ha

Stresses — daily — average crop cycle
soil salinity — none — none
temperature (Transpiration) — none — none
water stresses
canopy expansion — X — 1 %
stomatal closure — none — none
early senescence — none
weed infestation — none — none
soil fertility — none

Climate
INPUT 9 November 2017
growing degrees °C.day
CO2 : 406.21 ppm
ETo : . mm
Rain : . mm
Irri : . mm

from : 1 August 2017
to : 8 November 2017
GD : 1450.8 °C
ETo : 559.4 mm
Rain : 27.1 mm
Irri : 450.0 mm

Soil water balance
OUTPUT 8 November 2017
From: 1 August 2017 to 8 November 2017
Ex: 0.4 mm/day — Total 80.0 mm
Trx: 3.6 mm/day — Total 378.8 mm
Evaporation (E) : 0.2 mm/day — 41.5 mm
in growing cycle — 41.5 mm
Transpiration (Tr) : 3.6 mm/day — 378.8 mm
Surface Water : 0.0 mm
Runoff : 0.0 — 0.0
Infiltrated : 0.8 — 477.1
Drained : 0.2 — 108.2
Capillary Rise : 0.0 — 0.0
Groundwater table absent

Figure 18 AquaCrop simulations results of irrigation requirements for tomato

Table 44 Generated irrigation schedule for tomatoes at Msange irrigation scheme

Irrigation event	Day on growing cycle	Net irrigation (mm)
1	5	10
2	10	20
3	20	30
4	30	60
5	40	60
6	50	60
7	60	60
8	70	60
9	80	60
10	90	30

Table 45 Evaluated irrigation schedule generated for Msange irrigation scheme

	Maize	Onion	Tomatoes
Growing cycle, days	90	120	100
Biomass, t/ha	20.397	17.625	12.809
Dry yield, t/ha	9.791	14.103	10.888
Net irrigation, mm	340	545	450
WP_{ET}, kg/m^3	3.27	2.47	2.59
Harvest Index, %	48	80	85

4.6.3 Improving agronomic practices

Enhanced agronomic practices, for example, nutrient management, weed management and land leveling can increase crop yield essentially without influencing ET and in this manner, may bring about increased water productivity (Hill et al., 2001). Chances for enhancing water productivity rely upon adopted practices, water use efficient crops, decreasing water losses and ensuring perfect agronomic conditions. An imperative principle for water efficiency is that taking endlessly water pressure will just enhance water productivity if different burdens, for example, nutrient inadequacies, weeds and infections are expelled (Bouman, 2007), in any case, water management ought to run as one with nutrient management, soil management and pest management (Bindraban et al., 1999; Rockstrom and Barron, 2007).

One of the agronomic practices is to assessing the effects of plant density on yield. In most crops plant densities have been optimized; however, there are situations where it is necessary to assess the role of plant density on water use and yield. To judge the impact of drastic changes in plant population on yield, the farmer should try a range of diverse values of plant density and change accordingly the maximum canopy cover that can be reached and the resulted yield.

In this study, the following planting population were compared; 83,333 against 41,667 plants/ha, 444,444 against 500,000 plants/ha and 41,667 against 27,778 plants/ha of maize, onion and tomatoes respectively grown at Msange irrigation scheme assuming non-limiting soil fertility. In case of maize yield was 9.569 t/ha for the low density and 9.791 t/ha for the high density. Onion yield was 14.103 t/ha for the low density and 14.172 t/ha for the high density. Likewise, tomato yield was 10.698 t/ha for the low density and 10.888 t/ha for the high density. It is depicted that when planting density is reduced there is also decreases in crop yield and when increasing planting density there is consequently increase in crop yield.

4.6.4 Soil quality improvement

Soil quality is one of the three parts of environmental quality, excluding water and air quality (Andrews et al., 2002). Water and air quality are mostly characterized by their level of contamination that effects specifically on human and animal consumption and health (Carter et al., 1997). Contrasting to air and water, soil quality isn't restricted to the level of soil contamination, yet is usually portrayed significantly more extensively as the capacity of a soil to work within natural and managed ecosystem boundaries (Doran and Parkin, 1994). Accordingly, practices, for example, upgrading organic matter, averting soil compaction, avoiding intemperate tillage, use of cover crops are critical in enhancing soil quality.

Management of organic matter: Regardless of whether your soil is having high or low organic matter, addition of new organic matter each year maybe the most vital approach to enhance and maintain soil quality. In the field, the use of crop residues, crop rotation, ideal nutrients and water management, ground cover, compost or farm yard manure, and mulching promotes soil fertility.

Table 46 Organic manure requirements for Msange as per test recommendations

Crop	**Total** (t/ha)	**Recommended application** (kg/ha)		
		N	**P**	**K**
Maize	10	50	25	40
Onion	12.5	63	31	50
Tomatoes	12.5	63	31	50

In general practice, application of 4 - 5 t/ha organic manure or maize is recommended each year for soils having low to very low fertility status. Organic manure application for tomato of 3 - 5 t/ha is recommended for soils having medium to very low fertility status, however half of the organic manure should be broadcast and incorporated during final land preparation. The remaining organic manure should be applied in pits prior to planting. Likewise, the value of organic manure application of 2 - 4 t/ha is recommended for soils having medium to very low fertility status for onion and all organic manure during preparation of land.

***Tillage management**:* Decreasing tillage limits the loss of organic matter and ensures the soil surface is protected with plant residue. Tillage is utilized to losses surface soil, set up the seedbed, and control weeds and pests. However, tillage can likewise separate soil structure, speed the disintegration and loss of organic matter, increment the danger of erosion and obliterate the habit of helpful micro-organisms.

Fertilizers and pests management: An essential capacity of soil is to support and detoxify chemicals; however soil's ability for detoxification is restricted. Pesticides and chemical fertilizers have profitable advantages; however they additionally can harm living organism and pollute air and water when mismanaged. Supplements from natural sources additionally can pollute when misapplied or over applied. Productive pest and supplement management through testing and soil monitoring incorporate; applying just important chemicals at right time and taking advantages of not using for pest control, for example, crop rotation, cover crops, and manure management.

In this study determination of fertilizer requirement was done using digital STFR meter during soil analysis for soil chemical properties. Therefore, chemical fertilizer application will base on the soil test values. The fertilizer dose of the tested soil were estimated direct by STFR meter after selecting type of crop, in this case onion, tomato and maize from test values of organic carbon, phosphorus and potassium. P and K fertilizers are applied as basal application and nitrogenous fertilizers in about three splits.

Table 47 Fertilizer requirements for Msange as per test recommendations

Details	**Quantity** (kg/ha)	**N** (kg/ha)	**P** (kg/ha)	**K** (kg/ha)
Maize				
DAP	163	29	75	0
UREA	300.5	138	0	0
Onion				
DAP	163	29	75	0
UREA	314	144	0	0
Tomato				
DAP	163	29	75	0
UREA	246	113	0	0

Application of sulphur and micronutrients should be done on the basis of its critical value in soil. If the soil test value is less than the critical value, the soil is said to be deficient and application is recommended.

Table 48 Fertilizers application requirement for yield goal (maize 8 ± 0.8 t/ha)

Soil analysis interpretation	**Fertilizer recommendation** (kg/ha)		
	N	**P**	**K**
Optimum	0 – 65	0 – 18	0 – 37
Medium	66 – 130	19 – 36	38 – 74
Low	131 – 195	37 – 54	75 – 111
Very low	196 – 260	55 – 72	112 - 148

Table 49 Fertilizers application requirement for yield goal (tomato 80 ± 8 t/ha)

Soil analysis interpretation	**Fertilizer recommendation** (kg/ha)		
	N	**P**	**K**
Optimum	0 – 40	0 – 12	0 – 25
Medium	41 – 80	13 – 24	26 – 50
Low	81 – 120	25 – 36	51 – 75
Very low	121 – 160	37 – 48	76 – 100

Table 50 Fertilizers application requirement for yield goal (onion 16 ± 1.6 t/ha)

Soil analysis interpretation	**Fertilizer recommendation** (kg/ha)		
	N	**P**	**K**
Optimum	0 – 30	0 – 15	0 – 40
Medium	31 – 60	16 – 30	41 – 80
Low	61 – 90	31 – 45	81 – 120
Very low	91 – 120	46 – 60	121 – 160

Crop diversity management: Diversity is useful for a few reasons. Each plant contributes a one of a kind root structure and sort of buildup to the soil. Diversified variety of soil organisms can help control pest and a diversity natural practices can lessen weed and disease infection. Diversity over the landscape can be increased by utilizing strips, small fields, or strip contour farming. Diversity after some time can be increased by utilizing crop rotations. Changing vegetation over the scene or after some time builds plant diversity, as well as the types of insects, microorganisms, and wildlife.

Diverse crops have distinctive prerequisites for soil nutrients so changing the crop consistently keep the soil fertility from getting to be depleted. Another advantage is that it reduces problems associated from pests, weeds and diseases. Diverse of pests and diseases lean toward various crops, so a rotation keeps the development of specific pests and infections. The diverse cultivation systems required for various crop types can likewise keep any one specific weed developing. Lastly, crop rotation or diversity reduces outcome for crop failure. There is dependably the hazard that a crop will fail. On the off chance that an extensive variety of crops is developed, at that point the disappointment of one crop will have a substantially littler effect than if just a couple of crops are developed. A general framework for arranging a rotation is set out underneath. This can be part of the planning practice; however, it is constantly flexible depending on local climatic conditions and the market situation. For vegetables, a rotation of at least 4 years is highly recommended.

Table 51 Crop rotation system using five plots versus five growing cycles (ARC, 2016)

	Plot 1	**Plot 2**	**Plot 3**	**Plot 4**	**Plot 5**
Cycle 1	Leaf crops	Legumes	Brassicae	Root crops	Solanaceae
Cycle 2	Solanaceae	Leaf crops	Legumes	Brassicae	Root crops
Cycle 3	Root crops	Solanaceae	Leaf crops	Legumes	Brassicae
Cycle 4	Brassicae	Root crops	Solanaceae	Leaf crops	Legumes
Cycle 5	Legumes	Brassicae	Root crops	Solanaceae	Leaf crops

Table 52 Plant families under crop rotation system

S/N	**Plant Family**	**Types of crops under rotation**
1	Solanaceae	Pepper, eggplants, tomatoes, potatoes, chill pepper
2	Brassicae	Cabbage, Pak, Cauliflower, Broccoli, Mustard, Radish
3	Cucurbits	Cucumbers, Squash, Courgette, Pumpkin, melon
4	Alliums or Liliaceae	Onions, shallot, chive, garlic
5	Apiacae or Umbelifeae	Carrot, celery, parsley, coriander, fennel
6	Legumes	Cowpea, pegionpea, mung bean, chick pea, groundnuts, lintel
7	Leafy crops	Spinch, colaloo, cassava leaves, pumpkin leaves, Corchorus
8	Root and tubers	Cocoyams, yams, sweet potato, tannia, cassava
9	Grasses and cereals	Maize, sorghum, millet

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSION

Performance assessment is a stock taking activity to evaluate the accomplishments of irrigation system which result from a large number of activities stating with planning, design and construction, O&M and application of water to grow crops (Small and Svendsen, 1990).

In this study a number of external performance indicators were worked out to evaluate the performance of Msange irrigation system in Tanzania. The external performance indicators adopted were water supply, agricultural productivity, economic performance and environmental quality. The specific indicators used for assessing water supply were RWS, RIS and WDC. Agricultural outputs were assessed considering OCP, OCA, OIS and OWC. BCR ratio and O&M fraction were used to assess economic performance, and SQI used to evaluate environmental quality of Msange irrigation scheme. The results show that the water productivity was low for all evaluated crops, maize, onion and tomatoes. But in this case the physical water productivity for tomatoes was higher compared to that of onion and maize.

Generally, it can be concluded that Msange irrigation scheme performed moderately and hence improvement measures are required for improving water productivity. As there is enough supply of water from the source, there is an opportunity to increase irrigated area so that more income can be generated from the irrigation.

Therefore, for the improvement measures of water productivity and scheme performance soil quality management is a critical measure on irrigation. According to the results obtained water productivity needs to be improved through good management practices. This also can be improved by regulating water deliveries, optimizing irrigation water and improving agronomic practices. Furthermore, it is required from the government or stakeholders to give on-farm trainings on water management and agronomic practices for farmers engaged in irrigation.

5.2 RECOMMENDATIONS

From the above results and conclusion the following recommendations can be drawn for the better operation and management of irrigation schemes:

- Training of farmers on irrigation water management aspects, proper irrigation scheduling, crop water requirement and cropping calendar is needed for better operation.
- Monitoring of flow measurements should be maintained to account for the total water used during production at any particular growing season.
- To keep the scheme in operation, pipes should be checked and maintained regularly, example for burst, termite beet and vandalism so as to reduce the possibility for water loss and maximize water productivity by crops.
- Record on water use, crop production, O&M, farm inputs like seeds, fertilizers, and pesticides should be kept properly by irrigators' organization to help during estimation of production cost, O&M cost for the next season, and performance evaluation.
- Soil analysis studies should be carried out periodically at least 5 to 10 years to establish new concentration necessary for plant nutrients management.
- To improve the status of the soil, management of organic matters like organic manure, compost and incorporating high biomass cover crops and reduce frequent tillage are highly recommended.
- To ascertain system capacity performance evaluation adopting technical or field performance indicators such as system efficiency and distribution efficiency is required.
- It is recommended to evaluate the performance of newly constructed or rehabilitated irrigation systems after operation in order to identify causes for poor functioning and failure of most irrigation schemes in Tanzania for enhanced productivity.

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APPENDICES

Appendix 1 Average weather data from Singida meteorological station 2012 - 2016

Meteorological Station: Singida **Location:** Latitude $04^{0}48'$ **S** and Longitude $34^{0}43'$ **E**
Altitude: 1530 m (above mean Sea Level) **WMO Index No.:** 63810

Month	**Temperature, ^{0}C**		**% Relative Humidity**	**Wind Speed** km/day	**Sunshine** hrs	**Rainfall** mm
	Min.	Max.				
January	17.10	26.88	55.80	56.05	218.81	169.2
February	17.04	27.64	58.20	75.11	206.16	82.6
March	17.46	27.96	60.00	115.59	239.50	92.3
April	16.82	26.10	60.80	110.55	248.48	124.5
May	15.52	25.62	57.00	157.92	275.72	3.0
June	14.22	25.30	53.40	153.10	287.35	0.0
July	13.50	25.72	45.00	157.30	280.95	0.2
August	14.16	26.36	46.20	181.99	279.07	0.0
September	15.10	28.06	42.40	193.07	274.74	0.1
October	16.76	29.36	42.80	184.87	309.80	19.6
November	17.63	29.20	45.80	159.84	272.04	45.8
December	17.40	27.48	52.00	89.11	220.62	163.32

Appendix 2 Mean T_{Max}. and T_{Min}. (^{o}C) from Singida Meteorological Station 2012 to 2016

	2012		**2013**		**2014**		**2015**		**2016**	
Month	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**	**Max**	**Min**
January	27.4	16.9	27.6	17.4	26.8	16.9	26.3	16.8	26.3	17.5
February	28.2	16.9	28.0	17.1	25.9	16.6	28.7	17.3	27.4	17.3
March	27.4	16.9	27.5	17.6	26.6	17.0	29.1	17.6	29.2	18.2
April	26.2	16.6	25.9	16.7	26.2	16.5	26.2	17.0	26.0	17.3
May	26.2	15.7	25.4	15.4	25.6	15.4	25.4	16.1	25.5	15.0
June	24.2	14.5	25.1	13.4	25.7	14.5	26.5	14.9	25.0	13.8
July	26.1	13.6	25.7	13.2	25.7	13.7	25.9	13.9	25.2	13.1
August	27.0	14.2	25.9	13.8	26.5	14.7	26.5	14.2	25.9	13.9
September	28.6	15.1	28.6	15.5	27.0	15.1	28.6	15.4	27.5	14.4
October	30.0	17.1	29.5	16.3	28.7	16.8	29.4	17.5	29.2	16.1
November	29.2	17.2	29.7	17.8	29.2	17.4	28.1	17.8	29.8	17.9
December	27.6	17.5	27.0	17.5	26.9	17.1	27.0	17.2	28.9	17.7

Appendix 3 Avg. monthly Wind speed (Km/day) from at Singida Met. Station 2012 to 2016

Month	2012	2013	2014	2015	2016
January	059.72	047.79	041.31	060.40	071.02
February	090.75	048.34	053.40	084.12	098.94
March	105.97	071.84	083.13	191.71	125.28
April	121.44	053.37	115.16	119.04	143.72
May	176.22	102.75	148.61	186.26	175.75
June	136.27	096.12	178.15	170.18	184.80
July	063.24	109.46	223.69	204.58	185.55
August	081.45	153.97	198.84	244.07	231.60
September	095.90	159.23	218.17	253.55	238.52
October	110.75	177.34	191.14	223.36	221.76
November	113.69	149.11	196.08	147.69	192.64
December	060.44	073.25	101.81	062.55	147.50

Appendix 4 Monthly mean RH (%) from Singida Meteorological Station 2012 to 2016

Month	2012	2013	2014	2015	2016
January	58	49	45	67	60
February	54	50	58	62	67
March	59	59	61	59	62
April	61	60	62	58	63
May	71	57	57	52	50
June	66	54	48	50	49
July	42	47	44	47	45
August	41	52	43	50	45
September	38	40	45	49	40
October	37	41	49	40	47
November	43	40	54	41	51
December	56	43	53	58	50

Appendix 5 Monthly Sunshine hours from Singida Meteorological Station 2012 to 2016

Month	2012	2013	2014	2015	2016
January	160.9	229.2	222.1	183.3	298.5
February	218.8	126.5	204.2	244.3	237.0
March	234.0	228.9	222.8	245.5	266.3
April	214.5	226.3	267.5	218.8	315.3
May	263.2	289.9	281.9	257.0	286.6
June	292.4	304.5	288.7	283.1	268.1
July	266.2	316.6	296.5	254.6	300.9
August	250.4	305.7	290.0	243.1	306.1
September	290.2	284.3	261.5	277.6	260.1
October	294.7	416.7	281.2	258.1	298.3
November	289.2	270.9	286.1	231.2	282.8
December	223.2	222.1	204.5	180.7	272.6
Total	**5009.7**	**5234.6**	**5121**	**4892.3**	**5408.6**

Appendix 6 Daily rainfall data from Singida Meteorological Station for the year 2012

Day	J	F	M	A	M	J	J	A	S	O	N	D
1.	0.3	0.0	14.8	0.4	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0
2.	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
3.	0.0	0.0	7.6	Tr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.0	0.0	16.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	9.7	0.0	4.3	0.0	3.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.	0.1	0.0	0.6	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.1
8.	0.1	0.1	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.	23.8	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8
10.	0.0	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.2
11.	4.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.	15.8	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2
13.	Tr	0.3	8.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
14.	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	12.0	0.2	16.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.	0.3	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9
17.	0.0	0.0	5.7	15.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6
18.	Tr	2.7	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.	7.8	2.8	0.0	Tr	1.3	0.0	0.0	0.0	0.0	0.0	0.0	Tr
20.	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
22.	1.7	6.2	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.6
23.	0.0	6.2	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	4.7	3.8
24.	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8
25.	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.8
26.	0.0	12.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	27.1
29.	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.9
30.	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	37.1
31.	03.8		11.6		0.0		0.0	0.0		6.3		15.1
Total	**107.1**	**52.6**	**97.6**	**38.3**	**4.8**	**0.0**	**0.0**	**0.0**	**0.0**	**6.3**	**36.4**	**201.9**

NB: TR - mean rainfall < 0.05 mm

Appendix 7 Daily rainfalls (mm) from Singida Meteorological Station for the year 2013

Day	J	F	M	A	M	J	J	A	S	O	N	D
1.	28.2	2.1	0.0	9.5	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0
2.	3.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
3.	16.9	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4.	5.2	0.0	0.0	28.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
5.	0.1	0.0	0.0	39.5	1.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	0.0	0.0	40.8	39.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	13.4
7.	0.0	0.0	0.8	56.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.	10.6	0.0	20.2	38.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.	0.4	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.0
10.	0.5	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.	0.0	2.1	Tr	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.0
12.	0.0	12.6	8.0	21.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2
13.	0.4	11.5	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
14.	0.0	9.6	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
15.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.	0.0	4.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.3
17.	0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.3
18.	0.0	0.0	0.0	10.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1
19.	2.0	6.6	10.0	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	Tr
20.	0.0	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.	8.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0
25.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	0.0
26.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	30.0	0.0
27.	6.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.2	1.1
28.	26.3	0.0	10.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	8.4
29.	5.8		5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6
30.	3.3		0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
31.	17.8		36.8		0.0		0.0	0.0		0.0		4.5
Total	**235.9**	**51.1**	**140.2**	**266.7**	**3.1**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**46.1**	**116.0**

NB: TR - mean rainfall < 0.05 mm

Appendix 8 Daily Rainfall (mm) from Singida Meteorological Station for the year 2014

Day	J	F	M	A	M	J	J	A	S	O	N	D
1.	0.0	0.0	0	0.6	0	0.0	0.0	0.0	0.0	0.4	0.0	2.7
2.	8.4	3.4	0	5.9	0	0.0	0.0	0.0	0.0	0.8	0.0	3.1
3.	0.0	0.0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	18.0
4.	0.0	30.4	0	0	0	0.0	0.0	0.0	0.2	0.0	0.0	0.0
5.	5.7	0.2	0	0	0.5	0.0	0.0	0.0	0.2	0.0	0.0	0.0
6.	0.0	1.0	4.1	0	Tr	0.0	0.0	0.0	0.0	0.0	0.0	0.0
7.	1.2	0	5.1	1.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
8.	26.6	0	0	0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.	18.2	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	31.1	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.	Tr	0	2.5	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
12.	6.8	5.1	8	9.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.	2.3	0	51.7	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
14.	10.1	0	6.7	0.2	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	5.3	0	0.1	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
16.	0.0	2.5	0	0	0	0.0	0.0	0.0	0.0	32.6	0.0	0.0
17.	6.2	5.9	0	0	0	0.0	0.0	0.0	0.0	19.1	0.0	2.7
18.	1.2	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
19.	3.0	40.3	2.3	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	10.3	2.2	0	0	0	0.0	0.0	0.0	0.0	0.0	12.9	4.0
21.	19.4	0	Tr	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.	0.2	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	20.3
23.	36.3	0	0.2	0	0	0.0	0.0	0.0	0.0	0.0	0.0	83.6
24.	1.8	10.6	0.8	0	0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
25.	10.6	0	0.3	0	0	0.0	0.0	0.0	0.0	0.0	0.0	9.0
26.	4.9	7.5	0	0	0	0.0	0.0	0.0	0.0	0.0	0.3	2.6
27.	0.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.7	0.0
28.	1.0	0	0	0	0	0.0	0.0	0.0	0.0	0.0	23.0	12.6
29.	0.0		0	0	0	0.0	0.0	0.0	0.0	0.0	0.6	0.8
30.	0.0		12.1	0	0	0.0	0.0	0.0	0.0	0.0	14.6	32.7
31.	0.0		0	0	0		0.0	0.0		0.0		14.7
Total	**210.6**	**109.1**	**93.9**	**17.7**	**1.0**	**0**	**0**	**0**	**0.4**	**52.9**	**52.1**	**240.5**

NB: TR - mean rainfall < 0.1 mm

Appendix 9 Daily Rainfall (mm) from Singida Meteorological Station for the year 2015

Day	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
1.	0.4	5.8	0.0	0	0.2	0.0	0.0	0.0	0.0	0.0	1.3	0
2.	0.0	1.7	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	8.4	0
3.	0.0	3.5	0.0	45.1	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0
4.	24.5	0.2	1.1	1	3.9	0.0	0.0	0.0	0.0	0.0	0	0
5.	0.0	0.0	0.0	9.6	0.0	0.0	0.0	0.0	0.0	0.0	0.1	6.4
6.	0.3	0.0	0.0	43	1.9	0.0	0.0	0.0	0.0	0.0	0	0
7.	0.3	6.6	0.0	4.5	0.0	0.0	0.8	0.0	0.0	0.0	0	59.7
8.	12.9	1.3	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.5
9.	8.1	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	1.1
10.	0.3	0.0	0.0	14.1	0.0	0.0	0.0	0.0	0.0	0.0	0	8.5
11.	2.4	0.0	0.0	6.7	Tr	0.0	0.0	0.0	0.0	0.0	3.5	0.2
12.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	12.1
13.	3	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0.1
14.	0.0	4.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	20.9
15.	14.6	0.0	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0	1.0
16.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	0.6
17.	0.0	14.2	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	3.4	4.4
18.	16.5	2.2	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	1.7
19.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	8.4
20.	27.3	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	5.1
21.	0.7	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	19.9
22.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	4.0
23.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	9.8	0
24.	0.0	2.8	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
25.	0.0	0.7	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	6.3
26.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	50.6	0
27.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0
28.	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
29.	5.6		15.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0	0
30.	12.1		8.5	31.1	0.0	0.0	0.0	0.0	0.0	7.1		0
31.	1.0		0.1		0.0		0.0	0.0		1.9		6.1
Total	**130.0**	**43.0**	**24.7**	**158.8**	**6.0**	**0.0**	**0.8**	**0.0**	**0.0**	**9.0**	**89.0**	**167.0**

NB: TR - mean rainfall < 0.05 mm

Appendix 10 Daily Rainfall (mm) from Singida Meteorological Station for the year 2016

Day	J	F	M	A	M	J	J	A	S	O	N	D
1.	20.5	16.1	0	2.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0
2.	0	16.1	0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2
3.	0	22.5	0	67.4	0.0	0.0	0.0	0.0	0.0	29.6	0.0	26.8
4.	0.1	0	0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
5.	0	Tr	0	12.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6.	0	14.8	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7
7.	0	23.8	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
8.	41.0	6.8	44.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9.	26.2	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10.	6.3	14.3	7.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
11.	1.0	4.6	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1
12.	0	0.8	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
13.	0	6.5	0	0	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0
14.	0	0.2	0	5.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15.	0	12.2	0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Tr
16.	0	0	0	12	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
17.	36.5	0	4.3	11.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.8
18.	0.3	17.1	22.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
19.	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20.	0.7	0.6	0	25.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
21.	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22.	0.8	0	Tr	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
23.	0	0	1.2	Tr	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
24.	0	0	1	0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	0.0
25.	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
26.	6.6	49	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
27.	0.4	9.8	2.7	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
28.	8.0	0	12.1	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
29.	0	0	0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7
30.	1.6		0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	Tr
31.	12.4		8.6		0.0		0.0	0.0		0.0		3.4
Total	**162.0**	**156.8**	**104.7**	**141.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**29.6**	**5.4**	**91.2**

NB: TR - mean rainfall < 0.05 mm

Appendix 11 General characteristics data of the scheme

S/N	Description	Possible options
1.0	**Location**	
1.1	Date of visit:	*30/06/2017*
1.2	Scheme name:	*Msange Irrigation Scheme*
		Country Tanzania
		District Singida
		Village Msange
		Access 45 km from Singida town
		Latitude $4^0 37'29.85''$S
		Longitude $35^0 2'56.24''$E
2.0	**Climate and Soils**	
2.1	Climate:	*Semi-arid*
2.2	Average annual rainfall & temperature:	*Rainfall 500 - 800 mm*
		Temperature range 12 - 30 °C
2.3	Predominant soil types:	*Clay to Silt*
2.4	Soil analysis:	*Physical properties*
		Chemical properties
2.5	Topography:	*Moderately flat*
3.0	**Institutional**	
3.1	Year first operational:	*2014*
3.2	Type of management and support:	*Water users association*
		Government
3.3	Utility functions:	*Irrigation service*
		Domestic water supply
3.4	Type of revenue collection:	*Charge on volume of water supplied*
		Charge on crop type (rare in practice)
3.5	Land ownership:	*Private*
4.0	**Socio-economic**	
4.1	Farming system:	*Vegetable crops*
4.2	Marketing:	*Private traders*
		Local markets
4.3	Pricing:	*Government controlled prices*
		Local market prices
5.0	**Water sources and availability**	
5.1	Water sources:	*Groundwater*
5.2	Water availability:	*Sufficient*
5.3	No. and duration of irrigation season (s):	*Seasons : 2 each 5 months*
		Season 1: January - May
		Season 2: June - November
5.4	Water quality and irrigable land	*EC =2.67 dS/m; command area 10 ha*

S/N	Description	Possible options
5.6	Total number of irrigation water users:	*58 (M = 34 & F = 24)*
5.7	Provision for non-crop related water uses:	*Domestic and animal use*
6.0	**Irrigation infrastructure**	
6.1	Method of water abstraction:	*Groundwater pumping*
6.2	Water delivery infrastructure:	*Pipelines*
6.3	Type of water control equipment:	*Gated, manual operation*
6.4	Location of water control equipment:	*Controlled at mainline and sub-main level*
6.5	Discharge measurement facilities location:	*Main line level*
6.6	Types of measuring facilities:	*Flow meters*
7.0	**Water allocation and distribution**	
7.1	Types of water distribution:	*On-demand*
7.2	Frequency of irrigation scheduling;	*Daily*
7.3	Predominant irrigation methods:	*Drip/trickle irrigation*
8.0	**Cropping**	
8.1	Main crops grown in each season:	*Crop 1- Maize, Mwanga variety*
		Crop 2 - Onions, Bombay Red variety
		Crop 3 - Tomatoes, Money maker variety
		Crop 4 - Mixed vegetables
8.2	Growing cycle and average yield:	*Maize = 90 days, yield 3 - 4 t/ha*
		Onion = *120 days, yield 8 - 12 t/ha*
		Tomatoes = *100 days, yield 10 - 12 t/ha*
9.0	**Drawbacks**	
9.1	Physical constraints to irrigated area:	*Lack of funds & willingness of farmers*
9.2	Sign of soil salinity:	*Observed*
9.3	Crop pests and diseases:	*Observed*
9.4	Utilization of potential area:	*Not fully utilized*
9.5	Operation and maintenance:	*Not satisfactory*
9.6	Supervision of operation:	*Not satisfactory*
9.7	Agricultural production:	*Low yield*
		Farmers do not pay O&M fee
		Lack of agricultural equipments
		There is no irrigation schedule
		Inconsistent cropping pattern

Appendix 12 Information on irrigation data and structures

S/N	Description	Possible options
1.	Types of irrigation:	*Drip irrigation*
2.	Field irrigation (in case of drip):	*Inline drip emitter*
3.	Irrigation time:	*Irrigation interval 4 days*
		Irrigation hours 2.5hrs
6.	Location of water source:	*Latitude* 04^0*37.505'S, Longitude* 35^0*02.947'E*
		Altitude1600 m
7.	Pump:	*Discharge 15.54* m^3/h *(2014)*
		Pumping test (m^3/hr)*: 42*
8.	Power of prime mover:	*28.7kW/38.2 Hp*
9.	Point on the field:	*Latitude* 04^0*37.499'S*
		Longitude 035^0*02.989'E*
10.	Field dimension:	*Length 347m*
		Width 312 m
11.	Size of pipeline (diameter):	*Main line PVC 90mm , 75mm*
		Sub-main PVC 63mm, 50mm
12.	Drip line:	*16 mm with emitter spaced at 30 cm distance*
		Emitter flow rate 1 l/h
		Distance between laterals: 50cm + 100cm
14.	Storage tank:	*Volume 75* m^3
		Connecting pipes HDPE 90 DIN, PN 10
15.	Source for domestic use:	*Domestic Point (DP)*
		Connection to DP: HDPE 50 DIN, PN 8
16.	Distance of storage to field:	*750 m*
17.	Other irrigation facilities:	*Pressure regulator, control valve, gate valve, Disc filter 3 inch, check valves, Ball valve 2 inch, Kinetic air valve, air release valve and different connectors.*