ASSESSMENT OF SURFACE IRRIGATION POTENTIAL AND OPTIMIZATION OF CROPPING PATTERN: CASE STUDY OF DANSE WATERSHED, OROMIA REGION

Bayush Moges Yifru

A Thesis Submitted to the Department of Water Resources Engineering,
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama Science and Technology University

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Co-advisor: Dr. Zelalem Biru (PhD)

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners have read and evaluated the MSc Thesis entitled "Assessment of Surface Irrigation Potential and Optimization of Cropping Pattern : Case Study of Danse Watershed,Oromia Region, Ethiopia" prepared and presented by Bayush Moges Yifru.

This is, therefore, to certify that the thesis has been accepted as partial fulfillment of the requirement of the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

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DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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This MSc Thesis has been submitted for examination with our approval as a thesis advisors.

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ADVISORS APPROVAL SHEET

To: Water Resources Engineering Department

Subject: Thesis Submission

This is to certify that the thesis entitled "**Assessment of Surface Irrigation Potential and Optimization of Cropping Pattern: Case study of Danse Watershed, Oromia Region**" submitted in partial fulfillment of the requirements for the degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering), the Graduate program of the department of Water Resources Engineering, and has been carried out by **Bayush Moges Yifru [ID №: PGR/18279/11]** under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby she can submit the thesis to the department.

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Major Advisor	Signature	Date
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Co -Advisor	Signature	Date

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ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
AMC	Antecedent Soil Moisture Condition
CN	Curve Number
CR	Consistency Ratio
CROPWAT	Crop Water Assessment Tool
CWR	Crop Water Requirement
DEM	Digital Elevation Model
ETc	Crop Evapotranspiration
ET_O	Reference Crop Evapotranspiration
ETB	Ethiopian Birr
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
GLCN	Global Land Cover Network
HSG	Hydrologic Soil Group
IWR	Irrigation Water Requirement
IFPRDI	International Food Policy Research Institute
Kc	Crop Coefficient
LGP	Length of Growing Period
LP	Linear Programming
LU/LC	Land Use Land Cover
MoWIE	Ministry of Water Irrigation and Electricity
MoA	Ministry of Agriculture
N	Not Suitable
NMSA	National Meteorological Service Agency

NRCS	Natural Resources Conservation Service
OIDA	Oromia Irrigation Development Authority
OWWDSE	Oromia Water Works Design & Supervision Enterprise
Pef	Effective Rainfall
PCM	Pairwise Comparison Matrix
S_1	Highly Suitable
S_2	Moderately Suitable
S_3	Marginal Suitable
SCS	Soil Conservation service
SRTM	Shuttle Radar Topography Mission
USDA	United State Department of Agricultural
UTM	Universal Transverse Mercator
WOA	Weighted Overlay Analysis

ABSTRACT

Irrigation is an important investment for improving rural income through increased agricultural production. The development of irrigation holds significant potential to enhance productivity. Planning and decision making is required for Irrigation development projects based on the assessment of irrigable land together with available water resources. This study was initiated with the objective of estimating available surface water, assessing land suitability and optimization of cropping pattern in Danse watershed. The availability of water was determined from surface runoff using curve number method. As a result, the weighted curve number of the watershed was estimated as 84. Using the mean annual precipitation of Ejere station from 1987-2016, the annual volume of surface runoff generated in the watershed was 18.64 Mm^3. However, all runoff volume generated in the watershed was not used for irrigation and 1/3 of runoff from rainfall suggested for other losses, the rest runoff volume 6,213,333 m^3 can be used by the farmers for crop production. Land suitability for surface irrigation was identified by considering the irrigation suitability factors such as soil, slope and land use/land cover through implementing Arc-GIS 10.4. Soil suitability was examined in terms of soil depth, texture and drainage. The suitability of each parameter analyze individually based on FAO criteria for surface irrigation development and then the weighted overlay analysis was provided to get the overall suitability. The result of the weighted overlay analysis revealed that out of the total 2170 ha of land 85.36 ha were highly suitable, 1475.68 ha moderately suitable, 596.67 ha marginally suitable and 4.78 ha of the area were unsuitable for surface irrigation development. To grow crops on these identified irrigable areas, four dominant crops were selected and their irrigation water requirement was calculated by using CropWat 8.0 model. Optimization of cropping pattern was performed with the available land and water resource to maximize the net benefit from crop production using Lingo software. Result signifies that from the dominant crops area allocation of 164 ha onion, 8 ha Tomato, 5 ha Cabbage and 15 ha wheat the maximum production benefit was 57,748,130 Birr. Hence, in order to get the optimum benefit out of the land, proper utilization of its resources is inevitable. Therefore, this study would help farmers, decision makers, investors and planners in better identification of profitable irrigation investment opportunities in the watershed and the outputs bring relief for other researchers as an input.

Keywords: Cropping pattern, Curve number, Land suitability, Linear programming, Lingo, Optimization, Runoff, Water availability

1. INTRODUCTION

1.1 BackGround

Water scarcity and food insecurity are the main problems in the world and the population growing every year is not proportional to the land and water resources in recent decades (Vijay, 2016). A key challenge for the agricultural sector is to feed an increasing global population. Large increases in food production are necessary for the world increasing population. Much can be obtained by placing more lands under irrigation. Productivity is also declining in rain-fed agriculture globally; to increase food production water has been considered as the most important component for the transformation of low productive rainfed agriculture into most effective and efficient irrigated agriculture. It is obvious that optimal utilization of water resources in irrigated agriculture provides supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. In this regard, sustainable food production can be expected through optimal use of water resources in conjunction with development of land potential. Therefore, Overall development depends on food production through increasing irrigable areas with maximum benefits in service of growing population (Mohammed *et al*., 2017).

Irrigation in Africa has the potential to enhance agricultural productivities but food production is almost entirely rainfed, leaving farmers and rural communities vulnerable to more erratic rainfall patterns and climatic extremes. The area equipped for irrigation currently slightly more than 13 million hectares makes up just 6 percent of the total cultivated area (FAO, 2005). Most of Africa's poor live in rural areas and depend on agriculture for their livelihoods. As a result, agricultural development is the key to end poverty on the continent. Although agricultural productivity per capital has not kept pace with population increase. In Africa, about 12.2 million hectares benefit from irrigation, which is equal to only about 8.5% of the cultivated land (IFPRDI, 2012).

The historical background of Ethiopia shows that agriculture is the dominant activity to sustain community life and the base for people’s basic fulfillment. According to Belete (2006) the agricultural economy of Ethiopia is largely based on rainfed agriculture, which employs 85% of the population and contributes approximately 50% of the gross domestic product. Majority of the population depends on the rainfed agriculture with limited use of irrigation for agricultural production.

The major problem associated with the rainfall dependent agriculture in the country is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. Consequently, food security often turns into famine with the slightest adverse climatic incident. Population growth also attributed for the lack of sufficient food supply. So that, the increasing food demand in the country can be met in one or a combination of three ways: increasing agricultural yield, increasing the area of irrigable land and increasing cropping intensity (Awulachew *et al.,* 2005). Therefore, to create such basic development strategies, Irrigation is one means by which agricultural production can be increased to meet the growing food demands in Ethiopia. Recently, High percentage of irrigation development was seen in Oromia based on Awash river basin.

Oromia is one of the region in Ethiopia, which is characterized by huge surface irrigation potential and vast geographical diversity consisting of high and rugged contoured mountains divided by the great East African Rift Valley. According to OIDA (2002) report, this region is the largest in Ethiopia with total coverage of 3530.07 ha or 34% of the national land and provides livelihood to 22.35 million or 37% of the national population. The region has 63 river systems and 688 tributary streams, which annually generate 58 Bm^3 of surface water that is comparable to half the nation's surface water resources. Most of the report shows that about 92,000 ha of land have been under both traditional and modern irrigation. Four major categories of irrigation schemes are known to exist in the region. They are traditional, large-scale, modern communal and private. As documented by OIDA (2006) 1.7 Mha land is suitable for surface irrigation development but from this only less than 10% of the above resource is utilized for irrigation due many challenges including limited financial resources, technical challenges and improper or inefficient irrigation water delivery.

Irrigation has been the world oldest agricultural civilization for thousands of years ago. In Ethiopia, traditional irrigation was practiced before centuries. Modern irrigation had started at the beginning of the 1960s by private investors and was concentrated in the middle Awash valley (Yalew, 2011). Several methods of irrigation are used today depending on water availability, the type of irrigated crop and the financial investment the grower is willing to make. Selection of applicable irrigation method is a prerequisite for wise utilization of scarce physical resources. The available technology, the slope of the terrain, people's socio-economic status are among the limiting factors in selecting the appropriate method of irrigation.

Surface irrigation that can be set with relatively low initial investment and available technology is paramount importance. It is the oldest and still the most widely used method of water application by gravity flow to agricultural lands, offers a number benefits for the less skilled poor farmers. Under such circumstances, more than 90% of the world uses surface irrigation (Saymen, 2005). According to FAO (2000) surface irrigation systems are labor intensive than rain-fed agriculture keeping other things unchanged. Therefore, irrigation can increase employment opportunities and income. Surface irrigation development requires favorable topography and information on land and water resources for proper planning. Therefore, planning process for surface irrigation has to integrate information about the suitability of the land, water resources availability and water requirements of crops.

Assessing available land and water resources for irrigation is important for planning their use (Mandal *et al*., 2017). This study was concentrated on quantitative assessment of the physical resources of water and land with respect to their availability and suitability. Moreover, to build up irrigation schemes in the study area; it needs to recognize water resource potential and suitable irrigable land resources. Distribution of water resources to the crop area was planned in the way to optimize the available land and water resources to achieve maximum benefits. An economically efficient cropping pattern defines the optimal crop area and water allocation for seasonal, annual and perennial crops subjected to constraints on land and water availability. The optimization problem was attempted to find a suitable combination out of many feasible combinations of resources and their allocations, which maximizes a benefit, subjected to given constraints. To optimize the available resources, the mathematical programming model like linear programming (LP) was used. LP model is more popular because of the proportionate characteristic of the allocation problem. The linear programming model quantifies an optimal way of integrating constraints to satisfy the objective function and maximize crop production and profits (Jalal *et al*., 2016).

1.2 Statement of the Problem

Ethiopia has an important opportunity in water-led development, but it needs to address critical challenges in the planning and design of irrigation systems according with land suitability and water availability. Specially Oromia is gifted with abundant water and land resources, but due to the information gap regarding to water availability and land suitability, its agricultural system is not yet fully utilized (Berhanu, 2018). The impact of unwise use of land resource and absence of land utilization according to its potential suitability is still a serious problem. In addition, food insecurity and poverty in our country are also attributed to the poor performance of the agricultural sector (Alemu and Worku, 2017).

In the study area, the population is increasing and Agriculture is the main source of income. Farmers are mainly depends on rainfed agricultural practice. However, the rainfall is not enough to produce sufficient food for the growing population. Most of the farmers in the watershed grow one crop per year during the rainy seasons. Cereals and vegetables are the major crops but the production and benefits from existing resources is very low. Such problems occur due to a lack of irrigation projects in the area. In this respect, the study was carried out to assess the potential of water and land for surface irrigation development and enhance agricultural land management and cropping patterns to increase the agricultural production with efficient use of land resources.

In Danse watershed, the development of irrigation is very important for refining the livelihood of the people but the effort to establish irrigation schemes in the study area was constrained by several uncertainties. First, the availability of water for surface irrigation has not been known. Second, the suitability of the land has not been identified and the water requirements of crops commonly grown in the watershed have not been estimated. Besides, one of the principal challenges during the initial stages of development of a new irrigation project is the selection of a viable cropping pattern that can be effectively implemented by farmers. Therefore, in order to alleviate this problem, the study was assessed potential irrigable land and water to maximize the net benefit from crop cultivation.

1.3 Objectives of the Study

1.3.1 General objective

The main objective of this study was to assess the water and land resources potential for surface irrigation and optimization of the cropping pattern in the study area.

1.3.2 Specific objectives

In order to achieve the general objective of the study, the following specific objectives were adopted.

i. To estimate the available water for surface irrigation in the study area.
ii. To assess the potential land suitability for surface irrigation.
iii. To optimize the cropping pattern in order to maximize the net benefit from crop production.

1.4 Research Questions

In this study, the following research questions were addressed:

a. How much volume of surface runoff is available for surface irrigation?
b. How much potential irrigable area is available in Danse watershed for surface irrigation?
c. What are the best combinations of resources to obtain the maximum benefit from the existing resources?

1.5 Significance of the Study

In developing countries like Ethiopia, owing to the rapid growth of the population, it is unquestionable to plan development activities that can ascertain fast improvement in the living standard of the nation. This can be achieved by the optimum development of water and land resources. Especially the need for the optimal development of water resources has become more urgent than ever before because water is becoming a scarce resource due to the growing demand for its use in various purposes (Netsanet, 2007). Irrigation has increased the amount of land under cultivation and the yields on cropland. It has also decreased the uncertainty of water supplied by rainfall. Belay and Bewket (2013) reported that irrigation would provide farmers with sustained livelihoods and improve their general well-being.

Access the potential of surface irrigation was studied to make the fragmented land more profitable. Therefore, assessing surface irrigation in terms of suitable land and available water is a very important option for solving the problem. The study contributed to the efforts working towards attaining technically feasible and socially desirable use of water and land to the initiatives striving to identify better strategies for irrigation development. The study also helps to identify available water and irrigable land in the watershed and estimate the total irrigation water requirement of selected crops for surface irrigation development. The study provides a good input at times of planning for future irrigation projects aimed at foreseeing future development in the watershed.

1.6 Scope of the Study

An investigation was carried out starting from estimation of available surface water for surface irrigation. The study also focused on land suitability assessment to identify suitable area for surface irrigation through evaluation of soil physical property, land use/land cover and slope of the watershed. Identifying suitable potential land for surface irrigation was done to assess the potential of land and to choose the suitable land area for irrigation. Surface irrigation potential was conducted in the study area by considering basic land suitability parameters and available water. Finally, the study was focused on optimal allocation of water and land resources to improve crop production through area allocation per unit of water by providing optimal crop patterns in order to decrease excessive loss of water and unwise uses of land and to maximize the benefit gained from crop production. Therefore, the study targeted on determining irrigation potential of Danse watershed in terms of land suitability and assessed available water for surface irrigation to satisfy irrigation water demand of selected crops as well as optimize the available water and land resource to increase the benefit from crop cultivation.

1.7 Thesis Layout

The thesis organized in to five chapters which are briefly summarized below.

Chapter one contains an introductory section where the background, statement of the problem, objectives of the study, research questions, scope and significance of the study are represented. Chapter two describes a literature review relating to the study regarding to specific objectives of the study. Chapter three deals materials and methods, overview of study, data sources and data Analysis. Chapter four gives the results and discussion. Finally, Chapter five presents conclusions and recommendations of the thesis.

2. LITERATURE REVIEW

2.1 Irrigation Potential

Irrigation development is crucial to improve smallholder livelihood through increase their crop production, increase crop variety and lengthen their agricultural seasons. According to Edmealem (2018) the area that can be potentially irrigated depends on the physical resources of land, soil and water combined with the irrigation water requirements. Sustainable management of land and water resources is essential for the alleviation of poverty, economic development and the enhancement of the well-being of the Ethiopian people (MOWR, 2002). Therefore, Irrigation practice expansion for potentially suitable lands and optimally using the available water is the most essential.

2.1.1 Irrigation potential in Ethiopia

The main slogan of Ethiopia in the new millennium is to pull the country out of pulverize poverty and leading the country to development (Hamda, 2014). Agriculture is one of the world's most important activities supporting human life. In Ethiopia, it directly supports 85 percent of the population's livelihoods, over 46 percent of gross domestic product (GDP) and almost 90 percent of export value (World Bank, 2005). The estimations of irrigation potential in Ethiopia differ from one source to the other due to a lack of standard or agreed criteria. Ethiopia has 12 river basins which account annual runoff volume 122 billion m^3 of water and 2.6 - 6.5 billion m^3 of groundwater potential within an average of 1575 m^3 of physical available water per person per year was estimated (Awulachew *et al.*,2007). Ethiopia has essential irrigation potential assessed from both available land and water resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed areas under irrigation. The country has special features to practice agricultural activities because of its geographical and environmental factors. Despite efforts of the government to expand irrigation, the country has not achieved sufficient irrigated agriculture to defeat the problems of food insecurity and rural poverty, as well as to create economic dynamism in the country. Recent studies indicated that Around 74 million hectares or 66% of the country suitable for agriculture (Getenet *et al.,* 2019).

2.1.2 Irrigation potential in Awash basin

Awash River Basin is one of the twelve river basins in Ethiopia. The River starts from the high plateau near Ginchi watershed in the central highlands of Ethiopia, flows along the Rift Valley into the Afar Triangle and terminates in salty Lake Abbe on the border with Djibouti.

The estimated irrigation potential in this river is 134,121 ha. Out of these 30,556 ha were allocated (Awulachew *et al*., 2007). According to the study conducted by Hassen (2004) Awash basin has an estimated irrigation potential of 206,000 ha and this potential was estimated based on gravity surface irrigation systems on lands up to a maximum slope of 5%. Another study has shown that about 159,530 ha of land including medium and large-scale irrigation schemes has been irrigated in 2012. However, the basin suffers from severe environmental degradation, annual flooding due to mismanagement of land and water resources, socio-economic constraints, poor agricultural practices resulting in low yield and benefits (Belete *et al*., 2013).

2.2 Availability of Surface Water

According to Ningaraju *et al*. (2016), water is the precious gift of nature becoming scarce needs to be conserved. Water scarcity is one of the major water-related issues that most countries are facing due to increased water demand resulting from rapid population growth, urbanization, industrialization and economic development. The major challenge facing planners and managers is that the physical availability of water and land is fixed; yet their demand is growing (Meron, 2007). Due to this, the problem is how to balance demand and supply under these increasingly complex and difficult conditions. For many countries, the only solution is to manage the available land and water resource in the country efficiently and sustainably. To achieve this reliable information base is necessary which can identify the resources available, their allocation, use or misuse, the components involved, their abilities, limitations and the infrastructure on hand. Water availability in the area is one of the important considerations in both the formulation of spatial plans and the evaluation of the effectiveness of actual land use in providing sustainable water resources. Therefore, water resources development is basic and crucial infrastructure.

2.2.1 Surface runoff

Accurate estimation of surface runoff from rainfall is important for land and water resource management in a drainage area. Runoff varies spatially due to changes in soils, land use, slope and temporary changes in soil water content. As runoff has a spatial variability, every portion of the earth surface produces a different volumes of runoff base on their geo-hydrological environment.

Rainfall and runoff are the important elements that contribute more water to the various activities performed in a watershed. Understanding the quantity of surface runoff generated in a catchment is very important for decision making in irrigated agriculture. Rainfall-runoff relationship is one of the most important phenomena. Rainfall, land use and soil condition are considered important factors in surface runoff estimation (Thankuriah and Ranjan, 2014). The estimation of runoff volume is an important aspect of engineering planning, environmental impact assessment and water balance calculations.

2.2.2 Curve number method

Curve Number is an index to represent the potential for stormwater runoff within a drainage area (Ashish and Patil, 2014). The curve number of hydrological parameters used to describe the storm water runoff potential for drainage areas and function of land use, soil type and soil moisture as well as the empirical parameters used in hydrology for predicting direct runoff infiltration from excess rainfall (Shereif *et al.,* 2014). The SCS-CN method is a widely used method for estimating the surface runoff volume for a given rainfall event. The SCS approach involves the use of simple empirical formula, tables and curves. The empirical equations require the rainfall and watershed coefficient as inputs. The watershed coefficient is called curve number that represents the combination of a hydrologic soil group and land use and land treatment classes. SCS- CN method is widely used by hydrologists, water project planners and engineers (Zeenat *et al*., 2018).

According to Patil *et al*. (2008), the natural resources conservation services curve number (NRCS-CN) method is one of the most widely used methods for quick and accurate estimation of surface runoff from ungauged watersheds. The traditional SCS-CN method for calculating the composite curve number is very tedious and consumes a major portion of the hydrologic modeling time. Therefore, geographic information systems (GIS) was employed in combination with the SCS-CN method. The integration of GIS with the SCS-CN method provides a powerful tool for estimating runoff volume (Abouzar *et al*.,2014). Some applications of GIS are the estimation of curve number (CN) by using the digital data analysis, vegetation cover, land use and hydrologic soil groups. Curve number method is a versatile and widely used approach for quick runoff estimation and relatively easy to use with minimum data and gives adequate results (Gupta and Panigraph,2008). Also, in rainfall-runoff modeling, more accurate characterization can be achieved.

The selection of curve number is based on the land use pattern and HSG (Hydrological Soil Group) present in the study area. Land use/land cover is one of the very important variables for runoff estimation. The SCS-CN method provides a rapid way to estimate runoff change due to land-use change. The hydrologic soil group refers to the infiltration potential of the soil after prolonged wetting. There are mainly four hydrologic soil groups A, B, C and D with respect to rate of runoff potential and infiltration rate. As described in USDA-NRCS (2004) soils with a hydrological group of HSG-A and HSG-B, have low and moderately low runoff potential respectively when they are saturated, whereas the soil in HSG-D and HSG-C have high runoff potential.

Rainfall depth and curve number are the basic parameters used for computing direct runoff. However, the computation of exact values for the curve number depends on the antecedent moisture condition (AMC) of the catchment. Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. It is a very important factor for determining the final CN value. SCS developed a guideline for adjusting CN based on AMC and the total rainfall in the 5 days period preceding a rainfall and three levels of AMC were defined accordingly, AMC-I for dry, AMC-II for normal and AMC-III for wet conditions. CN_{II} is considered the base CN, and is applied for moderate antecedent moisture condition (AMC_{II}). It can be adjusted for calculating CN_{III}, which is applied for near-saturated antecedent moisture condition (AMC_{III}), or which is applied for dry antecedent moisture condition (AMC_{I}).

2.3 Land Suitability for Surface Irrigation

Land suitability is the fitness of a given type of land for a defined use. Suitability measures how well the qualities of a land unit match the requirements of a particular form of land use (Mamenie, 2017). In agricultural based community, land Suitability refers to the ability of a portion of land to tolerate the production of crops sustainably. The social, economic and environmental factors analyzed before a final land suitability can be given for a specific land utilization. It also deals with the assessment of land performance for the specific use that is crop production. Such kind of analysis allows identifying the main limiting factors for agricultural production and enables decision-makers to develop crop management able to increase land productivity. Land suitability assessment plays an important role in planning and managing sustainable land use (Mohamed *et al.*, 2017). It provides useful information and helps in optimizing agricultural land use. Ethiopia has a considerable land resource for agriculture, which is about 73.6 Mha (66%) of the country's area, which is potentially suitable for agriculture (Tadesse and Madduri, 2018).

Land suitability analysis is a method of land evaluation that assesses the possible uses of land for different purposes, which measures the degree of appropriateness of land for a certain use. Therefore, land suitability analysis can answer the questions regarding which land use is to apply under certain conditions and where the best site to apply this land use. In land suitability assessment particular attention is given to the physical properties of the soil and the terrain conditions in relation to methods of irrigation. In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (FAO, 2007). Land suitability assessment plays an important role in the country to have sustainable agricultural development and for planning and managing sustainable land use. Its evaluation provides information on the constraints and opportunities for the use of the land and guides decisions on optimal utilization of the land and water resource.

2.3.1 Structure of land suitability classification

The land may be classified in its present condition or after improvements for its specified use. Four categories, namely. Orders, Classes, Subclasses and Units are recognized in the FAO Framework classification. Land suitability orders indicate kinds of suitability whether the land is assessed as suitable or not suitable for the use of under consideration. There are two orders represented by the symbols S and N for suitable and not suitable, respectively. Land suitability classes reflect the degree of suitability within Orders. The classes are numbered consecutively in the sequence of decreasing degree of suitability within the order. Land Suitability Subclasses reflect kinds of limitations or kinds of inputs and improvements required within Classes (i.e. S2d, etc.) and land Suitability Units reflect minor differences in the required management within Subclasses (e.g. S2d-2, etc.). According to FAO (1976) framework of land suitability classification, the following suitability orders and their classes were discussed below.

Order S (Suitable): Land on which sustained use under consideration is expected to yield benefits, which justify the inputs without unacceptable risk of damage to land resources. The classes under this order are:

S_1 (highly suitable): land having no significant limitation to a sustained application of a given use. This land is the best possible and does not reduce productivity or require increased inputs.

S_2 (moderately suitable): land having limitation which in the aggregate are moderately severe for a sustained application of a given use. Land that is suitable but has limitations either reduce productivity or require an increase of inputs to sustain productivity compared with those needed on S_1 land.

S_3 (marginally suitable): land having limitation which in the aggregate are severe for a sustained application of a given use and will reduce productivity or benefits. Land with limitations severe that benefits are reduced or the inputs required sustaining production need to be increased so that this cost is only marginally justified.

Order N (Not Suitable): Land, which has qualities that appear to preclude sustained use of the kind under consideration. Land may be classed as "Not suitable" for a given user for some reasons. It may be that the proposed use is technically impracticable, such as the irrigation of rocky steep land or that it would cause severe environmental degradation such as the cultivation of steep slopes. However, the reason is economic that the value of the expected benefits does not justify the expected costs of the inputs that would be required. Land Evaluation requires a comparison of the benefits obtained and the inputs needed on different types of land. It is a vital link in the chain leading to the sustainable management of land resources by considering the execution and interpretation of land in terms of the requirements of alternative forms of land use. The classes under this order are:

N_1 (temporarily not suitable): land-having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost. The limitations are severe as to preclude successful sustained use of the land.

N_2 (Permanently not suitable): land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land for a given land use.

2.3.2 Land suitability evaluation factors

To reduce the human influence on natural resources and to identify appropriate land use, it is essential to carry out scientific land evaluations. Such kind of analysis allows identifying the main limiting factors for agricultural production and enables decision-makers to develop crop management able to increase land productivity (Temsegen and Yonas,2016). As extensively discussed in FAO land evaluation guidelines the land suitability factors for surface irrigation method and the given land utilization types can be expressed corresponding to suitability classes. In this study, the factors considered for land suitability evaluation narrated separately in the following sub-sections.

2.3.2.1 Slope

Slope is the gradient or inclines of a surface and commonly expressed as a percent. It is an important factor for the land suitability assessment for surface irrigation. It affects the suitability of an area in terms of land preparation for irrigation and irrigation operation

(Kassaye *et al*.,2019). The slope gradient of the land has a great influence on the selection of the irrigation methods (Mandal *et al*., 2017). Slope is the means by which gravity induces the flow of water and other materials, so it is of great significance in the gradational process of land escape evolution and soil development. According to FAO standard guidelines for the evaluation of the slope gradient, mostly slopes, which are less than 2%, are very suitable for surface irrigation. However, slopes that are greater than 8% are not widely recommended (FAO, 1999). Slope is important for soil formation and management because it influences runoff, drainage, erosion and choice of irrigation types. It is one of the evaluation parameters in irrigation suitability analysis. Based on FAO land suitability classification there are four slope classes (S1, S2, S3 and N) in the watershed.

2.3.2.2 Soil

Soil is a major factor in the suitability of irrigation land. Soil physical properties like soil texture soil depth and drainage conditions are some of the factors that highly constrain the suitability of the soil for agricultural production. The assessment of soils for irrigation involves using physical properties that are permanent in nature that cannot be changed or modified. Soil texture, soil drainage, soil depth and soil type are the major physical properties of soil which are very important for the evaluation of irrigation potential. They affect the root growth of a plant, infiltration of water into the soil and the production of crops (Fasina *et al*., 2008). Soils are the world's natural resource and a soil map is a spatial representation of these resources. On loam or clay soils all irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are preferably suited to surface irrigation.

The land suitability of the watershed with regard to soil establishes by evaluating the soil suitability parameters; soil texture, depth and drainage suitability through overlay analysis. Soil physical properties define the movement of air and water through soil, as well as conditions affecting germination, root growth, and erosion processes. According to the research conducted by Tesfaye (2014) soil Physical properties are the most dominant factors that determine the land suitability for irrigation. These physical properties are discussed in the following sub-sections.

Soil Texture: Texture refers to the relative proportion of sand, silt and clay in a mass of soil. The proportion of sand, silt and clay is used to determine the textural class of the soil. It helps to determine the capacity of the soil to retain moisture and air, both of which are necessary for plant growth. Soils with a greater proportion of larger particles are well aerated and allowed water to pass through the soil more quickly. Soil textures are classified by the fractions of each soil separate (sand, silt and clay) present in a soil. Coarse textured soils contain a large proportion of sand; medium textures are dominated by silt, and fine textures by clay (FAO, 2008). The Classification is typically named for the primary constituent particle size or a combination of the most abundant particle sizes. Soil texture is very important for hydrologic soil group determination.

Soil Depth: Depth is the dimension from the soil surface to bedrock, hardpan and water table to specified soil depth. Soil depth refers to the thickness of the soil materials. In addition, Effective soil depth is the depth of the soil at which the root growth of crops is strongly inhibited. Soil depth plays a major role in influencing plant growth and yield.

Soil Drainage: Soil drainage is a natural process by which water moves across though and out of the soil because of the force of gravity**.** The drainage condition of a land development unit commenced with regard to specific land utilization type and texture. Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. The suitability of land decrease when drainage condition comes under problem. According to FAO (1997) evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage area can be classified as well drained, moderately well-drained, imperfectly drained, poorly drained and very poorly drained.

2.3.2.3 Land use / land cover

Land use and land cover are often used interchangeably. However, they are quite different. The GLCN (2006) defines the land cover as the observed (bio) physical cover and may take place on one or more than one piece of land and several land uses may occur on the same piece of land. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, land-use is defined as a series of activities undertaken to produce one or more goods or services. FAO (1996) described the structure of the suitability classification in detail. The framework has the same structure. Each category retains its basic meaning within the context of the different classifications and as applied to different kinds of land use.

Land use /land cover of the study area is one of the factors used to evaluate the land suitability for surface irrigation. Land use land cover provides a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation (Melaku, 2003). Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for surface irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn *et al*.,2004).

2.4 Estimation of Irrigation Water Requirements (IWR)

Water requirement is the quantity of water regardless of its source required by a crop. In other words, it is diversified patterns of crops in a given period for its normal growth under field conditions at a place (Awulachew *et al*., 2007). In other words, the Irrigation water requirement is the amount of water that is needed by the crop on the optimal growth condition without water deficiency and it is expressed the net water requirement for irrigation (Juwono *et al*., 2018). The most important of computed irrigation water demand is that knowledge of the total quantity of water required from its sowing time up to harvest. Under the same condition, different crops require a different amounts of water and the quantities of water used by a particular crop are different in the entire life span (initial, development, mid-season, late-season stage) of the crop period (Mamenie, 2017). Initially, during seeding, sprouting and early growth, a crop uses water at a relatively slow rate. The rate will increase with the growth of crop reaching the maximum in most crops as it approaches flowering and then declines towards maturity (MoA, 2011).

2.4.1 Reference crop evapotranspiration (ET_O)

The evapotranspiration rate from a reference surface is known as Reference Crop Evapotranspiration. The reference surface is a hypothetical grass reference crop with specific characteristics. ET_O expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. The only factors affecting ET_O are climatic parameters. The FAO Penman-Monteith method is recommended as the sole method to determine ET_O.

2.4.2 Crop evapotranspiration (ETc)

Crop Evapotranspiration under standard condition (ETc) is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions and achieving full production under the given climatic conditions. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate.

2.4.3 Net and gross irrigation water requirements

The Net Irrigation Requirement (NIR) is the water quantity required for the growth of the crop. It is the amount of water necessary to reach the field capacity of the soil. The total amount of water applied through irrigation is termed as gross irrigation water requirement. Gross irrigation requirements includes net irrigation requirement plus losses in water application and others. CropWat is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes (Berhanu *et al*., 2015).

2.5 Optimization of Cropping Pattern

Cropping pattern is defined as the proportion of area under various crops at a point of time in a unit area.it indicates the yearly sequence and spatial arrangement of crops and fallow in an area. In other words, it is an activity of regulating time, place, type and crop area in the irrigation sites. However, cropping pattern aims to make the use of irrigation water availability as efficient as possible. On the other hand, improved allocation of water in irrigation and drainage networks aims at different factors that among them, maximizing the farmers income is one of the most important ones (Singh *et al*.,2001). Today, the agricultural sector around the world is under more pressure for limiting its water use because of the increasing water demand (Homayoun *et al*., 2014). These calls for increasing production per unit area and per unit water. However, this needs scientific utilization of the water resources and optimal allocation to achieve maximum benefits from the production. According to Mohammed *et al*. (2016), the cropping pattern is one of the most influential factors in irrigation management which has direct relationship with the optimal allocation of land and water resources.

The growing demand of food for large population can only be met by optimum utilization of available water and efficient allocation of available land to different crops. Land and water are the key factors for the sustainable agricultural development of a nation. Due to the rapid change in population and urbanization, land and water resources are becoming very limited. Subsequently, crop optimization has received extensive attention in recent years and mathematical models were developed to determine the optimal use of the available resources for maximizing the net benefits from crop production subjected to some constraints (Fazal *et al.,*2019). Optimization of cropping patterns plays an important role in high-benefit and water-saving agricultural management. An optimal cropping pattern depends upon the water availability to meet the maximum irrigation potential as well as the maximum economic return (Singh *et al*., 2018). Although the selection of the optimum cropping system is a scientific and professional challenge, it is believed that it can be scientifically addressed using optimization techniques such as a linear programming model.

2.5.1 Linear programming model

Overall development depends on food production in service of an existing or growing population with maximum benefits and optimal utilization of water and land resources. Management of this water and land resources is also one of the main financial development (Ahajani *et al*., 2013). Hence, there is a necessity to implementation of techniques in optimum usage of such available resources. Also Keeping given socio-economic conditions, the study made an attempt to develop optimum cropping patterns with the constraints of available resources and ultimately getting maximum net benefits. In recent years, mathematical models have been developed to determine the optimal use of the available resources for maximizing the net benefits subjected to some constraints. Among these different models, Linear Programming (LP) is one of the best and simple techniques for optimizing an irrigated area where various crops are competing for a limited quantity of land and water resources. Linear programming models can handle a large number of constraints and thus are an effective tool to aid in the optimization process. The optimal use of land and water for agriculture appears to be a vital and unavoidable task due to water and land limitations globally. Cropping pattern is one of the most influential factors in irrigation management, which is in direct relationship with the optimal allocation of land and water resources (Mohammad *et al*.,2016).

Many studies have suggested Linear Programming as an effective tool in various decision-making problems in agriculture as it can efficiently handle a large number of linear constraints and variables simultaneously (Rajni *et al*.,2018). According to Mahek and Bhatt (2014) in irrigated agriculture, where various crops are competing for a limited quantity of land and water resources, linear programming is one of the best tools for the optimal allocation of land and water resources. Several researchers applied LP models to develop an optimal cropping pattern within the available resources and constraints of their study area. Singh and Panda (2012) developed LP model taking into account various hydrologic and economic factors like yield, cost of production of the crops, the unit cost of irrigation water and groundwater, quality of mixed water and net irrigation requirements. The model results show a reduction in rice, mustard, barley, and gram areas against an increase in cotton, sugarcane, wheat, millet, and sorghum under optimal cropping pattern. The net annual return from the study area has increased by 26%. Musekwab (2013) developed LP model that helped to determine the optimal cropping pattern for an irrigation scheme in Masvingo, Zimbabwe. As a result of the optimal solution, a farmer's income could be increased by 87%. A weekly LP model was also formulated for determining the optimal cropping pattern and reservoir water allocation for an existing storage based irrigation system in India (Prasad, 2011).

Aghajani *et al*.(2013), used a linear programming model for the optimal land and water resources allocation to maximize net annual returns from a command area. Berhanu et al. (2013), used a linear programming model to obtain an optimized cropping pattern for the Koga Irrigation Dam project in Ethiopia. In addition, Aparnathi and Bhatt (2014) introduced surface and groundwater as constraints to their linear programming model to optimize the cropping pattern for a project understudy in their region. Similarly, Sara *et al*. (2017), carried out a study on a linear optimization model developed to maximize the net annual return from the three old regions of Egypt. Twenty-eight crops are selected for the study according to their importance. The study also focuses on finding the optimal cropping pattern for the old lands of the three regions in Egypt based on the available data from 2008 to 2012 to give the maximum profitability to the farmers. The results of optimization show that it is impossible to increase the gross net benefit from these crops by limiting the allocated areas for the non-strategic crops and increasing that for tomatoes while keeping the strategic crops with their areas that satisfy their self-sufficiency values. In general, LP is one of the best approaches to mathematical optimization that utilizes numerous concepts of mathematics to allocate limited resources among competing demands in an optimal way. It uses models in mathematics to describe problems of concern (Huang *et al*., 2016).

2.6 Overview of GIS Application

A Geographic Information System (GIS) is a software used for capturing, storing, querying, analyzing and displaying geographically referenced data (Good child, 2000). GIS is a computer-based tool for handling spatial data in digital form tasked. large quantities of data can be maintained and retrieved at greater speeds and lower cost. Some of the basic applications of GIS are presented below.

2.6.1 Mapping

A map is the most common view for users to work with geographic information. Mapping is the main application of GIS where things are editing tasks as well as for a map-based query and analysis. It is the most common view for a user to work with geographic information system and the primary application in any GIS related works (Mamenie, 2017). The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text and a symbol legend.

2.6.2 Watershed delineation

According to the CA (2007), sub-basins or basins more limited in size (typically from tens of square kilometers to 1,000 square kilometers) are often called watersheds. A watershed can be defined as the area of a catchment or a drainage basin that drains into a common outlet. Delineation of a watershed means determining the specific boundary or the area of the watershed. GIS uses DEM data as an input to delineate watersheds with the integration of Arc SWAT or we can implement by a hydrology tool in ArcGIS which is spatial analysis (Winchell *et al*., 2008). DEM of 30*30 m provides good terrain representation from which watersheds can be derived using ARC-GIS procedures.

2.6.3 Weighted overlay analysis

The weighted overlay analysis is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problem has often required the analysis of different factors using GIS. For instance, finding an optimal site for irrigation requires weighting of factors such as slope, soil and land use/land cover (Yang, 2003).

A weighted overlay analysis uses an evaluation scale from 1 up to 9 (from the most to the least suitable factor), to prioritize the influence of these factor values. Weighted overlay only accepts integer raster's as ingredients such as a raster of LULC, soil types and slope. A weighted overlay method along with the analytic hierarchy process provides a very assuring outcome for the site suitability assessment of agricultural land use. The identification of different criteria depended on the majority that influences the product yield of agriculture. The method can be useful to the multi-level hierarchical structure of various constraints and criteria (Pramanik, 2016).

2.6.4 GIS as a tool for irrigation potential assessment

GIS approach allows integration of the spatial variability of terrain and other relevant parameters. The merit of it is found to be beneficial in delineating areas of various suitability ratings for a detailed assessment (Ibrahim *et al*., 2015). In the past several studies have been made to assess the surface irrigation potential in Ethiopia by using GIS as a tool.

Negash (2004) conducted a study on irrigation suitability analysis in Ethiopia, case of Abaya Chamo lake basin. It was a Geographical Information System (GIS) based and taken into consideration soil, slope, land use land cover and water resource availability in perennial rivers in the basin to identify potentially irrigable land.

The study conducted by Meron (2007) carried out similar work on surface irrigation suitability analysis of the southern Abay basin by implementing GIS techniques. This study considered soil, slope and land cover /use factors to find suitable land for irrigation concerning the location of the available water resources and to determine the combined influence of these factors for irrigation suitability analysis.

Girma (2015**)** assesses the suitability of Walga sub-basin for surface irrigation development and producing a geo-referenced map of potentially irrigable sites. The methodology of the existing suitability encompasses the evaluation of slope, LULC, major soil physical properties such as texture and depth, drainage and PH. Suitability of the area's slope, soil, land use land cover and surface water resources were evaluated and a geo-referenced map of each parameter was presented on Arc GIS. The overall suitability map of the area of the intended irrigation system was produced using a suitability model developed on Arc GIS. The result of the suitability model revealed that about 45.72% (135519.18 ha) of lands were in the range of highly suitable to marginally suitable for surface irrigation development. Potentially suitable sites for surface irrigation development were evaluated for the selected crops (Maize, soya bean and Sesame). By maintaining 20% of the stream flows for downstream ecological balance, flows in each stream can satisfy gross irrigation water requirements of the selected crops in the potentially irrigable sites.

3. MATERIALS AND METHODS

3.1 Descriptions of the Study Area

3.1.1 Location

Danse watershed is located in East Shoa zone of Oromia regional state, upper Awash Sub-basin in Lume woreda with the capital located at 50 km of Addis Ababa. It lies between 8° 41' 56" - 8° 45' 08" North latitude and 39° 13' 53" - 39° 15' 43" East longitude with projection system UTM and datum ADINDAN. The watershed encompasses four rural kebeles namely Danse shanbure, Haro, Nanawa and Tilti gerbi. The total area coverage of the watershed that obtained through watershed delineation is 2170 ha.

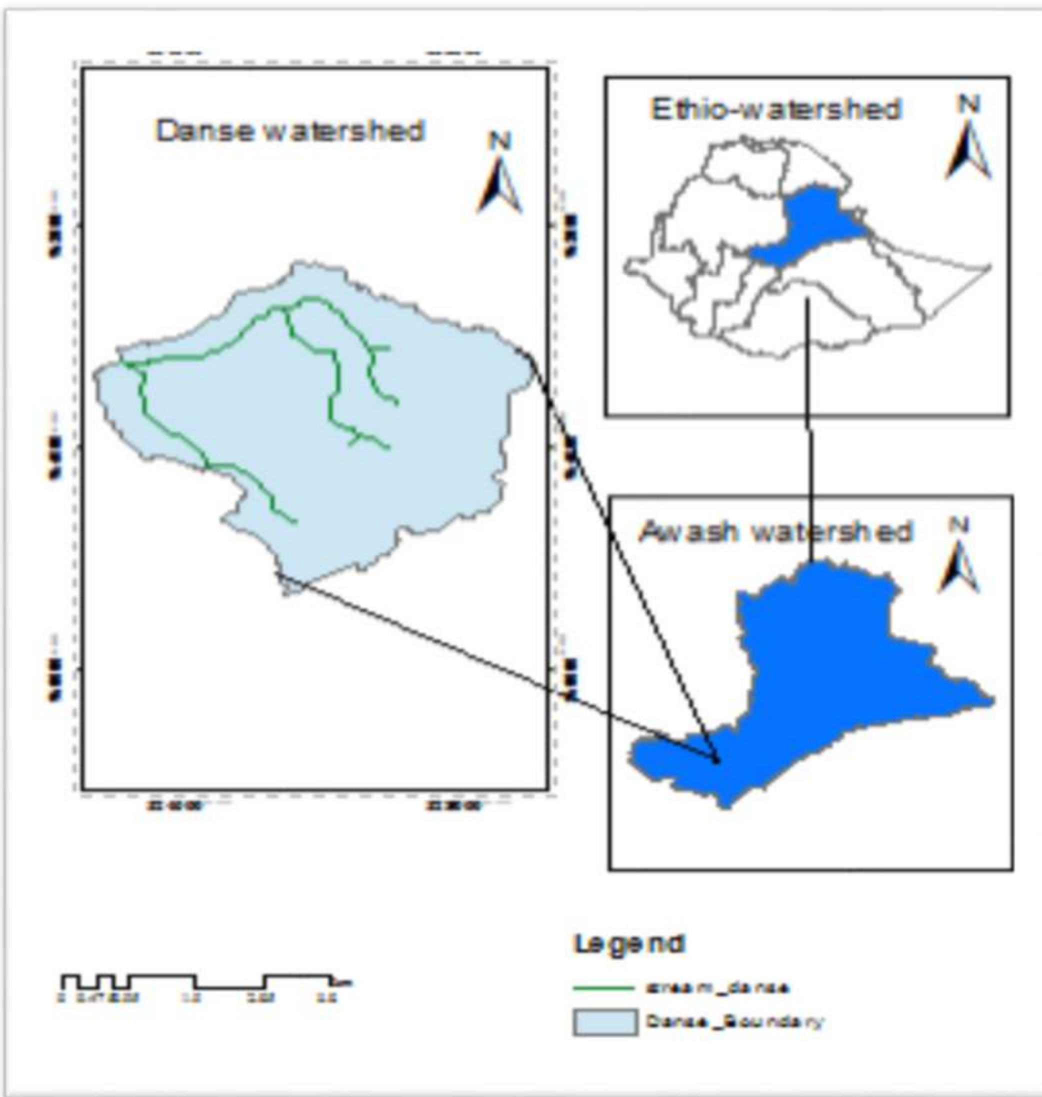

Figure 3.1 Location map of the study area

3.1.2 Topography

The elevation of the watershed boundary extends from 2087 to 2480 m a.m.s.l. The maximum elevation of Danse watershed is located in the northeast and southeast part of the watershed and the minimum elevation of this watershed is located in the northwest part of this watershed. The study area falls in the slope ranges of (0-58 %); 55 % the area falls in the slope ranges of (0-8 %) and the remain area has slope grater than 8 %.

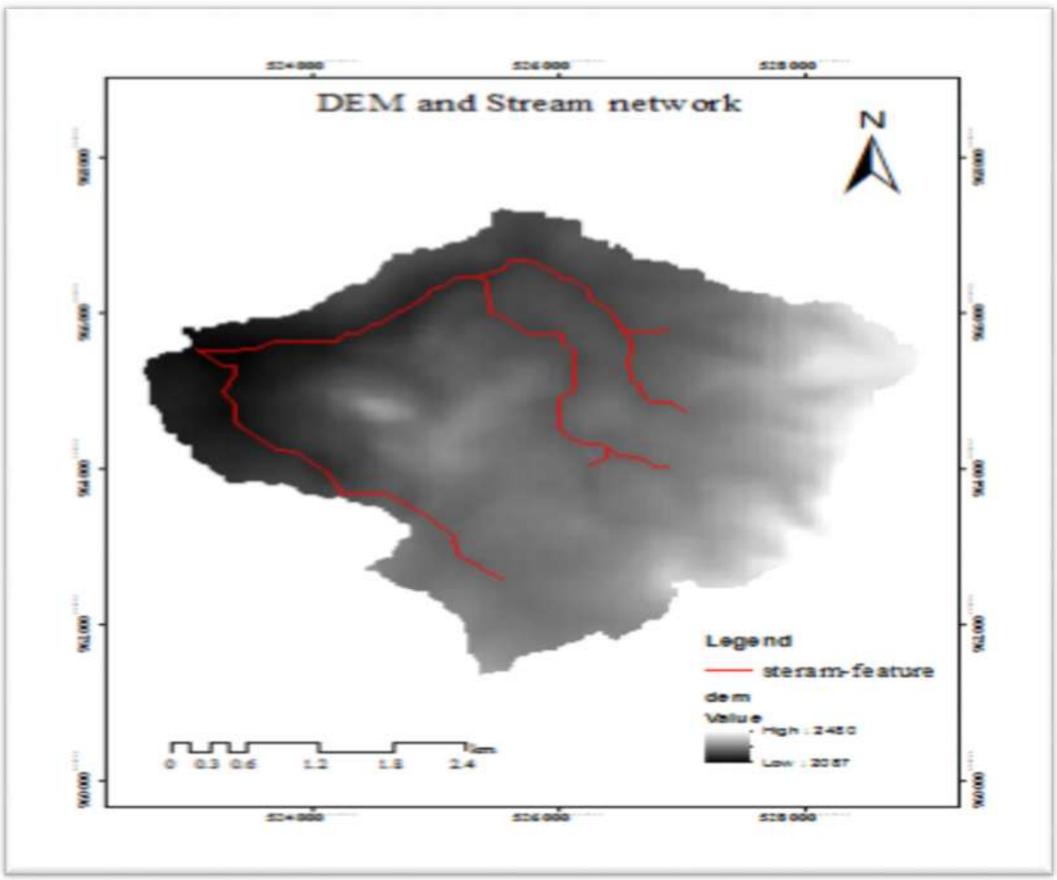

Figure 3.2 Topographic map of Danse watershed

3.1.3 Climate

Agricultural activities and land use patterns are closely related to the temporal and spatial patterns of climatic elements; and the success of land use strongly depends on the climatic situation of an area (Dula, 2010). Temperature and rainfall are the most important elements in characterizing the climatic condition of a given watershed area. Climatic zone indicates an altitude increase with decreasing temperature and increasing precipitation. In most parts of the country, annual precipitation follows a bimodal distribution. The central and most of the eastern part of the country has two rainy periods and one dry period. Those seasons with their local name of Kiremt rains from June to September, small Belg rains from February to May and dry Bega season from October to January (Tibebe and Zemadim, 2015). The mean annual rainfall in Danse watershed estimated as 990.5 mm and the mean minimum and maximum temperature ranges of the watershed are 10.2 and 26.4 (°C) respectively.

3.1.4 Soil type and land use land cover

According to the FAO/UNESCO soil classification system, the dominant soil groups in the watershed are Pellic Vertisols, umbric Leptosols and chromic cambisols. Most of the area was covered by Pellic vertisols with an area coverage of around 1178 ha. Chromic Cambisols covered 794 ha of land. The remaining area of land covered by Umbric Leptoslos. Danse watershed has five types of land use/cover such as cultivation, grassland, Shrubland, settlements and water body. From this land use/land cover cultivated land is the most dominant. During the field visit, most of the land was covered by Wheat, Teff, Maize, Onion and Potato.

3.2 Data Collection

Primary and secondary data was very important for the study to accomplish the objectives. Primary data collection includes field observation, questionnaire, interview of experts and farmers. Secondary data were collected from published and unpublished materials, reports, proceedings and the information was also collected from zonal and district level offices of irrigation authority, responsible organizations, literatures and FAO guidelines. Secondary data include crop types, hydrologic, climatic, land use land cover and soil datas.

Generally, to achieve the objectives of the study different data inputs were collected from the study area and different data sources. In this study to quantify the amount of available water and land resource potential for surface irrigation and to optimize cropping pattern, the following datas were collected from the responsible organization.

3.2.1 Meteorological data

All meteorological data (rainfall, temperature, relative humidity, wind speed, and sunshine hour) of Ejere, Mojo and Bologeorgis stations were collected from National Meteorology Agency (NMSA). One of the meteorological station (Ejere) is found inside the watershed. The other meteorological stations found outside the watershed. The metrological data were used to estimate irrigation water requirements of selected crops (Onion, Tomato, Cabbage and Wheat) using CROPWAT 8.0. Besides, the rainfall data used to estimate the volume of surface runoff in the watershed.

3.2.2 Agronomic data

The data was collected from FAO guidelines, Lume wereda Agriculture development office and from randomly selected farmers by preparing interviews through self-made questions from all kebeles in the watershed. Agronomical data includes types of crop, sowing and harvesting time, maximum root depth, crop coefficient, cost of crop production, the selling price of the dominant crops and yield of crop production.

The Questionnaire analysis showed that the survey form was used to gather information in the watershed and 10 farmers from each kebeles and 6 experts from Lume agricultural office were selected for the interview. The data was used to compute crop water requirement of selected dominant crops and for the analysis of optimizing cropping patterns to assess the most combination of crops to maximize farmer's benefit from the production of selected crops.

3.2.3 Soil and land use land cover data

Soil and land use/land cover data were used for runoff curve number estimation and land suitability analysis for surface irrigation. The data was obtained from Oromia Water Works Design & Supervision Enterprise (OWWDS). Both the land use map and soil map were prepared to a scale of 1:250,000.

3.3 Material and software

The materials and software used in this study were including DEM, soil data, LULC data, Arc GIS 10.4, CROPWAT 8.0, Lingo 17.0 and Microsoft excel to effectively execute and to assess the irrigation potential and cropping pattern optimization. Arc-GIS software is used for determining the curve number for estimating surface water and land suitability analysis for surface irrigation. CROPWAT 8.0 software was used to determine the crop water requirements of selected crops in the watershed. Finally, Lingo was used to find the value of each decision variable and the optimal solution in the cropping pattern.

3.4 Methods of the Study

After desk study of the previous finding related to the present study and all the necessary data were collected from different data sources further analysis was performed. The study consists of three main parts. First quantified the available water then determined the land suitable for surface irrigation and finally optimized the cropping pattern. Before starting the assessment of the irrigation potential of Danse watershed delineation of the watershed, filling of missing data and data quality checking was done.

3.4.1 Digital elevation model

DEMs are point elevation data stored in digital computer files. These data consist of x, y grid locations and point elevation or z variables. They are generated in a variety of ways for different map resolutions or scales. The point elevation data are helpful as an input to the Arc-GIS and the data can further be processed to give important derivative products such as slope, flow accumulation, flow direction and delineate watersheds (Negash, 2004). Many agencies provide DEM data 30m resolutions because, DEM of 30*30 m provide good terrain representation. In this study, the DEM data was obtained from 30 by 30 m resolution SRTM DEM and used as input data in ArcGIS for delineation and to derive a slope map of the study area for irrigation suitability analysis.

3.4.2 Delineation of the watershed

The watershed delineation of the Study Area was performed through spatial analysis Arc-GIS 10.4 tools. The following steps were followed for watershed delineation using the hydrology tool in ArcGIS.

Fill sink: This function fills the sinks in a grid, if cells with higher elevation surround a cell; the water is trapped in that cell and cannot flow. The Fill Sinks function modifies the elevation value to eliminate this problem. The main function of this tool is to remove imperfections in the DEM to enable water flow to the watershed outlet.

Flow Direction: This function computes the flow direction for a given grid. The value in any given cell of the flow direction grid indicates the direction of the steepest descent from that cell to one of its neighboring cells.

Flow Accumulation: The function uses the flow direction grid to compute the accumulated number of cells that are draining to any particular cell in the DEM.

Outlet (pour) points: The placement of pour points is an important step in watershed delineation. A pour point should exist within an area of high flow accumulation because it is used to calculate the total contributing water flow to that given point.

Delineating Watershed: To delineate the watershed, pour points are snapped to the stream and then use this grid to delineate the watershed. Finally, convert watershed raster to polygons. Converting raster to a polygon shape file is used to calculate the area and to clip other data sets to the watershed boundary (Merwade, 2012). In watershed delineation, the Digital Elevation Model (DEM) with 30 m pixels was used. In this study, the watershed delineation showed that Danse watershed covers a total area of 2170 ha.

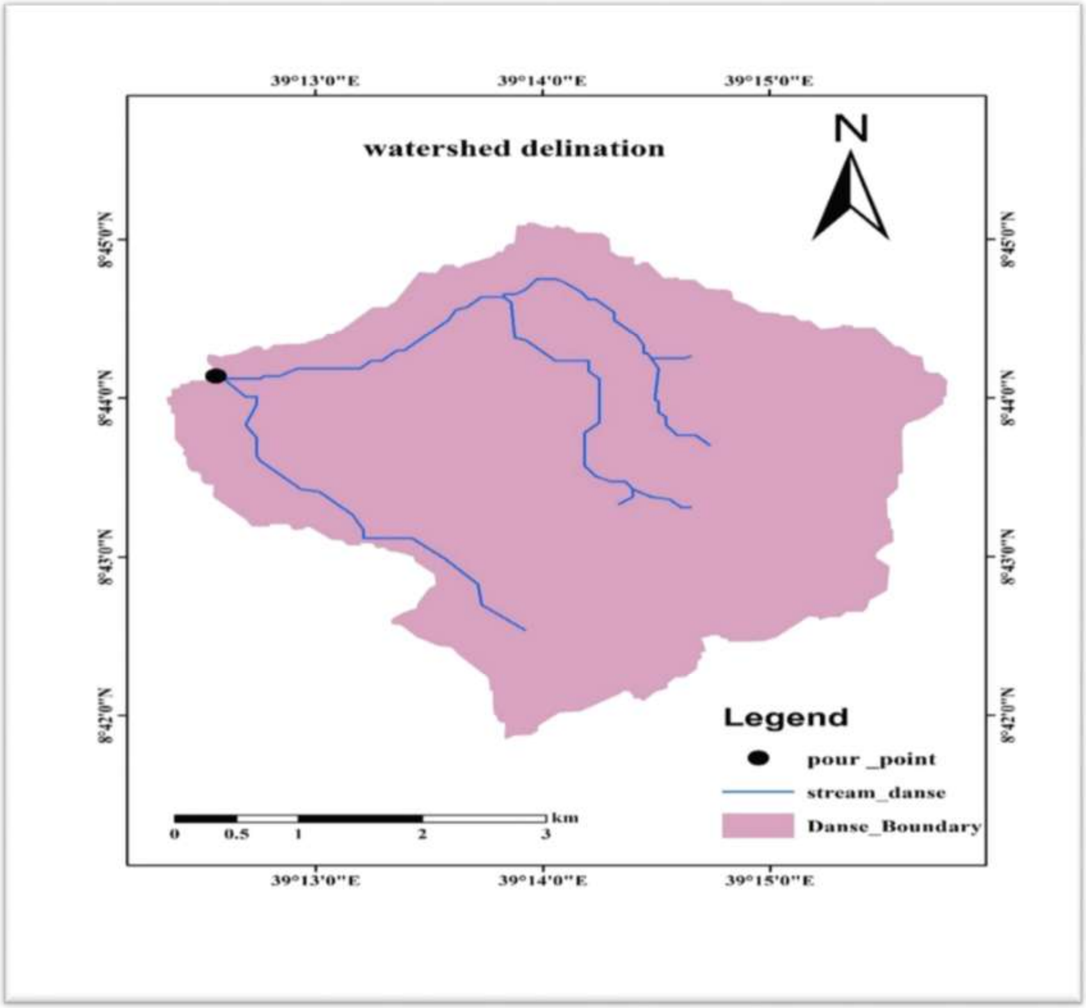

Figure 3.3 Watershed delineation

3.5 Data Preprocessing and Checking

Collected data can contain errors due to the failures of the measuring devices or the recorder. Therefore, before using the data for specific purposes, checking for missed data and removing errors is very essential. In this study, rainfall data was fill by using the arithmetic mean method and data consistency checking was performed by a double mass curve.

3.5.1 Filling missing rainfall data

Before using the rainfall record of a station, it is necessary first to check the data for continuity and consistency. To fill missing rainfall data, the normal rainfall is used as a standard of comparison. The normal rainfall is the average value of rainfall at a particular date, month or year over a specified 30-year period. Simple arithmetic mean and normal ratio method are the common methods used for filling missing rainfall data. To calculate the percent of difference to decide whether to use arithmetic mean or normal ratio method, the following equation has been used.

$$\text{Percent difference} = \left(\frac{N_x - N_i}{N_x}\right) * 100 \tag{3.1}$$

Where, Nx = the normal annual rainfall amount from the missing data station,

Ni = the normal annual rainfall amount from one of the nearby stations.

For this study, the missing values of rainfall recorded were completed by using the Arithmetic mean method. The method is used for the difference between the normal annual precipitations at surrounding gauges are within the range of 10% of the normal annual precipitation of station with missed data. This method can be used to calculate monthly as well as annual missing rainfall values. The missing data estimated by;

$$P_x = \frac{1}{M}\left(P_1 + P_2 + P_3 + \ldots P_m\right) \tag{3.2}$$

Where, P_x = missing rainfall data at station x,

P_1, P_2, P_3 and P_4 = precipitation at surrounding gauges station,

M = the number of nearby gauge stations.

3.5.2 Consistency of rainfall data

To prepare the rainfall data for further application, their consistency was checked using double mass curve analysis. A plot of accumulated rainfall data at the site of interest against the accumulated average at the surrounding stations was used to check the consistency of rainfall data. The rainfall data of Mojo, Ejere and Bologeorgis stations from the year of 1987-2016 were collected for consistency checking.

Double mass curve compares data for a single station with that of a pattern composed of the data from other stations. The data of the annual rainfall of the doubtful station and the average rainfall of the group of base stations covering a long period was arranged in the reverse chronological order. To check the degree of consistency, Nemec (1973) provided the value of the coefficient of correlation as follows:

Table 3.1 Correlation coefficients

Range of correlation coefficient	Description
r =1	Direct linear correlation
o.6≤ r <1	Good direct correlation
0 < r < 0.6	Insufficient reciprocal correlation
r = -1	reciprocal linear correlation

Source: Nemec(1973)

3.6 Estimation of Surface Water Availability

Estimation of runoff in a watershed is very important to manage scarce water resources efficiently. Knowing runoff volumes is important in managing watersheds and assessing projects. Runoff from a watershed produced by given precipitation may be estimated using various models. Out of these models, the SCS-CN model is widely used for estimating surface runoff volume for a given rainfall event for a small to medium sized ungauged watershed. The method is well suited for small watershed and it requires details of soil physical properties, land use and rainfall data. The method utilized in this study was, Land use and soil type shapefiles were first obtained and compiled in a GIS-based database. The major advantage of employing GIS in rainfall-runoff modeling is that more accurate sizing and catchment characterization can be achieved. Furthermore, the analysis can be performed much faster, especially when there is a complex mix of land use classes and different soil types.

The curve number for each polygon was determined from the soil and land use information. The weighted area curve number has been determined in order to find a representative curve number by integrating attributes of various thematic layers in GIS using the areas of the different land cover and soil types as a weighting factor. The curve numbers are assigned by integrating land use and land cover with the soil map. Based on the results of soil classification and land use, the study area was classified into three hydrologic soil groups (B,C,D). The weighted curve number was first obtained for AMC-II and then estimated to AMC-I or AMC-III depending on the 5-day antecedent rainfall depth that depends on the dormant or growing season.

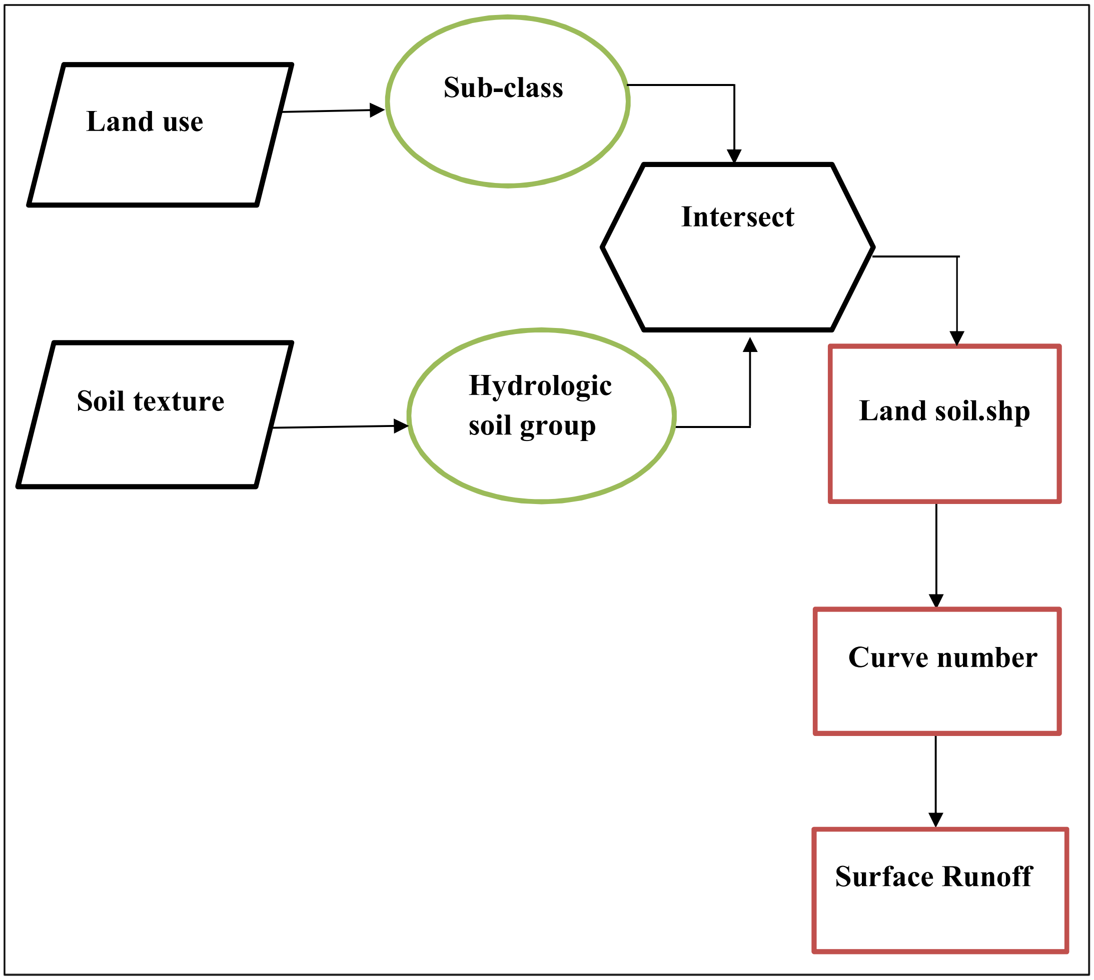

Figure 3.4 Flow chart for surface runoff estimation

In this study, the integration between SCS Curve number method with Geographic Information System (GIS) was able to provide the estimation of runoff value. Soil and land use datas were used as input. The thematic maps such as Land use/ Land cover and soil map were prepared in the Arc GIS environment and intersected using GIS techniques to generate new and smaller polygons associated with HSGs and land use cover names. This step keeps all the details of the spatial variation of soil and land use. The curve number database was built based on the intersected land, soil layer. All input and output are stored in the newly generated layer after intersection and operation were performed.

Generation of curve number requires a Hydrological soil group (HSG) map, land use land cover map and drainage boundaries. Hydrologic soil groups play an important role in the determination of surface runoff. Soil texture is very important for hydrologic soil group determination. Soil textures are classified by the fractions of each soil separate (sand, silt, and clay) present in a soil. From different kinds of literature and USDA guidelines, the hydrologic soil group of the watershed was determined depending on soil texture.

Table 3.2 Hydrologic soil group for USDA soil texture classes

Soil texture	**Hydrologic Soil Group(HSG)**
Sand, loamy sand, sandy loam	A
Loam, Silt loam, silt	B
Sandy clay loam	C
Clay, clay loam, silt clay, sandy clay, silty clay loam	D

Clay, clay loam and silty clay loam are classified as fine-textured soils while sandy clay loam, loam, and silt loam are classified as medium textured soils and the others like sandy soils are classified as coarser-textured soils.

Table 3.3 Soil infiltration rate

Hydrologic soil group	**Minimum infiltration rate (mm/hr)**
A	7.6 - 11.4
B	3.8 - 7.6
C	1.3 - 3.8
D	0 - 1.3

Source: Soil Conservation Service classification (USDA, 1974)

Infiltration is the process when rain or irrigation water which is supplied to a field seeps into the soil. The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles). The infiltration rate of soil depends on different factors. Soil texture is an important determining factor. In sandy soil, the infiltration rate is higher than in silty soil.

Table 3.4 Curve number values for land use and hydrologic soil classes.

Land use categories	Hydrologic soil group			
	A	B	C	D
Settlements	80	85	90	95
Open grass land	68	79	86	89
Water body	100	100	100	100
Open shrub land	49	69	79	84
Cultivated land	67	78	85	89

Source: (United States Department of Agriculture, 1986)

The primary goal of using the SCS-CN method for this study is to determine the runoff amounts that result from rainfall events to manage and save water for future demand. SCS-CN method provides an empirical relationship for estimating surface runoff. The standard SCS-CN method is based on the following relationship between rainfall, P (mm), runoff, Q (mm) and initial abstraction (I_a).

Initial abstraction is all loss before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation and infiltration. I_a is highly variable but generally is correlated with soil and land cover parameters. The method is based on an assumption of proportionality of the following form (SCS, 1972).

$$\frac{P - I_a - Q}{S} = \frac{Q}{P - I_a} \tag{3.3}$$

Where, P = total storm rainfall,

Q = actual direct runoff,

S = potential maximum retention, and

I_a = initial abstraction.

Solving for Q from Eq. (3.3) leads to the following.

$$Q = \frac{(p - I_a)^2}{p - I_a + S} \tag{3.4}$$

Where, Q = runoff (mm),

P = rainfall (mm),

S = Potential maximum retention after runoff begins,

I_a = initial abstracts (mm)

The surface runoff depth was computed using the curve number method developed by the Soil Conservation Service Curve Number (SCS-CN) of the United States Department of Agriculture (USDA, 1986). To calculate the runoff depth, the rainfall of the area from 1987-2016 for 30 years was considered.

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{3.5}$$

Where, Q = runoff depth (mm),

P = Average monthly precipitation (mm),

S = potential maximum retention after runoff begins (mm)

The maximum water retained in the watershed estimated as:

$$S = \frac{25400}{CN} - 254 \tag{3.6}$$

The curve number (CN) was computed based on the hydrological soil group and land cover of the study area. A high value of CN implies a higher potential generation of runoff and has a range of 0–100 (NRCS, 2004).

An area-weighted average curve number for the entire watershed is used to estimate the runoff depth of a watershed. For a watershed with sub-areas that have different soil types and land covers, a composite curve number is determined by weighting the curve number values for the different sub-areas in proportion to the land area associated with each. Area weighted composite curve number for various conditions of land use and hydrologic soil conditions are computed as follows:

$$CN_C = \frac{CN_1 A_1 + CN_2 A_2 + \ldots + CN_i A_i \ldots + CN_n A_n}{\sum_{i=1}^{n} A_i} \tag{3.7}$$

Where, CN_C = the weighted CN for the watershed,

CN_i = curve number for each land use land cover and soil group polygons,

A_i = area of each polygon,

n = number of a polygon in each drainage basins.

SCS developed three antecedent soil-moisture conditions and labeled them as I, II and III according to soil conditions and rainfall limits for dormant and growing seasons.

Antecedent Moisture Condition (AMC)

Antecedent soil moisture condition is defined as the wetness index of the soil. Antecedent moisture is the relative wetness or dryness of a watershed, which changes continuously and can have a very significant effect on the flow during wet weather. Antecedent moisture conditions are high when there has been a lot of recent rainfall and the surface is moist. Antecedent moisture conditions are low when there has been little rainfall and the surface becomes dry. Antecedent soil moisture condition had a significant effect on runoff and an increase in value indicates an increase in runoff.

Table 3.5 Classification of Antecedent Moisture Conditions

Antecedent moisture condition	**Five day antecedent rainfall in mm**	
	Dormant season	**Growing season**
I	< 12.5	< 35
II	12.5 – 27.5	35-52.5
III	>27.5	>52.5

AMC is an indicator of watershed wetness and the availability of soil storage before a storm. The CN values were adjusted based on AMC. Three levels of AMC are used: AMC-I for dry, AMC-II for normal and AMC-III for wet conditions. The CN values were adjusted based on the season and 5-day antecedent precipitation (Viji *et al.,*2015). Mathematically, adjustment to CN values for the cases of AMC-I and AMC-III conditions was estimated by using the following equations (Schiariti,2010).

AMC I: The soils are practically dry (i.e. the soil moisture content is at the wilting point).

$$CN_I = \frac{4.2CN_{II}}{10 - 0.058CN_{II}} \tag{3.8}$$

AMC III: The soils are practically saturated from antecedent rainfalls (i.e. soil moisture content is at field capacity).

$$CN_{III} = \frac{23CN_{II}}{10 + 0.13CN_{II}} \tag{3.9}$$

3.7 Assessment of Land Suitability for Surface Irrigation

Land evaluation is primarily the analysis of data about the land, its soils, climate and vegetation in terms of realistic alternatives for improving the use of that land. The assessment of land suitability for a particular irrigation system, a well-developed and suitable database and framework is quite important. Suitability of land for surface irrigation method and the given land utilization types was assessed by using GIS techniques. Factors that affect the suitability of an area for surface irrigation were identified based on literature and expert opinion. Identification of suitable land for surface irrigation was carried out by considering the suitable slope, suitable soil texture, depth, drainage and land cover/use. Irrigation suitability of each physical land parameter had been classified based on the FAO guideline for land evaluation in to S1, S2, S3 and N suitability classes independently in which the final potentially irrigable land has been identified by weighting the factors of suitability.

3.7.1 Slope suitability analysis

Slope is the most important topographic factor to identify suitable sites for surface irrigation. To derive the slope suitability map of the study area, 30 m spatial resolution DEM was used to generate slope by using ArcGIS 10.4 from spatial analysis tool-surface-slope. The Slope derived from the DEM was classified based on the classification system of FAO (1996) using the “Reclassification” tool, which is an attribute generalization technique in ArcGIS.

First Rating factors were given for each slope gradient of the study area based FAO guidelines. Using this rating the watershed was reclassified into four classes according to its land qualities and characteristics of the slope for the selection of the land for suitability of surface irrigation potential. The four classes of slope for surface irrigation suitability were, from 0-2% as highly suitable (S1), 2-5% as moderately suitable (S2), 5-8% as marginally suitable (S3) and >8% as not suitable (N). This type of land classification is very common and widely used in many scholars and recommended by FAO guidelines (FAO, 2006).

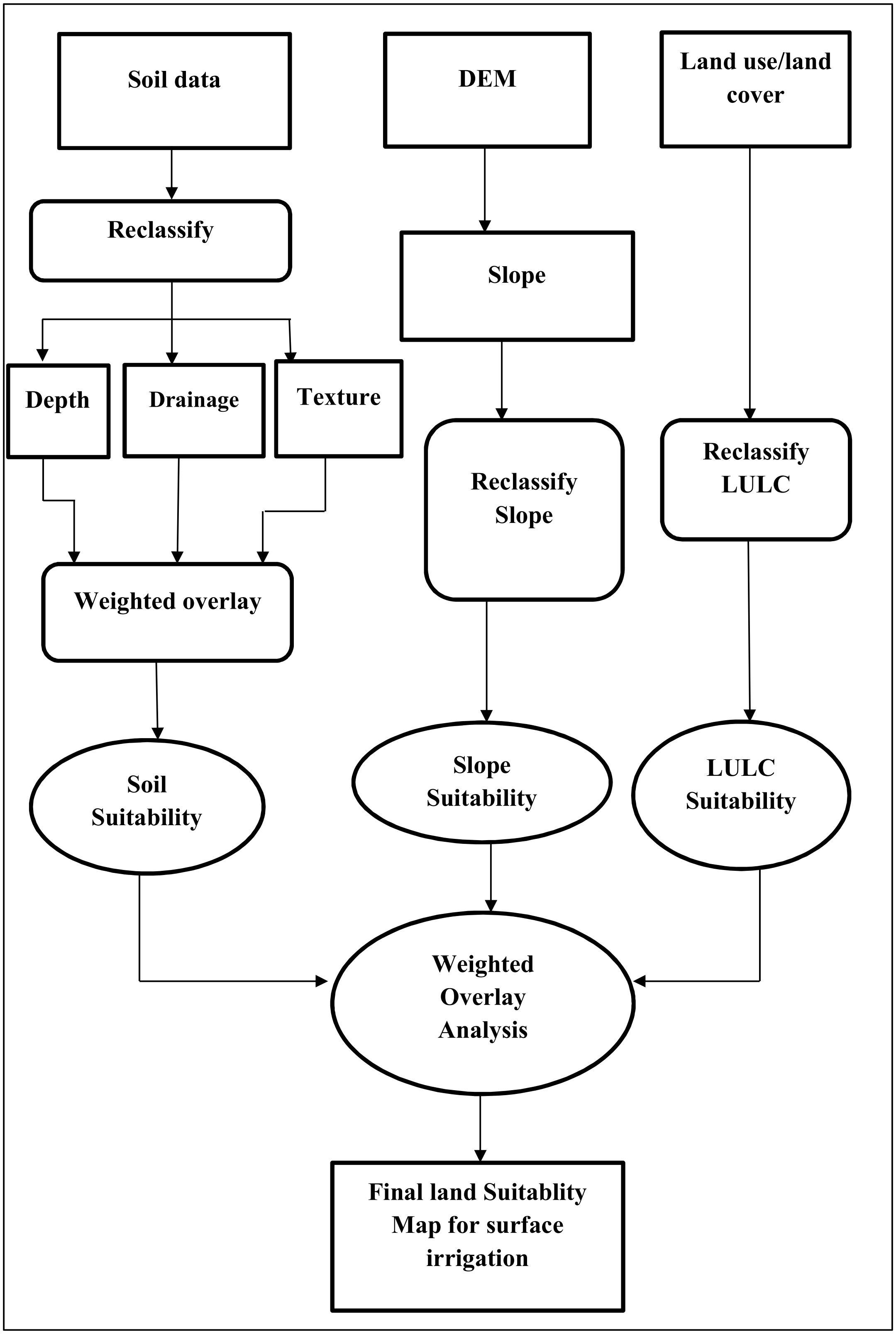

Figure 3.5 Flow chart of land suitablity for surface irrigation

Table 3.6 Slope Suitability Classification for surface irrigation

S.N	Slope type	Slope range (%)	Factor Rating
1	Horizontal	0-2	S1
2	Very flat	2-5	S2
3	Flat	5-8	S3
4	Steep	>8	N

Source: FAO (1996), an interactive multi-criteria analysis for land resource appraisal.

The reclassified raster slope map of the area was converted to a polygon (feature) using the conversion tool on Arc GIS 10.4 and the area of each polygon was calculated on the attribute table of the slope shape file.

3.7.2 Soil suitability analysis

Physical soil properties are the most dominant factors that determine the land suitability for irrigation. Those soil properties are including soil depth, soil texture and soil drainage. Soil drainage, texture, and soil depth were extracted from the soil map for the suitability rating. The soil map was redefined into four classes specifying its suitability for surface irrigation. First preparing soil feature layers of each physical soil parameters; soil texture, soil drainage and soil depth then, the feature layers were converted into raster layer using the conversion tool "To Raster". The soil vector layer was converted into a raster layer using conversion tools- to raster-feature to raster in the Arc GIS. The rasterized soil map of the study area was then reclassified based on texture, depth and drainage classes.

Finally, soil suitability map of each soil physical parameter was developed with the factor rating of S1, S2, S3, and N through reclassified the raster layers based on the FAO soil classification guideline. To identify potentially suitable soils for the intended irrigation system, the three soil suitability factors (depth, texture and drainage) were weighted on Arc GIS 10.4. In the soil suitability evaluation of a percent influence for weighted overlay analysis were taken 1 by 4 by 1(a scale for overlay analysis). The percentage of influence was given to soil in an equal manner in the weighted overlay analysis.

In the way of weight overlay tool in spatial analyst tool (Arc GIS version Spatial analyst > overlay > weighted overlay analysis) three determinants reclassified raster soil map was performed to determine soil suitability for surface irrigation. Then the new value was reassigned for each soil factor. The new value was given based on a common evaluation scale factor rating from 1 to 4 for weighted overlay analysis. 1 represent highly suitable, 2 represent moderately suitable, 3 represent marginal suitable and 4 represent not suitable area of land and the percentage (%) of influence was given to soil in an equal manner in the weighted overlay analysis on Arc GIS 10.4. The factor of rating for each selected soil physical parameters was shown below.

Table 3.7 Soil suitability factor rating

S.N	**Soil texture Class**	**Soil Depth Range(cm)**	**Soil Drainage**	**Factor Rating**
1	C, SiC, SC	>120	Well	S1
2	Si-CL,CL-C	100-120	Imperfectly	S2
3	SL, SCL	50-100	Poor	S3
4	Course Sand	< 50	Very poor	N

C = Clay, SC = Sandy Clay, SiC = Silty Clay, Si = Silt, L = Loam, CL = Clay Loam, Si-CL= Silty Clay Loam, SCL = Sandy Clay Loam, SL = Sandy Loam

(Source: FAO guideline for land evaluation (1991) modified by the OWWDSE land evaluation team based on practical observation (2010).

3.7.3 Land use land cover suitability analysis

LULC map of the watershed was rasterized and used in the evaluation process to identify potentially suitable sites for surface irrigation.The land use types in the watershed are discussed below.

Cultivated land: Areas used for crop cultivation and grouped as highly suitable for surface irrigation systems. This land cover type is the dominant and relatively large as compared to the other land cover types, which covers 1692 ha of the total area of the watershed.

Grassland: Land area covered by open grass used for grazing purpose or pasture, which covers 33.4 ha of the total area of the watershed.

Shrubland: An area dominated with shrubs, bushes and small trees mixed with some grasses. Lands covered by small trees, bushes or a mixture of small trees and small grasses are categorized as moderately suitable for surface irrigation systems, which covers 368 ha of the watershed.

Settlement: This land cover class covers local areas which covering an area of 75 ha of the total area of the study.

Waterbody: This land unit covers some part in the study area occupying 1.6 ha of the watershed land area.

Table 3.8 Land use/land cover suitability criteria

Category	Suitability class	Description of land cover types
S1	Highly Suitable	Cultivated – dominantly, moderately Grassland – open, bushed, shrubbed Bushland – open, riparian
S2	Moderately suitable	Woodland – open, riparian Bushland - dense
S3	Marginally suitable	Forest - open Cultivated – Irrigation, state farm
N	Not suitable	Woodland – dense Bamboo Urban area

Source: FAO (1996) an interactive multi-criteria analysis for land resource appraisal

3.7.4 Weighing of irrigation suitability factors

Potentially irrigable land was obtained by creating irrigation suitability analysis which involved the weighting of values of all data sets such as soil, slope, land use and land cover. Weighted overlay is one method of modeling suitability. ArcGIS uses the following process for this analysis. Each raster layer is assigned a weight in the suitability analysis. Assigning a weight to each raster in the overlay process allows controlling the influence of different criteria in the suitability model.

After irrigation suitability parameters were assessed and their suitability map layer of each criteria was developed separately, an overlay analysis was done to generate one suitability map. Potentially irrigable areas were obtained using soil suitability, slope suitability and land use land cover suitability on Arc GIS 10.4 through weight overlay analysis. To identify potentially irrigable land for surface irrigation, The three suitability parameters identify potentially irrigable sites in the watershed as highly, moderately, marginally and unsuitable class for surface irrigation development.

3.7.5 Analytical hierarchy process

Land suitable for surface irrigation was determined with a GIS-based multi-criteria evaluation, which considers the interaction of slope, soil and land use land cover. First, the suitability factor has to be identified and these are soil factors (texture, drainage, and depth), land use land cover and slope ranges of the watershed. One of the benefits of using AHP method is that it allows the users to focus judgment separately on each of several properties essential for making a sound decision (Saaty, 1980).

The weights were developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. In pairwise comparison, each factor was matched head-to-head (one to one) with each other and a pairwise or comparison matrix was prepared to express the relative importance. A scale of importance was divided from a value of 1 to 9. The available values for the comparison are the member of the set: {9, 7, 5, 3, 1, 1/3, 1/5, 1/7, 1/9}, with 9 representing absolute importance and 1/9 the absolute triviality (Saaty, 1991).

The importance or preference of each criterion relative to the rest of the criteria on suitable land selection for surface irrigation was expressed by assigning weights. This was done based on related review literature, field observation and on expert judgment to fill out a pairwise comparison matrix from which a set of weights referred to as Eigenvectors together with consistency ratios were generated for each of the criteria being considered. (Cherenet *et al*., 2010). The procedure for using AHP can be summarized as:

1. Model the problem as a hierarchy containing the decision goal, the alternatives for reaching it and the criteria for evaluating the alternatives.

2. Establish priorities among the elements of the hierarchy by making a series of judgments based on pairwise comparisons of the elements.
3. Synthesize the judgments to yield a set of overall priorities for the hierarchy.
4. Check the consistency of the judgments.
5. Come to a final decision based on the results of the process

Table 3.9 AHP method for pairwise comparsion matrix

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance of one over the other	Experience and judgment strongly favor one activity over another
5	Essentials of strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in the practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate value between the two adjacent judgment	When compromise is need
Reciprocals	Values of inverse comparison	Invers of the first to the other activity

Source (Saaty, 1991)

3.8 Computation of Irrigation Water Requirements

Reference evapotranspiration, effective rainfall, crop pattern data, and soil data were used for CropWat model analysis. It is a decision-support computer program developed by the FAO to calculate reference evapotranspiration (ETo), crop water requirement (CWR), irrigation scheduling and irrigation water requirement (IR) using rainfall, soil, crop and climate data. The major crops identified from the survey analysis were used in the calculation of crop water requirements. First, monthly maximum and minimum temperature, relative humidity, sunshine hour and wind speed data were fitted in CropWat 8.0 model. Then, the model calculated crop evapotranspiration values based on the FAO Penman-Monteith equation. Methodologies for crop water requirements have been developed to predict the amounts of water needed to obtain optimal crop yields based on climatological data, crop coefficients and to some extent by taking into account the influence of other factors on CWR.

The panel of experts recommended the adoption of the Penman-Monteith method as a standard in estimating ETo and is considered as the more accurate method to calculate ETo. CROPWAT 8.0 software allows the user to either enter measured ETo values or to input data on temperature, humidity, wind speed and sunshine hours which allows CROPWAT to calculate ETo using the penman-Monteith formula.

The crop water use can be determined by multiplying the reference ETo by a crop coefficient (Kc). The crop coefficient adjusts the calculated reference ETo to obtain the crop evapotranspiration. The values of ETc and CWR (Crop Water Requirements) are identical, whereby ETc refers to the amount of water lost through Evapotranspiration and CWR refers to the amount of water that is needed to compensate for the loss. ETc can be calculated directly from ETo and Kc.

$$ETc = ETo * Kc \tag{3.10}$$

Where, ETc = crop Evapotranspiration,

ETo = Reference Evapotranspiration and

Kc = crop coefficient

ETo is the rate of evaporation from an extensive surface of green grass cover of uniform height, actively growing, completely shading the ground and with no shortage of water and expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors. Kc is the crop coefficient during the initial, mid and development stages. Different crops will have a different crop coefficient and resulting water use. Kc data can be obtained from FAO references, guidelines and from different literatures for each of the proposed crops. The values of Kc are varying with the crop types, its stage of growth, growing season and the prevailing weather condition. ETc was calculated using CROPWAT version 8.0 and Kc values present the relationship between reference ETo and crop evapotranspiration.

Net irrigation water requirement depends on the climate and cropping pattern. The mean monthly rainfall data and Hydro-Meteorological data are used in calculating the net irrigation requirements for dominant crops in the study area. The different losses such as runoff, seepage, evaporation and percolation take place during the application and transport of irrigation water. Operations such as leaching, transplantation and land preparation require certain amounts of water. Thus, CWR includes ET, losses during the application of water needed for these purposes (salam *et al*.,2019).

$$NIR = ETc - P_{ef} \tag{3.11}$$

Where, NIR = the net irrigation requirement of crops,

ETc = crop Evapotranspiration

P_{ef} = effective rainfall.

Effective rainfall (P_{ef}) is the portion of rain, falling during the growing period of the crop, which is available to meet the consumptive water need or the evapotranspiration the requirement of the crop. It is the part of the rainfall that is effectively used by the crop after losses by surface runoff and deep infiltration. The average rainfall for 30 years is used and the data on the monthly basis was given in CROPWAT for calculating effective rainfall. Rainfall data from 1987-2016 was taken to calculate effective rainfall and USDA Soil Conservation Service method was selected from the four methods(Fixed percentage, dependable rain empirical formula, USDA Soil Conservation Service) given in CropWat 8.0 model.

Gross irrigation water requirements of the crops at the identified potential irrigable sites were estimated based on efficiency from the source to the identified command area. Then, gross irrigation water requirement was computed using the following formula;

$$GIWR = \frac{NIR}{E} \tag{3.12}$$

Where, GIWR = the gross irrigation requirement of crops and

E = overall Efficiency of irrigation in percentage.

The irrigation efficiency expresses the percentage of the quantity of water used efficiently for the growth of the crop in the field to the quantity of intake water from the water source. In the Ethiopian standard of surface irrigation system, E mostly accounts in the range of 40% up to 60% under surface irrigation system. However, for the estimation of gross irrigation requirements in the study area, E was taken as 50% for surface irrigation.

3.9 Optimization of Cropping Pattern

Optimization of cropping pattern plays an important role in high benefit and water-saving agricultural management. An optimal cropping pattern depends upon the water availability to meet the maximum crop production as well as the maximum economic benefits. Model development, use of tool to find an optimal solution and sensitivity analysis to evaluate the solution are the three main steps for working with optimization.Linear programming model was formulated to optimize the cropping pattern aiming at maximizing net benefits and efficient allocation of scarce water resources and arable land among the competing crops.

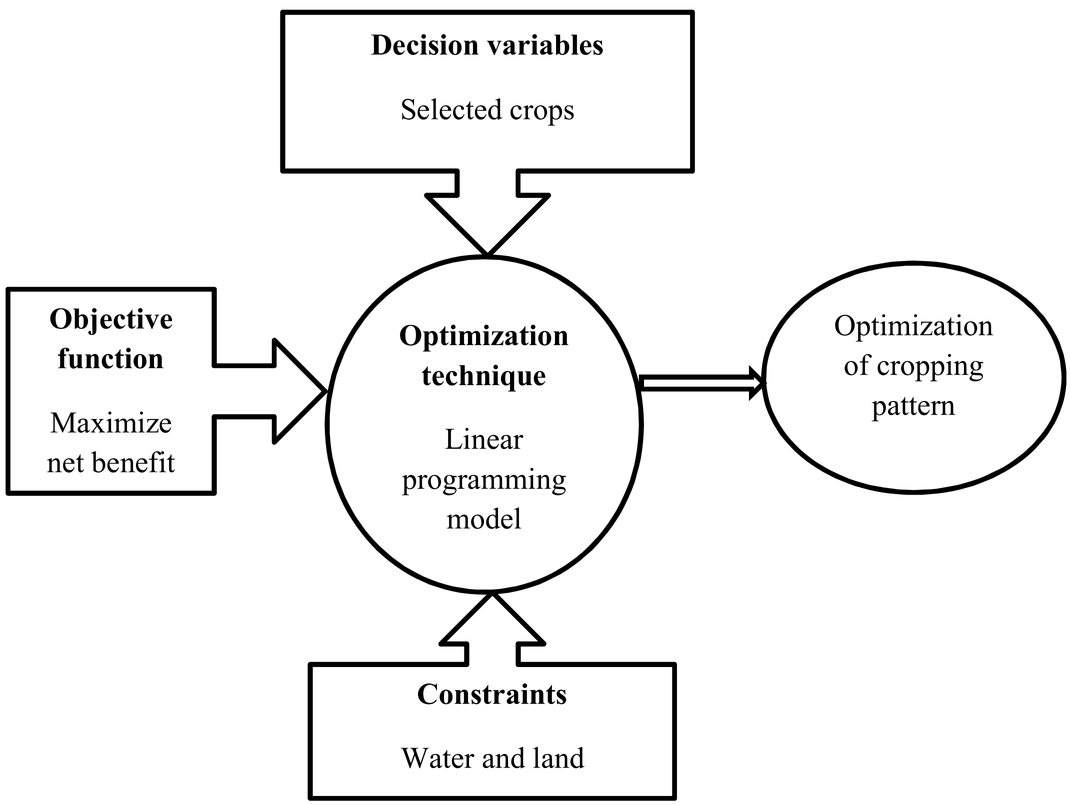

Figure 3.6 Flow chart for optimization of cropping pattern

This study was intended to optimize the cropping pattern to produce the maximum benefit of agricultural products. The optimization analysis was carried out by using linear programming. The linear programming model quantifies an optimal way of integrating constraints to satisfy the objective function. Linear programming model was applied for Danse watershed using agronomic data from 2009-2012. The model aimed to generate desired alternatives for crop area based on maximizing the net benefit per unit of irrigation water and given constraints. The crops selected for the model were the dominant crops in the watershed.

3.9.1 Decision variables

Decision Variables are the combination of mathematical expressions in the objective function to be optimized by the model. The variables which would be found and give the best value for the aim that could be reached. The goal is to find values for the coefficient of decision variables to provide the best rate of the objective function. The decision variables in Danse watershed are the proposed major crops in the cropping pattern. The selected crop types are Onion, Tomato, Cabbage and Wheat. Crops selection was made based on local cropping patterns, farmer's practice, preference, the value of crops to sustain the area with food security and their economic value to improve livelihood and income of the farmers accordingly.

The four decision variables X_1, X_2, X_3 and X_4 and their coefficients C_1, C_2, C_3 and C_4 for study area are presented in table 3.10.

Table 3.10 decision variables

S.N	Crop type	Decision variable	Coefficient
1	Onion	X_1	C_1
2	Tomato	X_2	C_2
3	Cabbage	X_3	C_3
4	Wheat	X_4	C_4

3.9.2 Objective function

The Objective Function is a mathematical expression that combines the decision variables and their coefficients to achieve the goal of maximum farm benefits (Anon., 2001). The study was intended to maximize the difference between gross benefit and costs associated with crop production.

$$\text{Maximize } \; Z=\sum_{i=1}^{N}\left(C_i X_i\right), \text{ for i =1, 2, 3…N} \tag{3.13}$$

Where, Z = total net benefit,

C_i = net benefit from the i^{th} crop and

X_i = crop area under i^{th} crop (ha).

i = an integer about the crop (1, 2…, n)

The objective function was maximization of total benefit in Ethiopian Birr (ETB). Then the decision variables are irrigated land and water for each of four dominant crops in the project area: Onion, Tomato, Cabbage and wheat were determined by maximizing the developed model subject to land and water resources availability constraints.

3.9.3 Constraints

Constraints are mathematical expressions to represent limits in the model related to available resources. The model assesses and identifies possible solutions that respect these limits in order to achieve the optimum objective function.In this study water and land are taken as a constraint.

- **Water availability:**This constraint represents minimization of the use of irrigated water. The total water requirement for different crops should be less than or equal to the total water available at the field during the year. Mathematically expressed as:

$$\sum_{i=1}^{N}(CWR_i A_i) \leq W_t \tag{3.14}$$

Where, CWR_i = water requirement for the i^{th} crop,

A_i = command area under i^{th} crop and

W_t = total water available for irrigation.

i = an integer about the crop (1, 2…, n)

It is necessary to assess the irrigation requirement for various crops for crop management in any area. Hence, crop water requirement for selected crops is determined by using CropWat 8.0.

- **Land area constraints**: The total area allocated for each crop in the season must be less than or equal to the sum of the actual cultivated area. In other words, the sum of the cropped area should not be greater than the total cultivable area.

$$\sum A_i \leq A_T \tag{3.15}$$

Where, A_i = command area of i^{th} crop and

A_T = total available irrigable command area.

i = an integer about the crop (1, 2…, n)

- **Non-negativity constraints**: the non-negativity constraint is all the area should not be less than zero to avoid negative solutions. The negativity constraints with respect to all the decision variables have been imposed. So that, all the decision variables are positive in nature.

$$xi \geq 0 \quad (3.16)$$

The linear programming model was developed to maximize the net benefit per unit of irrigation water and given land constraints. Given the four decision variables (n = 4), then the objective function could be developed as follows.

$$\text{Maximize } Z = C_1x_1 + C_2x_2 + C_3x_3 + C_4x_4 \quad (3.17)$$

Where, C1, C_2, C3 and C_4 represent the net benefit from selected crops,

X_1, X_2, X_3 and X_4 represent the Area of dominant crops.

Net benefit is the difference between gross benefit and production cost.

Gross benefit expressed as:

$$G_B = \sum_{i=1}^{n} \left(P_i Y_i X_i \right) \quad (3.18)$$

Where, G_B = Gross benefit obtained by n crops in area A, in Ethiopian Birr.

P_i = Sale price of the crop product i, in birr per quintal.

Y_i = Yield of i^{th} crop activity, in Qu ha^{-1}

X_i = Irrigated area with crop i, in ha and

i = an integer about the crop (1, 2…, n)

Production cost expressed as:

$$C_T = \sum_{i=1}^{n} C_i X_i \quad (3.19)$$

Where, C_T = Total production cost (Birr)

C_i = the production cost for crop i (Birr/ha)

Then the objective function becomes

$$N_B = \sum_{i=1}^{n}(P_iY_iX_i) - \sum_{i=1}^{n}(C_iX_i) \tag{3.20}$$

Where, N_B = the net profit (Birr)

Data collected for the cost of production studies includes all of the requisite baseline requirements for the calculation including data on yields, farm inputs (fertilizer, insecticides, herbicides fungicides and organic manure), agricultural implements number per farm, purchased prices, parts and repair Labour by crop under study.

Table 3.11 Average cost of production and selling price (2009-2012)

Crop Type	**Selling price (Birr/Qt)**	**production rate(Qt/ha)**	**Gross benefit (Birr/ha)**	**Production cost(Birr/ha)**
Onion	1725	246	424,350	109,069
Tomato	1550	339	525,450	225,394
Cabbage	1175	208	244,400	71,603
Wheat	1560	194	302,644	117,470

Sources: Data from farmers and local agricultural center.

The objective function can be extended after calculating all the available data. The formulated LP model based on summarized data was given by:

Maximize $Z = 315,281x_1 + 300,056x_2 + 172,797x_3 + 185,174x_4$ (3.21)

Subject to constraints:

- Constraint on gross water requirement of crops

$$8204x_1 + 8084x_2 + 8454x_3 + 5376x_4 \le 6,213,333 \text{ m}^3 \tag{3.22}$$

- Constraints on land allocation

$$x_1 + x_2 + x_3 + x_4 \le 192 \text{ ha} \tag{3.23}$$

- Non - negativity constraint

$$x_1 \ge 0, x_2 \ge 0, x_3 \ge 0, x_4 \ge 0 \tag{3.24}$$

- **Practical codding in LINGO software**

```
!   Model;
! Objective function: Max Z = { };
      Subjected to;
! Constraints: water avalablity { };
            : land area  { };
        ! End
```

4. RESULTS AND DISCUSSION

4.1 Surface Water Availability Assessment

It was attempted that the runoff behavior of the study area varied with respect to the land use land cover type, soil condition and rainfall amount. The higher the CN value, the runoff was found to be high while lower CN value accounted for lesser runoff. From the weighted curve number at CN_{II}, the potential maximum retention (S) was 48. Runoff depth from the historical precipitation data of ejere station (1987-2016) from the mean annual rainfall value of 990.5mm was estimated as 859 mm. The expected annual surface runoff volume to be harvested was 8590 m^3/ha or 18.64 Mm^3 for the entire whole watershed (2170ha).

Table 4.1 Annual surface Runoff at different moisture conditions

Description	**AMCI**	**AMCII**	**AMCIII**
Curve Number	69	84	92
Maximum potential retention	114	48	22
Annual runoff depth (mm)	790	859	888
Annual runoff volume (m^3/ha)	7900	8590	8880
Annual runoff volume (Mm^3)	17.14	18.64	19.27

It was attempted that the runoff behavior of the study area varied concerning the land use/land cover type, soil condition and rainfall amount. The higher the CN value, the runoff was found to be high while the lower CN value accounted for lesser runoff.

The total direct runoff volume generated in the watershed was estimated as 8590 m^3/ha and from the whole watershed (2170 ha) a total of 18,640,000 m^3 of runoff volume was generated. However, all runoff volume generated in the watershed was not used for irrigation and 1/3 of runoff from rainfall suggested for other losses or environmental requirements, the rest runoff volume 6,213,333 m^3 can be used by the farmers for crop production.

Similarly, Stephen *et al*. (2018) carried out a study in the Cyili sub-catchment, southern province of Rwanda, which has an irregular rainfall pattern and unexploited runoff water. Soil Conservation Service Curve Number method (SCS-CN) with an average daily rainfall data recorded from 1971 to 2016 was applied to estimate the runoff in the study area. The expected seasonal surface runoff volume to be harvested by the farmers was 3008 m^3 ha per season and 1.29 Mm^3 per season for the entire whole sub-catchment (430 ha).

In addition,the study agrees with the finding of Srivalli and Singh (2017), the Estimation of runoff Potential was carried out for Gadela watershed located in Udaipur district, India by SCS-Curve number approach along with GIS. The calculated average runoff depth from 1995-2014 for 20 years was 184.04 mm from 535.65 mm average rainfall.

4.2 Identification of Potential Irrigable Area

To find suitable land for irrigation, the individual suitability factors consisting of the slope, soil and land use were used as inputs for the irrigation suitability analysis. The factors were prepared for a weighted overlay with Arc GIS Map 10.4 spatial analysis tool. The analysis results of surface irrigation suitability evaluation factors are presented in the following sections.

4.2.1 Slope suitability

The slope suitability table elaborates the total amount of slope classes in the percentage of area coverage and the result shows from highly suitable to not suitable ranges in terms of slope suitability for surface irrigation. Table 4.2 shown that 4.32 % of the total area where highly suitable for surface irrigation, 19.38 % of the total area where moderately suitable, 28.05 % of the total area where marginally suitable and the remain 48.25 % of the total area where currently not suitable for surface irrigation in the study area. Therefore, in terms of slope suitability, most parts of the total area (51.75 %) were potentially suitable for surface irrigation in the study area. Therefore, the results indicated that a large portion of the study area is suitable for surface irrigation in terms of slope suitability.

In agreement with Temsegen and Yonas (2016), the result of land suitability in the Guanghua Badiya river basin of Abaya district Borena zone for the development of surface irrigation system indicated that 9.32% (1303 ha) highly suitable, 32.5% (4558 ha) moderately suitable, 23.82 %(3335 ha)marginally suitable and 34.30 (4802 ha) not suitable for surface irrigation systems. Hence, the majority of the study area is highly to marginally suitable for surface irrigation. The slope suitability map of the watershed and the area coverage was described in Table (4.2) and Figure (4.1) below.

Table 4.2 Slope Suitability Class of the Watershed

S.N	Slope (%)	Suitability classes	Description	Area (ha)	Area (%)
1	0-2	S1	Highly suitable	93.26	4.32
2	2-5	S2	Moderately suitable	420.45	19.38
3	5-8	S3	Marginally suitable	587.01	28.05
4	>8	N	Not suitable	1068.71	48.25
Total				**2170**	**100%**

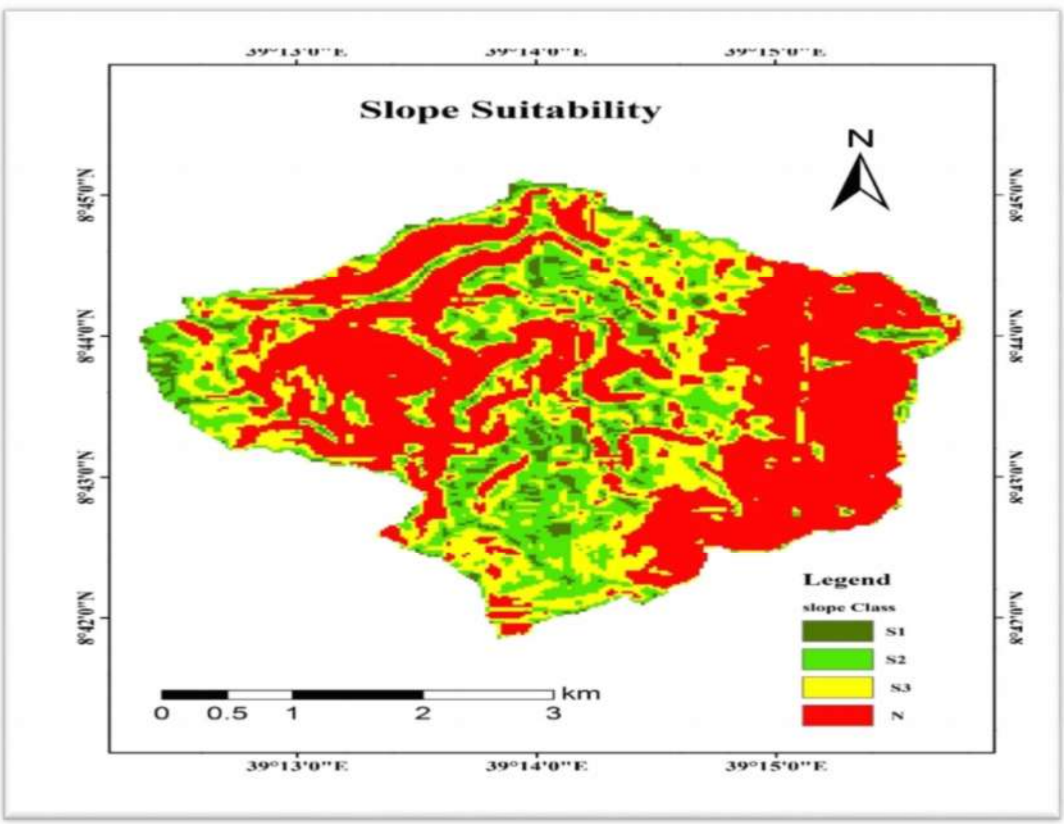

Figure 4.1 Slope suitability map of Danse Watershed

4.2.2 Soil suitability

In soil suitability, different factors affect water holding capacity, infiltration and drainage problem of the soil. To develop surface irrigation within the study area, the most determinant soil suitability rating factors were assessed. There are several soil physical parameters to determine soil suitability analysis, but the three soil physical properties (texture, depth and drainage) were taken into account to evaluate soil suitability in the watershed. The results are presented in the following sub-sections.

4.2.2.1 Soil depth suitability

Soil depth is one of the important physical soil parameters used to evaluate soil suitability for surface irrigation development. Soil depth range was classified into three parts <50, 50-100, >120 cm. Soil depth in Danse watershed was evaluated for surface irrigation in terms of highly suitable, marginally suitable and not suitable class with the area coverage of 54.13, 23.47 and 22.40 (%) respectively. Based on the soil depth assessment most of the study area was dominantly suitable for surface irrigation development. As the result shows, 54.13 % of the total area was highly suitable for surface irrigation development concerning soil depth suitability.

Table 4.3 Soil depth suitability and area coverage in the watershed.

S. N	Soil depth rate(cm)	Suitability classes	Description	Area (ha)	Area (%)
1	>120	S1	Highly suitable	1174.74	54.13
2	50-100	S3	Marginally suitable	509.32	23.47
3	0-50	N	Not suitable	486.15	22.40
Total				**2170**	**100%**

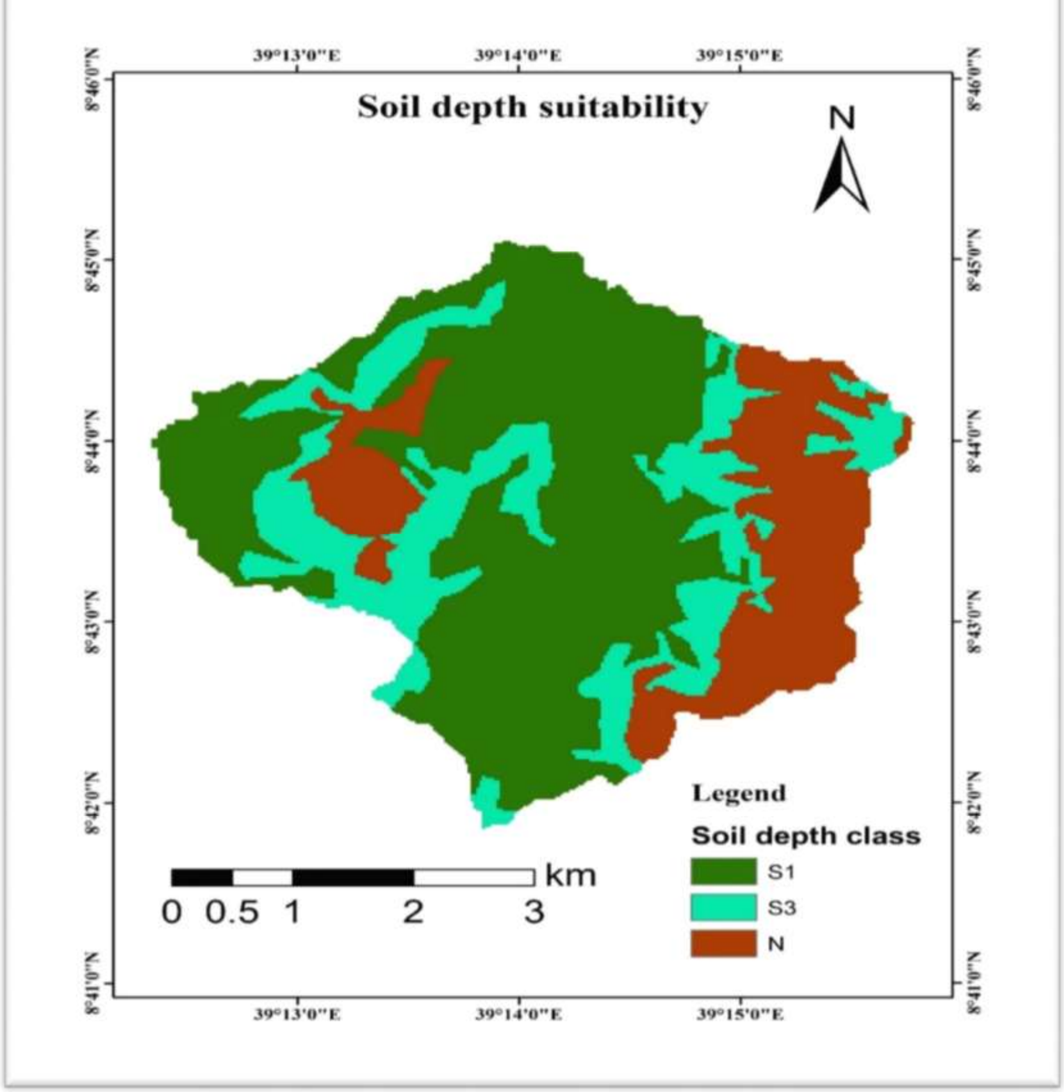

Figure 4.2 Suitability Map of Soil Depth

4.2.2.2 Soil drainage suitability

Soil drainage is an important parameter for evaluation of the area for surface irrigation. The drainage suitability map of the area shows the well-drained area, which covers 23.47 % indicates a highly suitable class and 54.13 % of the area covered by moderately suitable. The remaining unsuitable class or undrained area, which occupies 22.4 % was not suitable for surface irrigation. The soil drainage result analyzed as, Highly suitable drainage classes covers 509.32 ha, moderately suitable drainage classes have an areal coverage of 1174.74 ha and the marginally suitable drainage suitability classes have 486.15 ha of areal coverage.

Table 4.4 Soil drainage Suitability Class of the Watershed

S. N	Soil drainage rate	Suitability Classes	Description	Area (ha)	Area (%)
1	Well drain	S1	Highly suitable	509.32	23.47
2	Imperfect	S2	Moderately suitable	1174.74	54.13
3	poor	S3	marginally suitable	486.15	22.40
Total				**2170**	**100%**

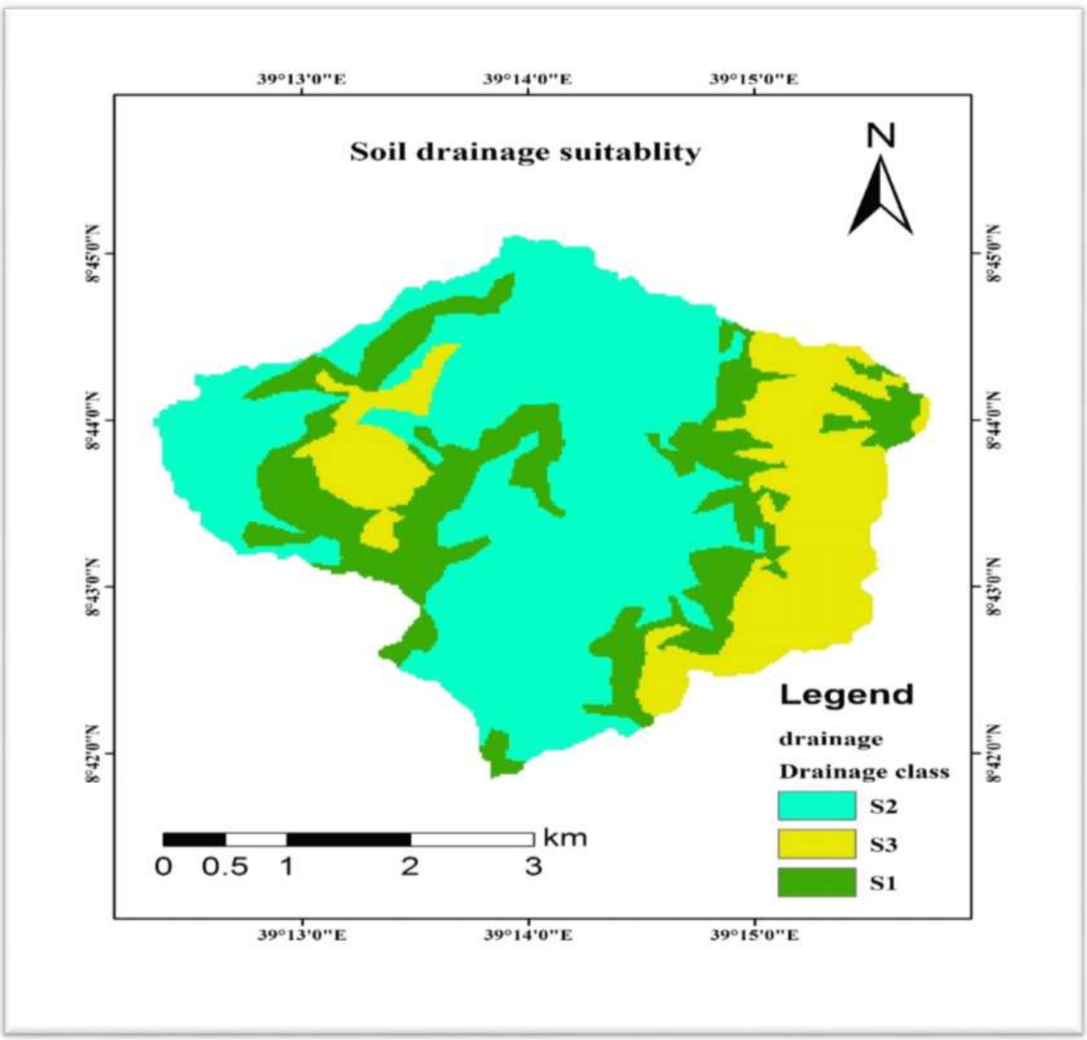

Figure 4.3 Soil drainage suitability of the Watershed

4.2.2.3 Soil texture suitability

Soil textural class suitability analysis for surface irrigation development of the area revealed that 54.13 % of the soils in the area were under highly suitable, 22.47 % of the soil were categorized under moderately suitable class and 23.4 % of the soil textural class in the area were categorized under marginally suitable class.

Table 4.5 clearly shown that 1174.74 ha of the total area was highly suitable for irrigation in the study area and 995.47 ha of the total area where ranges from moderately suitable to marginally suitable classes for surface irrigation. From the result found observed that most of the study area was suitable for potential surface irrigation in terms of soil texture.

Clay texture soils which have a good characterstis for irrigation was categorized as highly suitable class whereas,loam and sandy clay loam soils were categorized as moderately and marginally suitable soil texture classes respectively.

Table 4.5 Soil Texture Suitability Class of the Watershed

S.N	Soil texture	Suitability Factor	Description	Area(ha)	Area (%)
1	Clay	S1	Highly suitable	1174.74	54.13
2	Loam	S2	Moderately suitable	486.15	22.47
3	Sandy Clay Loam	S3	Marginally suitable	509.32	23.40
Total				**2170**	**100%**

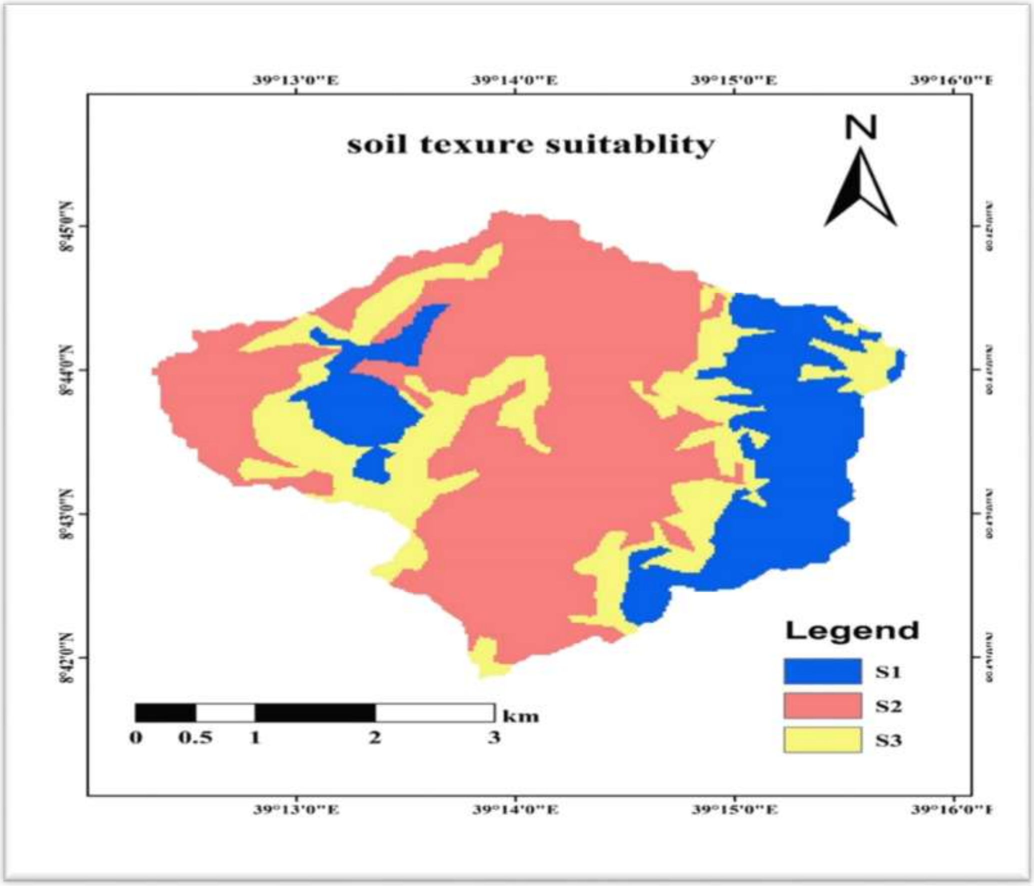

Figure 4.4 Soil Texture suitability of the Watershed

4.2.2.4 Overall Soil Suitability

In the suitability analysis of each parameter, soil depth has three suitability classes (highly suitable, marginally suitable and not suitable classes) for surface irrigation. Soil drainage and soil texture also have three suitability classes in the watershed (highly suitable, moderately suitable and marginally suitable classes).

Table 4.6 over all suitability of soil

S.N	Suitability Factor	Description	Area(ha)	Area (%)
1	S1	Highly suitable	1660	76.4
2	S2	Moderately suitable	509	23.6
Total			**2170**	**100%**

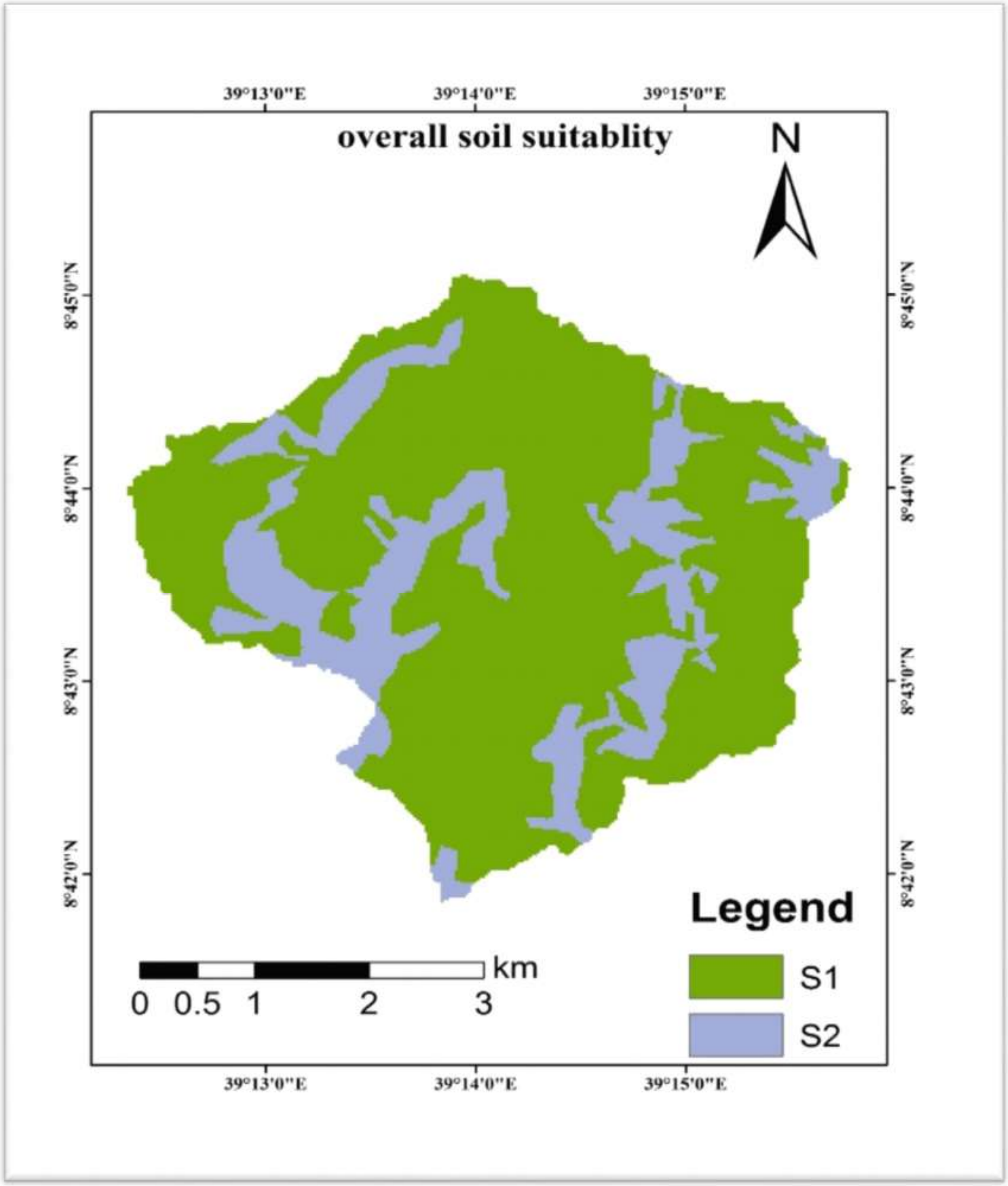

Figure 4.5 Overall soil suitability of Danse watershed

From figure 4.7 observed that the overall soil suitability of Danse watershed is cover by highly and moderately suitable classes for surface irrigation purpose. The soil suitability classes indicate 76.4 % of the area of the watershed was in the range of highly suitable and 23.6% of the watershed was categorized under moderately suitable class with respect to the combined effect of soil texture, depth and drainage classes. Therefore, the two suitability classes indicated that the soil of Danse watershed is suitable for surface irrigation. Similar finding reported by Fisum (2017) in overall soil suitability the result were obtained only two suitability classes. However, suitability classes are quite different. The classes are marginal and moderately suitable on the same influence of the weight of soil drainage, soil texture and soil depth. Due to soil suitability classification, most of the study area was categorized under marginal suitable which covers the area 29,410ha (80.69%) and the area 7040ha (19.31%) is moderately suitable. there is no area under highly and not suitable based on overall soil suitability for surface irrigation.

4.2.3 Land Use / Land Cover Suitability

According to land use/land cover suitability classification, most of the watershed area was categorized as highly suitable for surface irrigation. In this study, cultivated land use types were classified as highly suitable (S1) which covers 78 % of the watershed area. grassland, which requires land clearing and leveling classified as moderately suitable (S2) and covers 1.49 % of the total area. Shrub land, which requires higher initial investment for land preparation, were reclassified as marginally suitable (S3) with 16.95 % of area coverage. Settlement and water body were reclassified as not suitable (S4) with area coverage of 3.55 % of the watershed.

Table 4.7 Land use/ land cover Suitability Class of the Watershed

S.N	**Landuse type**	**Suitability Factor**	**Description**	**Area(ha)**	**Area (%)**
1	Cultivated	S1	Highly suitable	1692.29	78.02
2	grassland	S2	Moderately suitable	32.28	1.49
3	Shrubland	S3	Marginally suitable	367.81	16.95
4	settlement	N	Not suitable	75.84	3.45
5	waterbody	N	Not suitable	1.6	0.10
Total				**2170**	**100%**

The results clearly show that from the total area of the watershed 96 % (2092 ha) of the land use land cover type was suitable for surface irrigation. The remaining 4 % (77 ha) of the land was not suitable for irrigation.

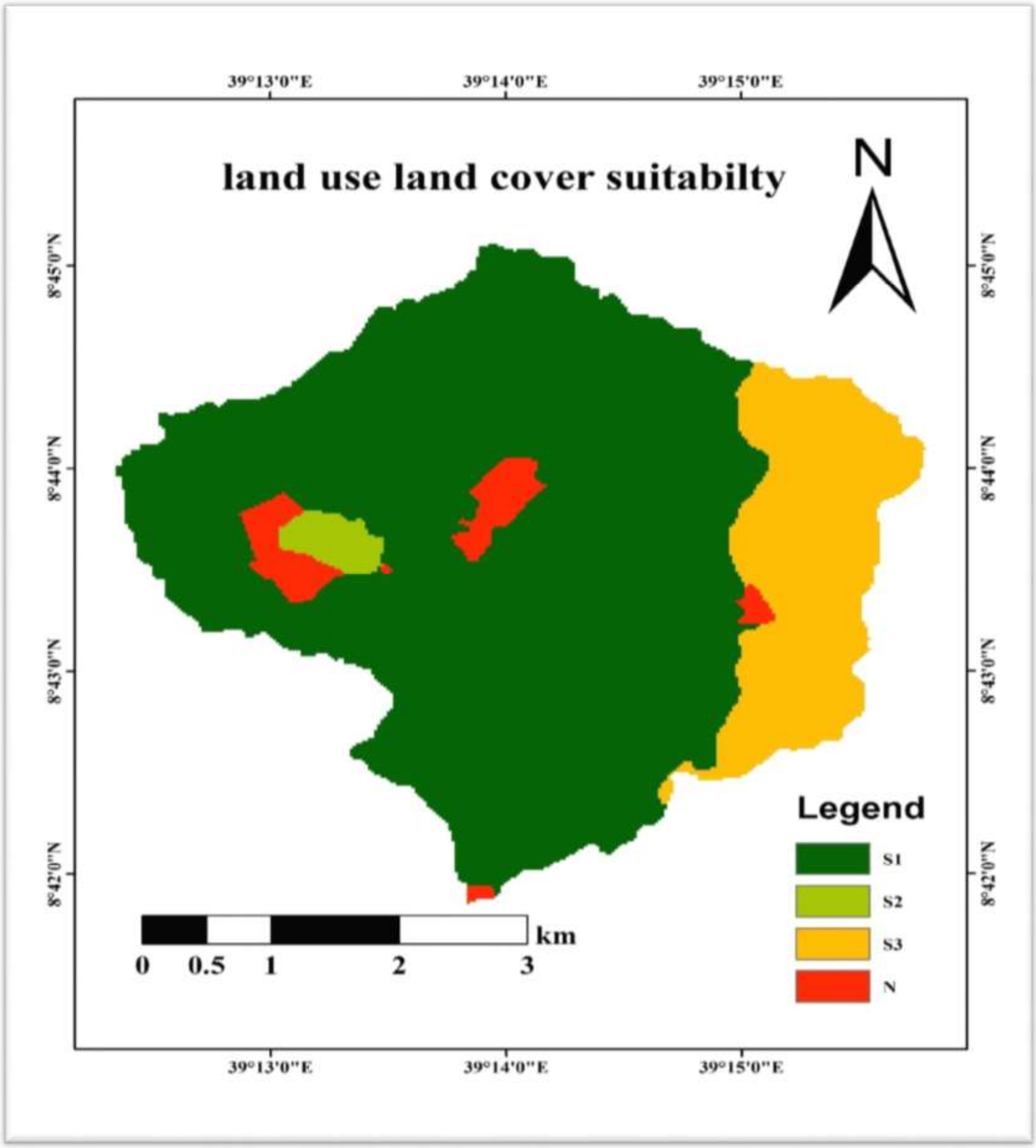

Figure 4.6 Land use/land cover suitability of the Watershed

4.3 Suitable land for surface irrigation

Potential irrigable sites were obtained using soil suitability, slope suitability and land use land cover suitability on Arc GIS 10.4 employing weight overlay analysis. Potentially irrigable land for surface irrigation in the watershed was identified based on their area coverage and geographic location.

4.3.1 Weighted suitability Analysis

Land suitability was determined by assigning weights to the factors that likely affect the irrigation potential of a certain land area. The determined relative importance values were used in the weighted overlay analysis. Factors derived have different degrees of influence on suitability evaluation. The factors considered in this study are slope, soil and land use land cover. The relative importance of each parameter has been determined. Therefore, the higher the weight, the more influence a particular factor would have on suitability evaluation. The final criteria weight in percentage analyzes of LULC, Soil and slope Suitability Factor Analysis was shown in Table 4.8 below.

Table 4.8 Weight of factor from comparison matrix

Factors	**Slope**	**Soil**	**LULC**	**Weighted factor**	**Weighted percentage**
Slope	1	3	5	0.632	**63.2%**
Soil	1/3	1	3	0.257	**25.7%**
LULC	1/5	1/3	1	0.106	**10.6%**
Total	**1.53**	**4.33**	**9**	**1**	**100%**

CR= 0.01

The result of the pairwise comparison matrix showed that the major factors were compared one to one and scored using a scale developed by saaty (1991). In the weighted overlay analysis, high weight of percentage influence was given for slope, since it is the main determinant factor in the evaluation of the given area for surface irrigation development. The credibility of the pairwise matrix consistency was evaluated using a consistency ratio. In the weighted overlay analysis, the consistency ratio (CR) is less than 0.1; which implies, the Consistency was in the acceptable range. Similarly, Getenet et al. (2019), found the consistency ration of 0.067 which was acceptable for weighting the factors to evaluate the physical land in Jabitenan district to develop irrigation suitability maps.

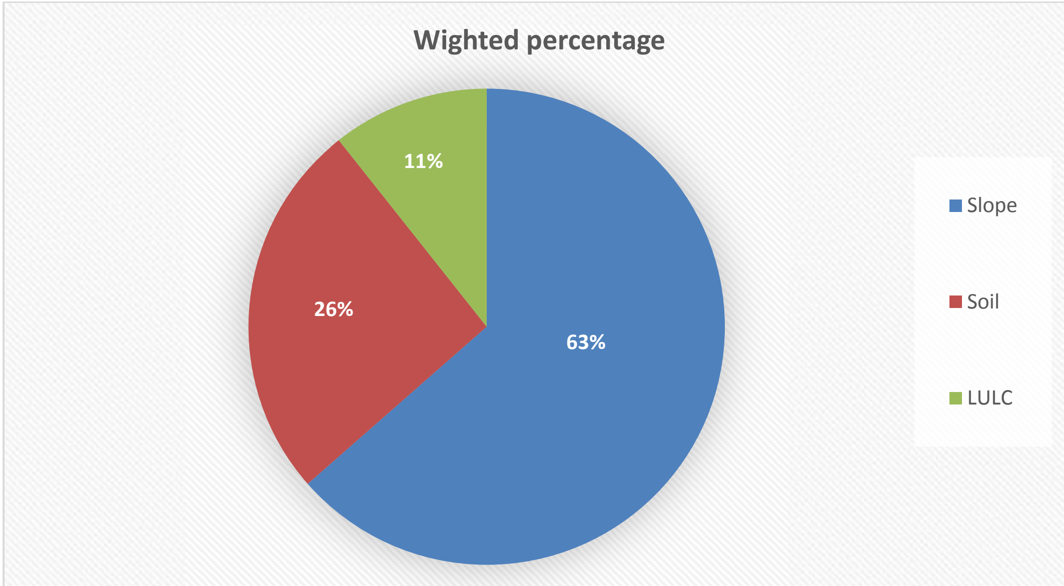

Figure 4.7 Weighted percentage influence of suitability factors

4.3.2 Potential Suitable Land for Irrigation

The final suitable area for surface irrigation was elaborated in a percentage layout where; S1, S2, S3 and N stands for highly, moderately, marginally and not suitable class for surface irrigation development respectively.

Table 4.9 Suitability Class of the Watershed

S. N	Suitability Factor	Description	Area(ha)	Area (%)
1	S1	Highly suitable	85.36	3.93
2	S2	Moderately suitable	1475.68	68.00
3	S3	Marginally suitable	576.67	27.50
4	N	Not suitable	4.78	0.57
Total			**2170**	**100%**

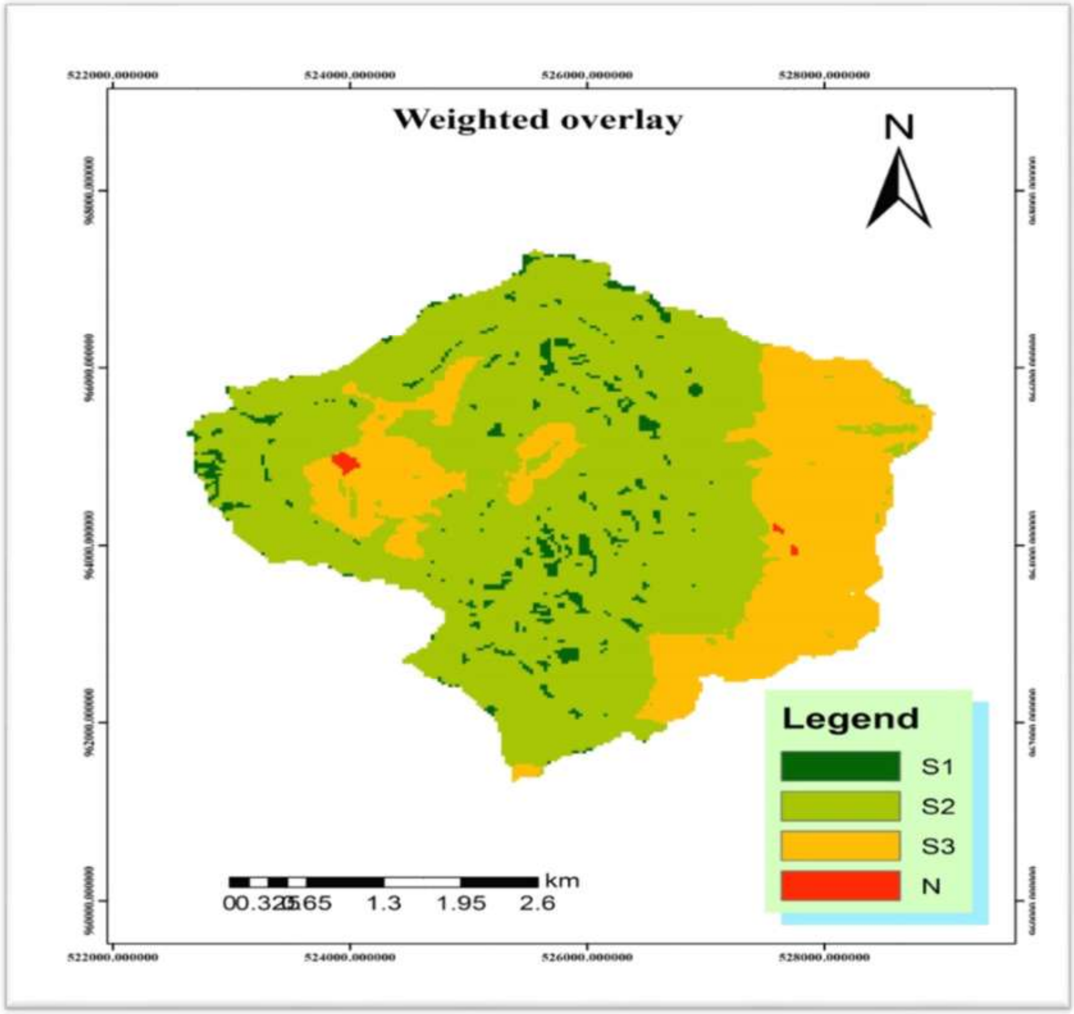

Figure 4.8 Final land suitability map of the watershed

The weighted overlay analysis (WOA) revealed that 3.93% of the total area was highly suitable, 68 % moderately suitable, 27.5% of the watershed was covered in marginally suitable class and the rest 0.57% was unsuitable for surface irrigation. The total suitable area for surface irrigation has a higher area coverage due to the combined effect of slope, soil and land cover land use.

The potential suitale land for Danse watershed was consistent with the findings of Temsegen and Yonas (2016), land suitability evaluation for Abaya district Borena zone. The result of the suitability of land evaluation ratings based on the qualitative land suitability for irrigation indicated that 9.32% (1303 ha) are highly suitable (S1), 32.5% (4558 ha) are moderately suitable (S2), 23.82% (3335 ha) marginally suitable (S3) and 34.30 (4802 ha) are not suitable (N) for surface irrigation systems. Hence, the majority of the study areas are in a range value of highly to marginally suitable for surface irrigation purposes.

In agreement with Albaji *et al*. (2009) and Abraham and Azalu (2013), the overall result showed that physical factors highly determined the suitability of the Danse watershed for surface irrigation. Albaji *et al.* (2009), reported that the most limiting factors for surface irrigation were physical parameters such as slope, stoniness and soil depth. Corroborating this suggestion, Abraham and Azalu (2013) stated that high slope; gravelly soil texture and shallow soil depth were limiting factors of land suitability evaluation for surface irrigation.

Generally, the assessment of land suitability for surface irrigation in Danse watershed showed that 76.4 % of the soil and 78% of the land use/land cover was highly suitable for surface irrigation development and 50.75% of the slope ranges from highly suitable to marginally suitable classes. This indicates the study agreed with the study conducted by Kebede (2010) in Dale wereda of Sidama zone for assessment of irrigation potential of the watersheds considering soil type, slope, land use land cover and distance from the water supply. The result shows that 86 % of the soil and 58.5% of the slope ranges from highly suitable to marginally suitable. In this study, 87.1% of the land use land cover was highly suitable for surface irrigation.

4.4 Irrigation Water Requirements of the Identified Command Area

The estimation of irrigation water requirement of selected crops was done using reference evapotranspiration, crop coefficient, crop water requirement or consumptive use, effective rainfall, net irrigation requirement and gross irrigation water requirement.

The average annual rainfall for the study area is 990.5 mm and the effective rainfall used by the crops is 704.2 mm which is 72.1 % of the average annual rainfall.

Table 4.10 Net and Gross irrigation water requirements

Crop type	**Net irrigation water requirement (mm)**	**Gross irrigation water requirement (mm)**	**gross water required (m^3 ha^{-1})**
Onion	410.2	820.4	8204
Tomato	404.2	808.4	8084
Cabbage	422.7	845.4	8454
Wheat	268.8	537.6	5376

Irrigation water requirements at the identified potential irrigable area under surface irrigation methods were estimated. The total net and gross irrigation water requirements are 268.8 mm and 537.6 mm for wheat, 410.2 mm and 820.4 mm for onion, 404.2 mm and 808.4 mm for tomato and 422.7 mm and 845.4 mm for cabbage respectively.

4.5 Optimization of Cropping Pattern

Optimization of cropping pattern for the study area was carried out with the objective of optimal cropping pattern to maximize the net annual benefits for the study area and at the same time conservatively utilize the available surface water and land resources. The study intended to find the optimal cropping pattern in Danse watershed, which maximizes the net benefit per unit area and unit land.

Linear programming model was applied and LINGO software was implemented to find the output. For this purpose, a linear programming model for maximization of net benefit was formulated using lingo software. The model applied to the watershed was found to be suitable for irrigation and cultivation decision making which gave optimum results for required variables such as irrigation water depth and cropping area allocation.

4.5.1 Optimal solution of the model

The Linear programming model was developed and solved by the Lingo model, which gave an optimum result. In this study, the cropping pattern optimization model was developed aiming to maximize net benefit per unit of irrigation water. Accounting for all identified constraints, the model maximized the net benefit (Objective Function) for Danse watershed. The LP model developed for the study area was run for maximum net benefits using LINGO Software. The result signifies the fact that the maximum production benefit from 192 ha of land allocation is 57,748,130 ETB from area allocation of 164 ha of Onion, 8 ha of Tomato, 5 ha of Cabbage and 15 ha of Wheat crop.

Similarly, Hasan & Mohammad (2015) formulated an optimization model to maximize profit from cultivation while satisfying several factors like cropping area, irrigation water supply, cropping cycle, market demand. The model was applied at Kalihati, Tangail, Bangladesh for the Agricultural year 2012-2013 with yearly water availability of 126798372 mmha and land availability of 17750 ha. The crops selected for the model were most traditional for the studied area and produced in large proportions compared to others. The model provided optimum value for the cropping area and irrigation water depth that maximizes the objective function. The net income worth for this project was 1,856,910,000 BDT.

The study also agree with the finding of Jalal *et al*. (2016). In this study, linear programming model successfully optimized the cropping pattern for maximum income while satisfying all of the imposed constraints for mekabo irrigation scheme in Tigray region of Ethiopia. The study considered agronomic and extension constraints. The optimal solution of the model using Microsoft Excel program including a linear programming solver tool was found the maximum benefit of 57,498 ETB/ha.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

To enhance agricultural production and productivity, the need for irrigation is unquestionable. The study assessed water availability, land suitability and optimization of cropping patterns. Assessment of water availability and land suitability for irrigation is important to utilize limited resources efficiently and for the sustainable production of crops and food security of the ever-increasing population in the study area.

The availability of water for surface irrigation was determined by curve number method and the weighted curve number of the watershed was estimated as 84 and the depth of runoff found that 8590 m^3/ha. Finally, the total available runoff volume of water is estimated as 18,640,000 m^3. However, all runoff volume generated in the watershed was not used for irrigation and 1/3 of runoff from rainfall suggested for other losses or environmental requirements, the rest runoff volume 6,213,333 m^3 can be used by the farmers for crop production.Therefore, based on the gross water requirement of the dominant crops, the volume of water can irrigate 192 ha of land per season in the watershed.

Land suitability for surface irrigation was evaluated by assessing soil, land use/cover and slope suitability. To identify soil suitability for irrigation soil texture, drainage and depth were considered. Each of the data layers was classified into different classes of suitability. The suitability analysis of the parameters indicates that 50.75 % slope of the study area were classified as potentially suitable for irrigation development. Weighted overlay analysis of the three soil physical factors was evaluated using weight overlay analysis on Arc GIS 10.4. Accordingly, 76.4 % of the soils in the watershed were highly suitable and 23.6 % moderately suitable for surface irrigation development due to the combined effect of soil texture, depth and drainage. The result of the LULC Suitability for the surface irrigation method revealed that the LULC types were categorized under highly suitable to marginally suitable which covers 96.5 %. However, waterbody and settlement are categorized under not suitable class which covers 3.5 % of the total land cover.

The overall suitability of the area for surface irrigation using the weighted overlay of the three factors (soil, slope and LU/LC) was evaluated on ArcGIS 10.4. Finally, 2157.71 ha (99.43) the total lands in the watershed were in the range of highly suitable to marginally suitable for surface irrigation development, whereas 4.78 ha (0.57 %) were unsuitable class due to the combined effect of slope, soil and land use land cover suitability. Wheat, Onion, Cabbage and Tomato were selected to be grown on the identified irrigable command areas.

An optimization model was formulated to find the optimal land allocation for the major crops and to maximize the net benefit from crop cultivation. The model provided the optimal cropping area for the selected crops that maximize the net benefit from irrigating the selected crops. Scenario was developed to find the best allocation of land based on the gross water requirement of crops. The result signifies the fact that the maximum production benefit from land allocation was 57,748,130 ETB. The value of the decision variables (the area allocation of each crop) was estimated as 164 ha, 8 ha, 5 ha and 15 ha for Onion, Tomato, Cabbage and Wheat respectively. Therefore, the optimization model guides the stakeholders to adopt the farm plans to achieve their desired objective such as maximization of benefit or minimization of costs under given constraints. Optimization of cropping pattern in the watershed is used to facilitate better decisions and to explore the beneficial cropping pattern for the major crops or the selection of profitable crops.

Generally, Irrigation investment plays an important role to maintain sustainable food security by improving agricultural production that is the core foundation for Ethiopia's economy, growth and long-term food security. The study develops an irrigation potential map of the watershed for future planning and development possibilities and it can help decision-makers, donors and experts in sound surface irrigation development in the watershed. The study also contributes to shift the current rainfed agriculture to irrigated agriculture.

5.2. Recommendation

The findings of this study enabled to make the following recommendations for farmers, policymakers, development actors and researchers who have a strong interest in the development of irrigation projects in Danse watershed. The following recommendations were drawn:-

- To collect the estimated amount of surface runoff generated from the rainfall, water harvesting structure or a storage structure were necessary. So that, I recommend the construction of a structure that can store the volume of water generated from the runoff.
- This study was limited to three soil physical properties which are soil texture, depth and drainage to assess land suitability for surface irrigation. Since other soil physical

and chemical properties may have their own influence to characterize the suitability of land for surface irrigation. Therefore, further research will be incorporate additional factors to assess land suitability over the study area.

- Irrigation suitability constraints such as water quality, environmental, economic and social terms should be assessed to get sound results in addition to those parameters considered in this study to evaluate land suitability for surface irrigation.
- In addition to surface irrigation, land suitability analysis for sprinkler and drip irrigation types should be carried out to increase the land area to be irrigated.
- Farmers are recommended to practice cropping patterns in the study area to get the maximum net benefit and to enhance the income of the farmers accordingly,Onion should be produced at a large extent because it is a beneficial crop.
- In this study, estimation of irrigation water requirement of the identified command area was carried out by selecting four crops only, but further research should be continued for different crops.
- Finally, further studies are recommended to increase the irrigation potential of Danse watershed.

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7 . APPENDIXES

Appendix Table 7.1 Annual Rainfall and Runoff Values (1987-2016)

Year	Rainfall(mm)	Runoff(mm)	Year	Rainfall(mm)	Runoff(mm)
1987	780.0	596.6	2002	741.0	559.1
1988	708.3	527.9	2003	1185.7	991.2
1989	908.3	720.5	2004	989.0	798.9
1990	844.7	658.9	2005	1016.4	825.6
1991	723.6	542.5	2006	1107.6	914.7
1992	871.8	685.1	2007	1014.3	823.6
1993	784.6	601.0	2008	962.1	772.7
1994	675.3	496.5	2009	798.1	614.0
1995	759.7	577.1	2010	935.6	747.0
1996	1033.5	842.3	2011	1034.6	843.4
1997	687.8	508.3	2012	1171.1	976.9
1998	1061.3	869.4	2013	1771.8	1569.7
1999	920.9	732.7	2014	2338.8	2132.7
2000	772.9	589.7	2015	505.3	337.1
2001	923.1	734.8	2016	1704.5	1503.0

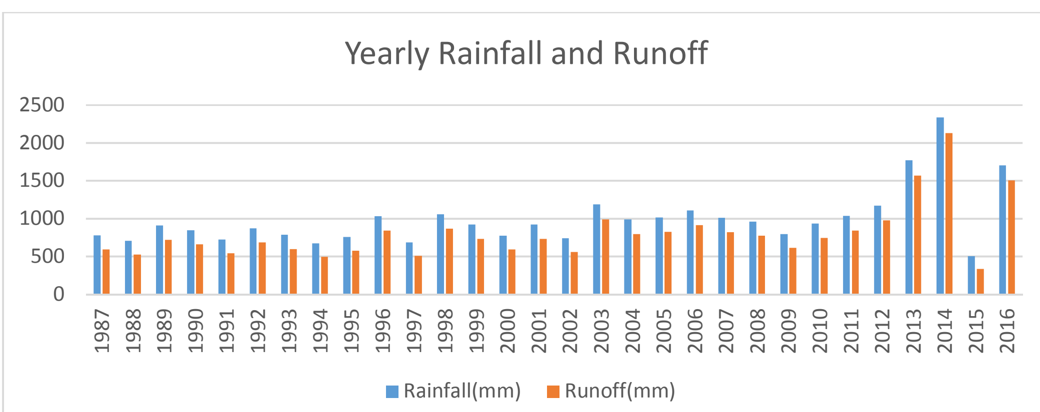


Figure 7.1 annual rainfall and runoff for Danse watershed for the period 1987 to 2016

Appendix Table 7.2 Mean monthly maximum temperature of ejere station

1987	23.8	25.9	27.0	27.1	26.4	29.0	29.0	28.8	27.6	26.1	24.9	23.7
1988	24.3	26.1	27.7	27.6	28.3	29.1	25.9	27.4	27.0	25.2	24.2	23.8
1989	23.7	24.8	27.3	25.3	27.1	28.9	24.9	27.7	27.0	25.4	24.8	23.8
1990	23.6	25.9	26.6	27.7	28.9	29.9	26.8	28.1	28.0	25.8	25.1	23.5
1991	24.9	25.8	27.9	26.6	26.2	30.0	26.9	28.5	27.9	25.6	24.7	24.0
1992	24.4	25.7	27.5	28.5	27.9	29.5	28.3	24.6	26.7	25.3	24.0	23.9
1993	24.1	24.5	27.4	27.0	27.6	29.2	26.5	27.0	27.8	26.0	24.6	24.2
1994	25.0	26.7	28.0	28.4	28.2	31.0	24.2	25.5	27.3	25.8	24.3	24.1
1995	24.3	26.6	27.6	27.9	28.1	29.3	27.3	28.9	27.8	25.7	25.5	24.7
1996	24.8	26.7	27.4	27.5	27.6	26.6	24.9	26.8	27.2	25.6	24.3	24.3
1997	25.0	25.2	27.8	26.7	27.8	29.2	28.5	28.6	28.5	25.6	24.0	24.5
1998	24.8	27.3	28.3	29.2	29.1	29.2	25.6	25.9	27.7	26.0	25.2	24.6
1999	25.6	27.6	28.5	28.6	29.4	30.7	27.7	29.6	28.5	26.2	24.7	24.1
2000	25.1	24.7	27.9	28.7	29.4	30.7	29.1	28.3	28.8	27.0	25.5	25.3
2001	25.4	27.4	28.5	28.8	30.3	31.6	30.2	28.5	28.1	27.1	25.4	25.1
2002	25.3	27.7	28.3	28.8	31.1	31.0	31.5	30.2	28.1	26.7	25.8	25.6

2003	25.8	27.7	28.0	28.6	29.5	30.3	29.2	27.9	28.2	26.6	25.3	24.0
2004	26.3	26.0	28.2	28.4	29.9	29.6	30.2	29.3	27.9	25.0	25.0	24.6
2005	25.6	27.6	28.2	28.4	28.4	29.3	28.8	29.5	28.7	26.4	25.2	24.3
2006	25.6	27.2	28.3	27.9	28.9	30.6	29.4	28.3	27.9	26.5	25.3	24.5
2007	25.1	27.3	28.5	28.4	29.5	29.3	28.1	28.9	28.6	26.0	24.5	24.1
2008	25.8	25.6	28.2	26.7	28.6	29.8	30.0	27.7	28.2	26.3	24.9	24.4
2009	25.2	26.5	28.0	27.8	28.9	30.2	29.3	28.9	28.6	26.2	25.3	24.2
2010	24.8	26.9	26.7	28.0	29.2	30.4	27.4	27.1	27.3	26.7	24.8	24.2
2011	23.8	24.4	22.5	22.9	23.8	22.3	19.9	20.2	22.0	23.7	23.1	23.6
2012	26.2	24.8	26.6	26.4	27.5	25.9	20.6	20.9	23.0	24.4	24.4	24.5
2013	25.5	26.5	27.4	28.2	28.2	26.7	21.8	20.7	22.7	23.4	23.7	23.2
2014	24.7	25.6	26.2	25.3	27.8	26.6	23.1	22.7	22.5	22.3	22.3	24.5
2015	24.7	25.6	26.2	25.3	27.8	26.6	23.1	22.7	22.5	22.3	22.3	24.5
2016	24.5	25.4	24.5	24.8	24.7	25.8	22.6	21.8	22.4	23.3	23.7	23.6
Average	**24.9**	**26.2**	**27.4**	**27.4**	**28.2**	**29.0**	**26.7**	**26.1**	**26.8**	**25.5**	**24.6**	**24.2**

Appendix Table 7.3 Mean monthly minimum temperature of ejere station

1987	6.3	8.0	10.8	8.4	10.9	14.0	13.8	12.6	9.4	8.0	5.3	5.5
1988	8.0	9.7	8.9	11.0	10.3	13.6	14.4	13.0	10.5	6.4	4.0	5.3
1989	6.6	8.4	9.1	10.6	9.8	13.4	13.8	12.5	9.5	6.1	6.4	9.1
1990	7.2	11.2	9.4	10.0	11.9	14.4	14.0	15.3	10.6	6.5	5.9	5.7
1991	7.8	10.5	10.2	9.8	8.9	14.0	13.3	13.4	10.1	6.4	5.5	6.3
1992	9.0	10.4	10.0	9.9	9.7	13.7	13.9	13.1	9.3	6.7	5.5	6.9
1993	9.0	9.6	7.3	9.8	10.9	14.3	14.0	12.4	10.8	7.6	5.3	5.1
1994	5.1	7.0	9.2	10.1	10.4	14.6	13.9	13.2	9.6	6.0	6.1	5.5
1995	5.4	9.0	10.0	9.9	10.6	13.4	14.6	13.4	10.0	6.9	5.8	5.9
1996	8.3	7.3	9.4	9.8	10.2	14.0	14.0	12.6	10.9	6.5	5.5	5.7
1997	10.0	5.9	9.8	9.7	10.8	13.5	14.4	13.0	10.3	8.7	9.5	7.7
1998	10.0	11.9	11.4	12.0	12.8	14.8	14.6	13.9	11.0	8.8	5.1	4.8
1999	7.2	7.3	9.9	9.2	12.3	14.5	14.2	13.1	10.4	7.2	5.1	4.8
2000	5.2	6.5	6.9	10.7	13.7	14.9	14.7	13.9	10.6	8.2	6.7	6.6
2001	7.5	7.4	10.6	9.9	13.0	14.7	14.6	14.3	9.2	7.3	6.5	6.8

2002	7.6	7.5	11.0	11.5	13.2	15.1	14.6	13.6	9.0	7.5	7.0	9.1
2003	8.3	8.7	9.9	11.5	10.6	13.9	15.0	14.1	10.6	6.9	7.5	6.7
2004	9.4	8.6	9.0	11.4	10.9	10.0	14.6	13.3	10.0	7.8	7.6	7.6
2005	8.2	7.9	10.1	10.8	12.5	14.4	14.5	12.9	10.9	7.2	6.3	5.0
2006	7.6	9.2	9.2	10.8	11.2	14.8	14.7	14.0	10.6	8.9	7.5	8.0
2007	7.9	9.6	9.0	9.5	12.2	14.8	14.4	13.1	11.7	6.4	6.8	5.0
2008	6.8	7.0	6.9	10.1	10.8	14.5	14.7	12.9	9.7	8.1	7.3	5.9
2009	8.3	8.8	9.6	11.0	11.3	14.0	14.5	15.5	9.7	8.4	6.0	9.4
2010	8.2	11.9	11.5	12.3	14.2	15.1	15.0	14.4	11.0	7.3	6.9	5.9
2011	11.0	10.9	10.4	11.0	11.0	10.6	11.5	11.9	11.4	9.5	10.4	9.0
2012	10.1	9.8	11.5	13.8	14.6	14.1	12.0	11.9	10.7	10.0	9.9	9.3
2013	7.4	10.7	9.6	10.0	11.8	8.4	10.9	11.7	10.8	11.0	10.4	8.8
2014	11.3	11.2	12.5	13.2	12.4	11.7	12.7	11.6	13.0	12.0	10.3	9.2
2015	7.9	8.4	10.6	10.8	12.1	10.1	11.8	11.6	11.9	11.5	10.3	9.0
2016	11.3	12.0	12.0	12.9	13.2	13.1	12.0	11.0	11.5	11.3	9.7	10.1
Average	**8.1**	**9.1**	**9.9**	**10.7**	**11.6**	**13.5**	**13.8**	**13.1**	**10.5**	**8.0**	**7.1**	**7.0**

Appendix Table 7.4 Long term (1987-2016) monthly climatic data

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	$MJ/m^2/day$	mm/day
January	8.1	24.9	53	54	7.9	19.3	3.35
February	9.1	26.2	49	55	8.3	21.1	3.79
March	9.9	27.4	50	56	8.5	22.4	4.19
April	10.7	27.4	53	58	8.1	22.0	4.21
May	11.6	28.2	47	61	7.7	20.9	4.12
June	13.5	29.0	47	63	6.5	18.7	3.94
July	13.8	26.7	59	59	5.4	17.2	3.58
August	13.1	26.1	62	55	5.4	17.5	3.57
September	10.5	26.8	59	54	6.3	19.0	3.77
October	8.0	25.5	53	57	8.3	21.2	3.88
November	7.1	24.6	50	57	8.9	20.9	3.60
December	7.0	24.2	52	55	8.4	19.5	3.30
Average	**10.2**	**26.4**	**53**	**57**	**7.5**	**20.0**	**3.78**

Appendix Table 7.5 Rainfall and Effective rainfall of the watershed

Monthly rain - untitled

Station: Ejere   Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	15.4	15.0
February	25.1	24.1
March	43.8	40.8
April	58.1	52.7
May	50.0	46.0
June	83.7	72.5
July	253.4	150.3
August	287.4	153.7
September	117.7	95.6
October	34.1	32.3
November	13.9	13.6
December	7.7	7.6
Total	990.5	704.2

Appendix Table 7.6 Irrigation water requirement of wheat

Crop Water Requirements

ETo station: Ejere   Crop: Wheat

Rain station: Ejere   Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.30	1.15	11.5	16.4	0.0
Oct	2	Init	0.30	1.16	11.6	8.7	3.0
Oct	3	Deve	0.30	1.15	12.6	7.3	5.3
Nov	1	Deve	0.48	1.78	17.8	6.2	11.6
Nov	2	Deve	0.76	2.75	27.5	4.0	23.6
Nov	3	Mid	1.04	3.65	36.5	3.5	33.0
Dec	1	Mid	1.14	3.89	38.9	2.8	36.1
Dec	2	Mid	1.14	3.78	37.8	1.9	35.8
Dec	3	Mid	1.14	3.80	41.8	3.0	38.8
Jan	1	Late	1.14	3.79	37.9	4.2	33.7
Jan	2	Late	0.93	3.13	31.3	5.0	26.3
Jan	3	Late	0.64	2.23	24.6	6.0	18.6
Feb	1	Late	0.38	1.40	9.8	4.8	3.0
					339.7	73.6	268.8

Appendix Table7.7 Irrigation water requirement of Onion

Crop Water Requirements

ETo station: Ejere | Crop: onion

Rain station: Ejere | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.70	2.69	26.9	16.4	10.5
Oct	2	Deve	0.72	2.80	28.0	8.7	19.3
Oct	3	Deve	0.85	3.23	35.5	7.3	28.2
Nov	1	Mid	1.00	3.68	36.8	6.2	30.6
Nov	2	Mid	1.05	3.77	37.7	4.0	33.7
Nov	3	Mid	1.05	3.66	36.6	3.5	33.1
Dec	1	Mid	1.05	3.56	35.6	2.8	32.8
Dec	2	Mid	1.05	3.45	34.5	1.9	32.6
Dec	3	Mid	1.05	3.47	38.2	3.0	35.2
Jan	1	Mid	1.05	3.49	34.9	4.2	30.7
Jan	2	Late	1.04	3.50	35.0	5.0	30.0
Jan	3	Late	0.99	3.45	37.9	6.0	32.0
Feb	1	Late	0.91	3.31	33.1	6.8	26.2
Feb	2	Late	0.83	3.15	31.5	7.7	23.8
Feb	3	Late	0.77	3.01	21.1	8.5	11.4
					503.3	**91.9**	**410.2**

Appendix Table 7.8 Irrigation water requirement of Tomato

Crop Water Requirements

ETo station: Ejere | Crop: Tomato

Rain station: Ejere | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.60	2.31	23.1	16.4	6.7
Oct	2	Init	0.60	2.33	23.3	8.7	14.6
Oct	3	Init	0.60	2.27	25.0	7.3	17.7
Nov	1	Deve	0.63	2.32	23.2	6.2	17.0
Nov	2	Deve	0.76	2.72	27.2	4.0	23.3
Nov	3	Deve	0.89	3.12	31.2	3.5	27.7
Dec	1	Deve	1.03	3.50	35.0	2.8	32.2
Dec	2	Mid	1.14	3.75	37.5	1.9	35.5
Dec	3	Mid	1.14	3.79	41.7	3.0	38.8
Jan	1	Mid	1.14	3.81	38.1	4.2	34.0
Jan	2	Mid	1.14	3.83	38.3	5.0	33.4
Jan	3	Mid	1.14	4.00	44.0	6.0	38.1
Feb	1	Late	1.10	4.00	40.0	6.8	33.1
Feb	2	Late	0.96	3.66	36.6	7.7	28.9
Feb	3	Late	0.84	3.31	26.5	9.7	16.8
Mar	1	Late	0.76	3.10	12.4	4.7	6.5
					503.2	**97.8**	**404.2**

Appendix Table 7.9 Irrigation water requirement of cabbage

Crop Water Requirements

ETo station: Ejere | Crop: cabbage

Rain station: Ejere | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.70	2.69	26.9	16.4	10.5
Oct	2	Init	0.70	2.72	27.2	8.7	18.5
Oct	3	Init	0.70	2.65	29.2	7.3	21.9
Nov	1	Deve	0.70	2.59	25.9	6.2	19.7
Nov	2	Deve	0.74	2.66	26.6	4.0	22.6
Nov	3	Deve	0.79	2.78	27.8	3.5	24.3
Dec	1	Deve	0.85	2.90	29.0	2.8	26.2
Dec	2	Deve	0.91	3.00	30.0	1.9	28.1
Dec	3	Deve	0.97	3.22	35.4	3.0	32.4
Jan	1	Mid	1.03	3.43	34.3	4.2	30.1
Jan	2	Mid	1.04	3.50	35.0	5.0	30.0
Jan	3	Mid	1.04	3.65	40.2	6.0	34.2
Feb	1	Mid	1.04	3.81	38.1	6.8	31.3
Feb	2	Mid	1.04	3.96	39.6	7.7	31.9
Feb	3	Late	1.04	4.10	32.8	9.7	23.1
Mar	1	Late	1.00	4.07	40.7	11.9	28.8
Mar	2	Late	0.96	4.01	16.0	5.5	9.1
					534.5	**110.5**	**422.7**

Appendix Table 7.10 Crop coefficient and maximum crop height

crop	Kc initial	Kc middle	Kc end	Maximum crop height(m)
onion	0.7	1.05	0.75	0.4
Tomato	0.6	1.15	0.8	0.6
cabbage	0.7	1.05	0.95	0.4
wheat	0.3	1.15	0.3	1.0

Appendix Table 7.11 length of selected crop growing period

Crop type	length of growing period (LGP) in days					planting date	harvesting date
	ini	dev	mid	late	Total		
Onion	15	25	70	40	150	Oct-1	Feb- 30
Tomato	35	40	50	30	155	Oct-1	Mar -5
Cabbage	40	60	50	15	165	Oct-1	Mar -15
Wheat	30	30	40	30	130	Oct-1	Feb -10

Appendix Table 7.12 The cropping calendar for the Danse watershed

Crop	Months											
	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep
Onion	***	***	***	***	***		***	***	***	***	***	
Tomato	***	***	***	***	***	***	***	***	***	***	***	***
Cabbage	***	***	***	***	***	***	***	***	***	***	***	
Wheat	***	***	***	***	***		***	***	***	***	***	

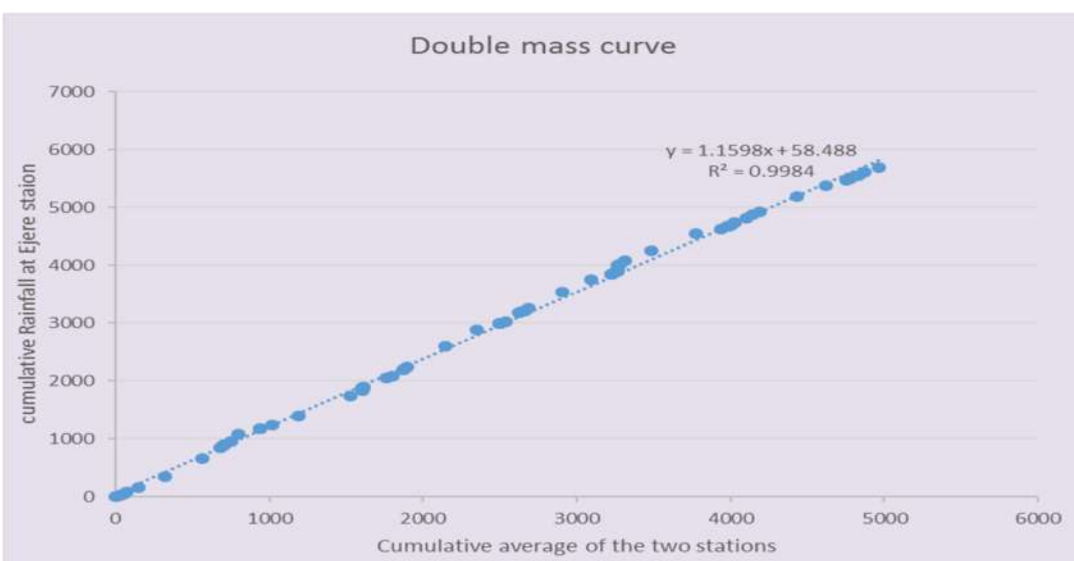
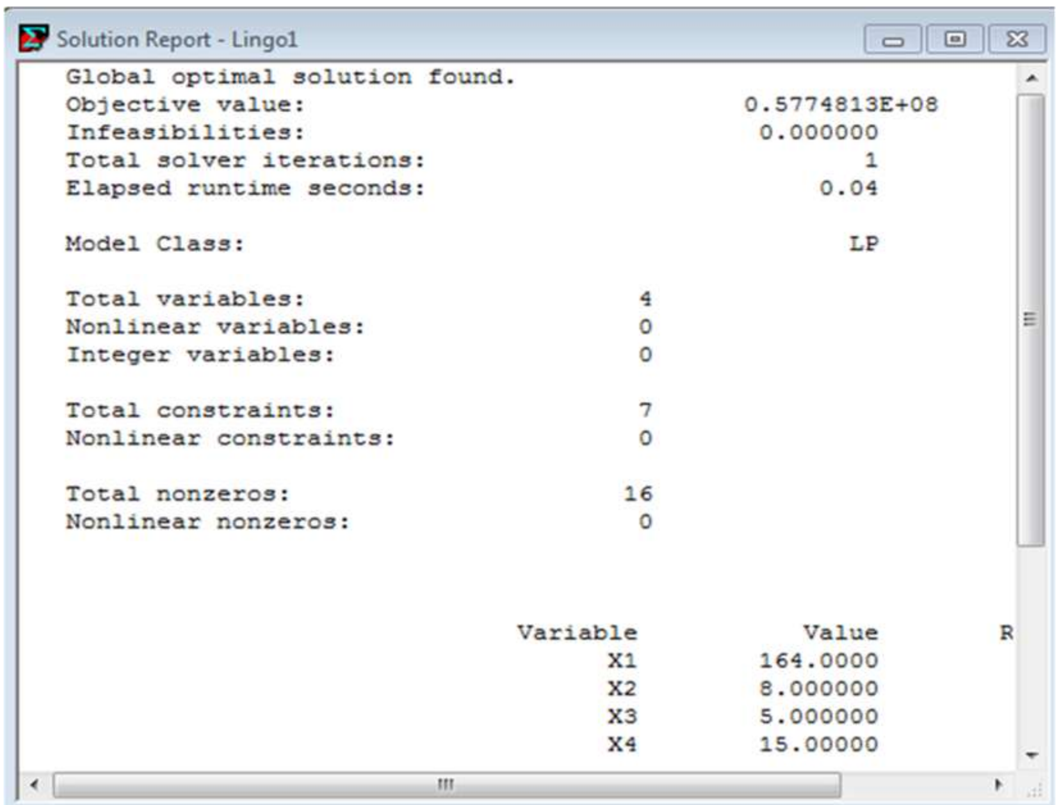


Figure 7.2 Double mass curve

Questioners for data collection

1. Which crops are the dominant in the agricultural farming system in the study area?
2. How much cost did onion required for production per season?
3. How much cost is needed for cultivating Wheat, Tomato and Cabbage crops?
4. What are the constraints for crop production in the existing farm land?
5. How much householders are exist in the watershed?

Appendix Table 7.13 Solution Report of LINGO



```
Solution Report - Lingo1

Global optimal solution found.
Objective value:                          0.5774813E+08
Infeasibilities:                           0.000000
Total solver iterations:                          1
Elapsed runtime seconds:                       0.04

Model Class:                                     LP

Total variables:                  4
Nonlinear variables:              0
Integer variables:                0

Total constraints:                7
Nonlinear constraints:            0

Total nonzeros:                  16
Nonlinear nonzeros:               0


                      Variable           Value        R
                            X1        164.0000
                            X2        8.000000
                            X3        5.000000
                            X4        15.00000
```