GIS-BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT: A CASE STUDY IN BILATE RIVER WATERSHED, SOUTH-WESTERN, ETHIOPIA

M.Sc. THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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A THESIS SUBMITTED TO THE
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This is to certify that the thesis entitled "**GIS BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT: A CASE STUDY IN BILATE RIVER WATERSHED SOUTH-WESTERN ETHIOPIA**" submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Irrigation and Drainage Engineering,** the graduate program of the **Department of Water Resource and Irrigation Engineering,** and has been carried out by **ALELU MANAMO Id.No.PGIrDrR/0002/11,**under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department for examination.

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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 my approval as Thesis advisor.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADLI	Agricultural Development-Led Industrialization
AHP	Analytical Hierarch Process
CR	Consistency Ratio
CWR	Crop Water Requirement
CI	Consistency Index
CROPWAT	Crop Water Requirement
EMWIE	Ethiopian Minisitery of Water Irrigation and Energy
DEM	Digital Elevation Model
ET0	Reference Crop Evapotranspiration
Eff	Efficiency
Etc	Crop Evapo-transpiration
FAO	Food and Agricultural Organization
GIS	Geographical Information System
GIWR	Gross Irrigation Water Requirement
GPS	Global Position System
HRU	Hydraulic Response Units
HWSD	Harmonized World Soil Data
IFAD	International Fund for Agricultural Development
IHA	Indicators of Hydrologic Alternation
IIDI	International Irrigation Development Institutes
ILRI	International Livestock Research Institute
IR	Irrigation Requirement
IWRM	Irrigation Water Resource Management
KM	Kilometer
LSAT	Land Space Technology
LULC	Landuse/Landcover
LS	Land suitability Square

M.A.S.L	Meters Above Sea Level
MCE	Multi criteria evaluation
Mha	Million hectares
MOA	Ministry of Agriculture
MOWE	Ministry of Water Resource and Energy
MOWR	Ministry of Water Resources
NIWR	Net Irrigation Water Requirement
NMSA	National Metrological Service Agency
N	Not suitable
RI	Random Index
RS	Remote Sensing
RVLB	Rift Valley Lake Basin
SWAT	Soil Water Assessment Tool
SqKm	Square Kilometer
SRTM	Shuttle Radar Topography Mission
S	Suitable
SWWDSE	South Water Works Design and Supervision Enterprise
Tmax	Maximum Temperature
Tmin	Minimum Temperature
UNESCO	United Nations Educational Scientific and Cultural Organization
WGXEN	Weather Generator

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ABSTRACT

The major problem associated with rainfall-dependent agriculture in Ethiopia is the high degree of rainfall variability and unreliability. As a consequence, food insecurity often turns into famine. Irrigation development is one of the key strategies to increase agricultural production and alleviate poverty. This study, therefore, aimed to assess the surface irrigation potential and land resources potential of the Bilate River Watershed for irrigation expansion. Watershed delineation, identification of potentially irrigable land, and estimation of irrigation water requirement and surface water resources availability of the study area were the steps followed to evaluate this irrigation potential. Irrigation potential was mapped by using GIS of the watershed; Arc SWAT model was used to estimate the water resources availability in the watershed; Analytical hierarchy process (AHP) comparison was used to conduct land suitability assessment and a CROPWAT 8.0 model was used to determine the crop water requirement for major crops of the study area. To identify potentially irrigable land, irrigation suitability factors such as soil physical properties, slope, land use/ land cover, and distances from the water supply (sources) are taken into account. The final results of the overall weighted overlay analysis *of irrigation land suitability indicate that 317,841ha (64%) are highly suitable (S1), 153,459ha (30.91%) are moderately suitable (S2), whereas 25,039ha (5.044%) are not suitable (N) for surface irrigation development.* The SWAT model was calibrated and validated. *The observed monthly streamflow values have a coefficient of determination (R^2) and Nash-Sutcliffe Coefficient (NSE) of 0.77 and 0.66 respectively for the calibration period and 0.81 and 0.64 for the validation period. The irrigation water demand required by five major selected crops which are grown in the study area throughout the growing season was found to be 663.04 m^3/s. The annual dependably simulated streamflow was 225.14 m^3/s. The estimated dependably available flow can potentially irrigate only an area of 53,645.77 ha for highly suitable areas. The result showed that the water demand of the crops was greater than the available dependably flow of the watershed. Therefore to increase the irrigation potential of the watershed sprinkler or drip irrigation methods can be used.*

Keywords: Land Suitability, Surface Water resources availability, irrigation water requirements, GIS, and MCE.

1. INTRODUCTION

1.1. Background

Agriculture in Ethiopia is crucial for the country's food security and the sector is the largest contributor to overall economic growth and poverty reduction. The national strategy for "agricultural development-led industrialization" (ADLI) puts agriculture at the forefront of Ethiopia's development process. This strategy is reflected in the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP). A central theme of the PASDEP is a call for accelerated market-based agriculture development with a focus on Ethiopia's 13 million smallholder farm households producing around 98% of the country's agricultural output (MoA, 2004).

Ethiopian Agriculture was characterized largely by rain-fed dependence that causes severe damage in agriculture due to shortage of rainfall and associated droughts historically have been major causes of food shortages and famines in the country (Woldeamlak, 2009). Over 85% of the Ethiopian population's livelihood base is agriculture-dependent, and thus development and technical support for the sector are of paramount importance. Thus technical support for the development of the available water resources and irrigation is inevitable and necessary to bring sustainable food production and agricultural development to achieve increased livelihood bases, income improvement, and generally to promote socio-economic development of the country (Gemachu *et al.*, 2018).

Irrigation in Ethiopia is considered a basic strategy to alleviate poverty and hence food security. Irrigation expansion is seen as significant leverage to food security, livelihoods, rural development, and agricultural and broader economic development (Hagos *et al.*, 2009). It is useful to transform the rain-fed agricultural system which depends on rainfall into the combined rain-fed and irrigation agricultural system (MoA, 2004). (Makombe *et al.*, 2011) Noted that irrigation development is a key for sustainable and reliable agricultural development which leads to overall development in Ethiopia.

Rainfall is available in multiple forms that can be used for agriculture and irrigation, these forms include surface water (perennial and seasonal rivers), groundwater, wetlands, soil moisture, and rainwater (captured or lost through evapotranspiration). However, these water sources are severely underdeveloped and under-utilized in Ethiopia, which implies that there is significant potential to increase water usage from these and other sources (Seleshi *et al.,* 2010). The irrigation sub-sector has to be given top priority in the overall development plans of the country with the critical objective of increasing the quality of agricultural production and sustain crop production and alleviate food security problems and also taking into consideration the available water resource and suitable irrigable land resources of the country, Ethiopia has huge potential in expanding irrigated agriculture according to (MoA, 2011). The country is endowed with ample water resources with 12 River basins with an annual runoff volume of over 122 billion m^3 of water. The potential and actual irrigated land are not precisely investigated, but the current estimation of the irrigable land in Ethiopia varies between 1.5 and 4.3 million hectares (Mha), averaged about 3.5 Mha (MOA, 2011). However, the country's irrigable land has been underutilized, and only 4 to 5% of the potential area has been developed for irrigation (Awlachew *et al.,* 2007). Consequently, the agricultural economy of the country is largely based on rain-fed cultivation, but while employing 85% of the population, it only contributes 50% to the gross domestic product (Berry and Cambell, 2003).

The use of land and water resources for the development of irrigation facilities could lead to a substantial increase in food production in many parts of the world (Temesgen and Yonas, 2016). Proper use of land depends on the suitability or capability of land for a specific purpose (Fasina, 2008). Irrigation developments played a key role in food security (Awlachew *et al.,* 2010) and (Jaruntorn *et al,* 2004). Irrigation potential created is the total area that can be irrigated from a project on its full utilization. This implies that before an area is to be reported under potential created, it is to be ensured that; water is available for the area to be irrigated in each season during a complete irrigation year (FAO, 1997).
The area which can potentially be irrigated depends on the physical resources 'soil' and 'water’, combined with the irrigation water requirements as determined by the cropping patterns and climate. Therefore, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation, and available water resources by basin (FAO, 1997).

Bilate River basin is among the major sub-basins that are part of the Abaya-Chamo basin, which is the sub-basin of the Rift Valley Lake Basin with high population pressure, and high variation of climatic parameters. This increase in population growth, economic development together with climate change is expected to cause an increase in water demand for different purposes such as irrigation, hydropower, industrial and domestic needs (Negash, 2004).

The Bilate Watershed has abundant water and land resources, but its agricultural system does not yet fully productive and mainly depends on rainfed agriculture. This resulted from no systematic land suitability assessment, land use planning, and lacking clarity, current land use, and irrigation land suitability description for potential natural resources in the area. Therefore, the objective of this study has identified available water in the Bilate River Watershed for surface irrigation, availability of water resources, and the irrigation water demand and supply (the gross irrigation requirement) for dominant crops cultivating in the study area also providing maps for a suitable site in terms of suitability parameters also assess the amount and pattern of streamflow under the current landuse/land cover, soil, and slope using Arc GIS 10.3, CROPWAT8.0, and Arc SWAT 2012.

1.2. Statement of the Problem

The major problem associated with rainfall-dependent agriculture in the Ethiopia is the high degree of rainfall variability and unreliability. Due to this variability, crop failures due to dry spells and droughts are frequent. As a consequence, food insecurity often turns into famine with the slightest adverse climatic incident, particularly, affecting the livelihoods of the rural poor. Hence, irrigation development is the solution for food insecurity in Ethiopia by reducing variation in harvest and intensification of cropping by producing more than one crop per year (Temesgen and Yonas, 2016).

The basic climatic conditions are major consequences of seasonal or annual fluctuations of rainfall. Due to, temporal and spatial variability of rainfall and its inadequacy, farmers of the watershed are not familiar with the double cropping system and growing cash crops that may have high crop water requirements in an integrated and sustainable manner (Worqlul *et al.,* 2015). Because of inadequate rainfall crop failure occurs frequently in the area and the farmers are leading a subsistence life (Weldeamlak *et al.,* 2002). To bring food security to the national as well as at the household level improvement and expansion of irrigated agriculture must be needed. Water resource and irrigation potential assessment is the important component of IWRM in a global or local aspect (Global Water Partnership, 2012), but the irrigation potential of many Rivers of Ethiopia was not studied in depth separately (Sultan, 2013).

Rainfall variability is the main challenge to agricultural production in Bilate River Watershed since agricultural practice in this study area was dependent on rain-fed agriculture. Surface irrigation is important to alleviate the problems occurred due to rainfall variability in space and time because it helps in supplying crops with the required amount of water for the whole growing season or supplements the rainfall during inadequacy (inundation irrigation) (FAO, 2003). However, irrigated agriculture is not practiced in an organized and sustainable manner in the Bilate River watershed due to a lack of adequate knowledge of the water resources potential for irrigation. This leads to unattractive cost-benefit ratios and a lack of adequate resources for operation and maintenance Negash (2004). Regardless of these problems, there is one perennial River and the vast amount of potentially irrigable land in the area. Yet, the amount and geographical location of potentially irrigable lands with possible surface irrigation methods are not identified so far. Surface irrigation offers several benefits for the less skilled and poor farmers. Because surface irrigation method is the most widely used and requires little knowledge to apply (Saymen, 2005). So, knowing the water resource potential and their corresponding users in a given River basin locally is a basic tool to implement the integrated water resource management approach efficiently. Therefore, this study is aimed to identify surface irrigation potentials of the Bilate River Watershed and the location and extent of potentially irrigable lands in the area using the surface irrigation method. Watershed delineation, identification of potentially irrigable land, and estimation of irrigation water requirements and surface water resources availability of the study area were the steps followed to evaluate this irrigation potential.

1.3. Objectives

1.3.1. General Objective

The overall objective of the study was to assess the surface irrigation potential in the Bilate River Watershed using GIS and MCE.

1.3.2. Specific Objectives

The specific objectives of this study were to:

- identify suitable land for surface irrigation in the study area;
- assess the availability of Surface water resources;
- determine irrigation water requirements for major crops in the study area;
- develop a surface irrigation potential map by matching water resource potential and land suitability.

1.4. Research Questions

- How much area of irrigable land in the study area is potentially suitable for surface irrigation?
- What are surface water resources available in the area to meet crop water requirements?
- How much irrigation water is required for major crops grown in the Bilate River catchment?
- What is the spatial extent of surface irrigation potential in the study area that indicates surface irrigation potential related to available water and land suitability?

1.5. Significance of the study

Irrigation technology is one means by which agricultural production can be increased to meet the growing demand for food. This implies that irrigation is one of the ranges of technologies available to increase agricultural production and maximize household income to improve rural livelihood. Spatial information on irrigation is highly important for policy and decision-makers, who are facing the transition towards more efficient sustainable agriculture (Meier *et al.,* 2018) to understanding trends in food production and their associated drivers (Jain *et al.,* 2017). This study provides an assessment of the surface irrigation potential of the Bilate River Watershed by synthesizing the latest information sources. It confirms the availability of reliable and adequate surface water resources, identification of potentially irrigable land, and irrigation potential of available surface water, and knowledge of 5 crop water requirements which could be informed policy and decision-makers about the surface water irrigation potential of the study watershed that can be utilized as a foundation to support the advancement of economic and human development in the study area.

1.6. Scope of the study

The scope of the study is to identify suitable land for surface irrigation development, evaluation of the availability of surface water resources, the potentially irrigable land for surface irrigation development of the Bilate River watershed by considering various parameters such as slope, soil, landuse/land cover, and River proximity through the implementation of GIS applications, and other related models like ArcSWAT, AHP, and CROPWAT model.

1.7. Limitation of the study

This was study limited to soil physical properties that were soil depth, texture, and drainage, slope, Landuse/land cover, and River proximity (distance from water resources) due to time, and budget constraints. Given that, many other factors have their influence to distinguish land for surface irrigation development. But chemical property of soil, Soicial and Enviromental factors are not considered.

2. LITERATURE REVIEW

2.1. Definition and Concepts of irrigation potential

The definition of irrigation potential is not straightforward and implies a series of assumptions about irrigation techniques, investment capacity, national and regional policies, social, health, and environmental aspects, and international relationships, notably regarding the sharing of waters. Irrigation potential is an important indicator of the extent of land suitable for irrigation development. this means that it is the possibility for irrigation development. The area which can potentially be irrigated depends on the physical resources soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate. In countries like Ethiopia which has ample water resources, the concept of irrigation potential also comprises some considerations of suitability and economic feasibility of irrigated lands (FAO, 2015).

2.1.1. Irrigation Potential in Ethiopia

Agriculture is the core driver for development and long-term food security in Ethiopia and irrigation development is in its infancy stage and not contributing its share to the growth of the agriculture sector (Abeyou *et al.*, 2015). The high dependency on rain-fed agriculture and erratic rainfall requires an alternative means to improve agricultural production and productivity. These can be achieved through an optimal development of surface irrigation (FAO, 2003).

Due to lack of standard or agreed criteria for estimating irrigation potential in the country, the estimations of the irrigation potential of Ethiopia differ from one source to the other: The earlier report, for example from the World Bank (1973), showed the irrigation potential at a low of 1.0-1.5 million hectares, and a high of 4.3 million hectares. There have also been different estimates of the irrigation potential in Ethiopia. According to the Ministry of Agriculture MoA (1986), the total irrigable land in the country measures 2.3 million hectares. The International Fund for Agricultural Development IFAD (1987) on the other hand gives a figure of 2.8 million ha. A total of 3.7 million ha had been identified as potentially irrigable land by MoWIE (2002).

In Ethiopia, under the prevalent rainfed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands coupled with climate variability has aggravated the incidence of poverty and food insecurity. Water resources management for agriculture includes both support for sustainable production in rain-fed agriculture and irrigation (Awulachew *et al.,* 2005). Not overlooked should be soil protection and maintaining soil fertility.

Currently, the MoWR (Ministry of Water Resources) has identified 560 irrigation potential sites on the major River basins. The total potential irrigable land in Ethiopia is estimated to be around 3.7 million hectares (MoWR, 2002). Also, similar studies estimated that the country's irrigation potential is close to 5.3 million hectares, comprising of over 3.7 million hectares from surface water sources (Rivers and Lakes), over 1.16 million hectares from groundwater sources, and about 0.5 million hectares from rainwater harvesting (Awlachew *et al.,* 2010).

2.1.2. Irrigation Development in Ethiopia

Irrigation development is vital to sustainable and reliable agricultural developments in Ethiopia. Subsistence-dominated smallholder farmers' economy can be improved through the use of irrigation in Ethiopian Agriculture (MoA, 2011b). Similarly, make use of irrigation agriculture is going to be a means for increased agricultural production to meet the growing food demands of rapid population growth. Irrigation development in Ethiopia can be considered as a cornerstone of food security and poverty reduction tool as it has the power to stimulate economic growth and rural developments (Hagos *et al.,* 2009). As a result, irrigation infrastructures are increasing year after year, which shows countrywide positive development implications and experiences in small and large-scale irrigation schemes. In Ethiopia, farm size per household is 0.5ha and the irrigated land per household ranges from 0.25 ha - 0.5 ha in the Ethiopian context (MoA, 2011a). As a result, individual land holdings per household are too small to feed the household. With this limited landholdings, increasing food demands of the population depends on either one or a combination of increasing agricultural yield, increasing the area of arable land, and increasing cropping intensity by growing two or three crops per year using irrigation (MoA, 2011a). (Belay and Bewket, 2013) explained that irrigation water is critical to poverty alleviation through increased productivity in rural areas to improve food security and rural livelihoods. Smallholder irrigation has recently received significant focus from local governments to enable farmers to cultivate crops twice or more per year. (Bacha *et* *al.*, 2011) in the study of the impact of small-scale irrigation on household poverty in central Ethiopia, reported that land productivity, asset ownership, credit utilization, extension support, resilience to poverty, mean off-farm income, and mean food consumption and expenditure on food and non-food assets were significantly higher for irrigators than non-irrigators.

2.2. Need for irrigation

Irrigation is the process of applying water to the command area in the consideration to be necessary when the rainfall is short or uneven (erratic) distribution in the time of crop growth. It is important to satisfy the crop requirement for sustaining crop production. Irrigation can be applied in supplemental or full depending on the adequacy of rainfall. Moreover, the need to sustain a double cropping system in the dry season and assuring of growing high-value crops are among the factors that necessitate irrigation (FAO, 1992).

In this regard, sustainable food production that can be expected through an optimal development of water resources in conjunction with the development of land depends on the method of irrigation considered (FAO 2003; Panigrahy *et al.,* 2006).

These methods, however, can be broadly classified into three categories: surface (basin, border, and furrows), sprinkler, and drip/micro irrigation methods. Surface irrigation is the application of water by gravity flow to the surface of the field, either the entire field is flooded (basin irrigation) or the water is fed into the small channel (furrow) or strip of land (borders). It is the oldest and still the most widely used method of water application to agricultural lands.

Surface irrigation is the application of water by gravity flow to the surface of the field, either the entire field is flooded (basin irrigation) or the water is fed into the small channel (furrow) or strip of land (borders). It is the oldest and still the most widely used method of water application to agricultural lands.

Surface irrigation offers several benefits for the less skilled and poor farmers. Irrigation has contributed significantly to poverty alleviation, food security, and improving the quality of life for rural populations. Under such circumstances, more than 90% of the world uses surface irrigation, even if local irrigators have the least knowledge of how to operate and maintain the system (Saymen, 2005).

Furthermore, these systems can be developed at the farm level with minimal capital investment. The major capital investment on the surface system is mainly associated with land grading, but if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning (FAO, 1995).

Therefore, the planning process for surface irrigation has to integrate information about the suitability of the land, water resources availability, and water requirements of irrigable areas in time and place (FAO, 1997).

Determining the suitability of land for surface irrigation requires a thorough evaluation of soil properties and topography (slope) of the land within field (Jaruntorn *et al*, 2004; 2008; and Lilles, 2014).

Since all kinds of rural land are involved by different land-cover/use types, its suitability evaluation for surface irrigation also guides in cases of conflict between rural land use and urban or industrial expansion, by indicating which areas of land covers/uses are most suitable for irrigation (FAO, 1993). The suitability of the land must also be evaluated on the condition that water can be supplied to it.

2.3. Challenges of irrigation in Ethiopia

Many of the schemes were under severe challenges due to salinity, siltation, or sedimentation problem. For instance, from five to eight years after the irrigation project was commenced salinity and sedimentation became very severe (Girma and Fentaw, 2003). The same source indicated that the main cause of salinity was poor irrigation water management. Inefficient drainage systems along the canals have caused severe siltation problems (Mintesinot *et al.*, 2004). The majority of farmers raised salinity problems as minor while few farms reported severe problems in poor canal management. The drainage system is also the cause of irrigation practice. Due to the poor scheme management, land and soil productivity is declining with years of irrigation. In consequence, the yield per hectare has been declining year after year. It is directly related to the water use system adapted by the farming community (Wagnew, 2004). The other aspect of poor scheme management is inadequate and late maintenance of canals due to lack of effective coordination, inefficient control system, weak linkage with relevant stakeholders, and lack of regular training is the individuality of much water user association (MoA, 2011a).

2.4. Opportunities of irrigation in Ethiopia

Irrigation can donates to increase food production, promotes economic growth and sustainable development, creates employment opportunities, poverty reduction, and protects the environment from degradation and pollution. Furthermore, it increases sub-surface water levels and recharges groundwater (Nata and Asmelash, 2007; Abraham *et al.*, 2011; Lijalem, 2013).

2.5. Land suitability evaluation for surface irrigation development

Land suitability is the fitness of a given type of land for a defined use, or suitability is a measure of how well the qualities of a land unit match the requirements of a particular form of land use. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defining uses (Meron, 2007). Land evaluation is primarily the analysis of data about the land its soils, climate, vegetation, etc in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources, and the terrain conditions concerning methods of irrigation considered (FAO, 2007). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (Hailegebriel Shiferaw, 2007) and (Kebede, 2010) conducted a study on GIS-based surface irrigation potential assessment of River catchments for irrigation development in Dale Woreda Sidama zone, SNNP And (Meron, 2007) carried out similar work on surface irrigation suitability analysis of southern abay basin by implementing GIS techniques.

As extensively discussed in FAO land evaluation guidelines (FAO, 1976, 1983, 1985), the suitability of these factors for surface irrigation methods and the given land utilization types can be expressed corresponding to the following suitability classes.

2.5.1. Structure of the suitability classification

According to FAO's Framework for Land Evaluation, the arrangement of the land suitability classification is described recognizing quantitative, qualitative, and current or potential suitability in four classifications of decreasing generalization. Each category has been retained its basic meaning within the context of the different classifications and as applied it different kinds of land use (FAO, 1976).

According to FAO (1976, 1979, 1990, 1991, 1997), generally, a land suitability map is classified into two classes, i.e., Suitable and Not suitable. These classes are further classified based on their benefits and limitations.

1. Order S-suitability classification

- S1 (highly suitable):- land having no significant limitation to the sustained application of a given use;
- S2 (moderately suitable):- land having limitations which in the aggregate are moderately severe for a sustained application of a given use;
- S3 (marginally suitable):- land having limitations which in the aggregate are severe for a sustained application of a given use and will reduce productivity or benefits.

2. Order N suitability classification

- N1 (temporarily not suitable):- land having limitations that may be surmountable in time but which cannot be corrected with existing knowledge at a currently acceptable cost;
- N2 (permanently not suitable):- land having limitations that appear as severe as to preclude any possibilities of successful sustained use of the land of given land use.

2.5.2. The basic physical factors in determining the suitability of land for surface irrigation:

2.5.3. Soils

The assessment or evaluation of soils for irrigation involves using properties that are permanent that cannot be changed or modified. FAO (1997) identifies all soil properties are not suitable for surface irrigation due to different factors even the soil's salinity and alkalinity are possibly improved.

Fasina (2008) states soil properties include drainage, texture; depth, salinity, and alkalinity are the most determinant factors for the selection of irrigation methods. There may be physical property factors like infiltration, poor internal drainage which causes salt buildup. The evaluation of physical and chemical soil properties to predict its performance for specific use is an essential part of land evaluation. Accordingly, some soils considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro-irrigation and selected land utilization types (Kebede, 2010). Identifying soil type means identifying the method of irrigation depending on soil properties in addition to the slope of the watershed.

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. Besides, 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 Texture: Texture refers to the relative proportion of sand, silt, and clay in a mass of soil. the proportion of sand, silt, and clay are 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 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 the unit commenced concerning 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 the 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.

2.5.4. Slope

The slope is the gradient or inclines of a surface and is often expressed as a percent. The slope is important for soil formation and management because it influenced drainage, runoff, erosion, and the choice of irrigation types. The slope gradient of the land has a great effect on the selection of irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, mostly slopes which are less than 2% are highly suitable for surface irrigation, between 2% and 5% moderately suitable, and 5% up to 8% marginally suitable. But slopes, which are greater than 8%, are not widely recommended for surface irrigation development (FAO, 1999).

2.5.5. Landuse/land cover

Land use/land cover and are often used interchangeably. However, they are quite different. The GLCN (2006) defines the land cover as the observed (bio) physical cover, as seen from the ground or through remote sensing, including vegetation (natural or planted) and human construction (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock, or sand surfaces also count as land cover. Given land use 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 can be defined as a series of activities undertaken to produce one or more goods or services. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for surface irrigation with precise and quantitative economic evaluation (Jaruntorn *et al.*, 2004).

2.5.6. Distance from water resources

It is significant to make sure that there will be no absence of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle FAO, (2001). Therefore, water supply (water quantity and seasonality) is an essential factor to evaluate the land suitability for irrigation according to the volume of water during the year which is available FAO, (1985). Computing the amount of water that is available for surface irrigation and locate the exact location to be economical addressed to transport from the source to the command area. Surface irrigation water sources should be above the command area to irrigate the entire area by gravity through surface irrigation. It is also necessary that the location of water preferably near the command area minimize the length of the conveyance structure to be economical. Therefore, distance from water sources to command area, nearness to Rivers, is useful to reduce the conveyance system (irrigation canal length), evaporation losses, and thereby developing the irrigation system to be economical (Silesh, 2010).

2.6. Surface water resource availability

Ethiopia has a diversified climate ranging from semi-arid desert type in the lowlands to humid and warm (temperate) type in the southwest (Beyene, 2010). Hurni (1982), Osman (2001), and Seleshi and Demaree (1995) also described high inter and intra-annual rainfall variability in Ethiopia. The mean annual rainfall of Ethiopia ranges from 141mm in the arid area of the eastern and northeastern borders of the country to 2,275mm in the southwestern high lands (Berhanu, 2013). The complex topographical and geographical features of the country have a strong impact on these spatial variations of climate and different rainfall regimes in Ethiopia (NMSA, 1996; Zeleke, 2013).

Ethiopia is also endowed with a substantial amount of water resources. The country is divided into12 basins; 8 of which are River basins; 1 lake basin; and the remaining 3 are dry basins, with no or significant flow out of the drainage system. Almost all of the basins radiate from the central plateau of the country that separates into two due to the Rift Valley. Basins drained by Rivers originating from the mountains west of the Rift Valley flow toward the west into the Nile River basin system, and those originating from the Eastern Highlands flow toward the east into the Republic of Somalia. Draining in the Rift

Valley originate from the adjoining high lands and flow north and south of the uplift in the center of the Ethiopian Rift Valley. Since almost all River basins originate from the highlands and high rainfall areas, they have a huge amount of surface water running in the River basin systems, and Ethiopia is considered to be the water tower of the Horn of Africa. This potential is not fully utilized and translated into development because of many factors including limited financial resources, technical challenges, and lack of good governance in the water sector.

Table 2.1: Summary of the spatial variability of surface water in Ethiopia

Flow direction	Basins included in the section	Area coverage share (%)	Surface water share (%)
West	Abbay,BaroAkobo, Mereb, and Tekeze	38.75	69.83
East	Genale-Dawa and Wabishebele	33.34	7.58
South	OmoGibe, Rift Valley lake basin	5.15	17.94
Northeast	Awash	9.79	3.95
No flow	Aysha, Dinakle, and Ogaden	12.96	0.69

(Source:-MOWIE, 2013)

2.6.1. Application of SWAT model for assessment of water resources availability

Several hydrologic models are widely used for the assessment of water resources. Rainfall-runoff models have broadly been used in hydrology over the last century for several applications, and play an important role in optimal planning and management of water resources in catchments (O 'Loughlin *et al.,* 1999; Munyaneza *et al.,* 2013). Oyebande (2001) reported that the main challenge associated with applying a successfully rainfall-runoff model lies in the lack of monitoring data, mainly rainfall spatial distribution over the catchment area, since rainfall is the primary input in any hydrological model. Another potential problem is having no reliable flow data that can lead to reliable calibration and validation of catchment parameters.

Those models include SCS-CN (NEH, 1985), HEC-1, HEC-HMS (HEC 1990, 2001), SWAT (Arnold *et al.,* 1996), the MIKE BASIN (Supiah and Normala, 2002), WatBal (Water Balance Model) (Loucks, 2006; Mugatsia, 2010), WatBal is lumped conceptual model which consists of two major components. The first one calculates the potential evapotranspiration using the Priestley Taylor method and the other component calculates the water balance of the basin (Kaczmarek,1993). The WEAP model simulates the natural hydrological processes (e.g., rainfall, evapotranspiration, runoff, and infiltration) to enable assessment of the availability of water within acatchment (basin) (Sieber*et al.*, 2005), etc.
Several hydrological models were used for the assessment of surface and groundwater availability at a River basin level. The assessment of water availability at a watershed level is realized by quantifying runoff generated in the watershed using hydrological models (Daniel, 2011). Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. Hydrological modeling is a process of determining the operation of the hydrological system in the transformation of rainfall into runoff. They are primarily used for hydrological prediction and for understanding hydrological processes. From those hydrological models SWAT model was the widely used model because of the availability of the model on a minimum investment of time and cost, the ability of the model to produce the intended output to meet the objective of the project, ability of the model considered to produce the outputs needed to meet the aims of a particular project, Possibility to prepare a list of assumptions made by the model, ability to check the assumptions likely to be limiting in terms of the known response of the catchment and the ability to make a list of inputs required by the model and deciding whether all the information required by the model can be provided within time and cost constraints.

Soil and Water Assessment Tool (SWAT) is a physically-based continuous-event hydrologic model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying soils, land use, and management conditions over long periods (Arnold *et al.,* 1998, 2000; Neitsch, 2001). SWAT was applied for watershed delineation. And it is embodied in ArcGIS that can integrate various readily available geospatial data to accurately represent the characteristics of the watershed.
SWAT uses Hydrological Response Units (HRUs) to describe the spatial heterogeneity in terms of land use, soil types, and slope within a watershed as a physical-based model. To

simulate hydrological processes in a watershed, SWAT divides the watershed into sub-watersheds based upon drainage areas of the tributaries. The sub-watersheds are further divided into smaller spatial modeling units known as HRUs, depending on landuse/land cover, soil, and slope characteristics. One of the main advantages of SWAT is that it can be used to model watersheds with less monitoring data. For simulation, SWAT needs a digital elevation model; landuses/land cover map, soil data, and climate data of the study area that is used to model watersheds with less monitoring data.

2.7. Assessment of irrigation water requirements

The irrigation 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 beneath 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 as 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 amount 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 *et al.,* 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).

CROPWAT software is a decision support system developed by the land and water development division of FAO for planning and management of irrigation. CROPWAT is meant as 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. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rainfed conditions or deficit irrigation. Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO (2001). The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions.

There are two new versions of the CROPWAT: one is CROPWAT v 8.0 that contains a complete version in Pascal, developed with the assistance of the Agricultural College of Velp, Netherlands. It overcomes many of the shortcomings of the original 5.7 version. CROPWAT 8.0 is a DOS application, but it runs without any problem in all MS-WINDOWS environments. Another one is CropWat for Windows that is written in visual basic and operates in the Windows environment. It has been developed with the assistance of the International Irrigation & Development Institute (IIDS) of the University of Southampton, UK. Both versions use the same FAO (1992) Penman-Montieth method for calculating the reference crop evapotranspiration. These estimates are used in crop water requirements and irrigation scheduling calculations. Some of the interpolation methods used in CROPWAT for Windows are slightly different (up to 2%) from those used in CROPWAT 8.0.

Calculation methods

The values of a decade or monthly Reference Crop Evapotranspiration (ET_O) are converted into daily values using four distribution models (the default is a polynomial curve fitting). The model calculates the Crop Water Requirements using the equation:

$CWR = ETo * Cultivated\ area$……………………………………………………….(2.1)

This means that the peak CWR in mm/day can be less than the peak ET_O value when less than 100% of the area is planted in the cropping pattern.

The average values of crop coefficient for each time step are estimated by linear interpolation between the Kc values for each crop development stage. The "Crop Kc" values are calculated as Kc*Crop Area, so if the crop covers only 50% of the area, the "Crop Kc" values will be half of the Kc values in the crop coefficient data file

For crop water requirements and scheduling purposes, the monthly total rainfall has to be distributed into equivalent daily values. CROWAT for Windows does this in two steps. First, the rainfall from month to month is smoothed into a continuous curve (the default curve is a polynomial curve, but can be selected other smoothing methods available in the program e.g. linear interpolation between monthly values). Next, the model assumes that the monthly rainfalls are in 6 separate rainstorms, one every 5 days (the number of the rainstorms can be changed). The model has available for Effective Rainfall methods (the USDA SCS method is the default).

Crop water requirement was determined from the interrelationships of the ETc, soil type, bulk density of the soil, field capacity and permanent wilting point of the soil, and the effective root zone of the crop grown at the project site. The crop ET (ET_C) was estimated by FAO Penman-Monteith equation (FAO, 1998).

$$Etc = Kc * ETo \quad (2.2)$$

The CROPWAT program (version 8.0) developed for the FAO Penman-Monteith method (FAO, 2005) was utilized for estimating the crop water requirement of each of the seven crops studied. To ensure the integrity of computations, the weather measurements were made at 2m (or converted to that height) above an extensive surface of green grass, shading the ground.

Reference evapotranspiration (ET_O): It was calculated from climatic data using the FAO Penman-Monteith method Since FAO Penman-Monteith Modified equation to determine ET_O as follows:

$$ETo = \frac{0.408\,\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \quad (2.3)$$

Whereas:-

ET_O- reference evapotranspiration (mm day-1)

Rn- net radiation at the crop surface (MJ m-2 day-1)

G-soil heat flux density (MJ m-2 day-1)

T-mean daily air temperature at 2 m height (°C)

U_2-wind speed at 2 m height (m s-1)

e_s- Saturation vapours pressure (kPa)

e_a- actual vapour pressure (kPa)

(e_s-e_a)-saturation vapour pressure deficit (kPa)

Δ-slope vapour pressure curve (kPa °C-1)

ϒ- psychroetric constant (kPa °C-1).

$$ea = e^{\circ}(Tmin) = 0.611\exp\left(\frac{17.27Tmin}{Tmin+237.3}\right) \quad (2.4)$$

To fill the gap of solar radiation the Hargreaves' radiation formula, adjusted and validated at several weather stations in a variety of climate conditions, becomes:

$$Rs = KRs * (Tmax - Tmin)^{0.5} * Ra \quad (2.5)$$

Whereas:-

Ra extra-terrestrial radiation (MJ m-2 d-1)

Tmax _maximum air temperature (°C)

Tmin _minimum air temperature (°C),

kRs _adjustment coefficient (0.16-0.19)

Accordingly, the FAO Penman-Monteith method was used to determine reference evapotranspiration (ETO) in the case of this study.

By dividing the available water by the gross irrigation water requirement (GIWR) the maximum irrigated area was calculated. Because of the scale, assumptions had to be made to the definition of areas to be considered homogeneous in terms of rainfall, potential evapotranspiration, cropping pattern, cropping intensity, and irrigation efficiency. First, the major irrigation cropping patterns were delineated. Second, the climatic zones were defined, based on climate stations. The combination of the cropping zones with the climate zones resulted in the study areas, homogeneous in irrigation cropping characteristics and climate. The model to calculate the Net irrigation water requirement (NIWR) was run for three scenarios and divided by the efficiency to calculate the GIWR. The influence of selecting, cropping pattern zones, and the estimations used for cropping intensity and irrigation efficiencies is of prime importance for the final results.

2.7.1. Irrigation efficiencies

The amount of water needed during a growing season depends on the crop, yield goal, soil, temperature, solar radiation, and other biophysical factors. In general, long-season crops require more water than short-season crops. Some crops benefit from irrigation during the entire season, while others are more sensitive during specific growing periods. In general, the irrigation water requirements are determined using tools like FAO's CROPWAT or ClimWat. The overall approach is however based on the so-called FAO56 approach (Allen, 1998). However, with the advantage of satellites more and more location-specific information is being used to assess water balances.

2.8. Overview of GIS application

Clearly, the increased availability of large, geographically referenced data sets and improved capabilities for visualization, rapid retrieval, and manipulation inside and outside of the GIS will demand new methods of exploratory spatial data analysis that are specifically tailored to this data-rich environment (Wilkinson *et al.,* 1996; Gahegan *et al.,* 1999) as cited inYared (2014). A GIS is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data Good child (2000) as cited in Yared (2014). Geographically referenced data are data that describe both the locations and characteristics of spatial features such as roads, land parcels, and vegetation stands on the Earth's surface. The ability of a GIS to handle and process geographically referenced data distinguishes GIS from other information systems. It also establishes GIS as a technology important to a wide variety of applications. Using GIS databases, more up-to-date information can be obtained or information that was unavailable before can be estimated and complex analyses can be performed. This information can result in a better understanding of a place, can help to make the best choices, or prepare for future events and conditions. The most common geographic analyses that can be done with a GIS are narrated separately in the subsequent sub-sections.

2.8.1. Role of GIS for land suitability analysis

The distinguishing feature of GIS is its capability to perform an integrated analysis of spatial and attributes data. GIS can be used not only for automatically producing maps, but it is unique in its capacity for integration and spatial analysis of multi-source datasets such as data on land use, population, topography, hydrology, climate, vegetation, transportation network, public infrastructure, etc. The data are manipulated and analyzed to obtain information useful for a particular application such as land-use suitability analysis (Malczewski, 2003) Analytical Hierarchy Process (Saaty, 2008) is the common approach for land suitability analysis. (Gemachu Ayala,Bayisa Muleta,Tadele Geremu, 2018)

According to Prakash (2003), the ultimate aim of GIS is to provide support for the spatial decisions making process. In multi-criteria evaluation, many data layers are to be handled to arrive at the suitability, which can be achieved conveniently using GIS. In the context of land suitability analysis, GIS helps the user to determine what locations are most/least suitable for a specific purpose. In this way, the results of GIS analysis can provide support for decision-making. It also enables the creation and modifies any land suitability analysis that makes the best use of available data. Accordingly, the GIS was used in the current study to identify and show the potentially irrigable sites of the current study area. GIS is a tool that allows users to create users' interactive queries, analyze spatial information, and edit data (Nazir *et al.,* 2019). GIS has been an increasingly important means for understanding and dealing with the persuasive problem of water and related resource management in the world. GIS-based MCE was found to be a favorable tool to identify potential land inadequacy to growing different crops (Murayama, 2010). One of the most advantages of this tool is the opportunity of adjusting a standardized FAO land suitability framework for soil, slope, land use/land cover, and river proximity relative to irrigation potential assessment. For agronomic, environmental, and economic reasons, the need for specialized information about agricultural practices is expected to rapidly increase (Begue *et al.,* 2018). Accurate mapping of the distribution of irrigated land using remote sensing data at a regional scale can facilitate an improved understanding of patterns of water uses and food production (Chance *et al.,* 2017). Yet, studies that have used remote sensing to map irrigated lands remain relatively infrequent (Ozdogan *et al.,* 2010).

The main application in GIS is mapping where things are and editing tasks as well as for map-based query and analysis (Nazir *et al.,* 2019). A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. GIS can integrate Remote Sensing and different data sets to create abroad overview of the potential irrigable area. While the remotely sensed image of an area gives a true representation of an area based on land use/cover/use, grid interpolated climate data can serve many purposes and be used as a climatic database where meteorological data from gauging networks are not adequate. An application example in the continental United States, irrigation mapping methodology that relies on remotely sensed inputs from the Moderate Resolution Imaging Spectral radiometer (MODIS) instrument, globally extensive ancillary sources of gridded climate and agricultural data, and on an advanced image classification algorithm. The methodology involves four steps, first, climate-based indices of surface moisture status and a map of cultivated areas to generate a potential irrigation index. Second, identify remotely-sensed temporal and spectral signatures that are associated with the presence of irrigation. Thirdly, combine the climate-based potential irrigation index, remotely sensed indices, and learning samples within the decision trees supervised classification tool to make a binary irrigated/non-irrigated map. Finally, apply a tree-based regression algorithm to derive the fraction of irrigated area within each pixel that has been identified as irrigated (Ozdogan and Gutman, 2008).

2.8.2. AHP application for Weighted overlay analysis

A weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create integrated analysis (Malczewski, 1999). The purpose of weighting in land suitability analysis for irrigation is to determine the importance of each factor relative to other factors that affect land for irrigation. To prioritize the influence of the factor values, weighted overlay analysis uses an evaluation scale from 1(represents the least suitable factor) to 9 (represents the most suitable factor) (Saaty *et al.,* 1980). Weighted overlay accepts integer raster as input, such as a raster of land cover, soil type, and Euclidean (the straight line from the center of the source cell to the center of the surrounding cells) distance output to find suitable land for irrigation. AHP is a power full and flexible decision-making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decision need to be considered (Weerakoon *et al.,* 2014). AHP involves structuring multiple-choice criteria into a hierarchy, assessing the relatives for each criterion, determining an overall ranking of the alternatives, and completely aggregates various facets of the decision problem into a single objective function (Saaty, 2000). By organizing and assessing alternatives against a hierarchy of multifaceted objectives, AHP drastically reduces the complex decision cycle (Anonymous *et al*, 2015). According to (Shen *et al.,* 2015) the procedure used to establish the weights using the AHP method includes; - a) structure hierarchy, b) construct pair-wise comparison matrix, c) calculating the weights (the priority eigenvector), and d) consistency evaluation.

2.9. Irrigation potential assessment

In the past, several studies have been made to assess the irrigation potential and water resources by using GIS as a tools (FAO, 1987; FAO, 1995; FAO, 1997; Melaku, 2003; Negash, 2004; Hailegebriel, 2007; Meron, 2007; Kebede, 2010; Yared, 2014).

(FAO, 1987) conducted a study to assess land and water resources potential for irrigation in Africa based on River basins of countries. It was one of the first GIS-based studies of its kind at a continental level. It suggested a natural resource-based approach to assess irrigation potential. Its main limitations were in the understanding of criteria for defining land suitability for irrigation and in water allocation circumstances needed for computation of irrigation potential.

FAO (1997) studied the irrigation potential of Africa taking into consideration the above restrictions it focused mainly on quantitative assessment based on physical criteria (land and water) but relied deeply on information collected from the countries. A River basin approach had been used to insure consistency at River and basin levels. Geographic Information System (GIS) facilities were widely used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development.

Negash (2004) conducted a study on GIS-based irrigation suitability analysis in the Abaya Chamo Basin. As the author indicates a crop water requirement for selected crops was evaluated using CROPWAT 4.3 tool as an input of climate, soil, and crop data of the area under consideration was provided. It uses monthly data to estimate evapotranspiration. Monthly rainfall magnitude was converted into daily values each month through interpolation. In this study reference evapotranspiration (ETo) was mainly estimated by Penman-Monteith and Hargreaves method if all meteorological data was available, and only temperature data was available respectively. The cropping pattern was selected to fit with the local cropping calendar and the respective crop coefficient for the initial, mid and late seasons were identified based on the FAO guidelines. The intermediate Kc values were linearly interpolated between the pre-identified Kc values for different stages. Thus the evapotranspiration demand of the crop was determined as ETc = ETO x Kc mm/period. Effective rainfall was determined with the aid of the SCS method option in the program and deducted from the ETc value. Finally, the crop water requirement was estimated to take care of the rainy seasons as CWR = ETc – Peff and the net irrigation requirement was estimated as, NIWR = CWR x Acrop mm/period.

Yared (2014) conducted study in land suitability assessment for surface irrigation at azule catchment, arsi zone, Oromiya by considering identification of potential irrigable land, and estimation of irrigation water requirement and surface water resources of watershed. To identify potential irrigable land, irrigation suitability factors such as soil type, slope, and distance from water supply (sources) were taken into account and conducted by using GIS application.

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/landuse factors to find suitable land for irrigation concerning the location of the available water resource, and to determine the combined influence of these factors for irrigation suitability analysis, weighted overlay analysis was used in Arc-GIS. Land unit is obtained by the overlaying of selected theme layers, which has unique information of land qualities for which the suitability is based on the selected theme layers.

Kebede (2010) conducted a study on GIS-based surface irrigation potential assessment of River catchments for irrigation development in Dale Woreda, Sidama zone, SNNP. In this study irrigation suitability factors such as soil type, slope, landuse/land cover, and distance from water supply (sources) were taken into account and weighted overlay analysis of these factors has been accomplishing to identify potentially irrigable land. The irrigation suitability analysis of these factors indicates that 86% of soil and 58.5% slope in the study area are in the range of highly suitable to marginally suitable for the surface irrigation system. In terms of land cover/landuse, 87.1% of land cover/land Irrigation can donates to increase food production, promotes economic growth and sustainable development, creates employment opportunities, poverty reduction, and protects the environment from degradation and pollution. Furthermore, it increases sub-surface water levels and recharges groundwater (Nata and Asmelash, 2007; Abraham *et al.*, 2011; Lijalem, 2013).

use is highly suitable whereas 12.9% were restricted from irrigation development.

3. MATERIAL AND METHODS

3.1. Description of the study area

3.1.1. Location

The Bilate River Watershed is situated in Southern Nation, Nationalities and Peoples region in Rift Valley Lake Basin and located approximately 6º38′18"North - 8º6′57" North latitude and 37º47′6"East - 38º20′14"East longitude. In this study, the Sub-basin has a total area equivalent of 4,963.4 km² which is delineated by using 30m by 30m DEM in Arc SWAT software. The Bilate River Watershed is among the major watershed of the RVLB. It drains to the northern part of the Lake Abaya-Chamo Drainage sub-Basin. The Bilate River is the main perennial River that flows in the basin. It originates from the Gurage Mountain and flows south into Lake Abaya. The Bilate River flows from the Gurage Mountain in the north towards the south into Lake Abaya. It is one of the three main perennial Rivers such as Bilate, Gidabo, and Gelana that flow into Lake Abaya. The main source of water in the sub-basin is rainfall which comes from Gurage highland through Silte, Hadiya, and Kambata. Bilate River sub-basin is one of the major River watersheds in the RVLB having more land suitable for agriculture and it has to supply those most densely populated communities. The sub-basin provides resources for the livelihoods of the population; used as a source of food, drinking, wildlife, transport, grazing, and water for livestock, and as a repository for human and agricultural.

This makes the issue of water resource availability very crucial for effective water resource management and improves livelihoods.

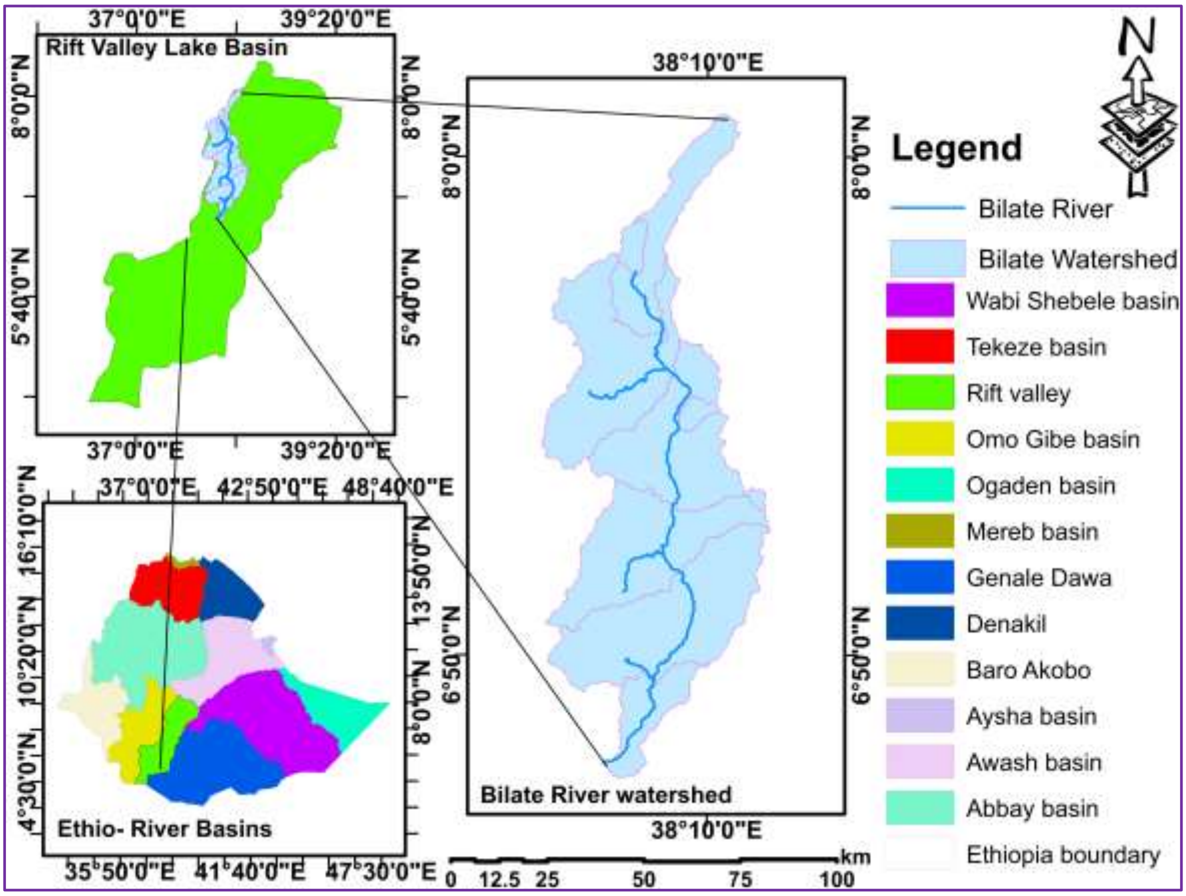

Figure 3.1: Location Map of Bilate watershed

3.1.2. Topography

The altitude of the catchment ranges from 1177 meters at Lake Abaya to 3328 meters at Mt.Ambaricho, and AlichoWiriroWoreda above sea level. This indicates that the topography of the area ranges from low land plain areas to highly mountains elevated terrains. The elevated and other mountainous areas of the watershed such as DugunoFango ridge, Mt. Dato, and Mugo ridge at North West and South-west part are indicators of steep slopes. Towards the center and the South, the morphology changes to quite gentle slopes though there are some steep slopes along with the River courses and hilly features. DEM was downloaded from the USGS Earth Explorer (URL1, URL2).

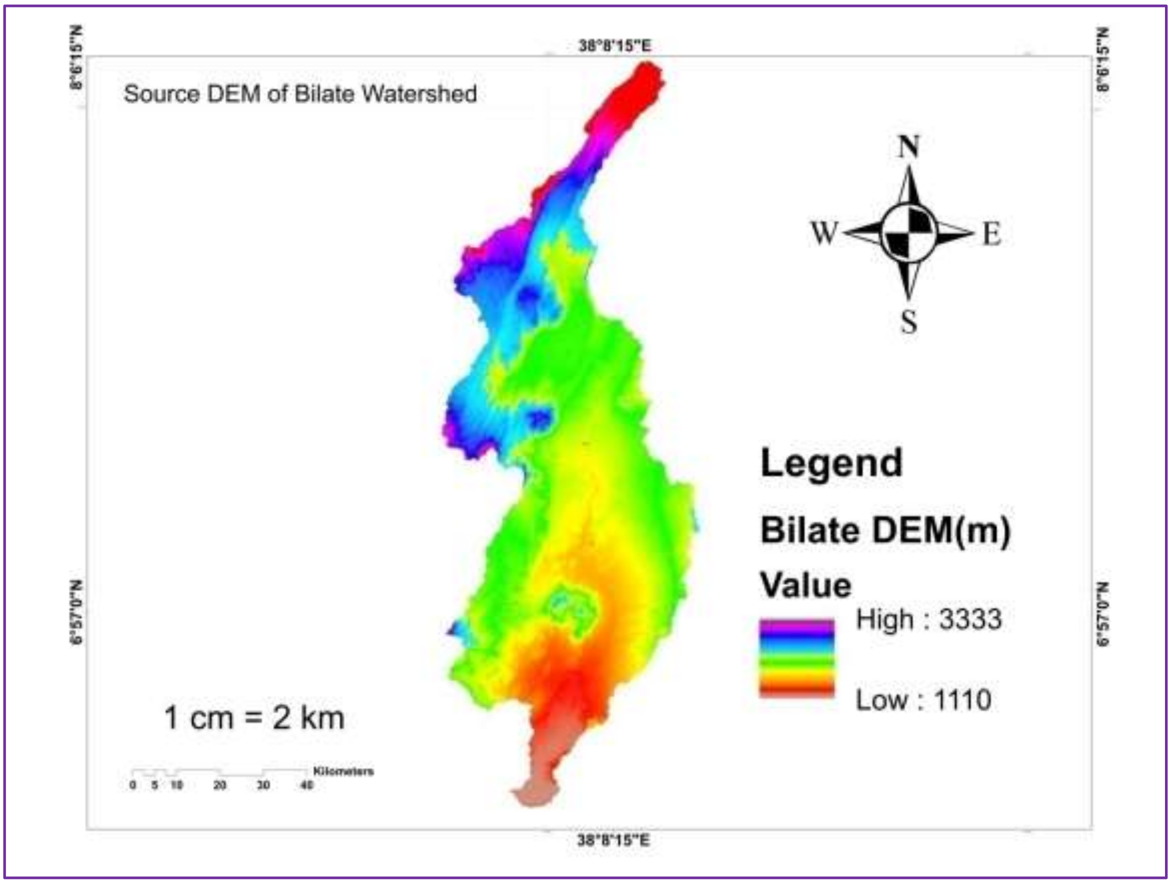

Figure 3.2: Elevation Map of Bilate watershed

3.1.3. Climate

The traditional way of classification of Ethiopia's climate is based on altitudes and temperatures. Based on such classification, there are five climate zones: (Wurch with cold climate greater than 3000 altitudes, Dega having temperate like climate-highland with 2500-3000 altitude, Woyina Dega has also warm climate with 1500-2500 altitude, Kola having hot and arid type with less than1500m altitude) and Bereha have hot and hyper-arid type climate. According to this classification, most portion of the study area fallen in the Woyina Dega and Kola zones.

The climate of the study area follows a humid to semi-arid tropical bimodal distributed precipitation pattern. Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects (Stefan *et al*, 2004). The analysis of data of 11 meteorological stations in the area and nearby stations shows the area receives an average rainfall of 1145.82mm per year. From the analysis it was observed that two rainfall patterns exist in the area, uni-modal in the northern and northwestern part which receives relatively higher precipitation (1366.92mm) and that of bimodal rainfall pattern in the Southern and South-Eastern receives relative mean annual precipitation amount of 998.16mm (Abdi and Kassa, 2014). The long-term mean annual temperature varies widely; it ranges from 16.65˚C in the highlands and around 27.10˚C in the lowlands.

Based on Analysis of 30 Years of data from 1990 to 2019 of 4 Meteorological stations data from Bilate, Bodity, Dintu, and Hossana stations the average annual rainfall distribution is 1087.4mm and generally, the temperature and rainfall pattern in all stations shows that there is a high spatial and temporal variation of rainfall and temperature in the study area. The average annual maximum and minimum temperature in the watershed area is about 31.91^{0}C and 6.91^{0}C at Bilate and Bodity Station respectively.

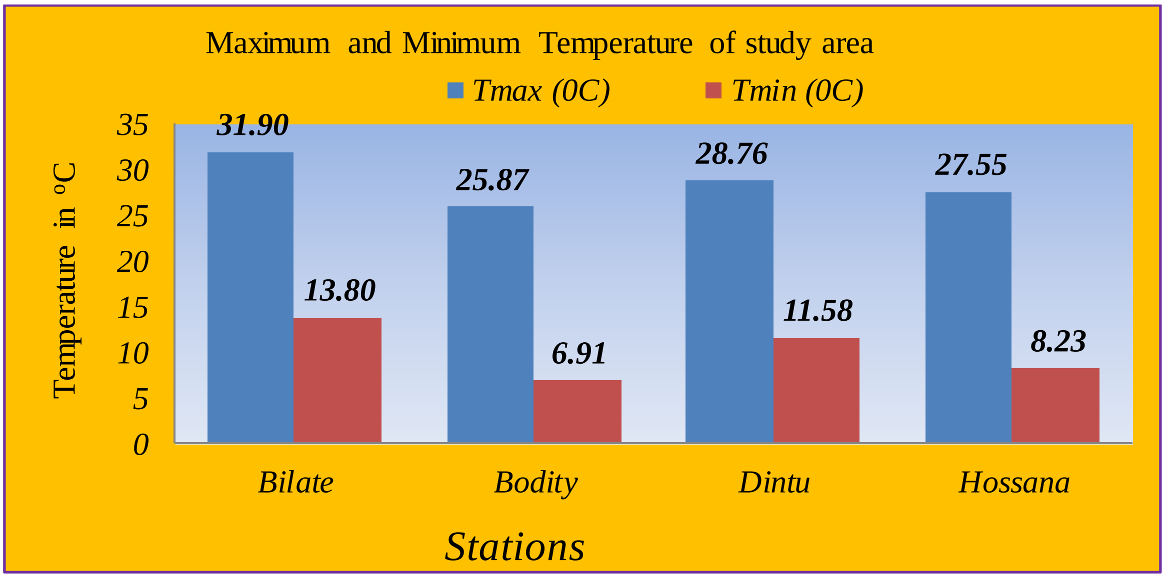

Figure 3.3: Long-term mean annual maximum and minimum temperature of the study area (1990-2019)

I. Temperature

The mean monthly maximum and minimum temperatures recorded for meteorological stations in the Bilate River Watershed are presented in Figure 3.4 below. The mean monthly temperature was determined as the average of the maximum and minimum temperatures. Generally, the month of February had the highest temperature with the evaluation of 33.16 ^{o}c since January's exceptionally lowest temperature reading of 9.07 ^{o}c.

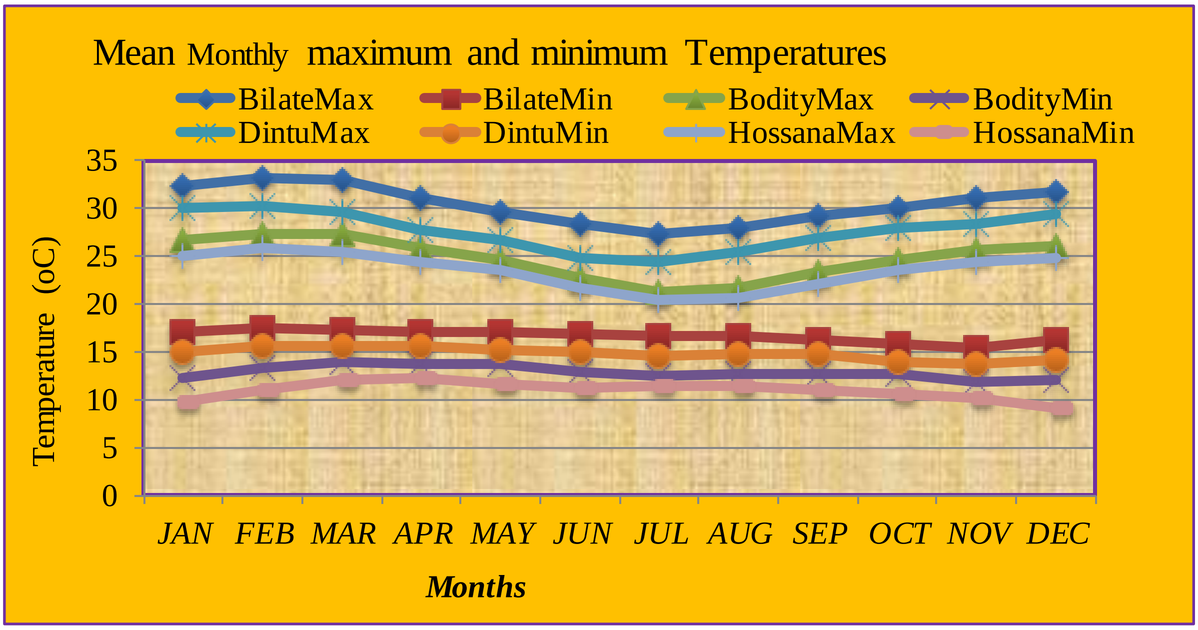

Figure 3.4: Long-term mean monthly variations of maximum and minimum air temperature (1990-2019)

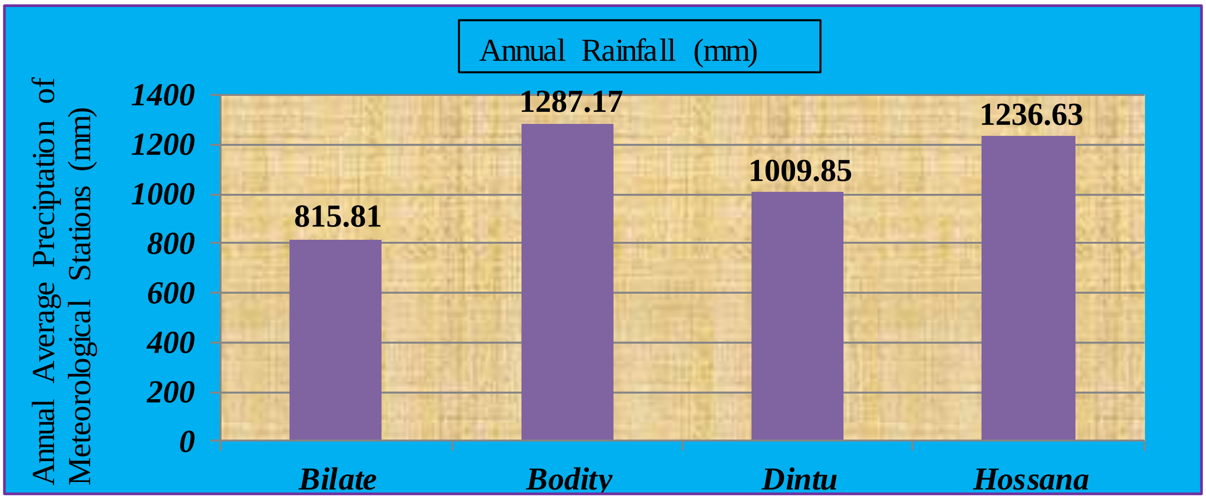

Figure 3.5: Average Annual Precipitation of the Meteorological Stations (1990-2019).

The precipitation of the Bilate River Watershed is characterized by a bimodal pattern having maximum precipitation during August, September July, June, October, and minimum January, February, November, and December.

II. Wind speed

Wind characteristics such as wind velocity. The frequency and direction of winds are important concerning the selection of irrigation methods, the rate of transpiration of crops the average wind was observed as 1.29 m/s or 111.11 km/day.

III. Sunshine

The maximum average monthly sunshine hour in Bilate Meteorological station was found to be 8.61 hours in January, whereas the minimum sunshine hour was 5.45 hours occurred in July with an annual average of 7.52 hours.

V. Relative humidity

Relative humidity was an input parameter to determine ETc. The Thirty years data (1990-2019) average monthly relative humidity taking from Bilate meteorological station 70.31% within an annual average of 61.56%.

3.1.4. Soil type

Soil is a key factor in determining the suitability of an area for agriculture in general and irrigation in particular. According to (FAO, 1998) soil classification, the leading soil type in the study area is clay soil in the upper and middle part of the watershed and sandy loam in the lower part of the watershed.

The major soil types in the Bilate watershed developed from Harmonized Soil Map of the World (HWSD) and FAO which is collected from the Ethiopian Ministry of Water Irrigation and Energy (EMWIE) and reclassified for the study area and shown below in Figure (3.5). These soils in the Bilate River Watershed are Vitric Andosols, Mollic Andosols, Luvic phaeozems, Eutric Fluvisols, Chromic Vertisols, Chromic Luvisols, Humic Nitosols, and Lithic Leptosols. There are several soil physical parameters to determine soil suitability analysis, but mainly there are three soil physical properties to evaluate soil suitability in the watershed. These are soil texture, soil depth, and soil drainage properties each data was taken according to FAO standards. The physical properties of these soil groups were used for irrigation suitability analysis. The major soil types and their area coverage of each soil type in the study area are summarized in Table 3.1 and Figure 3.5.

Table 3.1: Major Soil types of the study area

S/NO.	Soil type	Soil Code	Area(km^2)	Proportion (%)
1	Mollic Andosols	ANm	196.78	3.96
2	Vitric Andosols	ANz	1477.95	29.78
3	Eutric Fluvisols	Fle	4.64	0.09
4	Lithic Leptosols	LPq	568.84	11.46
5	Chromic Luvisols	LVx	1078.65	21.73
6	Humic Nitosols	NTu	723.27	14.57
7	Luvic phaeozems	PHi	56.74	1.14
8	Eutric Vertisols	VRe	846.32	17.05
9	Water body	WATR	9.83	0.20
	Sum		4963.02	100.00

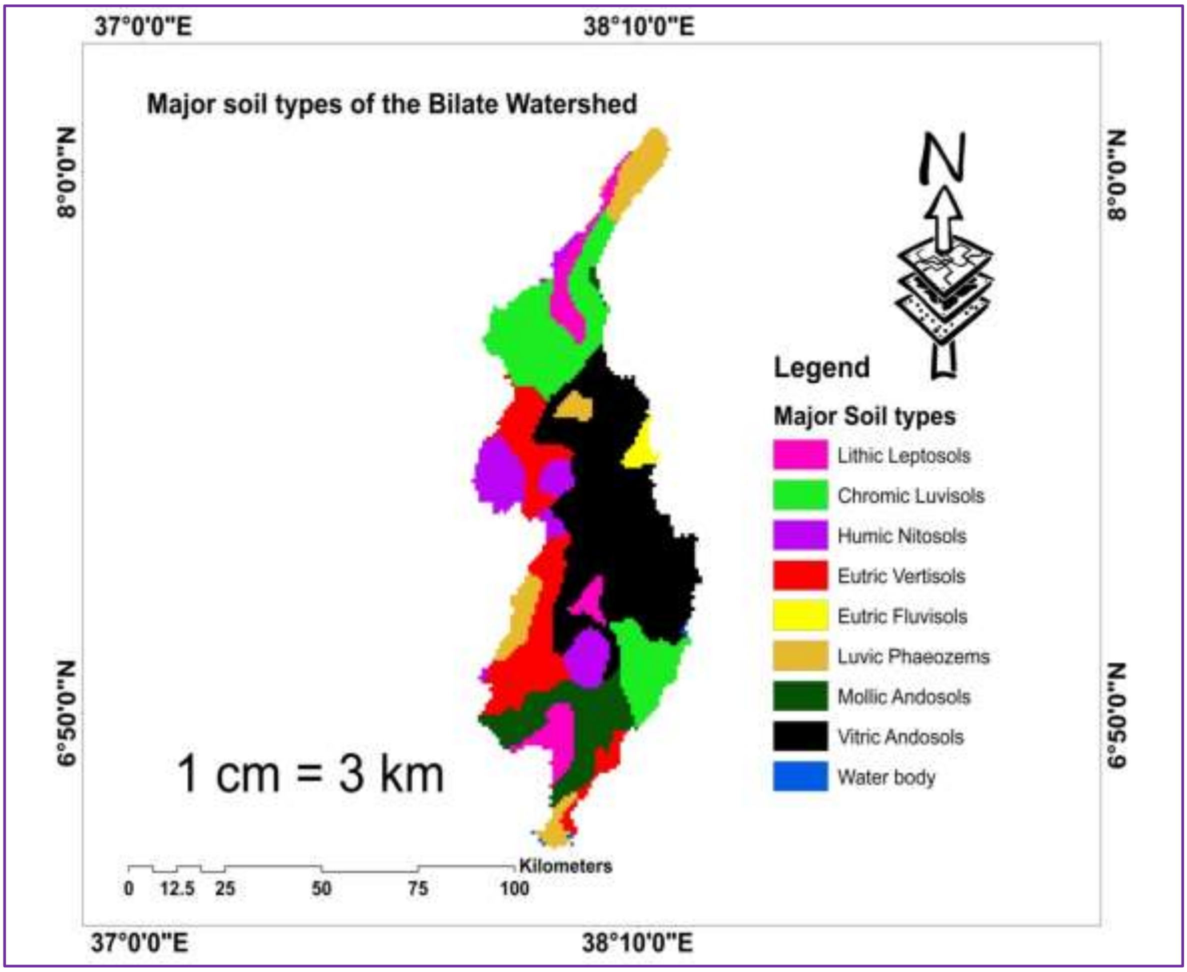

Figure 3.6: Major Soil Types of the study area

3.1.5. Major Crops of the study area

Crop production is the major source of income for households. Different crops are produced by a household because of a strong orientation towards self-efficiency. The main crops grown in the study area are Maize, Onion, Tomato, Potato, and Tobacco grown downstream and part of the watershed and Wheat additionally cultivated upper stream of the watershed and different types of grains and vegetables.

3.1.6. Landuse/Land cover

The land uses actual meaning is the technique in which land is used by people in an area to produce what is needed by the people for use through the involvement of labor, capital, and available technology.

According to (FAO, 2000), land use is considered by preparations, activities, and inputs people assume under a certain land cover type to produce, change, or maintain it.
The definition of land use in these ways indicates the direct connection between land covers and the action of people in their habitats.
Land cover is observed physical cover on the earth's surface. In other words, land cover is what is physically appearing on the ground surface as a natural or manmade entity.
The land use and land cover data were obtained by visual interpretation of remotely sensed images retrieved from USGS Land sat TM satellites classification system using maximum likelihood supervised classification tool in Erdasimage 2014.
In terms of areal coverage, the Watershed is mainly covered by the Forest, Wood Land, Shrub/bush, Agriculture, grassland, woodland, barren land, WetLand, water body (Boyo Lake), and Settlement covers a small area.
Table 3.2: Landuse/Land cover classification of the study area

S/ NO.	LULC- Classes	Area(km^2)	Proportion (%)
1	Forest	69.13	1.39
2	Wood Land	125.91	2.54
3	Shrub/bush land	269.41	5.43
4	Agriculture	3453.49	69.66
5	Grass Land	621.39	12.51
6	Barren Land	343.12	6.92

7	Wet Land	22.06	0.45
8	Water body	28.41	0.51
9	Settlements	30.52	0.58
	Total	4963.40	100.00

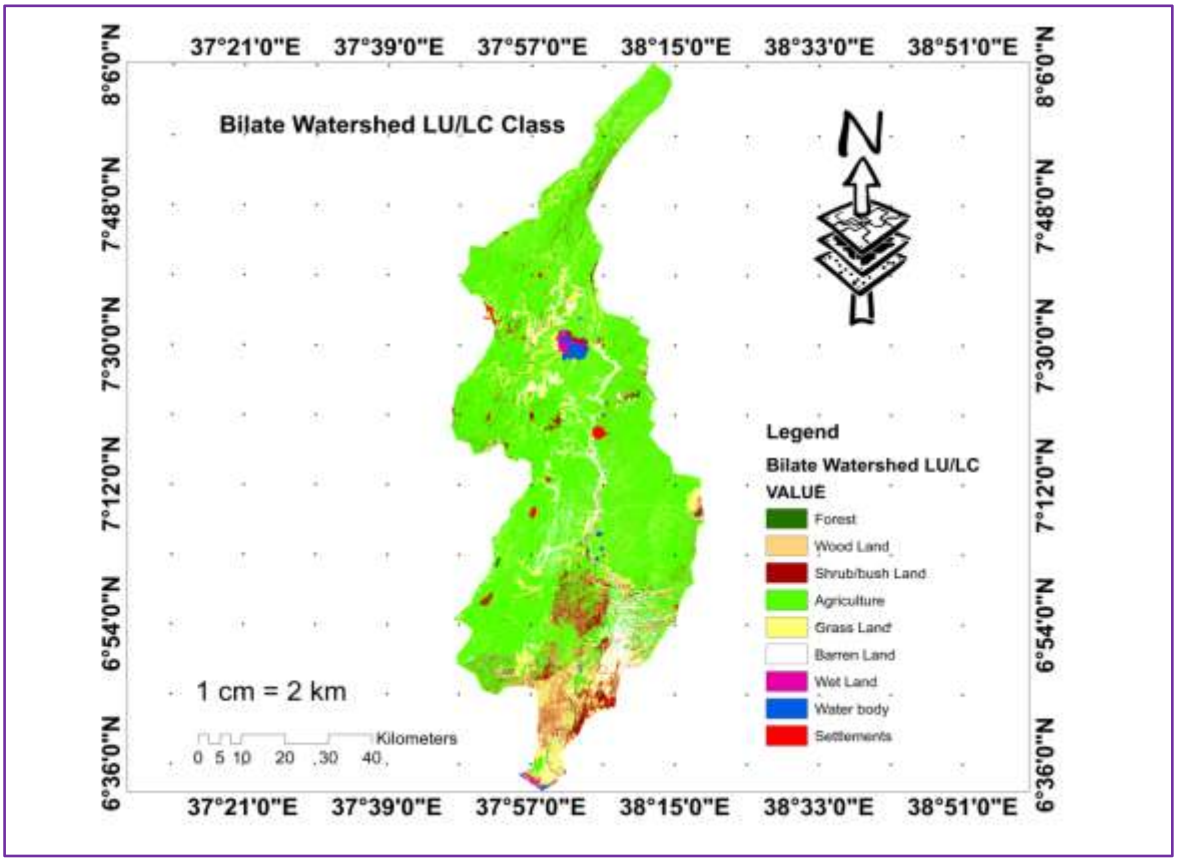

Figure 3.7: Landuse/Land Cover of the study area

3.2. Data collection and analyses

3.2.1. Identification of suitable land for surface irrigation development.

Land suitability analysis is an evaluation/decision problem involving several factors. The assessment of terrain conditions, and soil characteristics is an essential part of the land evaluation and forecasting exercise applied to agriculture (FAO, 2007). Their assessment provides information about the limitations of the land for surface irrigation development. The limitation of the land is derived from the quality of the land (Saptahy *et al.*, 2017). Hence, considered with the suitability classes (S1, S2, S3, and N) included physical land features such as soil, slope, landuse/land cover, and distance to water sources (Abeyou *et al.*, 2015). All the parameters have been taken into the explanation for investigation towards the classification of suitable areas for potential surface irrigation development and they are mapped separately.

Table 3.3: Land Suitability Classification Class of the study area

Classes	Suitability	Description
S1	Highly Suitable	Land Without any significant limitations
S2	Moderately Suitable	Moderately Suitable severe limitations. which reduce productivity or benefits or Increase required inputs.
S3	Marginally Suitable	Overall sever limitations; given land use only Marginally justifiable.
N	Not suitable	Limitations not currently overcome With existing knowledge within acceptable Cost limits.

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

For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources, and the terrain conditions about methods of irrigation considered (FAO, 2007). In addition to these factors, landuse/land cover types are considered as limiting factors in evaluating the suitability of land for irrigation (Hailegebriel, 2007). Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field (Fasina *et al.*, 2008).

The following evaluation factors are considered to meet this specific objective

- Soil texture;
- Soil depth;
- Soil drainage;
- Topographic factor (slope);
- Landuse/Land cover, and;
- Distance from water sources.

I. Soil Suitability assessment for surface irrigation

Soil data was collected from the GIS and remote sensing department and the ministry of Water, irrigation, and electricity. FAO soil database (FAO-UNESCO), Harmonized World soil data (HWSD-FAO), and the description of the soils from (FAO-UNESCO, 2014). The soil data were extracted from the 1:250,000 scale of the soil map developed by (MoWIE, 2007). The soil data is used to determine the suitability of an area for Surface irrigation development based on property.

Soil is an important determining factor for land suitability evaluation of surface irrigation development. The land suitability of the Watershed concerning soil has been recognized by evaluating the soil physical property suitable parameters: soil texture, depth, and drainage suitability through overlay analysis. Soil drainage, texture, and soil depth were extracted from the soil map for the suitability ranking the soil map was redefined into three classes specifying its suitability for surface irrigation. First preparing soil features layers of each physical soil parameter; soil texture, soil drainage, and soil depth. Then, the soil vector layer was converted into a raster layer using conversion tools- to raster-feature to raster in the Arc GIS 10.3. The rasterized soil map of the study area was then reclassified based on texture, depth, and drainage classes. Finally, a 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, 1997) soil classification guideline. GIS provides an advantage of mapping these properties of soils individually and make them ready for further overlay analysis to recognize which unit is the best or worst for the preferred surface irrigation development. The overlay analysis provides the user's flexibility in dealing with the relations of parameters concerned spatially and thereby displays the results spatially as map form (Nazir *et al.*, 2019). The soil parameters considered for this potential surface irrigation evaluation purpose are presented individually as follows.

A. Soil texture suitability for surface irrigation

Table 3.4: Soil texture suitability classification for surface irrigation of study area

S/NO.	Texture	Suitability classes
1	Siltyclay,clay	S1
2	Siltyclayloam,clayloam	S2
3	Sandyclay, siltloam	S3

4	Sandyloam,Course sand	N

Source: (FAO, 1997) Irrigation Potential in Africa, Basin approach.

B. Soil depth suitability assessment for surface irrigation

Soil depth is one of the important physical soil parameters used to evaluate soil suitability for surface irrigation development. The soil depth of the watershed soils was interpreted from geomorphology and soil map developed by (MoWIE, 2007). Soils in the watershed have a depth varying from <30cm, from 90-120, and >120cm. accordingly, the soil depth was reclassified into three classes (<0-50cm, 90-120cm, and >120cm) which are unsuitable, moderately suitable, and highly suitable for surface irrigation respectively.

Table 3. 5: Soil depth suitability for surface irrigation

S/NO.	**Factor soil depth(cm)**	**Factor of rating**
1	>120cm	S1
2	90-120cm	S2
3	90-50cm	S3
4	0-50cm	N

Source: (FAO, 1997) Irrigation Potential in Africa, Basin approach.

C. Soil drainage suitability assessment for surface irrigation

Drainage controls the continuous movement of water and salt through the soil profile. Without this continuous leaching, salt may build up to levels that may be harmful to the landscape and vegetation.

Table 3.6: Soil drainage suitability for surface irrigation

S/NO.	**Drainage**	**Suitable class**
1	Well drain	S1
2	Moderately drain	S2
3	Imperfectly drain	S3
4	Poorly drain	N

The factor of each chosen soil physical parameters combination as shown below table 3.7

Table 3.7: Soil combination suitability factor rating of surface irrigation

S/NO.	Soil Texture Class	Soil Depth Range(cm)	Soil Drainage	Factor Rating
1	C,SiC,SC	>120	Well	S1
2	SiC-CL,CL-C	100-120	Imperfectly	S2
3	SL,SCL	50-100	Poor	S3
4	Coarse Sand	<50	Very poor	N

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

(Source: FAO guideline for land evaluation (1997) modified by the MWEI land evaluation team based on practical observation (2007).

II. Slope Suitability assessment for surface irrigation

The slope is the most important factor to identify suitable land for surface irrigation and is often expressed as a percent. In the current study, a slope map was generated in percent for the entire area on Arc GIS 10.3 using DEM 30m by 30m of the area as input. The slope map generated was reclassified into four classes. The slope is important for soil formation and management because it influences drainage, runoff, erosion, and the choice of irrigation types. The slope gradient of the land has a great effect on the selection of irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, mostly slopes which are less than 2% are highly suitable for surface irrigation, between 2% and 5% are moderately suitable and 5% up to 8% marginally suitable. But slopes, which are greater than 8%, are not widely recommended for surface irrigation development (FAO, 1999).

Table 3.8: Slope suitability classification for surface irrigation

S/No.	**Slope**	**Percent (%)**	**Factor of Rating**
1	Horizontal	0-2%	S1
2	Very flat	2-5%	S2
3	Flat	5-8%	S3
4	Steep	>8%	S4

Source: (FAO, 1997) Irrigation Potential in Africa, Basin approach.

III. Landuse/Land cover suitability assessment of study area

SPOT5 satellite images, with acquisition dates between November 2016 and December 2017 that included three bands (1, 2 & 3) and with a spatial resolution of 1.5m, were obtained from the Ethiopian Mapping Agency. They were used to classify the land cover of the study area. Landuse/land cover (LU/LC) of the watershed includes the forest land, Woodland, Shrub/bushland, Agriculture, Grassland, Barren land, Wetland, Waterbody, and Settlement. Agriculture land is used for the Cultivation of annual crops. Different Land cover types are present in the Watershed. After recent land sat image of the area was reclassified into different landuse/land cover types on ERDASIMAGE2014 software, different suitability classes were given to each landuse land cover type. Based on these suitability classes, the LULC map of the watershed is rasterized and used in the evaluation process to identify suitable sites for the surface irrigation system.

Table 3.9: Landuse/Land cover of the Study area

Suitability Category	**Designation**	**Description of land cover types**
S1	Highly suitable	Agriculturally, Cultivated-dominantly, moderately Grassland, open bushed, and state farm.
S2	Moderately suitable	Wood land-open, riparian, bush land-dense.
S3	Marginally suitable	Forest open, cultivated- irrigation, shrub
N	Not suitable	Woodland, WetLand, Forest-dense, bamboo, urban and water bodies.

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

A. Image classification

Image classification is based on the different spectral characteristics of different materials on the Earth’s surface. According to Richards (1986), there are two approaches to classify spectral images, unsupervised and supervised. Unsupervised classification is the method in which image pixels are assigned to spectral classes without the user having detailed information about the study area Whereas, supervised classification is a method that requires the analyst to identify known areas i.e. the user has more information/previous knowledge about the study area. The classification was made by using supervised classification with maximum likelihood ERDAS imagine 2014.

B. Accuracy of image classification: Accuracy of image classification the accuracy is essentially a measure of how many ground truth pixels were classified correctly. When looking at the land cover map, it is important to memorize that no map is a perfect illustration of reality. There are always errors in maps and we need to keep in mind how correct they are, and whether that level of accuracy is adequate for the ways we want to use the map information (Awotwi, 2009). Based on the 1.5-meter resolution of the SPOT5 data used to create the map, it is important to keep in mind that the map will be most accurate for viewing geographic patterns over larger areas. The result of an accuracy assessment provides us with an overall accuracy of the map based on an average of the accuracies for each class on the map.

$$Overall\ accuracy = \frac{\text{No of the pixels were correctly classified}}{\text{Total no of pixel}} * 100 \qquad (3.1)$$

Kappa is used to measure the agreement or accuracy between the remote sensing derived classification map and the reference data as indicated by the major diagonals and the chance agreement, which is indicated by the row and column totals (Jensen *et al.*, 2003).
The Kappa factor is given by the formula (Jensen *et al.*, 2003):

$$Kappa = \frac{P_O - P_e}{1 - P_e} \qquad (3.2)$$

Where, P_o = is the proportion of correctly classified cases

P_e = is the proportion of correctly classified cases expected by chance

The producer's accuracy is the total number of correct pixels in a category divided by the total number of pixels of that category as derived from the reference data (column total). This statistic indicates the probability of a reference pixel being correctly classified and is a measure of omission error. The producer's accuracy gives how well a certain area can be classified (Jensen, 2003).

IV. Distance from water supply (source)

To identify irrigable land close to the water supply (Bilate River Watershed) was identified by creating Euclidian distance along the River to a specified distance using the buffer icon in the analysis tool and clip to the specified study area. Euclidean distance is the straight-line distance between two points on a plane, also known as 'distance as the flow flies' (ESRI, 2016). This tool was used when creating the irrigation land suitability map Spatial Analysis Tool in "ArcGIS 10.3'' was used. The distance between Rivers was reclassified and the reclassified distance was used for weighted overlay analysis together with other factors.

Table 3.10: Suitability of River proximity to water sources for surface irrigation

S/NO.	**Proximity to Water(source)** (km)	**Suitability Class**
1	Closer distance	S1
2	Moderately closer distance	S2
3	Marginally closer distance	S3
4	Furthest distance	N

Source: (Abeyou *et al.,* 2015) Assessment of surface water irrigation potential in the Ethiopian highlands: The Lake Tana Basin.

3.2.1.1. Application of ArcGIS Software to identify suitable land for surface irrigation development

GIS is computer software used for integrates, stores, capture, update, manipulate, edits, analyzes, shares, and displays geographic information and allows users to analyze spatial information, edit data in maps, and present the result of all these operations (ESK,1990 and Nazir *et al.,* 2019). The combination of land evaluation and GIS can provide an improved basis for addressing spatial land evaluation (Thapa and Murayama, 2008).

The General application of GIS software for this study was:-

1. To delineate the watershed of the study area;
2. To identify and reclassification of the suitability factors;
3. To weighted overlay analysis and to identify suitable land for surface irrigation development.

3.2.1.2. Approaches used to develop Land suitability for surface irrigation

MCE in a GIS environment is the best technique to evaluate different factors for a specific objective. It is concerned with how to combine the information from numerous criteria to form a single index of evaluation.

The purpose of weighting in land suitability analysis for surface irrigation for the significance of each factor to other factors that influence land for surface irrigation suitability and making on suitability on land mapping unit (Bagheri *et al.,* 2012). In pair-wise comparison, each factor was matched head-to-head (one to one) with each other and a comparison matrix was arranged to express the relative importance. A scale of importance is broken down from a value of 1 to 9 (Table below 3.11), the highest value 9 corresponds to absolute importance and a reciprocal of all scaled ratio was entered in the transpose position. These pair-wise comparisons are then analyzed to produce a set of weights that sum to l. The factors and their result weight were used as input for the MCE model for weighted linear combination. The procedure by which the weights are produced follows the judgment developed by Saaty under the AHP with a weighted linear combination applying a weight to each followed by a summation of the results to yield a suitability map.

I. Analytical hierarchy process

The AHP is the mathematical method that is applied to resolve highly complex decision making problem solving into hierarch structure; According to saaty and Vargas (2011), hierarch is defined as a representation of a complex problem in a multi-level structure where the first level is the goal/aim/objective, followed by sub-levels, criteria, and sub-criteria, and down to the last level of the alternatives. With this approach, a complex problem can be deconstructed into sections and then arranged into a form of the hierarchy so that the problem will appear more structured and systematic. The procedure used to establish the weights using the AHP method includes several steps:

II. Structural hierarchy

The relationship between objectives and their attributes has a hierarch structure (Malczewski *et al.,* 2004). At the highest level can differentiate the objectives and at lower the attributes can be designated Figure 3.8 below:

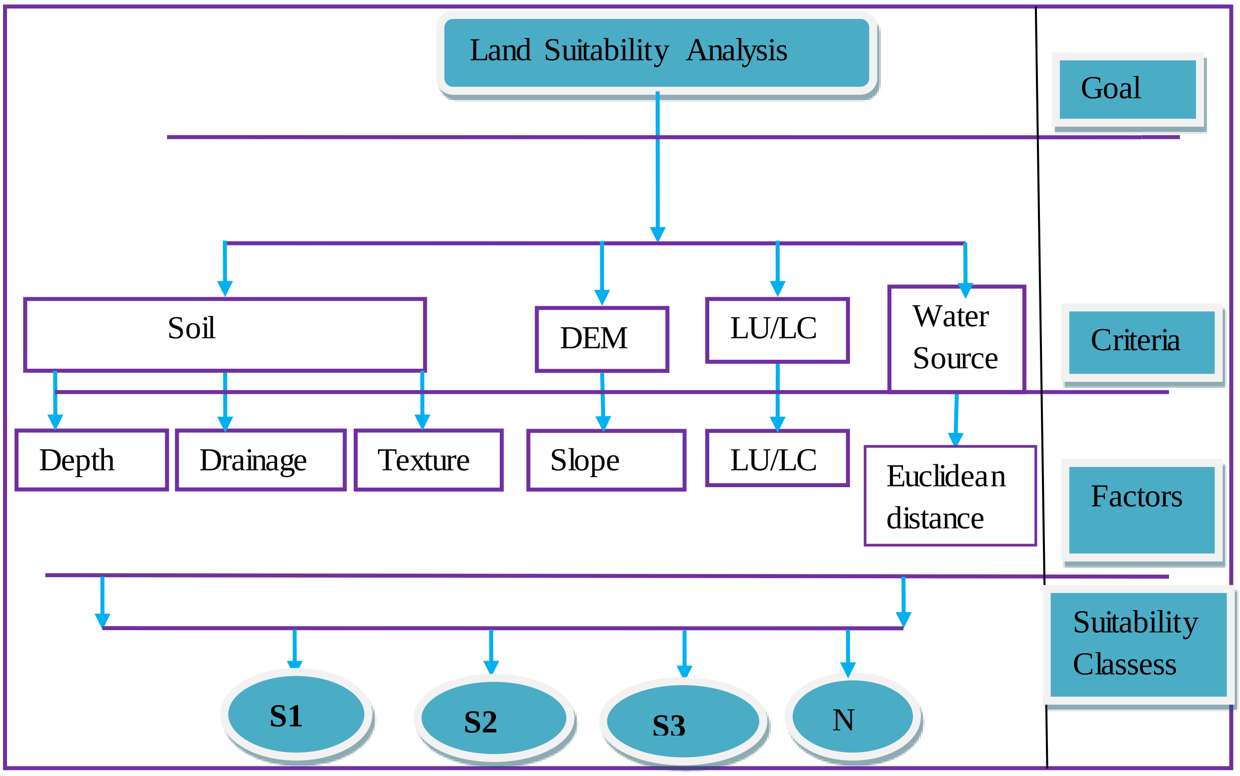

Figure 3.8: Hierarchical organization of criteria for surface irrigation development

III. Construction of pairwise comparison matrix

According to saaty (1987) technique weight of this nature can be derived by this principal Eigenvector of square reciprocal matrixes of pair-wise comparisons between the criteria. The comparison matrix is set up by comparing pairs of criteria involved to determine suitability for the standard objective, Ratings on a scale of values ranging from 1(equally important) to 9 (extremely more important) were used to express evaluation preferences (Ayla *et al.*, 2016).

Table 3.11: The AHP Pair-wise comparison scale and definition (Saaty, 1987).

Intensively important	**Definition**	**Explanation**
1	Equal important	Two factors contribute to the objective.
3	Somewhat more important	Experiment and judgment Slightly favorable one over the other.
5	Much more important	Experiment and judgment Strongly favorable one over other.
7	Very much important	Experiment and judgment Strongly favorable one over other. Its importance is demonstrated in the table.

9	More important	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals	If activity I have one of the above numbers assigned to it when compared with activity j has the reciprocal value when compared with i.	

IV. Calculating the criteria weights

The weights of individual criteria are calculated. First, a normalized comparison matrix is created each value in the matrix is divided by the sum of its column. To get the weights of the individual criteria, the mean of each row of this second matrix is determined. These weights are already determined and their sum is 1.

Table 3.12: pair-wise Comparison matrix calculation of criteria weights for land suitability evaluation for surface irrigation.

NO.	Factors	Soil depth	Soil Texture	Soil Drainage	Land use/cover	River proximity	Slope
1	Soil depth	1	2	2	7	2	1/3
2	Soil Texture	1/2	1	2	5	2	1/5
3	Soil drainage	1/2	2	1	3	1/2	1/5
4	Landuse/land cover	1/7	1/5	1/5	1	1/5	1/5
5	River proximity	1/3	1/2	1/2	5	1	1/3
6	Slope	3	4	4	14	4	1

V. Evaluate consistency of pairwise comparisons matrix

The AHP provides mathematical measures to determine the consistency of each judgment matrix. The weights we derived from the pairwise comparison matrix must be consistent. According to saaty (1987) to determine the consistency of the pair-wise comparison matrix, the consistency judgment has to be checked for the accurate value of N by CR. The CR weights of the judgment matrix characterized by a CR$\leq$ 0.1 should be used for further analysis. If the consistency ratio is greater than 0.1 the consistency matrix should be revised.

$CR = \frac{CI}{RI}$……………………………………………………………………………..(3.1)

CR= is consistency ratio

CI =is consistency index

RI= is the random index

Table 3.13: Random consistency Index Table has already provided by (Saaty,1987)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.3	1.4	1.5	1.48	1.5	1.5	1.56	1.57	1.58

$CI = \frac{\lambda\max - 1}{n - 1}$……………………………………………………………………………(3.1)

Where, λmax is the maximum or principal Eigenvalue

n=number of criteria

Creating weighted analysis in spatial analysis tools are used to find suitable land for surface irrigation. After individual criteria were assessed the irrigation suitability factors which were considered to do weighting Slope factors, Soil factors, River proximity factors, and Landuse/Land cover factors as input for Land suitability site for surface irrigation. Selected raster layers overlaid by recognizing their cell values to the same scale, giving weight values to each criterion, and integrating their weights cell values. The cell values of individual raster layers are multiplied by their weight values (Ayla *et al.,* 2016)

$LS = \sum_0^n Wi * Xi$……………………………………………………………………...(3.3)

Where, LS = is total Land suitability square

Wi = is the weight of selected suitability criteria

Xi = is the assigned sub-criteria square of criteria i, and n is the total number of Land suitability criteria.

Finally, in weighted total overlay, the cell values of rating of land suitability classes are multiplied by criteria weights. The resulting cell values were added to produce the final land suitability map.

3.2.2. Assessment of surface water resources availability using SWAT

The SWAT model is a semi-physically based model for evaluating land management practices, discharge, sediment transport, and nutrient cycling (Getnet *et al.,* 2019). Data inputs include digital elevation data (DEM), Landuse/land cover map, soil map, and weather data. SWAT simulates the hydrologic cycle for each Hydrologic Response Unit (HRU) based on the following water balance Equation (Getnet *al et.,* 2019).

$$SWt = SWt - 1 + (Rt - Qt - Et - St - Gt) \ldots\ldots (3.4)$$

where SW_t is the final soil water content at time t, SW_{t-1} is the soil water content at time t − 1, R is the precipitation, Q is the surface runoff, E is the actual evapotranspiration, S_t is the percolation and bypass exiting the soil profile bottom, and G_t is the return flow. Until recently, the water potential of the country was not accurately known, and even today this is still an argumentative issue. Water supply (water quantity and seasonality) is an important factor to evaluate the land suitability for irrigation according to the volume of water during the year which it is available (FAO, 1985). If water is in short supply during some part of the irrigation season, crop production will suffer, returns were decline and part of the scheme's investment will lay idle or invaluable (FAO, 2001). Quantifying the amount of water available for irrigation and the economic efficiency of the water was to transport to the exact/locations of irrigation, is important in the decision to expand its use. Agricultural activities and water potential are closely related to the temporal and spatial patterns of climatic variables such as rainfall, temperature, relative humidity, wind speed, and sunshine hours, and the success of surface water potential strongly depends on the climatic situation of an area. The availability of surface water resources for potential irrigation was assessed for the whole crop growing season. Gross irrigation demand for the selected major crops and the available dependable monthly flow of the River were calculated and compared. The measured streamflow data of the Bilate River Watershed in the River basin were used to calibrate and validate with the simulated SWAT streamflow output. Where possible, the source of water is preferable to be located above the area to irrigate the command area through the free surface flow without the requirement of power generation. The water supply should be near the irrigated area to minimize the length of the delivery channels which is also important to minimize evaporation loss on the channel.

The available surface water resources of the watersheds were estimated by using Meteorological and spatial data (obtained from NMSA and GIS database) of the study area by using the SWAT model. The streamflow discharge that is obtained from the ministry of water, Irrigation and Energy; the department of hydrology was used for calibration and validation by using SWAT-CUP after sensitivity analysis was performed.

There are four surrounding climatic stations in the Bilate River Watershed Bilate, Bodity, Hossana, and Bilatetena (Dintu) climatic stations. From those stations, Bilate station is the synoptic station selected for this study.

Un-gauged discharge estimation

Even though hydrometric stations are available in a River, usually it is not common for these gauges to be located precisely at Rivers confluence and sites of interest. There are several methods to estimate flows at un-gauged Catchments. Regional frequency analysis, areal ratio methods, and Arc SWAT are some of them. In this study, the SWAT model has been used because of:-

- The model simulates hydrological process in the watersheds
- It is readily and freely available
- The SWAT model is computationally efficient

3.2.2.1. Meteorological data

Filling missing meteorological and hydrological data

Although complete hydro-meteorological data is a prerequisite for successful water resource planning and management, significant data sets are usually missing due to interruption of measurements caused by natural and or human-induced factors.
Missing data is a common problem in hydrology. To perform hydrological analysis and simulation using data of long time series, filling in missing data is very important. The missing data can be filled using meteorological and/or hydrological stations located nearby, provided that the stations are located in the hydrological homogenous region. The rainfall, temperature, and other climatic data stations in the study area had missing data in their records and it is necessary to estimate the values to keep the continuous-time series of the data. Several methods have been proposed to estimate missing rainfall data for the stations. There are some techniques for filling missing rainfall data such as arithmetic mean method, simple linear regression, inverse distance, and normal ratio method. The station average method for filling missing data is conceptually the same as the station average method for estimating mean precipitation. This method may not be accurate when the total annual rainfall at any of the n-region gauges differs from the annual rainfall at the point of interest by more than 10 %, with the former basing the weights on the mean.

Missing records of rainfall stations were estimated by using the normal ratio method which is recommended to estimate missing data in regions where annual rainfall among stations differs by more than 10% (Digman, 2002). According to (Yemane, 2002), the estimation of missing rainfall data by weighting the observation at **N** gauges of their respective annual average rainfall values as expressed by the equation below the following.

$$PX = \frac{1}{N}\left(\sum \frac{PX}{Pi} * Pg\right) \qquad (3.5)$$

And normal annual precipitation at various stations are within about 10% of annual precipitation at station X, and the simple arithmetic average procedure is followed to estimate Px thus

$$PX = \frac{1}{M}(P1 + P2 + P3 + \cdots Pm) \qquad (3.6)$$

Where, PX=Missing data annual precipitation data at station X and M surrounding station, Px=The annual average precipitation at the gauge with missing data, Pi=annual average values of the neighboring stations, Pg=monthly rainfall data in all stations for the same month of missing stations, N=the total No of gauges under consideration and P1, P2, P3, represents precipitation data. Average monthly precipitation is tabulated in the Appendix Table (2-5).

Graphical Comparison of the rainfall data done by creating time-series plotting of monthly rainfall data showed that the four stations show a similar periodic pattern of records.

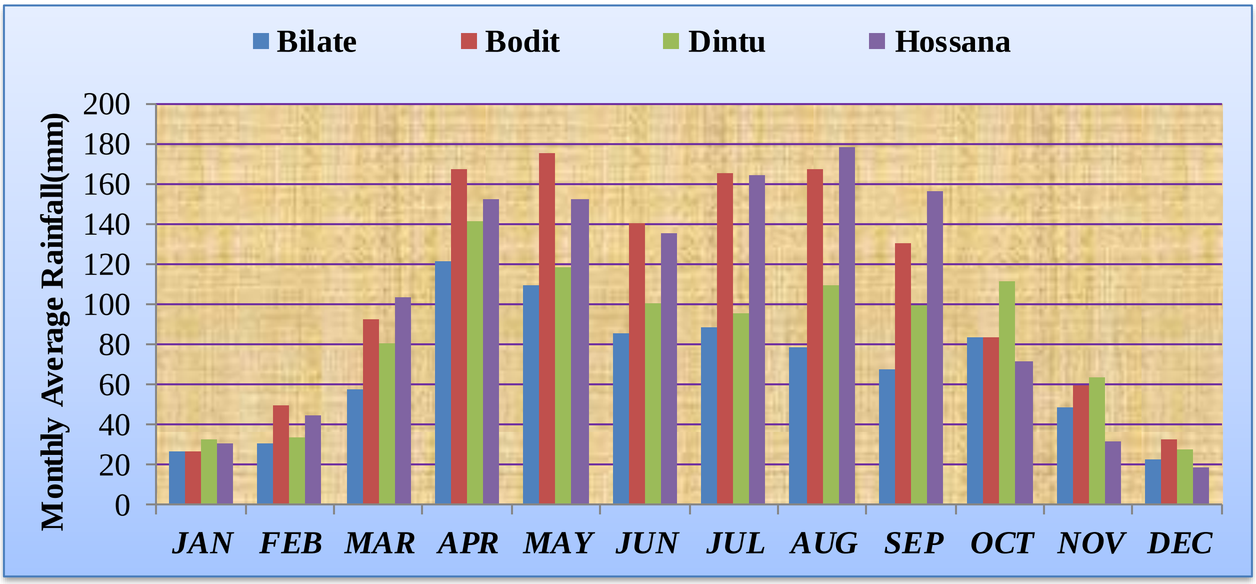

Figure 3.9: Mean Monthly Rainfall graph for selected meteorological Stations in Bilate watershed (1990-2019)

Consistency of rainfall data:- Before precipitation records are used in such studies, they should be tested and errors have to be removed to ensure that any trends are detected and not to changes in gauge location, in exposure, or observational methods. The consistency of rainfall data was checked using double mass curve analysis through plotting the graph of cummulative rainfall collected against the cummulative average records collected as the selected stations in the same periods. The double mass curve method was applied for consistency Figure 3.10.

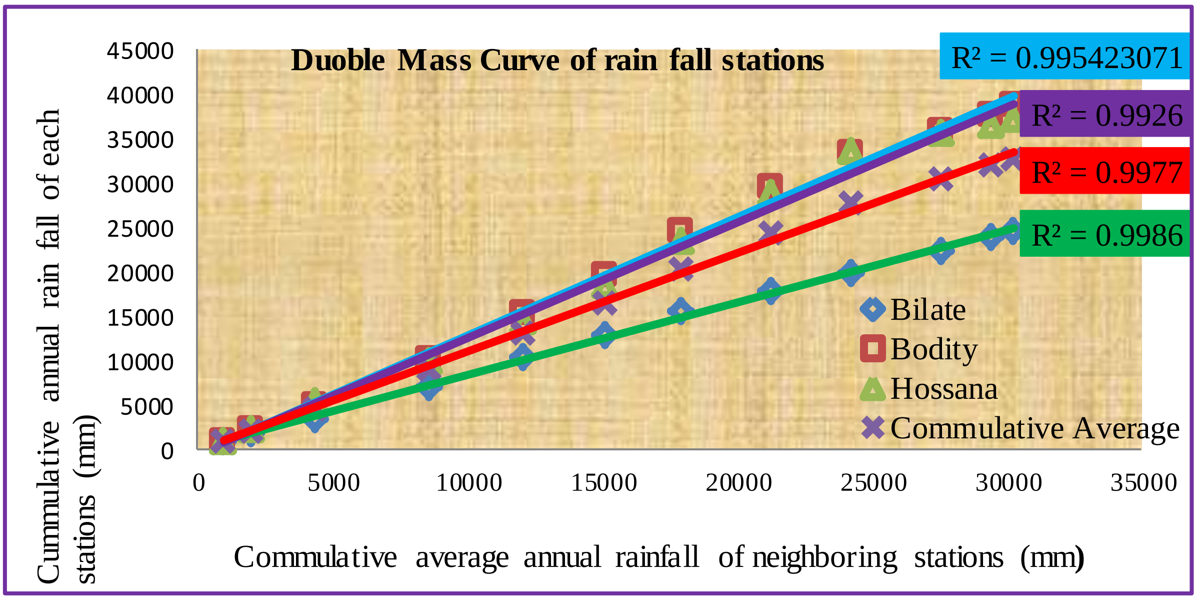

Figure 3.10: Double mass curve analysis of all rainfall stations

To check the degree of consistency, Nemec (1973) provides the value of the coefficient of correlation as follows:

$R^2=1$: direct linear correlation, $0.6 \leq R^2 < 1$: good direct correlation, $0.6 < R^2 < 0$: in sufficient-reciprocal correlation, $1 < R^2 < 0.6$: good reciprocal correlation and $R^2 = -1$: reciprocal linear correlation. As presented in the above Figure 3.10 all the stations have a good correlation between them. If the recorded data are not accurate the value of "$\mathbf{R^2}$" might be <0.6, and >1.

3.2.2.2. SWAT model set up and application

3.2.2.3. Arc SWAT model set up

The SWAT model is an ArcGIS extension with its user interface including SWAT project Setup, watershed delineator, HRU analysis, Write Input Tables, Edit SWAT input, and SWAT simulation. The initial step in initializing a watershed simulation is to partition the watershed into sub-basins.

The main steps in the arc SWAT model:-

- Project set up
- Watershed delineation
- HRU analysis
- Write input tables, and
- SWAT Simulation

The user has the option of allowing SWAT to automatically delineate the watershed and sub-Watersheds using the DEM or the user can provide predefined sub-basins. HRUs are portions of a Sub-basin and possess similar land uses, slope ranges, and soil attributes (Neitsch, 2005). The data required for the model are DEM, Soil data, Landuse/land cover data, precipitation, and other weather data. For calibrating the model and also for validation purposes, River discharge (streamflow) data and are required on the outlet of the watershed. The ArcSWAT2012 is an Arc View extension that provides a graphical user interface that allows for GIS data to be easily formatted for use in SWAT model simulations. The initial stage in using SWAT is a projects Setup so that important folders and databases should have been created to save all the data. GIS data such as DEM, Soil, Landuse/land cover, and all the data was collected and prepared to define each step.

3.2.2.4. Watershed delineation

The next step of the SWAT Model Setup is the delineation of the watershed from a DEM. Before going in hand with spatial input data i.e., DEM, LULC map, and soil map were projected into the same projection called UTM Zone 37N, which is a projection for Ethiopia. The watershed delineation part includes five main steps, DEM setup, stream definition, outlet and inlet definition, watershed outlets selection and definition, and calculation of sub-basin parameters. For the stream definition, the threshold-based stream definition option was used to create the minimum size of the sub-basins. To delineate the whole Bilate River Watershed an outlet was taken near Lake Abbaya where just it starts releasing from. The last work in delineating watershed is generating parameters for all the sub-basins. Finally, the stream channels were defined as DEM cells having at least a 4963.4 sqkm contributing area resulted in the sub-basin of Bilate Watershed being delineated. Based on this the Bilate watershed was divided into sub-basins and HRUs from the watershed area of 4,963.4 Km^2.

The topography is defined by a DEM that describes an elevation of any points in a given area at a specific spatial resolution. It is the basic input of the ArcGIS integrated SWAT hydrologic model to delineate the watershed, to extract information about the topography or elevation of the watershed, and to analyze the drainage patterns of the land surface terrain. Hence, the definition of a watershed, sub-basin boundaries, and streams was decided by selecting a threshold area or the minimum drainage area to define streams.

The watershed delineation showed that there were six sub-watersheds in the study area. Subwatershed 2 and subwatershed 4 are the major ones. The others such as sub-watershed 1, subwatershed 3, Subwatershed 5, and subwatershed 6 are sub-watersheds of the Bilate River watershed each covering areas 15,296.49 ha, 149,749.56 ha, 15,616.71 ha, 142,645.5 ha, 141,234.75 ha, and 31,796.01 4 ha, respectively.

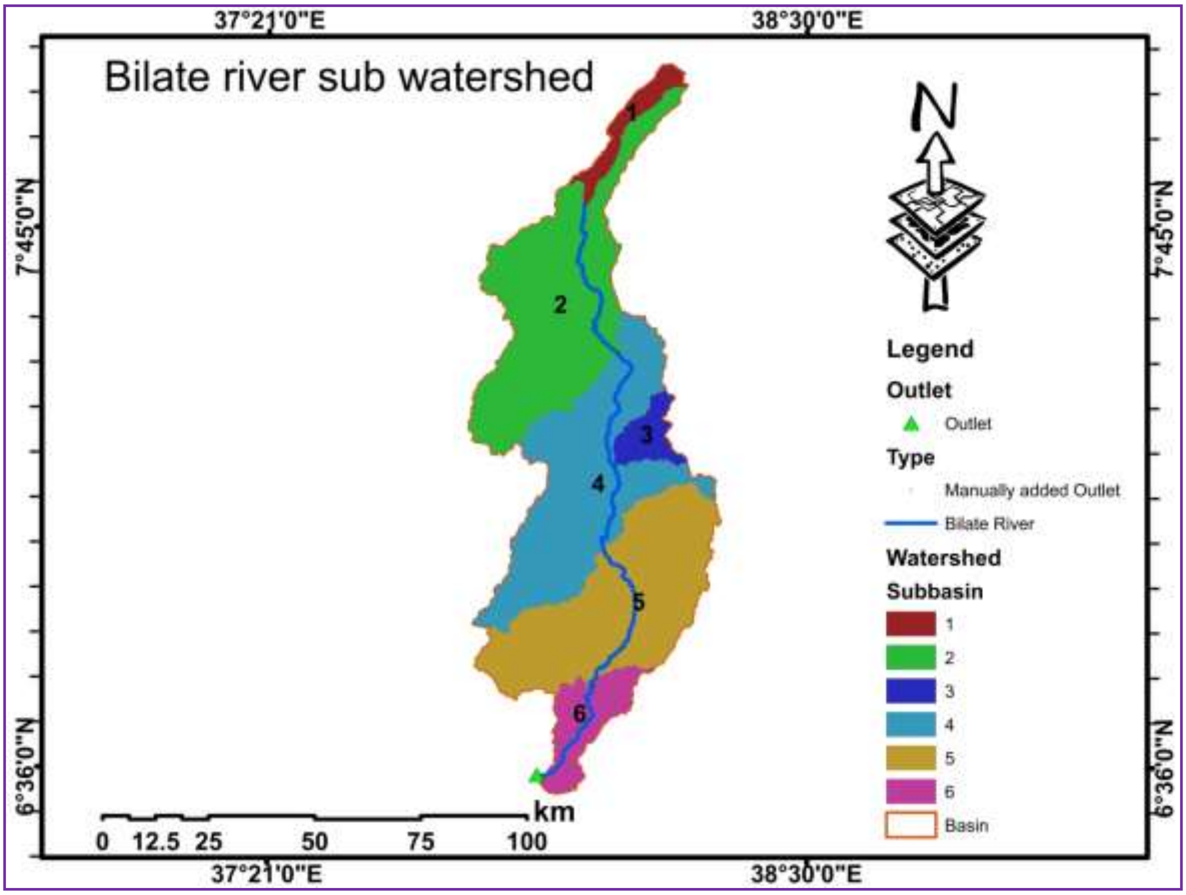

Figure 3.11: Bilate River subwatershed

3.2.2.5. Hydrological response unit analysis

HRU analysis becomes available after the water delineation is completed where the basic SWAT inputs; land use land cover and soil data are prepared to the study area and finally landuse land cover, soil data, and land slope are overlaid to the study area. The HRU Analysis tool in Arc SWAT helped to load the map of land use, map of soil, and slope map to the project for HRU definition. Then, prepared land uses maps and soils maps were loaded. For slope, the multiple slope option (an option that considers different slope classes for HRU definition) was selected. The LULC, soil, and slope map was reclassified to correspond with the parameters in the SWAT database. After reclassifying the land use, soil, and slope in the SWAT database, all these physical properties were made to be overlaid for HRU definition 6 sub-basins and 37 HRUs were obtained.

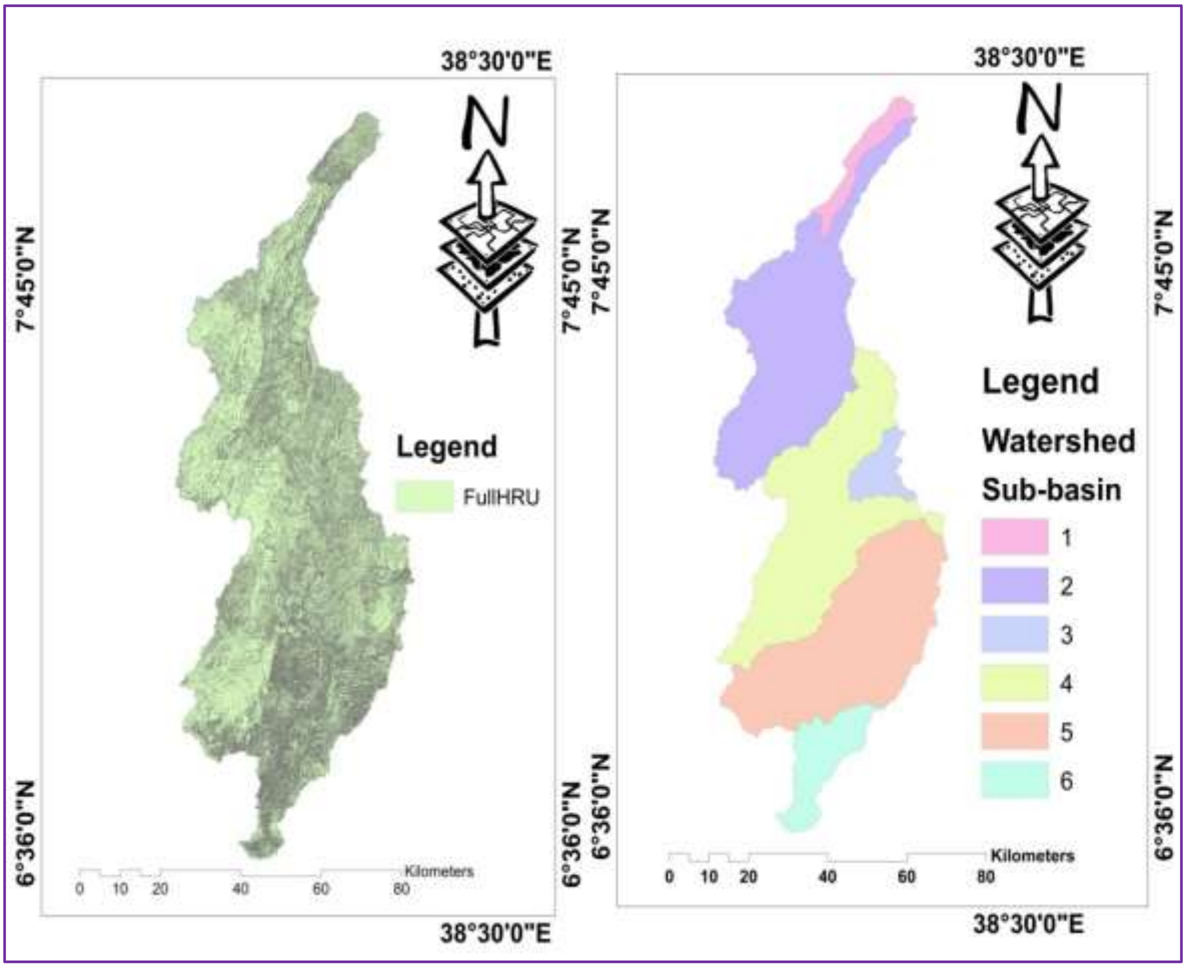

Figure 3.12: Full Hydrologic Response unit and Sub-basin for the Bilate Watershed

In this step, the land use map and soil map of the study area are used as the main inputs for the SWAT model, and they should be prepared in suitable SWAT format and inserted in the SWAT2012 database. The hydrologic response units approach lumps all the same LULC, soils types, and slopes classes within a sub-basin based upon user-defined thresholds. Fixing threshold level was used to eliminate the minor LULC in sub-basin, minor soil within a LULC area, and minor slopes class within a soil on the specific land use and land cover area. A watershed is subdivided into several homogenous sub-basins (hydrologic response units or HRUs) having unique soil, slope, and LULC properties and use for simulation purposes. Then, after successful completion of HRU analysis:

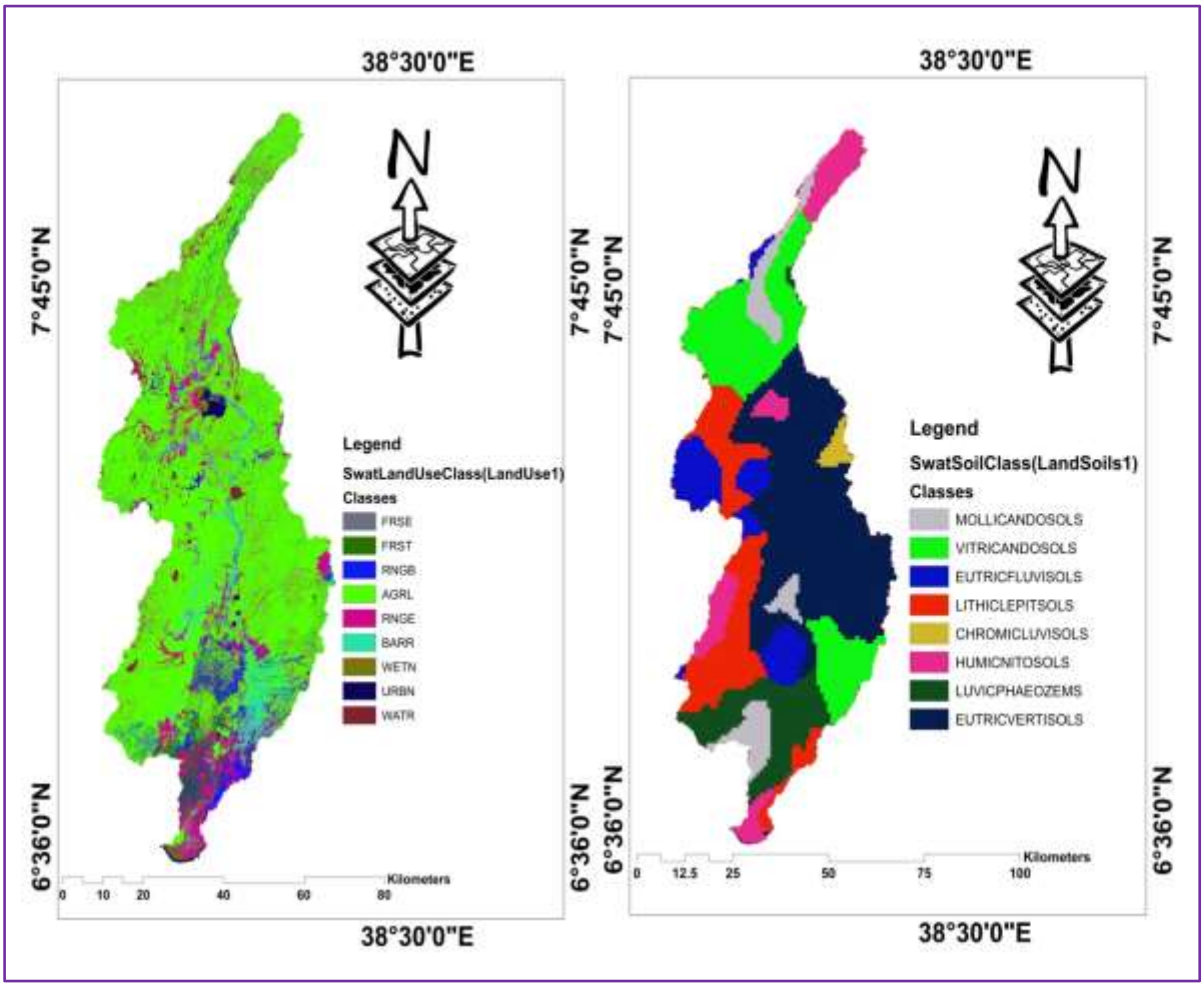

Figure 3.13: SWAT LU/LC and Soil classes of the study area

Write input tables become active after HRU analysis is successfully done where the entire SWAT Input data are written to the SWAT database for model processing.

Edit SWAT input is where the soil and LULC data properties are entered into the SWAT database in the form that the model understands the codes.

Weather data definition

All meteorological stations were having both temperature and precipitation data, but only Bilate and Hossana stations were synoptic stations (having all types of climatic data) used for generating remaining weather data for others (weather generator stations). After loading the WXGEN parameter and location table, the daily meteorological data (daily precipitation, daily minimum, and maximum air temperature) with the missing data filled with a missing data identifier of NA and including the corresponding location Table prepared according to the SWAT format were loaded into the model. SWAT takes data of each climatic variable from the nearest weather station measured from the meteorological stations. The meteorological stations of the study area are described in Table 3.14 below.

Table 3.14: Meteorological data of study area

S/NO.	Stations	Latitude (^{0}N)	Longitude (^{0}E)	Eleavation (m.a.s.l)	Period of record
1	Bilate	7.55	38.52	1361.00	1990-2019
2	Bodity	6.96	37.86	2043.00	1990-2019
3	Dintu	6.56	38.73	1496.00	1990-2019
4	Hossana	7.34	37.52	2306.00	1990-2019

I. Sensitivity analysis

Sensitivity analysis is the process of identifying the model parameters that exert the highest influence on model calibration or model predictions. All of the sensitive parameters are not equally sensitive depending on the nature of the model outputs and physical conditions of the study area. Identifying and minimizing the number of parameters to be used in the calibration step by making use of the most sensitive parameters that mostly control the behavior of the simulated values was one of the tasks in the sensitive analysis process. It is necessary to identify key sensitive parameters and the sensitive parameter precision required for calibration. SWAT-CUP version 2019 was used for sensitivity analysis, calibration, and validation. There are several sensitivity parameters in SWAT-CUP version 2019 with their maximum and minimum values respectively. A t-test is then used to identify the relative significance of each parameter for a given watershed or sub-watershed. The global sensitivities estimates of the average changes in the objective function resulting from changes in each parameter, while all other parameters are changing. This gives relative sensitivities based on linear approximations and, hence, only provides partial information about the sensitivity of the objective function to model parameters (Karim, 2007). T-stat provides a measure of sensitivity (larger in absolute values more sensitive) p-values determining the significance of the sensitivity. A value close to zero has more significance.

II. Calibration

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is the modification of parameter values and comparison of the predicted output of interest to measured data until a defined objective function is achieved (James *et al.*, 1982). Some times it is necessary to change parameters in the calibration process other than those identified during sensitivity analysis because of the type of miss-match of the observed variables and the predicted variables (White, 2005).

After each calibration, checking the model performance values R^2, NSE, and PBIAS values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, NSE > 0.5, and PBIAS < ±15 (Santh *et al* ., 2001).

III. Validation

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although "sufficiently accurate" can vary based on project goals (Refsgaard, 1997). Validation is the comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. The process continued (calibration process) till simulation of validation period stream flows confirmed that the model performs satisfactorily. Checking the R^2, NSE, and PBIAS values after each simulation and calibrate at least until the minimum recommended values were embraced by the model; $R^2 > 0.6$, NSE > 0.5, and PBIAS < ±20 (Santhi *et al.*, 2001)

IV. Evaluation of model performance

To evaluate the performance of the model during calibration and validation, statistical measures, as well as graphical representations at a daily time step, will be used. This will be employed to confirm the relationship between simulated or predicted values and observed values (Ndulue *et al.,* 2015) and to verify the strength of the model (Betrie *et al.*, 2011).

The coefficient of determination (R^2), the Nash Sutcliffe efficiency (NSE), the percent bias (PBIAS), and the ratio of mean squared error to the standard deviation of the measured data (RSR) (Ghoraba, 2015), (Betrie, *et al.,* 2011)and (Avelino *et al.,* 2015). Equations (3.7)-(3.10) will be used to determine NSE, PBIAS, RSR, and R^2, respectively. Other details of these measures such as their utility and satisfactory range of values are explained by (Moriasi *et al* ., 2007).

$$NSE = 1 - \frac{\sum_{i=1}^{n}(Q_i - S_i)^2}{\sum_{i=1}^{n}(Q_i - Q_{avg})^2} \quad \text{(3.7)}$$

$$PBIAS = \frac{\sum_{i=1}^{n}(Q_i - S_i)*100\%}{\sum_{i=1}^{n}(Q_i)} \quad \text{(3.8)}$$

$$RSR = \frac{\sqrt{\sum_{i=1}^{n}(Q_i - S_i)^2}}{\sqrt{\sum_{i=1}^{n}(Q_i - Q_{avg})^2}} \quad \text{(3.9)}$$

$$R^2 = \frac{[\sum_{i=1}^{n}(Q_i - Q_{avg})*(S_i - S_{avg})]^2}{\sum_{i=1}^{n}(Q_i - Q_{avg})^2 * \sum_{i=1}^{n}(S_i - S_{avg})^2} \quad \text{(3.10)}$$

Where Q_i is the observed daily discharge, Si is the simulated daily discharge, Q_{avg} is the average measured discharge, S_{avg} is the average simulated discharge and n is the number of observations. SWAT-CUP is an extension that was developed for SWAT. using this interface, any Calibration/uncertainty or sensitivity program can easily be linked to SWAT. The program can run SUFI2, GLUE, and Para Sol. The model leads the input data needed for running a calibration and validation program. Each SWAT-CUP project contains one calibration method and allows running the procedure many times until convergence is reached. It allows saving calibration iterations in the iteration history for later use. SUFI-2 algorithm, in particular, is suitable for calibration and validation of the SWAT model because it represents uncertainties of all sources (Abbaspour *et al.,* 2007) and this algorism was used for this study.

There is an intimate relationship between calibration and uncertainty and reporting uncertainty is not comfortable in modeling, it is a necessity. Without uncertainty, calibration is meaningless and misleading (Abbaspour *et al.*, 2007). In Sufi, uncertainty is parameters, expressed as ranges (uniform distributions), which account for all sources of uncertainties such as uncertainties of driving variables (e.g. rainfall) conceptual model, parameters, and measured data.

3.2.3. Determination of total irrigation water requirement for major crops in the study area

Irrigation Calendar and Dominant Crop were collected from the Ethiopian Ministry of Agriculture and Climatic data were collected from the National Meteorological Service Agency (NMSA) of Ethiopia were used as data input in CROPWAT 8 software to calculate Reference Evapotranspiration, Irrigation water requirement (IWR), Net irrigation water requirement (NIWR), Gross irrigation water requirement (GIWR) and effective rainfall (Peff). It is important to make a distinction between crop water requirements (CWR) and irrigation requirements (IR). Whereas crop water requirement refers to the water used by crops for cell construction and transpiration, the irrigation requirement is the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirement. Calculating the crop water requirements for each crop the most important data are as follows.

I. Climate data

Daily rainfall (1990-2019), Temperature (1990-2019), Relative humidity (1990-2019), Wind speed (1990-2019), Sunshine (1990-2019). Were obtained from the Ethiopian Meteorological Service Agency(EMSA) was used in CROPWAT-8 to calculate irrigation water requirements for Major Crops for Maize, Tobacco, Tomato, Onion, Potato, and Wheat.

II. Crop data

The major cultivated crops in the study area were Major Crops Maize, Tobacco, Tomato, Onion, Potato, and Wheat. The prominent details of crops considered for the study were as per FAO. Crop coefficient values (Kc) were obtained from available published data and FAO guidelines.

III. Soil data

Soil characteristics considered for estimation of crop water requirement are important to know available water content and depth of soil.

Crop evapotranspiration (ETc): The crop evapotranspiration (ETc) is the crop water requirement (CWR) for a given cropping pattern during a certain period. Crop evapotranspiration was calculated by multiplying the Kc values at each growth stage of the specific crop by the corresponding ET_O values.

$ETo * Kc$……………………………………………………………………………(3.11)

Where: ET_c=Crop evapotranspiration (mm/day) ET_O=Reference cropevapotranspiration (mm/day) K_c=Crop coefficient (fraction).

FAO Penman-Monteith method is standardized and recommended as the best method for determining reference ET_O. It was selected as an appropriate approach and used to estimate ET_O in this study. The evapotranspiration of this reference surface (ETo) can be unambiguously determined, and as the method which provides consistent ETo values in all regions and climates. (FAO, 56)

IV. Irrigation water requirement (IWR): Using the climate, rainfall, crop, and soil data inputs crop water requirement and irrigation water requirement of Major crops were calculated by the following expression in CROPWAT 8.0 software.

$ETc = ETo - Peff$……………………………………………………………(3.12)

Where:-IWR=Irrigation water requirement (mm), Peff=Effective rainfall (mm), ET_c=Crop evapotranspiration for a given crop (mm/day) Net irrigation water requirement (NIWR): The sum individual crop water requirements (CWR) calculated for Major irrigated crops MOWIE (2013).

Effective precipitation (Peff) was calculated on a daily soil balance empirically determined from FAO CROPWAT 8.0 model.

$Peff = 0.6 * Ptot - 10$ for Ptot<70mm…………………………………………(3.13)

$Peff$=0.8*$Ptot$-24 for Ptot>70mm

Where:-Peff=effective and dependable rainfall

Ptot=Mean monthly rainfall for the given month and year

$NIWR = \frac{\sum_{i=1}^{n} \text{IWRi} * \text{Ai}}{\text{A}}$…………………………………………………………………...(3.14)

Where: NIWR=Net irrigation water requirement (mm), Ai=the area cultivated with the crop i (ha), A=the area of the scheme (ha).

Gross irrigation water requirement (GIWR): 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;

$$GIWR = \frac{NIWR}{Ea} \qquad (3.15)$$

Where: Ea=Water application efficiency (%), GIWR=Gross irrigation requirements (mm), NIWR=Net irrigation water requirement (mm).

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, Ea 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, Ea was taken as **50%** for surface irrigation.

3.2.4. Irrigation potential by Water availability

Information on low flow is required for the amount of water available for surface irrigation application during the dry season. The River water available during the dry season at an exceedance probability of 80% monthly averaged discharge data obtained from The Ethiopian Ministry of Water, Irrigation and Electric city (MoWIE) determined by using Indicators of Hydrologic Alternation software (IHA). At these dependably River flows Irrigation Potential was determined.

Determination of exceedance probability (P) as follows:-

$$P = 100 * [\frac{M}{(n+1)}] \qquad (3.16)$$

Whereas: P= the probability that a given flow will be equaled or exceeded (% of the time)

M= the ranked position on the listing (dimensionless)

n= the number of events for a period of record (dimensionless)

The Irrigation Potential of the Bilate River Watershed was determined as the quotient of the exceedance probability of 80% monthly averaged discharge and the total depth of Irrigation (IR) of the dominant crops in the area for the growing season.

That is;

$$X(ha) = [\frac{Acrop * Eff * Q(80)}{IR}] \qquad (3.17)$$

Whereas:

A crop = Area covered by crop

Eff = Irrigation efficiency

Q (80) = is Runoff gauged location at 80% exceedance probability and

IR = Irrigation requirement

3.2.4.1. Determination of irrigation potential

To develop a map of irrigable areas, identification of suitable sites for irrigation was carried out by assessing the study area, by collecting available data from different ministers and agencies such as the Ministry of Water, Irrigation and Electricity, Ministry of Agriculture and Natural Resource, and Ethiopian National Meteorological Agencies. After collecting, the necessary data for the research and then filling of missed data and quality checking have been done carefully. An Arc SWAT model for estimating surface irrigation potential at the outlet of the watershed and GIS software for determining land suitability analysis for surface irrigation considering slope or topography, soil physical properties, distances from the source, and landuse land cover were implemented and the individual suitability of each factor was first evaluated and finally weighted to get potential irrigable sites.

In addition to this CROPWAT 8 method of the study has been summarized below the following conceptual framework Figure (3.14). The software was used to determine the crop and irrigation water demand for Maize, onion, tomato, potato, and tobacco crops in the watershed**.**

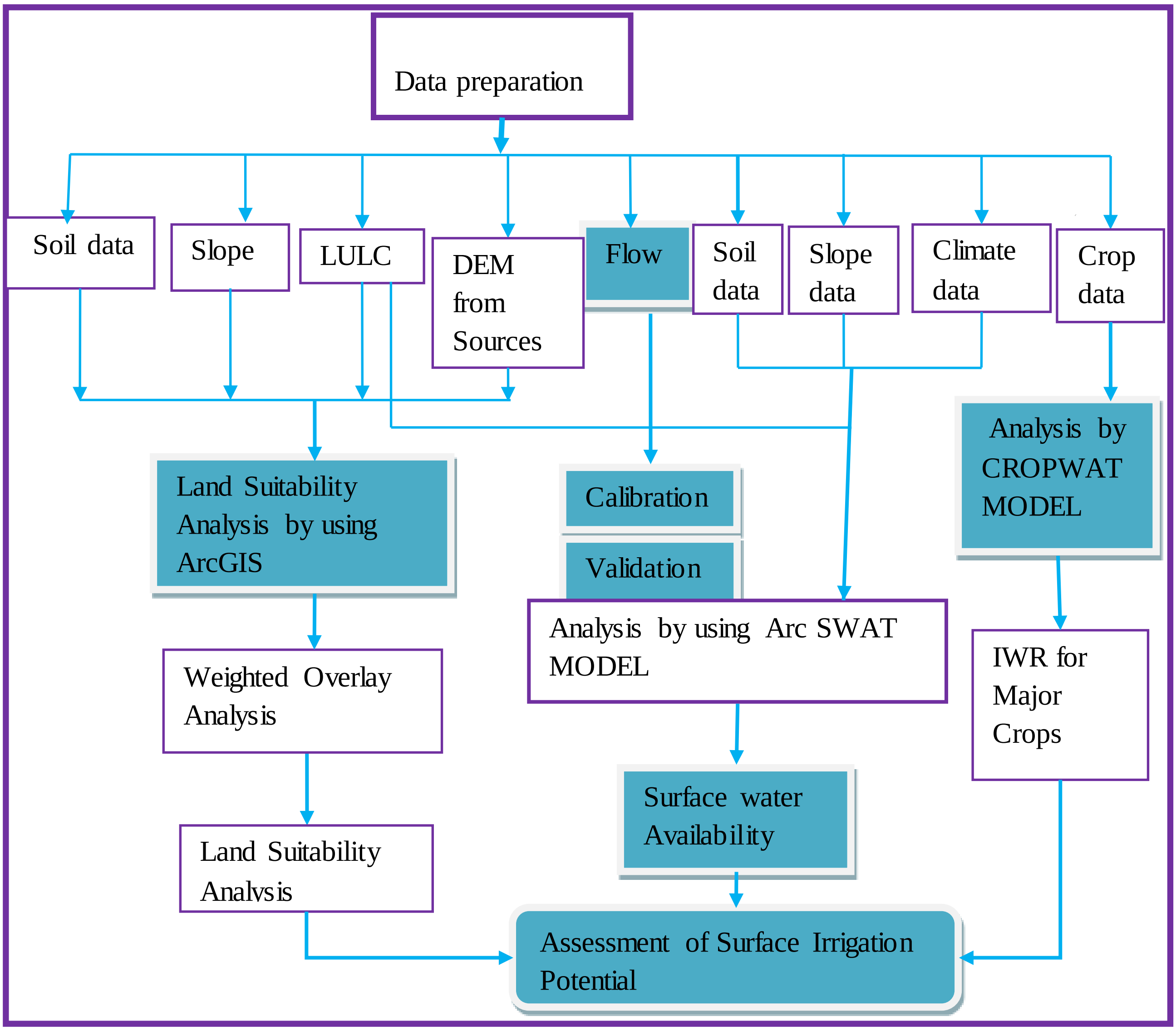

Figure 3.14: Conceptual Frameworks for surface Irrigation potential assessments

4. RESULTS AND DISCUSSION

4.1. Land suitability analysis for surface irrigation

4.1.1. Soil suitability analysis

For this study, the soil mapping unit of this area was used for analysis The physical property of the soil mapping units that is soil texture, soil depth, and soil drainage that were obtained from UNESCO/FAO guidelines used for interpretation and analysis.

A. Soil depth suitability analysis

Soil depth was considered as one of the factors that determine the selection of land for surface irrigation potential in the study area. Soil depth determines the root's growth as well as the presence of a volume of water air in the soil. The soil depth of the study area was divided into Three: >120 cm, 90-120cm, and <30 cm with a suitability class S1, S2, and N according to FAO (1991) respectively. The soil classes and the geographical location of the Watershed were illustrated in below Table 4.1.

Table 4.1: Soil depth suitability class of study area

S/NO.	Soil depth category(cm)	Area(km^2)	Area (%)	Suitability class	Suitability Class Name
1	<30	214.95	4.33	N	Not suitable
2	90-120	1287.71	25.94	S2	Moderately suitable
3	>120	3460.80	69.73	S1	Highly suitable
	Sum	4963.40	100.00		

The soil depth ranges from >120 cm, 90-120 cm and <30 cm covers an area of about 69.73% , 25.941%, and 4.33% of the total land area respectively.

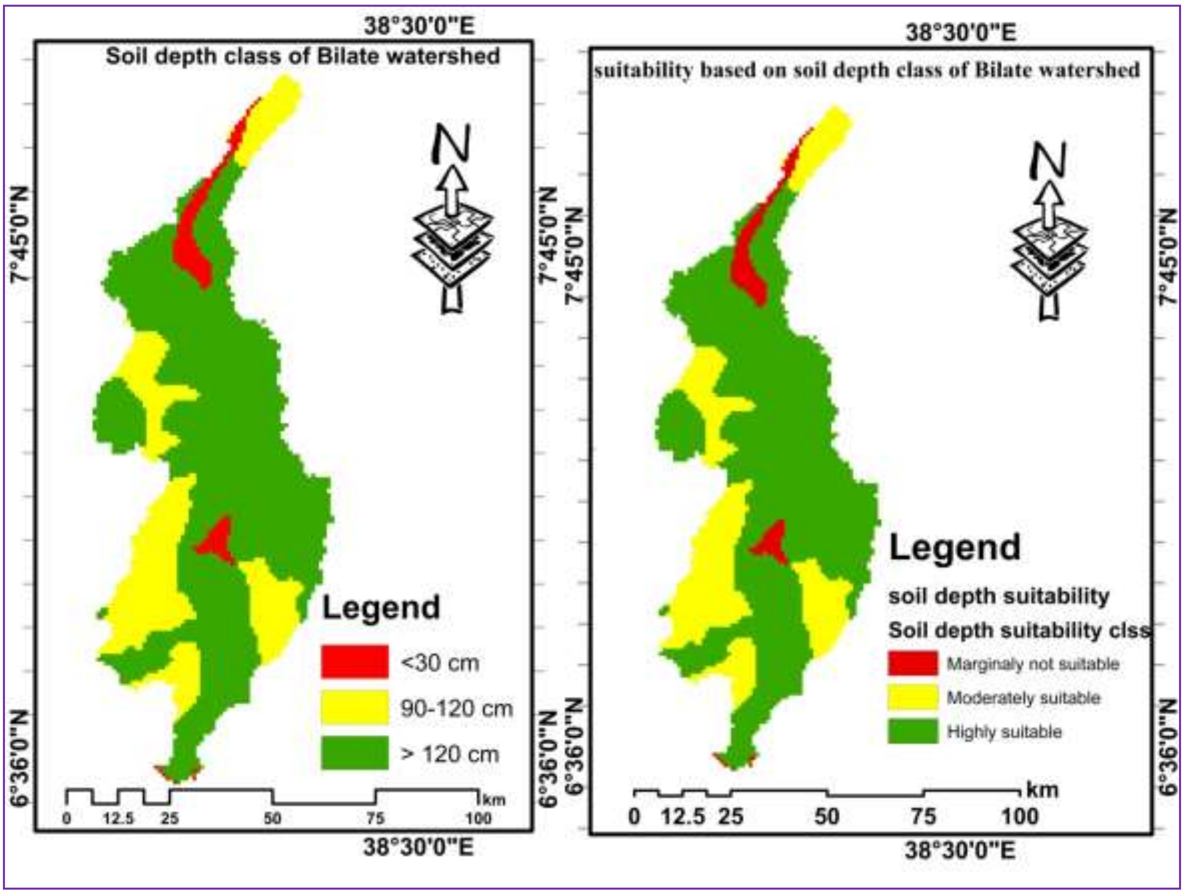

Figure 4.1: Soil depth suitability map of the study area

B. Soil texture suitability analysis

According to the (FAO,1999) guideline for soil evaluation, the soil texture of the study area was evaluated and classified into clay light (C), clay loam-clay (CL-C), loamy-clay loam (L-CL), Sandy loam (SL), silty clay-clay (Sic-C). The soil textural classes of investigated soils in the current study area vary from Sandy clay loam to clay loam. The results of texture class analysis are dominated by fine-textured soils. Table 4.2 elaborates the geographic distribution of identified soil textural classes and their suitability in the study area.

Table 4.2: Soil texture suitability class of study area.

S/NO.	Soil Texture Category	Area(km^2)	Area (%)	Suitability Class
1	Siltyclay Loam	2176.68	43.85	S2
2	Clay(light)	1309.44	26.38	S1
3	Clay loam	1477.27	29.76	S2
	SUM	4963.39	100.00	

The soil textural classes their area coverage was shown in Table 4.2: above as described in an area of about 43.85% of the total areas covered by the Silty clay loam Texture While about, 26.38% clay and 29.763% Clay loam of the total land area respectively.

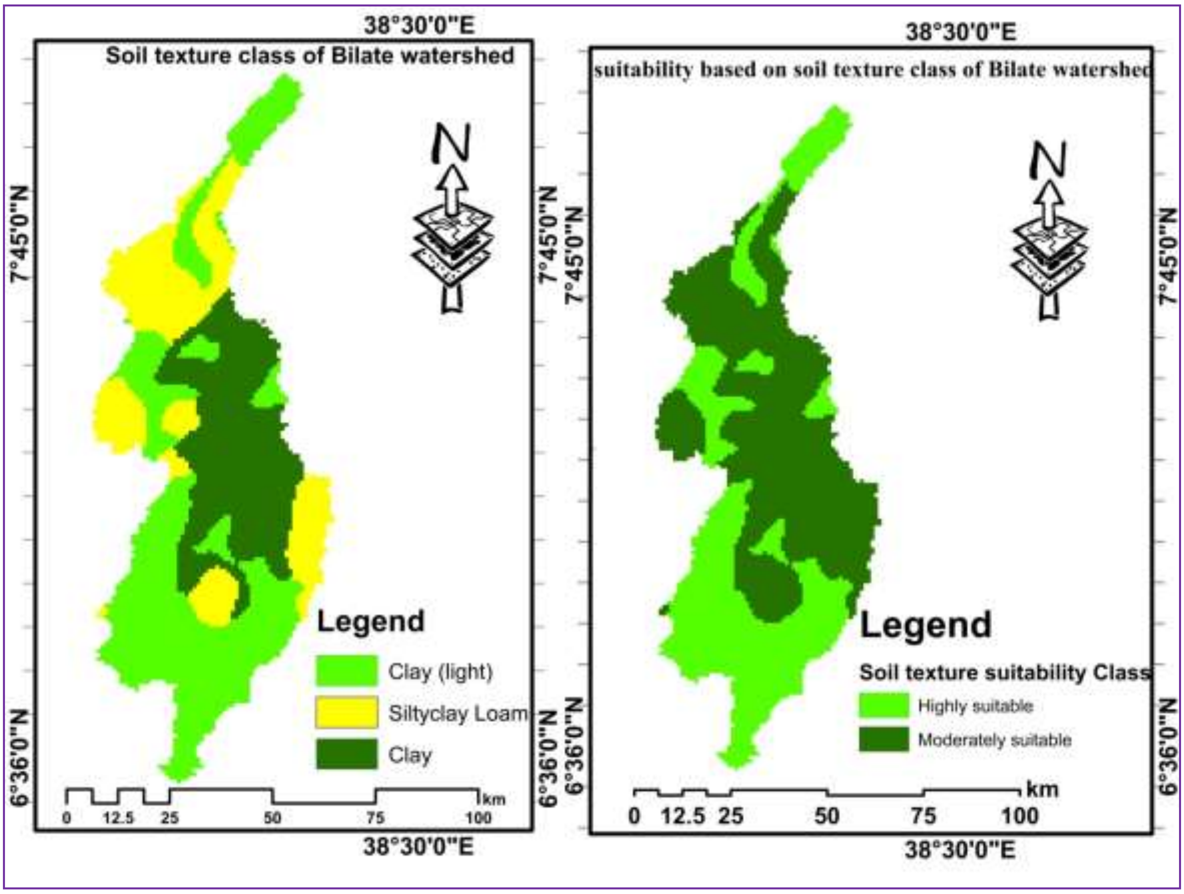

Figure 4.2: Soil texture suitability of study area

C. Soil drainage suitability analysis

Drainage controls the continuous movement of the salt and water through the soil profile the drainage result showed that about 80.6% of the watershed which was 3983.31 km^2 categorized as Moderately drained (S2) and 15.8% which covers 782.73 km^2 as marginally suitable (S3) for surface irrigation. While about 3.97% of the watershed which covers 197.34 km^2 was watershed regarded as not suitable for surface irrigation. According to guidelines of (FAO, 1999), the soil drainage category of the good drain was moderately suitable, poorly drain and marginally not suitable and imperfectly drain marginally suitable for surface irrigation.

Table 4.3: Soil drainage suitability class of study area

S/NO.	Soil drainage Category	Area(km^2)	Area (%)	Suitability Class
1	Moderately drained	3983.31	80.57	S2
2	Imperfectly drained	782.736	15.77	S3
3	Poorly drained	197.343	3.98	N
	SUM	4963.39	100.00	

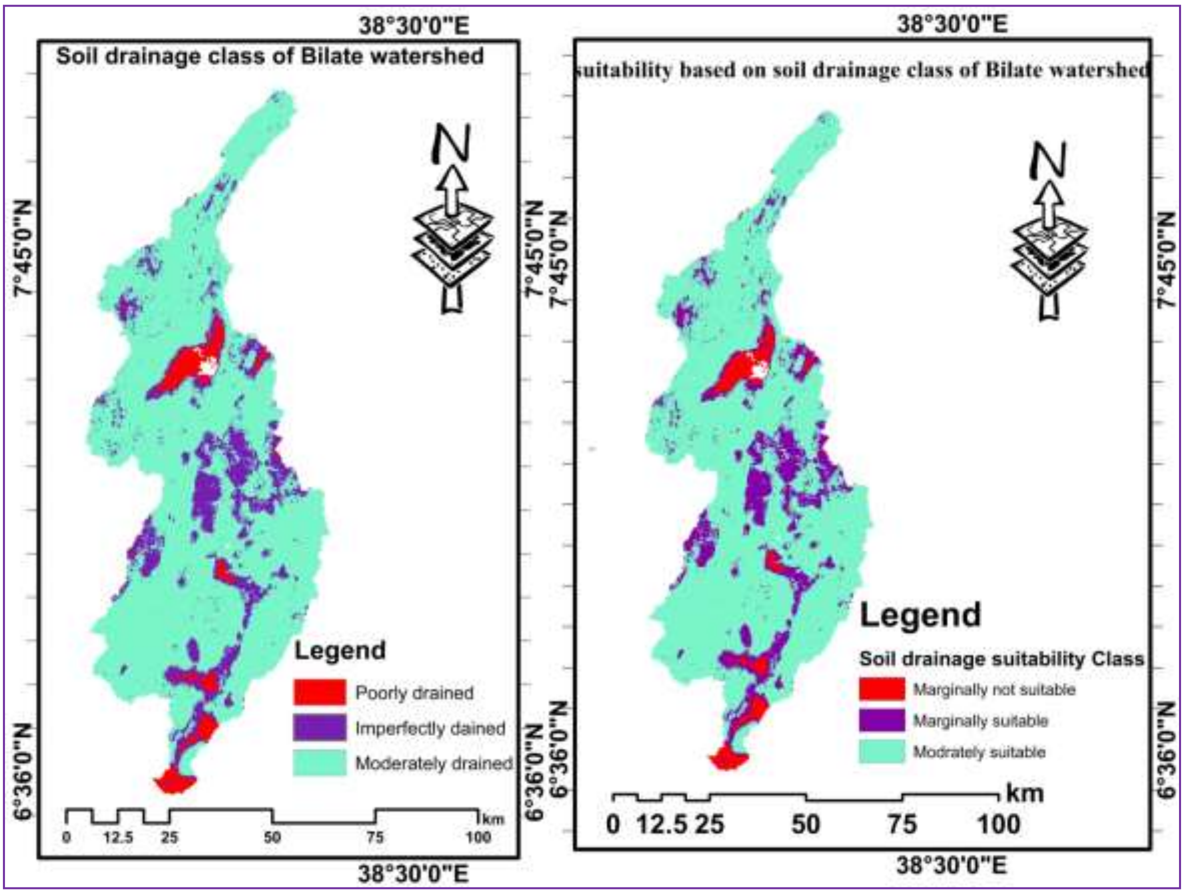

Figure 4.3: Soil Drainage suitability map of the study area

The final evaluation of Soil suitability for surface irrigation indicating soil depth, texture, and drainage after reclassification is tabulated in below Table 4.4:

Table 4.4: Analysis of soil suitability for surface irrigation development of the study area

NO	Soil Type	Soil Map Unit	Texture Suit	Depth (cm)	Drainage Suit	Texture Suit	Depth Suit	Drainage Suit	Soil Suit	Area (km^2)	Area (%)
1	Mollic Andosols	ANm	Si-C	>120	W	S2	S1	S2	S2	196.8	4.0
2	Vitric Andosols	ANz	SL	90-120	W	S1	S2	S3	S2	1478.0	29.8
3	Eutric Fluvisols	Fle	LS	>120	I	S2	S1	S2	S2	4.6	0.1
4	Lithic Leptosols	LPq	CL	<30	W	S2	N	S1	N	568.8	11.5
5	Chromic Luvisols	LVx	L	90-120	W	S1	S2	S1	S1	1078.7	21.7
6	Humic Nitosols	NTu	C(light)	>120	W	S2	S1	S2	S1	723.3	14.6
7	Luvics Phaeozem	PHi	L	>120	W	S2	S1	S2	S1	56.7	1.1
8	Euric Vertisols	VRe	C	>120	I	S1	S1	S2	S2	846.3	17.1
9	Water body	WBD							N	9.8	0.2
	SUM									**4963.2**	**100.0**

Finally, the soil suitability analysis indicates that the study area could be generally classified into nine suitability classes; S1 (Highly Suitable), S2 (Moderately suitability), and N (Marginally not suitable) for agricultural crop production through application technology as shown below (Table 4.5)

Table 4.5: Soil suitability reclassification result of the study area

S/NO.	Suitability Class	Area coverage(km^2)	Coverage (%)	Soil type
1	S1(Highly suitable)	1858.7	37.45	Humic Nitosols,Chromic Luvisols and Luvic phaeozems.
2	S2(Moderately suitable)	2525.7	50.85	Mollic Andosols,Viric Andosols, Euric Fluvisols and Euric Vertisols.
3	N(Marginally not suitable)	578.8	11.7	Lithic Leptosols and Waterbody
	SUM	4963.2	100	

Soil types having soil texture light clay and Loam soil depth greater than 120 cm, and well soil drainage was classified as highly suitable (S1). It covered 1858.7 km^2, (37.45%) of the total area coverage of the watershed. The second suitability class is moderately suitable classes (S2). It covered the area of 2525.7 km^2, (50.85%) in the study area and is comprised of soil type having soil texture clay, with a soil depth of 90-120 cm, greater than 120 cm, well soil drainage, and imperfectly soil drainage. These soil types are limited by their well and imperfect drainage condition while the other factors are optimum for surface irrigation. and the final soil suitability class was marginally not suitable (N). It covered the area of 578.8 km^2, (11.7%) in the study area (Lithic leptosol and water body) they were limited by their shallow soil depth while other factors were optimum for surface irrigation.

4.1.2. Slope suitability analysis

The slope was considered as one of the major factors that determine the selection of land for surface irrigation potential in the study area. Based on FAO land suitability classification there are slope classes (S1, S2, S3, and N) in the watershed (Figure.4.4). The slope map of the study area was derived from the Digital elevation in Arc-GIS 10.3, and reclassified into four for surface irrigation suitability, i.e., from 0-2% as highly suitable (S1),2-5% as moderately suitable (S2),5-8% as marginally suitable (S3),>8% as Not suitable (N).The suitability result indicates that ,924.3 km^2 (18.63%) highly suitable, 2048.8 km^2 (41.28%) moderately suitable, 1022.155 km^2 (20.6%) marginally suitable and

968.16 km^2 (19.5%) marginally not suitable. The slope suitability map of the study area is shown in below Figure 4.6.

Table 4.6. Slope suitability Classes for surface irrigation of study area

S/NO.	Slope Range	Suitability Class	Area (km^2)	Area (%)
1	0-2%	S1	924.303	18.62
2	2-5%	S2	2048.775	41.28
3	5-8%	S3	1022.155	20.58
4	>8%	N	968.161	19.51
	SUM		**4963.394**	100.00

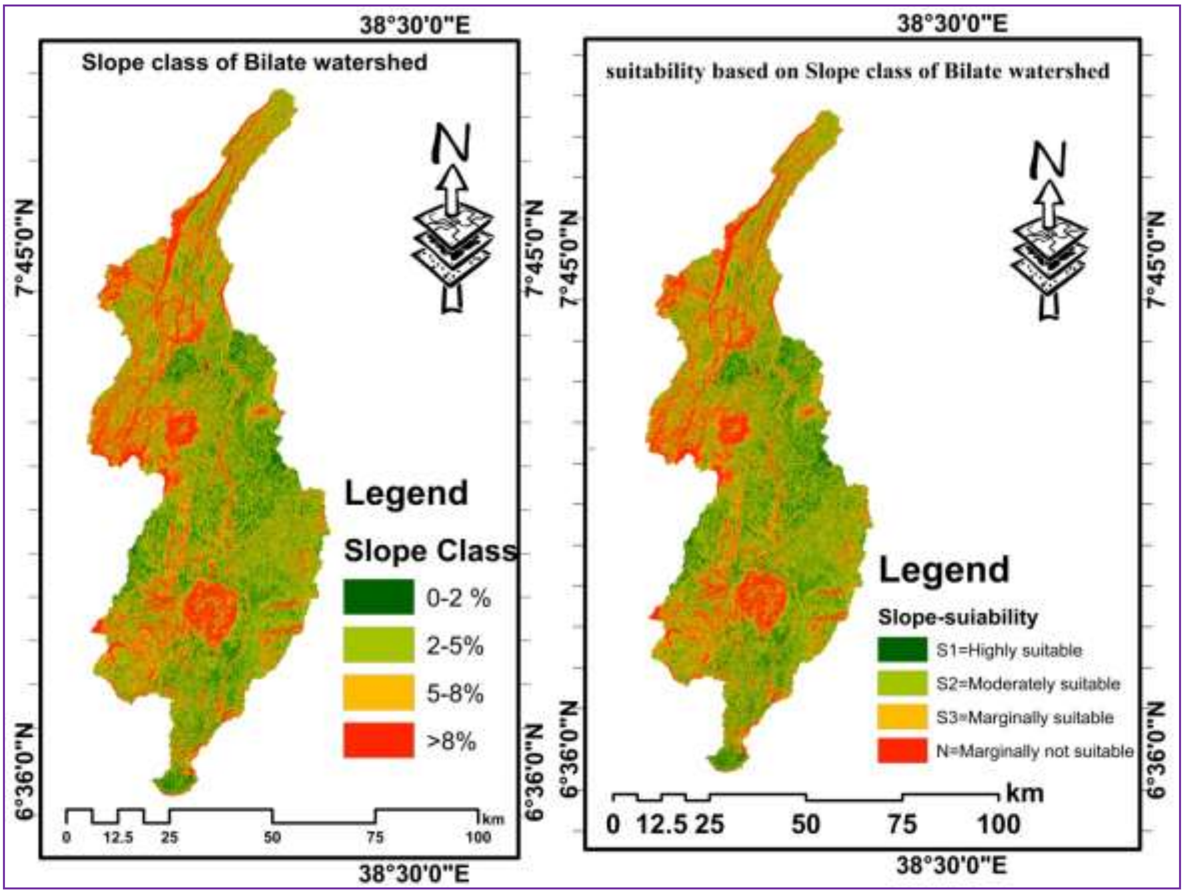

Figure 4.4: Slope suitability map of the study area for surface irrigation development

4.1.3. Landuse/Land cover suitability analysis

Landuse/land cover evaluation from SPOT5 image by supervised classification. The nine Landuse/land cover types in the watershed included dominantly Forest, Woodland, Shrub/bush, Agriculture, Grassland, Barren land, Wetland, Waterbody, and Settlements were available. All Landuse/land cover classes were classified with high accuracy except barren land which interfered with cultivated and shrublands of all land cover classifications, the wetland was classified with a high accuracy level. The land cover/use of the study area was classified with an overall accuracy of 90.73% and a Kappa coefficient of 0.82. The Kappa coefficient of 0.82 of the land cover classification in the study area represents a strong agreement according to (Rahman, 2007).

Table 4.7: Confusion matrix of SPOT LU/LC Classification

Classified Data	Forest	Wood Land	Agriculture	Grass Land	Shrub/ bush	Barren Land	Wet Land	Water body	Settlements	Total
Forest	65	0	0	0	0	0	0	0	0	65
Wood Land	2	9	0	0	0	0	0	0	0	11
Agriculture	0	0	200	5	8	20	0	0	0	233
Grass Land	0	0	0	30	0	0	0	0	0	30
Shrub/bush	0	0	0	0	11	0	0	0	0	11
Barren Land	0	0	0	3	4	74	0	0	0	81
Wet Land	0	0	0				8	0	0	8
Water body	0	0	0					5	0	5
Settlements	0	0	0						9	9
Column Total	67	9	200	38	23	94	8	5	9	453

Over all accuracy=411*100/453=90.73, Kappa coefficient=0.82.

The LU/LC result showed that about 69.568% of the watershed which was 3448.77 km^2 categorized as highly suitable (S1) that means Agriculture land covers the largest area of the landuse/land cover of all the land classes, 19.461% which covers an area 967.77 km^2 moderately (S2) suitable for surface irrigation that was land covered by Grassland and Woodland and 9.498% which covers an area of 470.94 km^2 marginally suitable for surface irrigation that was land covered by bush and shrub/barren land. While about 1.524% of the watershed which covers 75.9149 km^2 was watershed regarded as not suitable for surface irrigation that was land covered by wetland, Forest-dense, settlements, and Waterbody.

Table 4.8: Landuse/Land cover reclassification suitability classes for surface irrigation of study area.

S/NO.	LU/LC Classes	Area (km^2)	Area (%)	Suitability Class
1	Agriculture or Cultivated-dominantly	3448.77	69.568	S1
2	Woodland and Grassland	967.77	19.461	S2
3	Bushed and shrub/ Barren land.	470.94	9.498	S3
4	Wet land, Forest-dense, Settlements and water bodies	75.91	1.524	N
	SUM	**4963.39**	**100.000**	

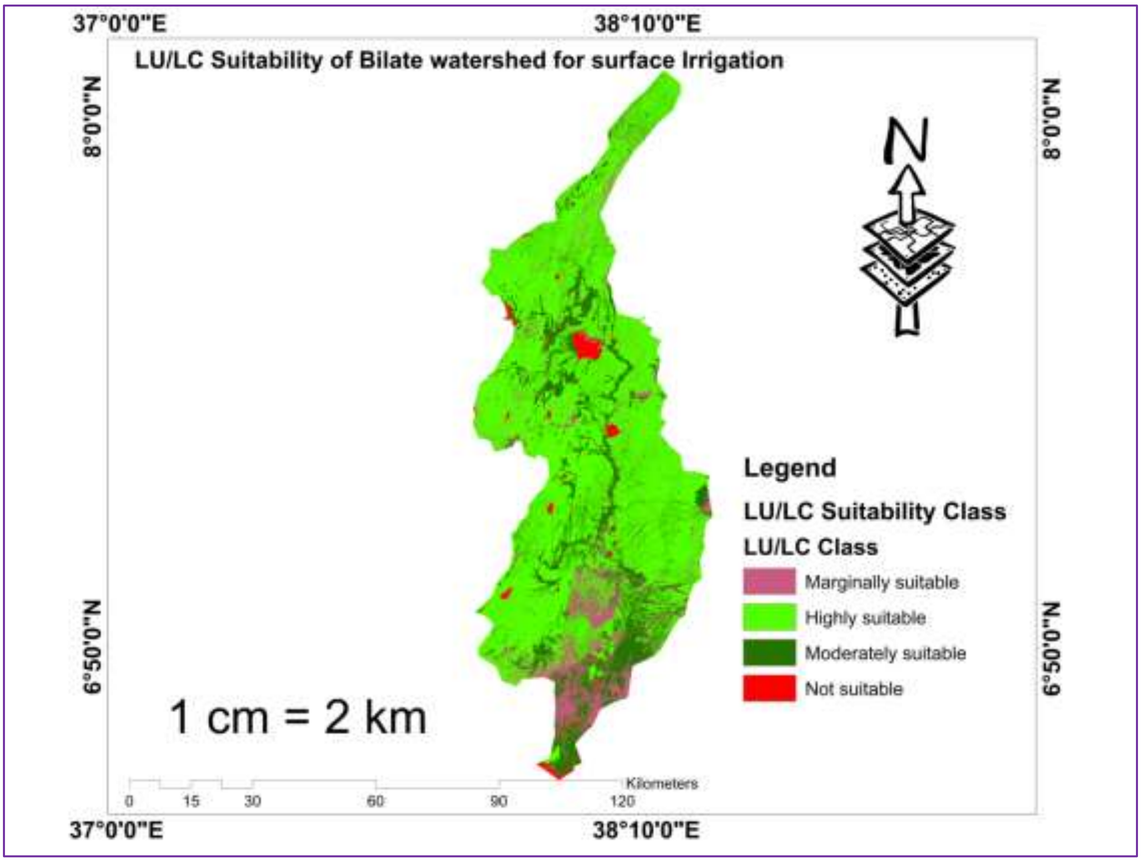

Figure 4.5: LU/LC Suitability map of the study area

4.1.4. River proximity analysis for surface irrigation of the study area

To identify irrigable land close to the River (water supply), a straight line (Euclidean distance) from watershed main points was calculated. Spatial proximities to water sources were computed using the spatial overlay of respective GIS. Influences of Euclidean distance parameters on agricultural land suitability below Table 4.6, were estimated using the clipped feature class was converted to raster using conversion tool and reclassified into suitability class based on its distance used to water source used' reclassified and shown in below Figure 4.6. Then reclassified distance used Weighted overlay analysis together with another factor.

Table 4.9: Proximity to River (water source) suitability analysis of the study area

S/NO.	Proximity to Water(source) (km)	Area(km^2)	Area (%)	Suitability Class
1	0-1.5	3828.25	77.14	S1
2	1.5-3	951.19	19.16	S2
3	3-4.5	97.15	1.94	S3
4	>4.5	86.80	1.75	N
	Total	4963.39	100.00	

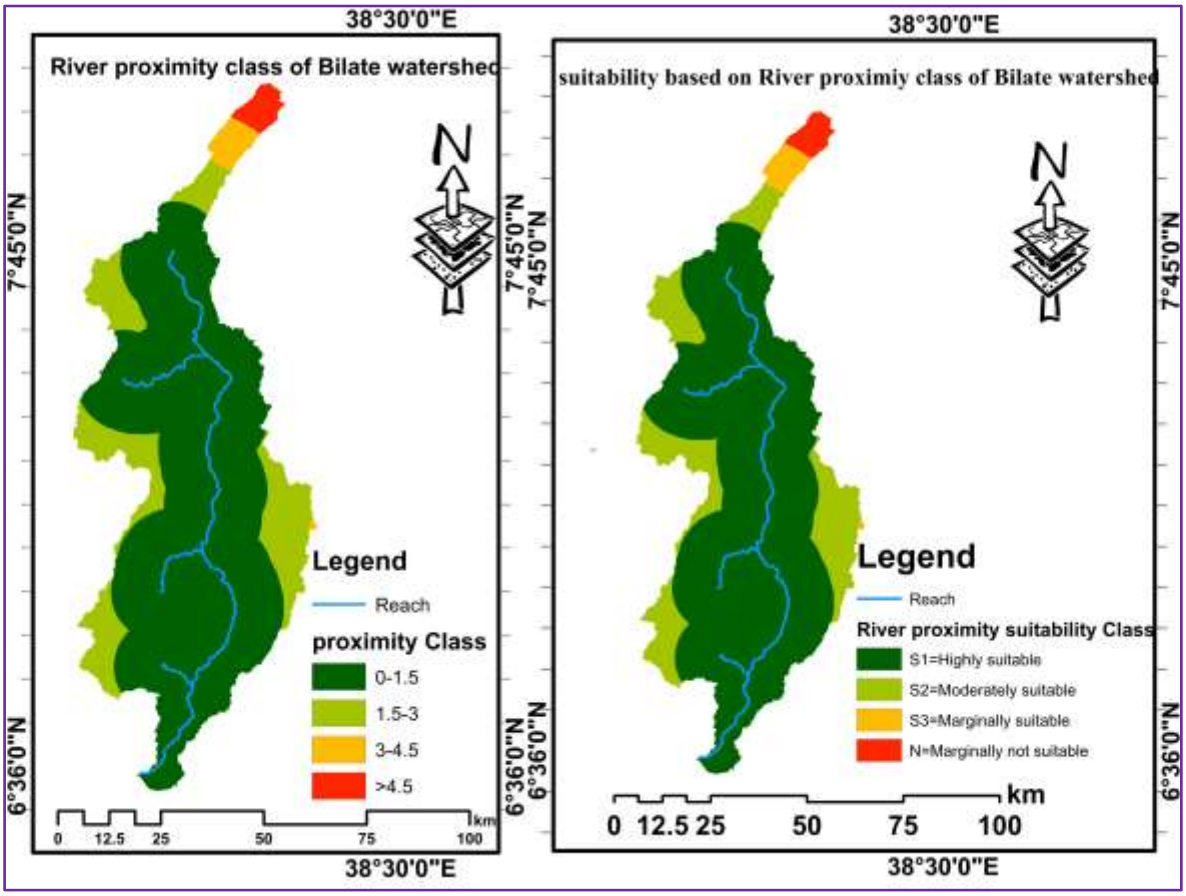

Figure 4.6: River proximity suitability map of the study area

4.2. Assessing weights using AHP for surface irrigation suitability mapping

Not all selecting factors are equally important suitability analyses. Comparisons are needed to identify the importance of each factor with the others.

For instance, how much is the effect of slope important relative to soil depth or other factors on land suitability. Hence, in this case, a comparison is among the factors. The pair-wise comparison matrix and overall weights of the factors selected for the study are shown in Table 4.9 were constructed first. The six factors are listed in the six columns and rows. The row factors were compared with the factors in the columns or their significance to irrigation and then using the scoring of Saaty (1980) Table 3.11, the pairwise comparison matrix below Table 4.9 was prepared. These for example, in Tale 4.10: the "slope" factor is far more important for determining the suitability of land than the factor land use in the column. Conversely, "land use" in the row of Table 4.10: is far less important than the slope in the column. Assigning of factors was made based on studies in the Bilate watershed and surface irrigation suitability factors.

The results in Table 4.12: shows that the factor "slope" is the most important factor since its values are greater than 1 in its row followed by "soil depth" and "River proximity". The weights of each calculated by using pair-wise comparision techniques are listed in Table 4.12: were, the greater the value the more important the factor. In this land suitability analysis, the consistency ratio (CR) is 0.0538 which indicates that the comparisons of land characteristics were consistent and that the relative weights were appropriately chosen.

Table 4.10: Pair-wise comparison matrix based on selected criteria for surface irrigation suitability analysis.

S/NO.	Factors	Soil depth	Soil Texture	Soil Drainage	Land use/ cover	River proximity	Slope
1	Soil depth	1	2	2	7	2	1/3
2	Soil Texture	1/2	1	2	5	2	1/5
3	Soil drainage	1/3	2	1	3	1/2	1/5
4	Landuse/land cover	1/7	1/5	1/5	1	1/5	1/5
5	River proximity	1/2	1/2	1/2	5	1	1/3
6	Slope	3	4	4	14	4	1
	SUM	**5.48**	**9.7**	**9.7**	**35**	**9.7**	**2.27**

Table 4.11: Procedural analysis of pairwise comparison matrix based on selected criteria's for surface irrigation suitability analysis

S/NO	Factors	Soil depth	Soil Texture	Soil Drainage	LU/LC	River proximity	Slope
1	Soil depth	1/5.5	2/9.7	2/9.7	7/35.00	2/9.7	0.334/2.268
2	Soil Texture	0.5/5.5	1/9.7	2/9.7	5/35.00	2/9.7	0.2/2.268
3	Soil drainage	0.334/5.5	2/9.79	1/9.7	3/35.00	0.5/9.7	0.2/2.268
4	Land/land cover	0.14/5.5	0.2/9.7	0.2/9.7	1/35.00	0.2/9.7	0.2/2.268
5	River proximity	0.5/5.81	0.5/9.7	0.5/9.7	5/35.00	1/9.7	0.334/2.268
6	Slope	3/5.5	4/9.7	4/9.7	14/35.00	4/9.7	1/2.268

Normalized comparison matrix

Normalizing the matrix means add the columns of the matrix and the divide each element in every column by the sum of the column.

Table 4.12: Normalized criteria's comparison matrix on suitability analysis for surface irrigation

S/NO.	Factors	Soil depth	Soil texture	Soil drainage	LU/LC	River proximity	Slope	Criteria Weight (%)
1	Soil depth	0.1818	0.206	0.206	0.2	0.206	0.147	19
2	Soil texture	0.09	0.103	0.206	0.1428	0.206	0.088	14
3	Soil drainage	0.06	0.206	0.103	0.0857	0.0515	0.088	10
4	LU/LC	0.02596	0.0206	0.0206	0.0285	0.0206	0.088	3
5	River proximity	0.09	0.0515	0.0206	0.1428	0.103	0.147	10
6	Slope	0.545	0.412	0.412	0.4	0.412	0.44	44
	SUM	**1**	**1**	**1**	**1**	**1**	**1**	**100**

To get the weight of the average of the factor of each row in the normalized matrix and weight percentage was calculated by the average of each row by 100.

Potentially irrigable areas by the intended irrigation method were obtained using an irrigation suitability analysis model developed by Arc GIS 10.3 Figure below 4.10. The suitability model involved weighting of values of data sets such as:-Soil, slope, land use/land cover, and River proximity to the water source. Rasterized and reclassified suitability maps of each parameter were used as input for the Weighted Overlay analysis tool. As elaborated below in Table 4.14 overall suitable areas for surface irrigation development in the watershed are identified with their area coverage.

Table 4.13: Weighting factors

Factors	**Criteria Weight**	**Criteria Weight (%)**
Soil depth	0.19116	19
Soil Texture	0.1393	14
Soil drainage	0.09905	10
Landuse/land cover	0.034034	3
River proximity	0.099251	10
Slope	0.43683	44
λmax	6.334	
CR	0.0538	

In the irrigation suitability analysis evaluation scale of 1 to 4 was used. 1 represents highly suitable, 2 represents moderately suitable 3 represents marginally suitable. In the weighted overlay analysis, a high weight of influences (% of influences) was given for slopes, since it is the determinant factor in the evaluation of the given area for surface irrigation development. The general weighted overlay result shows that result about 64.037% of the watershed which was 3178.4 km^2 categorized as highly suitable (S1), 30.91% which covers 1534.5878 km^2 categorized as moderately suitable (S2) and (5.044%) of 250.39 km^2 the total area categorized as not suitable (N) for surface irrigation development.

Table 4.14: Overall suitability of land for surface irrigation development

S/NO.	Area (km^2)	Area (%)	Suitability Class
1	250.39	5.04	Not suitable
2	3178.41	64.04	Highly suitable
3	1534.59	30.92	Moderately suitable
SUM	**4963.39**	**100.00**	

The next map shows the procedure of weighted overlay analysis based on soil depth, soil drainage, soil texture, River proximity, landuse/land cover, and slope of all physical properties.

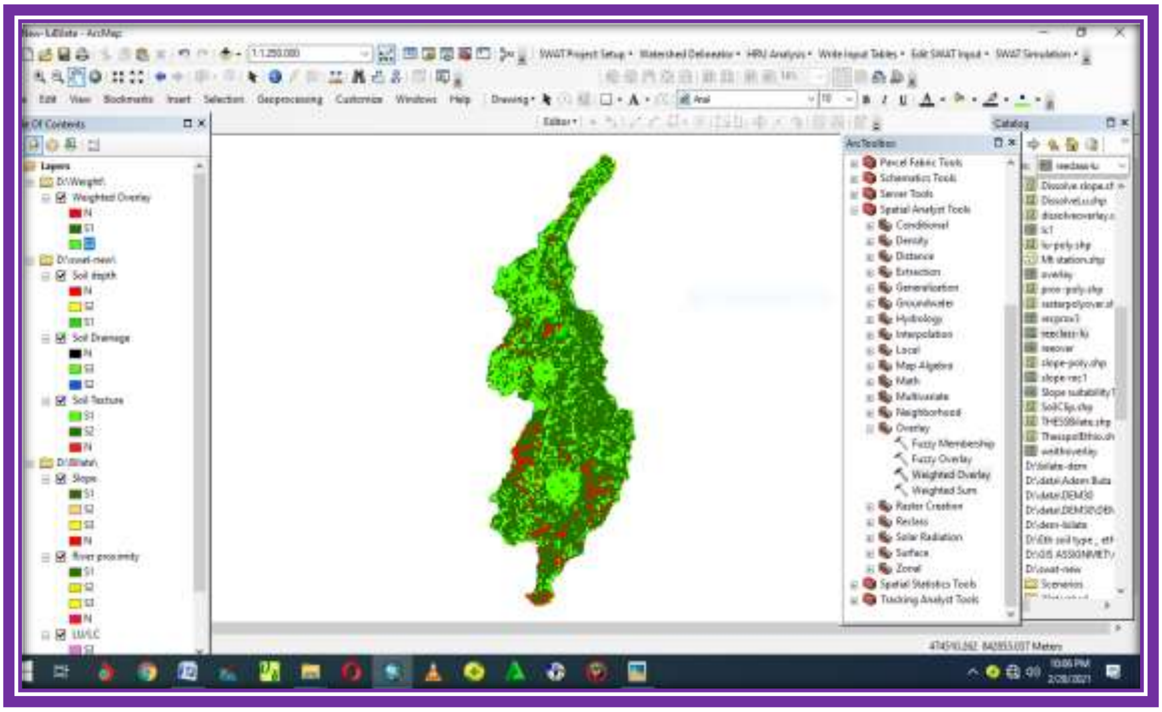

Figure 4.7: Procedural analysis of weighted overlay analysis for land suitability on Arc GIS 10.3. The weighted overlay analysis of the six parameters was evaluated in next Map 4.8 which indicates the overall suitability of land suitable for surface irrigation development of the study area.

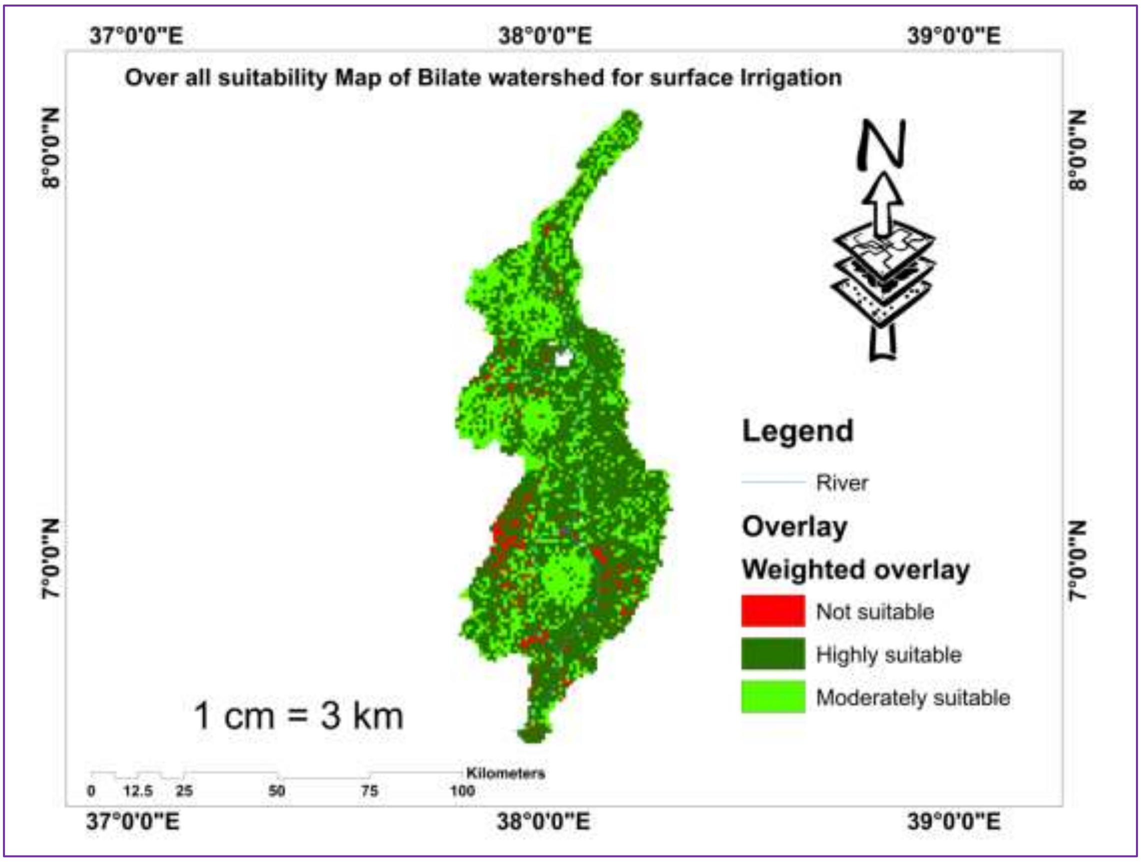

Figure 4.8: Overall land suitability for surface irrigation of the study area

Table 4.15: Overall suitability of the SubWatersheds for surface irrigation development

Sub-watershed	Suitability class	Suitability rate	Area(ha)
Sub-watershed **1**	Highly suitable	**S1**	9795
Sub-watershed **2**	Highly suitable	**S1**	95895
Sub-watershed **3**	Highly suitable	**S1**	10000
Sub-watershed **4**	Highly suitable	**S1**	91346
Sub-watershed **5**	Highly suitable	**S1**	90443
Sub-watershed **6**	Highly suitable	**S1**	20361

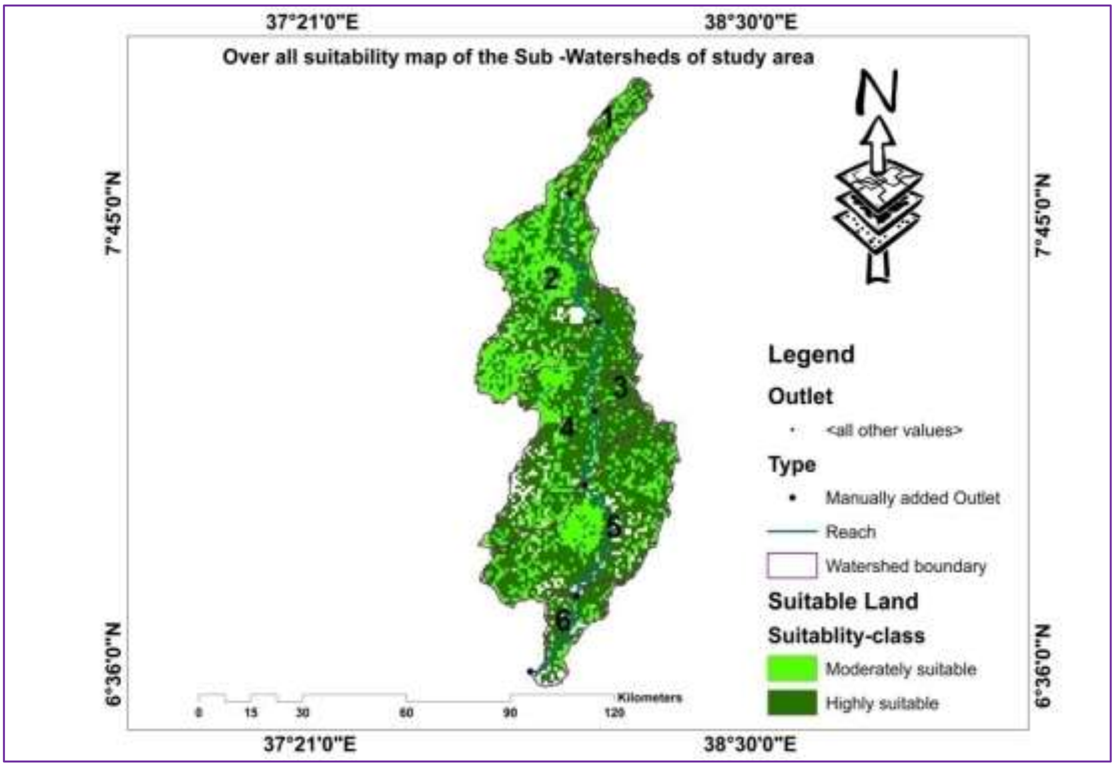

Figure 4.9: Overall land suitability map of sub-watersheds of the study area

The most suitable area for surface irrigation in the Bilate River Watershed was identified in sub-basin no 4 which has been classified based on the four important parameters which are River proximity, slope soil physical properties, and LULC type accordingly.

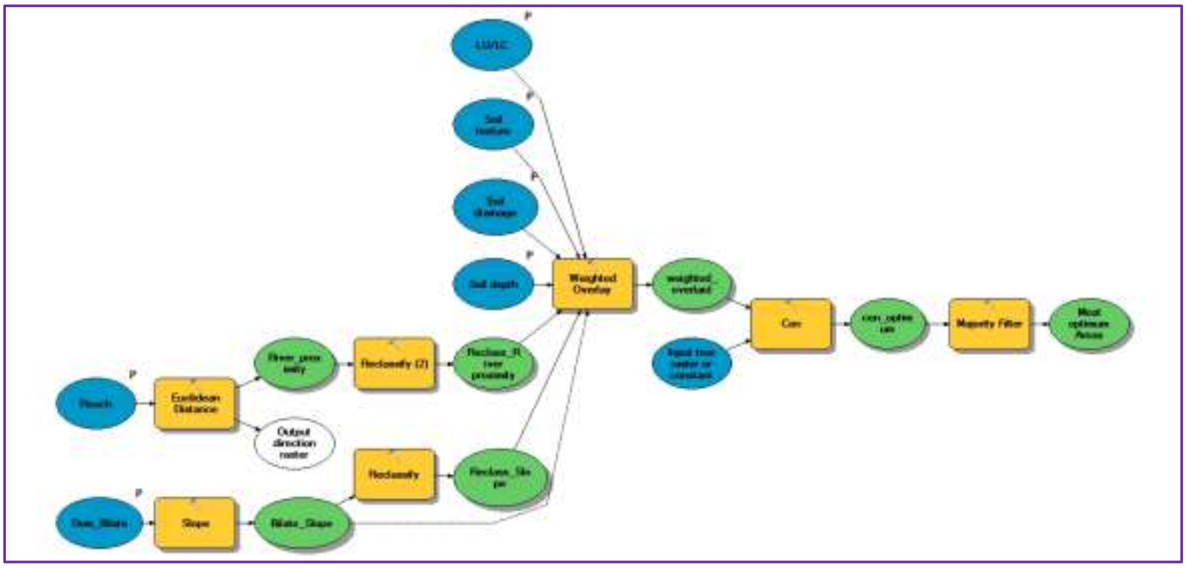

Figure 4.10: Irrigation suitability model

4.3. Assessment of surface water resources availability of study area

Water availability assessment has been analyzed from the simulated streamflow, realizing through the Arc SWAT model in each subwatershed. The observed flow data were used for calibration and validation by considering sensitivity parameters using SWAT- CUP Sufi_2 software. After successful sensitive analysis, calibration, and validation done Water availability assessment was analyzed from the simulated value of streamflow, implementing through the Arc SWAT model in each sub-watershed.

4.3.1. Sensitivity analysis

Sensitivity analysis was carried out to identify which model parameter is most significant or sensitive. Flow sensitivity analysis was carried out for a period of 26 years, which includes two years of warm-up periods (from January 1, 1990, to December 31, 1991). About 350, simulations have been done by SWAT sensitivity analysis at the watershed of sub-watershed no 6. Where the outlet of the watershed found in flow calibration with the output of 27 parameters was reported as sensitive in different degrees of sensitivity for flow. Among these 14 parameters, most of the parameters were grouped under a high sensitivity to medium sensitivity range. T stat provides a measure of sensitivity (large in absolute values are more sensitive) to the model whereas the P values determined the significance of sensitivity. When the value of P is close to zero indicates a higher significance. According to (Shiferaw, 2014) the degrees of sensitivity were ranged from 0<mean relative sensitivity<0.05 means small; 0.05<mean<0.6 means medium; 0.6<mean<1 means High and mean>=1 means very high. The most sensitive parameters have an effect when changed ranging from high to small and will be used for flow calibration. The result of SWAT sensitivity analysis revealed that 14 parameters are sensitive to the SWAT model among 27 hydrological sensitivity parameters and the most sensitive parameters were identified in the rank order at below (Table 4.16) in the hydrological process of the Bilate River watershed. The Table also indicates the best-fitted values of the model parameters using SWAT CUP Sufi_2 software that occurred from the SWAT CUP sensitivity analysis of the output.

Table 4.16: Results of SWAT's streamflow most sensitive parameters analysis of model calibration, validation, and fitted value.

NO.	Parameter Name	Description	Range	Min Value	Max Value	Fitted Value	Tstat Value	P Value	Sensitivity (Rank)
1	CN2	SCS-CN for moisture condition II	(-2)-2	-0.16	0.16	-0.0865	-2.58	0.0122	1
2	ALPHA_BF	Base flow alpha factor(days)	0-1	0	0.4	0.02	-2.105	0.038	2
3	GW_Delay	Ground water delay in(days)	30-450	30	60	45.8124	1.7375	0.0434	3
4	GWQMN	Threshold depth of water in the shallow aquifer required for return flow to occur(mm)	0-2	1	1.85	1.217	-1.651	0.0483	4
5	ESCO	Soil evaporation composition factors (unitless)	0-7	0.35	0.89	0.54	-1.573	0.0532	5
6	EPCO	Plant uptake Composition factor (Unit Less)	0-1	0.26	0.79	0.484	1.431	0.0841	6
7	GW_REVAP	Ground water evaporation coefficient (unitless)	0.02-0.2	0	0.2	0.12	-1.28	0.0863	7
8	SOL_Z	Soil Depth (mm)	0-3500	490	3000	2960	-1.16	0.1	8
9	SOL_AWC	Available water capacity of the soil layers	0-1	0.25	0.75	0.673	0.915	0.587	9
10	SOL_K	Saturated hydraulic conductivity.	0-2000	150	1000	886.56	0.152	0.879	10
11	REVAPMN	Threshold depth of water in the shallow aquifer required for evap oration to occur(mm)	0-500	70	300	255.67	-0.45	0.7319	11
12	SURLAG.bsn	Surface run-off lag time	0.05-24	0.05	22.6	20.8	-0.79	0.81	12
13	SOL-BD	Moist bulk density	0.9-2.5	1.8	2.2	1.9546	-0.03	0.73	13
14	CH-N2	Manning's "n" value for the main channel	0.01-0.3	-0.01	0.3	0.818	0	1	14

4.3.2. Model calibration and validation

Flow calibration was done for 16 years (from January 1, 1990, to December 31, 2007) which includes two years for model initialization (warm-up). Therefore, the model performance in calibration was considered from 1992 to 2007. This period was chosen because of its continuous time series data with less missed data. While conducting calibration auto-calibration was done. Auto-calibration allows the model to change the parameters until both observed and simulated flow data will be in the acceptable range automatically. After each simulation, the model goodness-of-fit was evaluated and the model performance after adjusting all the parameters of R^2, NSE, and PBias as many numbers of iterations and simulations for 26 years observed flow data at near Alaba kulito gauging station and the results are presented in Table 4.17 below. Since the acceptable ranges of parameters R^2, NSE, and Pbias are $R^2 > 0.6$, NSE > 0.5, and Pbias ±25% respectively (Santhi *et al.,* 2001). Therefore, it is confirmed that all the values obtained are in the acceptable range and the legend in the graph represents the observed and best estimations or simulated values. The calibration period of the observed and simulated flows is shown in Figure 4.12, the model was mostly overestimated and underestimated for some part of the year in a calibration period.

Table 4.17: R^2, Ens, and Pbias values for both calibration and validation

Model performance measure parameters	Calibration values (1992-2007)	Validation values (2008-2015)	Recommended	Remark
R^2	0.77	0.81	>0.6	Ok
Ens	0.66	0.64	>0.5	Ok
Pbias	19.8	21	±25	

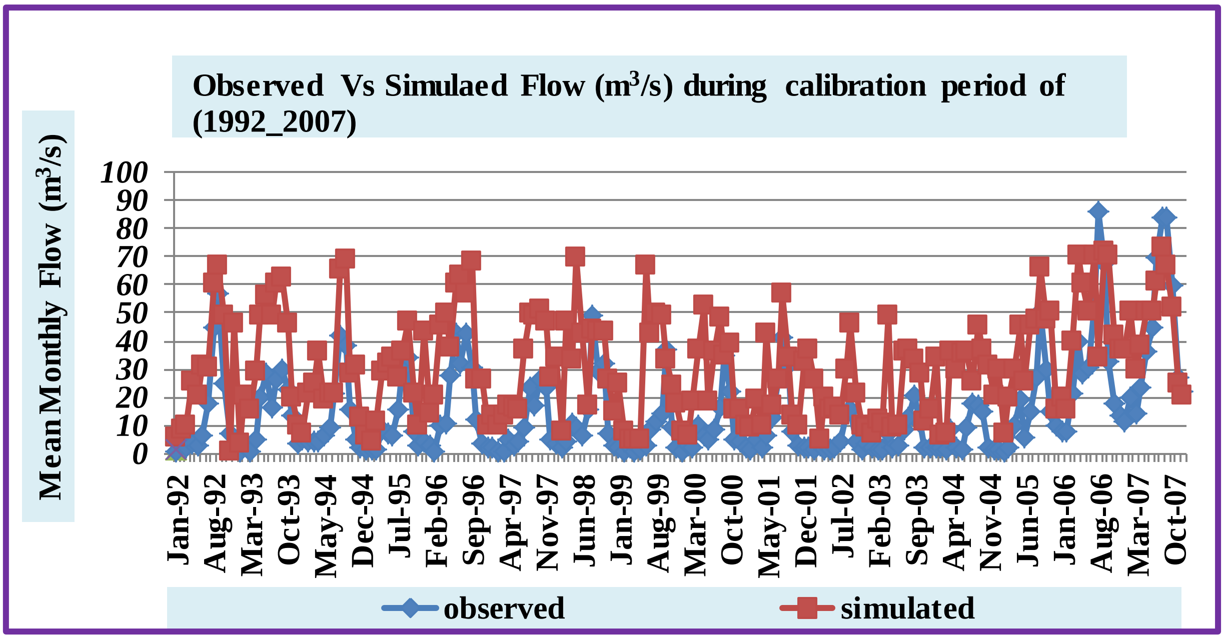

Figure 4.11: Observed and simulated monthly flow for the calibration period (1992-2007)

The calibration period of the observed and simulated flows is shown in figure 4.11 above, the model is mostly over-estimated and underestimated for some part of the calibration period.

Flow validation of the model for the watershed was carried out from January 1, 2008, to December 31, 2015, without further adjustment of the parameters. The objective functions that were used for evaluation like the coefficient of determination, Nash Sutcliff efficiency, and Pbias were in the acceptable range for the validation time of the model in the monthly time step and the R^2, NSE, and Pbias indicates in Table above 4.17.

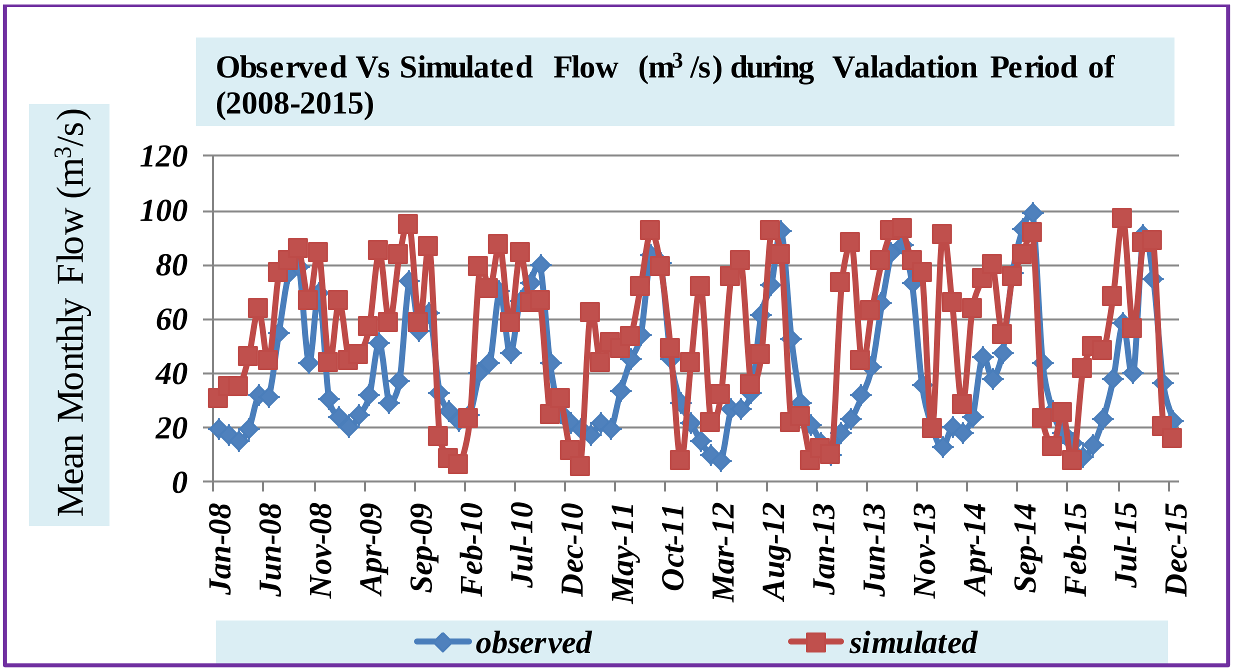

Figure 4.12: Observed and simulated monthly flow for the validation period (2008-2015)

The validation result shows that there are some under and overestimations in the model output is compared to the simulated and observed data but the overall validation result from the evidence there is the best correlation between the simulated model outputs and observed data.

After successful sensitive analysis, calibration, and validation Water availability assessment was analyzed from the simulated value of streamflow, implementing through the Arc SWAT model in each sub-watershed. The water resources availability assessment understands the potential of irrigation water supply in each sub-watershed obtained from the SWAT simulated outputs and comparing it with the irrigation water demand for dominant crops of each watershed.

The mean monthly predicted water yield during the dry period phase (December to April), important to irrigate the selected crops, followed the same trend as the annual water yield (Table below 4.19).

Available surface water resources on the study area were evaluated by using flow discharge obtained from the ministry of water of irrigation and electric city. The dependably flow for Bilate River at 80% exceedance probability was evaluated by using IHA software. But the effective irrigable area is determined based on streamflow. Water available was determined after little water was released for the ecological purpose.

Table 4.18: Bilate River simulated flow at 80% exceedance probability before 30% released for the ecological purpose (m^3/**s**)

Months	Sub-wate1	Sub-wate2	Sub-wate3	Sub-wate4	Sub-wate5	Sub-wate6
JAN	0.221	3.523	5.135	7.189	10.322	10.855
FEB	0.052	1.755	2.626	3.965	5.772	6.045
MAR	0.065	2.158	2.847	4.615	6.539	7.02
APR	0.117	10.699	21.671	40.235	48.529	50.037
MAY	0.689	42.627	59.488	89.583	92.56	101.92
JUN	0.663	56.264	80.769	103.805	84.24	96.59
JUL	0.65	61.854	85.15	81.848	105.3	116.87
AUG	1.755	52.338	70.408	98.787	100.62	96.59
SEP	1.157	69.004	87.464	94.692	88.66	86.58
OCT	1.534	35.997	49.803	69.498	99.502	92.482
NOV	17.2	23.998	37.908	53.924	78.299	82.901
DEC	0.468	6.006	11.804	19.136	30.537	32.63

Table 4.19: Bilate River simulated flow at 80% exceedance probability after 30% released for the ecological purpose (m^3/**s**)

Months	Sub-wate1	Sub-wate2	Sub-wate3	Sub-wate4	Sub-wate5	Sub-wate6
JAN	0.17	2.71	3.95	5.53	7.94	8.35
FEB	0.04	1.35	2.02	3.05	4.44	4.65
MAR	0.05	1.66	2.19	3.55	5.03	5.40
APR	0.09	8.23	16.67	30.95	37.33	38.49
MAY	0.53	32.79	45.76	68.91	71.20	78.40
JUN	0.51	43.28	62.13	79.85	64.80	74.30
JUL	0.50	47.58	65.50	62.96	81.00	89.90
AUG	1.35	40.26	54.16	75.99	77.40	74.30
SEP	0.89	53.08	67.28	72.84	68.20	66.60
OCT	1.18	27.69	38.31	53.46	76.54	71.14
NOV	12.04	18.46	29.16	41.48	60.23	63.77
DEC	0.36	4.62	9.08	14.72	23.49	25.10

4.4. Irrigation water requirements of Major crops for Study area

To determine the surface irrigation potential of the watershed knowing the water demand by selected crops is essential. Determination of irrigation water requirement of the five selected crops (maize, onion, tomato, potato, tobacco, and Wheat) in terms of water availability in the potential irrigable lands Bilate and Hossana climatic station was selected to calculate irrigation water requirement of the identified irrigable area, because of having complete climatic records and can represent the whole area of the Watershed.

Table 4.20: Monthly GIR water requirements for selected crops at Bilate station (mm/month)

Types of crops	Months	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	Total
1. Maize		35.4	160.6	192.7	152.7	0.0	0	0	0	0	0	0	0	541.4
2. Onion		81.3	117.0	115.1	135.6	25.9	0	0	0	0	0	0	0	474.9
3.Tomato		82.3	128.3	177.9	204.0	37.0	0	0	0	0	0	0	0	629.4
4. Potato		61.9	147.6	183.4	190.7	16.4	0	0	0	0	0	0	0	600.0
5.Tobacco		57.3	158.7	182.6	139.4	0.0	0	0	0	0	0	0	0	538.0
Total		**318.1**	**712.1**	**851.7**	**822.4**	**79.3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**2783.7**

Table 4.21: Monthly GIR water requirements for selected crops at Hossana station (mm/month)

Types of crops	Months	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	Total
1. Spring Wheat		0.0	50.9	65.6	30.1	0.0	1.9	0	0	0	0	0	0	148.4
2. Maize		33.1	124.1	144.9	52.6	0.0	0	0	0	0	0	0	0	354.7
3. Potato		57.7	120.1	137.3	79.1	4.1	0	0	0	0	0	0	0	398.4
4. Tomato		74.3	97.6	132.3	93.7	9.6	0	0	0	0	0	0	0	407.4
5. Onion		71.7	86.3	77.7	33.0	0.0	0	0	0	0	0	0	0	268.7
Total		**236.9**	**479**	**557.7**	**288.6**	**13.7**	**1.9**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**1577.7**

The analysis of results shows that Bilate climatic station is more water required than Hossana climatic station. However, Bilate climatic station is advisable to determine the irrigation potential of the Watershed. The value of the Irrigation Water requirement is given in the Table above 4.20 and 4.21.

Different crops have different crop water requirements in the study area. Crop water requirements of all crops such as maize, onion, tomato, Potato, and tobacco were presented for each month in Table 4.20 above. From all crops, Tomato has needed highest crop water requirement which recorded 629.4 mm/growing period and onion has the minimum crop water requirement in the study area was evaluated at 474.49 mm/growing period. Total GIR requirements were determined 2783.7 mm/growing period. The highest crop water requirement was required for all crops in February and the lowest crop water requirements were recorded for all crops in April.

Gross irrigation water requirement of Maize, Onion, Tomato, Potato, and Tobacco at the identified potential irrigable site covers 40%,15%, 15%,10%, and 20% of the highly suitable total irrigable area respectively under surface irrigation methods were estimated using climatic data for CROPWAT 8.0 model which are presented in Appendix Table 8, 9, 10, 11, 12, 13 and 14. The following Table 4.22 presents monthly gross irrigation water requirements of the dominant crops of Maize, Onion, Tomato, Potato, and Tobacco. These results give a general overview of monthly water demands for five crops of the full growth stage of Maize, Onion, Tomato, Potato, and Tobacco that should be abstracted from the sub-watershed during the local cropping period. Tables below 4.22 gross irrigation requirement of dominant crops in (m^3/s).

Table 4.22: Irrigation water requirement (Water Demand) of dominant crops (m^3/s)

Sub-watershed	Area(ha)	Crop types / Months	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	Total
Sub-watershed 1	3918	Maize	0.52	2.35	3.12	2.23	0.00								8.22
	1469.3	Onion	0.45	0.64	0.70	0.74	0.15								2.68
	1469.5	Tomato	0.45	0.70	1.08	1.12	0.21								3.56
	979.5	Potato	0.23	0.54	0.74	0.70	0.06								2.27
	1959	Tobacco	0.42	1.16	1.48	1.02	0.00								4.08
	9795	Total	**2.06**	**5.40**	**7.12**	**5.81**	**0.42**								**20.81**
Sub-watershed 2	38358	Maize	5.07	23.00	30.56	21.87	0.00								80.50
	14384	Onion	4.37	6.28	6.85	7.28	1.43								26.21
	14384	Tomato	4.42	6.89	10.58	10.96	2.05								34.89
	9589.5	Potato	2.21	5.28	7.27	6.83	0.61								22.21
	19179	Tobacco	4.10	11.36	14.47	9.98	0.00								39.92
	95895	Total	**20.18**	**52.82**	**69.72**	**56.92**	**4.10**								**203.73**
Sub-watershed 3	4000	Maize	0.53	2.40	3.19	2.28	0.00								8.39
	1500	Onion	0.46	0.66	0.71	0.76	0.15								2.73
	1500	Tomato	0.46	0.72	1.10	1.14	0.21								3.64
	1000	Potato	0.23	0.55	0.76	0.71	0.06								2.32
	2000	Tobacco	0.43	1.19	1.51	1.04	0.00								4.16
	10000	Total	**2.10**	**5.51**	**7.27**	**5.94**	**0.43**								**21.25**
Sub-watershed 4	36538	Maize	4.83	21.90	20.83	20.83	0.00								68.40
	13702	Onion	4.16	5.99	6.94	6.94	1.37								25.38
	13702	Tomato	4.21	6.56	10.44	10.44	1.96								33.60
	9134.6	Potato	2.11	5.03	6.50	6.50	0.58								20.73
	18269	Tobacco	3.91	10.83	9.51	9.51	0.00								33.75
	91346	Total	**19.22**	**50.31**	**54.22**	**54.22**	**3.90**								**181.87**
	36177	Maize	4.79	21.69	28.82	20.63	0.00								75.92

Sub-watershed 5	13566	Onion	4.12	5.93	6.46	6.87	1.35	24.72
	13566	Tomato	4.17	6.50	9.97	10.33	1.94	32.91
	9044.3	Potato	2.09	4.98	6.86	6.44	0.57	20.94
	18089	Tobacco	3.87	10.72	13.65	9.42	0.00	37.65
	90443	Total	**19.03**	**49.81**	**65.76**	**53.68**	**3.86**	**192.15**
Sub-watershed 6	8144.4	Maize	1.08	4.88	6.49	4.64	0.00	17.09
	3054.2	Onion	0.93	1.33	1.45	1.55	0.30	5.57
	3054.2	Tomato	0.94	1.46	2.25	2.33	0.44	7.41
	2036.1	Potato	0.47	1.12	1.54	1.45	0.13	4.71
	4072.2	Tobacco	0.87	2.41	3.07	2.12	0.00	8.48
	20361	Total	**4.28**	**11.21**	**14.80**	**12.09**	**0.87**	**43.26**

Table 4.23: Comparing of crop water demands and dependably available flows for dominant crops of the Bilate River Watershed

Sub-watershed	Area(ha)	Flow& IR (m^3/s)	Types of crops	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV
		Availble flow		0.36	0.175	0.04	0.05	0.087	0.53	0.51	0.5	1.35	0.89	1.18	0.776
Sub-watershed 1	3918	IR (m^3/s)	Maize	0.52	2.35	3.12	2.23	0							
	1469.25		Onion	0.45	0.64	0.7	0.74	0.15							
	1469.45		Tomato	0.45	0.7	1.08	1.12	0.21							
	979.5		Potato	0.23	0.54	0.74	0.7	0.06							
	1959		Tobacco	0.42	1.16	1.48	1.02	0							
	9795		**Total**	**2.06**	**5.4**	**7.12**	**5.81**	**0.42**							
		Available flow		4.62	2.708	1.35	1.66	8.23	32.8	43.3	48	40.3	53.1	27.7	18.46
Sub-watershed 2	38358	IR (m^3/s)	Maize	5.07	23	30.6	21.87	0							
	14384.25		Onion	4.37	6.28	6.85	7.28	1.43							
	14384.25		Tomato	4.42	6.89	10.6	10.96	2.05							
	9589.5		Potato	2.21	5.28	7.27	6.83	0.61							
	19179		Tobacco	4.1	11.36	14.5	9.98	0							
	95895		**Total**	**20.18**	**52.82**	**69.7**	**56.92**	**4.1**							
		Available flow		9.08	3.948	2.02	2.19	16.67	45.8	62.1	66	54.2	67.3	38.3	29.16
Sub-watershed 3	4000	IR (m^3/s)	Maize	0.53	2.4	3.19	2.28	0							
	1500		Onion	0.46	0.66	0.71	0.76	0.15							
	1500		Tomato	0.46	0.72	1.1	1.14	0.21							
	1000		Potato	0.23	0.55	0.76	0.71	0.06							
	2000		Tobacco	0.43	1.19	1.51	1.04	0							
	10000		**Total**	**2.1**	**5.51**	**7.27**	**5.94**	**0.43**							
		Available flow		14.72	5.53	3.05	3.55	30.95	68.9	79.9	93	76	92.8	53.5	41.48
Sub-	36538.4	IR (m^3/s)	Maize	4.83	21.9	20.8	20.83	0							

watershed	13701.9		Onion	4.16	5.99	6.94	6.94	1.37							
4	13701.9		Tomato	4.21	6.56	10.4	10.44	1.96							
	9134.6		Potato	2.11	5.03	6.5	6.5	0.58							
	18269.2		Tobacco	3.91	10.83	9.51	9.51	0							
	91346		**Total**	**19.22**	**50.31**	**54.2**	**54.22**	**3.9**							
		Available flow		23.49	7.94	4.44	5.03	37.33	64.8	81	77	107	68.2	76.5	60.23
Sub-	36177.2	IR (m^3/s)	Maize	4.79	21.69	28.8	20.63	0							
watershed	13566.45		Onion	4.12	5.93	6.46	6.87	1.35							
5	13566.45		Tomato	4.17	6.5	9.97	10.33	1.94							
	9044.3		Potato	2.09	4.98	6.86	6.44	0.57							
	18088.6		Tobacco	3.87	10.72	13.7	9.42	0							
	90443		**Total**	**19.03**	**49.81**	**65.8**	**53.68**	**3.86**							
		Available flow		25.1	8.351	4.65	5.4	38.49	78.4	74.3	90	74.3	66.6	71.1	63.77
Sub-	8144.4	IR (m^3/s)	Maize	1.08	4.88	6.49	4.64	0							
watershed	3054.15		Onion	0.93	1.33	1.45	1.55	0.3							
6	3054.15		Tomato	0.94	1.46	2.25	2.33	0.44							
	2036.1		Potato	0.47	1.12	1.54	1.45	0.13							
	4072.2		Tobacco	0.87	2.41	3.07	2.12	0							
	20361		**Total**	**4.28**	**11.21**	**14.8**	**12.09**	**0.87**							

4.5. Irrigation potential estimation

The irrigation potential of the River watershed in the study area was obtained by comparing irrigation requirements of the identified land suitable for surface irrigation and the available dependably monthly flows in the River watershed based on the method suggested by FAO (1997). Tables 4.23 present above the gross irrigation demand of the five crops commonly grown in the study area (Maize, Onion, Tomato, Potato, and Tobacco) and the available dependably monthly flows of the corresponding River watershed. Results of these analyses revealed that monthly irrigation water requirements of the five crops are more than the available dependably monthly water yield at each sub-watershed while the dependably monthly flows of Rivers are slightly less than the irrigation water requirements of the five crops at their corresponding command area. But in sub-watersheds 1, the irrigation water demand of the crop is more than the available dependably flow in December and April. Similarly, the irrigation water demand of the five crops in sub-watershed 4, more than the available dependably flow in April. Similarly, the irrigation water demand of the five crops in sub-watershed 5, more than the available flow in December and April and similar for the sub-watershed 6, As a result, the critical command areas were calculated according to (Micheal, 2008) to grow these crops. From Table 4.23 above the dependably available flow in February in sub-watershed 1 is 0.04 m^3/s whereas the Irrigation requirement of the five crops in February is 7.12 m^3/s giving a critical command area (that can be unreliable to irrigated using the available flows in sub-watershed River) of 2833.53ha.

Similarly, the critical command area for sub-watershed 4 was found at 10416.87ha respectively. As a result, the irrigation potential of subwatershed 1, 2, 3, 4, 5, and sub-watersheds 6 are 2833.53ha, 4344.53ha, 6861.17ha, and 10416.87ha, 14175.55ha, and 15014.12ha. However, for all watersheds, the dependably monthly available flows are less than the irrigation water demand of the five crops; therefore identified potential irrigable area was not taken as their irrigation potential. Therefore, the irrigation potential of the Bilate River Watershed in the study area is obtained and ranked below (Table 4.24). Based on the dependably available flow, the effective irrigable area can be estimated in each sub-watershed by using the equation (3.17).

Table 4.24: Summary of irrigation potential of the Bilate River watershed and their ranking for surface irrigation development possibilities.

Sub-watershed	Irrigation potential (ha)	Rank	Un-irrigated area (ha)
Sub-watershed **1**	2833.53	**6**	6961.47
Sub-watershed **2**	4344.53	**5**	91550.47
Sub-watershed **3**	6861.17	**4**	3138.83
Sub-watershed **4**	10416.87	**3**	80929.13
Sub-watershed **5**	14175.55	**2**	76267.45
Sub-watershed **6**	15014.12	**1**	5346.88
Total	**53,645.77**		**264194.23**

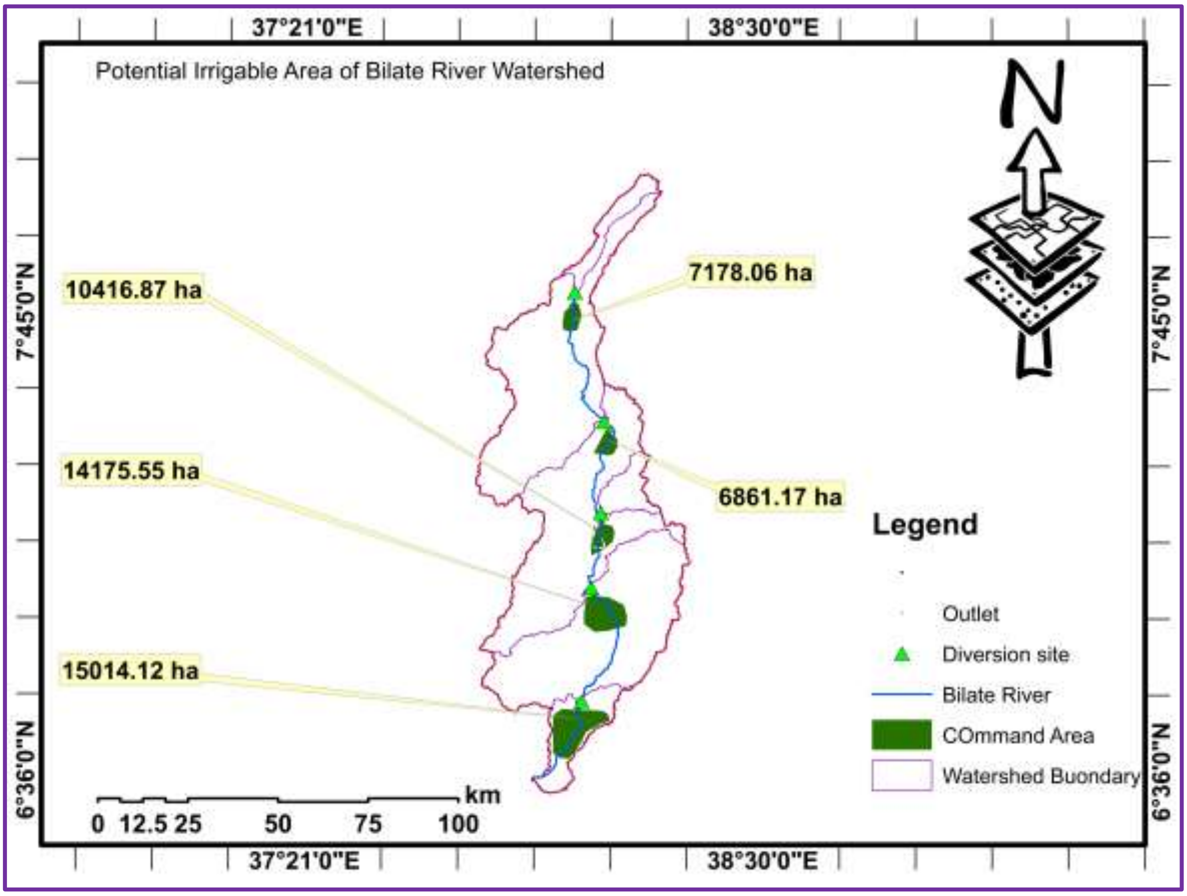

Figure 4.13: Potential irrigable area of Bilate River watershed

5. SUMMARY AND CONCLUSION

5.1. Summary

The assessment of available land and water resources for irrigation expansion was essential to increase irrigation productivity to enhance food security in the study area. The surface irrigation potential of Bilate River Watershed has located in the Rift valley Lake basin which was assessed in this study. The finding of this study was assessing surface irrigation potential of Bilate River Watershed which covers 4963.4 km^2 by considering physical factors such as soil depth, soil texture, soil drainage, slope, landuse/land covers, and Slope using weighted overlay analysis on GIS-based on Multicriteria Evaluation method (AHP). The land suitability result indicates that 69.73% of soil depth is highly suitable, 25.94% of soil depth is moderately suitable, and 4.33% of soil depth is marginally not suitable for surface irrigation development. In addition, 26.38% soil of texture is highly suitable and 73.61 moderately suitable. Whereas 80.57% of soil drainage was moderately suitable, 15.77% was marginally suitable and 3.98 marginally not suitable and 18.64% of Slope highly suitable, 41.28% Slope is moderately suitable, 20.58 Slope is marginally suitable and 19.51 marginally not suitable. In terms Landuse/land cover 69.568% of the land was highly suitable, 19.461% of the land was moderately suitable, 9.498% of the land was marginally suitable, and 1.524% of the land was marginally not suitable. In terms of River proximity Finally, land suitability analysis shows that 77.14% of River proximity was highly suitable, 19.16% was moderately suitable, 1.94% was marginally suitable, and 1.75% of the land was categorized as marginally not suitable for surface irrigation development of in the study area. When these factors are weighted using weighted overlay analysis in Arc GIS 10.3, the highly suitable land for surface irrigation development was 64%. And the available average annual dependably simulated streamflow of the watershed was estimated as 225.14 m^3 /s.

Surface water availability in Bilate River Watershed was simulated by using the SWAT model and calibrated and validated using SWAT_CUP version 2019 with the calibration and validation periods of (1992-2007) and (2008-2015) respectively. The result of the model shows that the values of R^2, NSE, and PBIAS were in the acceptable range. The result of the model performance shows that R^2=0.77, NSE=0.66, and PBIAS=19.8% for calibration and R^2=0.81, NSE=0.64, and PBAIS= 21 for validation.

The Gross Irrigation requirement of dominant crops such as Maize, Onion, Potato, Tomato, and Tobacco during the growing season was estimated by the available climatic data of nearby climatic station (Bilate) Soil data, planting date data of the study area were inputs for CROPWAT 8.0 model. The Gross Irrigation requirement of major crops shows that 663.04 m^3/s to irrigate the whole command area of 317,840 ha highly suitable area of Bilate River Watershed.

The overall land suitability result indicates that 64% (317,840ha) was highly suitable for surface irrigation development. The available dependably monthly flow obtained from the simulated output of the SWAT model was less than the Gross irrigation requirement of the irrigable land. Hence, the total Gross irrigation requirements of crops were 663.04 m^3/s estimated to irrigate the total suitable land of 317,840ha. But due to lack of available dependably flow, only 53,645.77ha can be irrigated by a total dependably annual flow of 225.14 m^3/s. Therefore, 53,645.77ha of suitable land was identified as potentially command area in the Watershed.

5.2. Conclusion

The main objective of this study was to assess surface irrigation potential study was conducted for the Bilate River Watershed Rift valley Lake basin which is located in South-Western, Ethiopia. The watershed areas obtained through, Watershed delineation, classification of potentially irrigable land, and assessment of irrigation water demand and surface water resources availability of Bilate River watershed were the steps followed to assess this irrigation potential. The total area coverage of Bilate River watershed obtained through watershed delineation is 4963.4 km^2. It had been carried out to assess and estimate suitable, irrigable land and irrigation potential of the Bilate River Watershed in the study area and a final land suitability map.

After successful model calibration and validation, dependably monthly water yield at each reach above sub-watershed which is important for crop production during the dry period was evaluated, the result of dependably monthly water yield at each sub-watershed was accessible in the Table above 4.18 and 4.19

The main irrigation suitability factors undertaken to this study were based on physical factors such as soil depth, soil texture, soil drainage, slope, landuse/land cover, and River proximity (distance from water resources) indicates that 95.7% of soil depth,100% of soil texture, 96.3% of soil drainage, 80.5% of slope, 98% of LU/LC and 98.2 distance from the water source of the study area were identified in the range of highly suitable(S1) to marginal suitable(S3) for surface irrigation expansion. Based on the factors which were considered for land Suitability slope was the most important factor in terms of determining the overall suitable land. But when all the above physical suitable area determination factors were weighted together using weighted overlay analysis in ArcGIS 10.3 software: 64% highly suitable (S1), 30.91% moderately suitable (S2), and 5.044 % not-suitable (N). In general, 94.9% of the land is highly suitable to moderately suitable for surface irrigation development.

The total Gross irrigation requirement of five major crops which is grown in the study area through the growing season was created to be 2783.7mm.
The total irrigation potential of the Bilate River watershed was found to be 53,645.77 ha which accounts for 20.3% of the total suitable land area of the Bilate River watershed.

Results of the study revealed that monthly irrigation water demand at the dry periods of five crops is more than the available dependably monthly flow at each sub-watershed. Therefore, Due to the lack of available dependably stream flow, 264,194.23 ha were not irrigated in the study area. To irrigate the whole irrigable area of the potentially suitable land, 663.04 m^3/s available dependably flows is needed.

5.3. Recommendation

This was study limited to soil physical properties that were soil depth, texture, and drainage, slope, Landuse/land cover, and River proximity (distance from water resources) due to time, and budget constraints. Given that, many other factors have their influence to distinguish land for surface irrigation development. Consequently, further research is recommended to be conducted integrating additional factors such as chemical characteristics of the soil acidity, alkalinity, and eclectic conductivity with the help of laboratory analysis to evaluate land suitability overhead the study area.

Irrigation potential analysis was done only considering surface irrigation which covers an area of 317,840ha. Further investigations are recommended to increase the irrigation potential by considering sprinkler and drip irrigation.

Since the analysis shows that the available streamflow (water supply) was less than irrigation water demand, the exploration of groundwater and constructions of different storage structures are recommended to expand surface irrigation development.

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APPENDICES

Hydrological data

Table in Appendix 1: Average Monthly steam Flow of Bilate river near Alabakulito (m3/s)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	1.2	3.0	8.1	15.3	7.2	9.3	16.9	20.6	23.5	16.2	3.6	0.8
1991	0.4	0.6	2.2	1.5	1.0	2.2	9.0	19.3	22.4	7.3	1.8	1.1
1992	0.7	2.5	2.1	3.2	2.9	6.4	17.9	44.5	56.7	24.9	6.8	2.1
1993	0.9	2.9	0.6	4.9	19.4	28.4	16.3	26.1	29.7	22.3	13.0	3.2
1994	4.5	3.7	4.0	4.1	6.2	8.8	21.3	41.6	38.0	15.7	4.7	1.6
1995	0.9	1.1	1.5	8.2	6.8	6.2	15.5	29.8	33.8	7.5	2.6	3.8
1996	2.4	0.7	9.6	10.2	27.2	42.7	32.0	42.7	30.5	11.8	3.2	1.7
1997	2.1	0.7	0.8	4.9	2.4	4.0	9.3	23.5	16.6	25.8	23.5	4.7
1998	3.1	2.3	4.1	10.3	9.1	6.1	15.4	48.5	29.0	31.5	7.0	2.5
1999	1.7	0.7	1.6	0.5	1.3	2.4	8.3	11.3	13.8	36.9	9.0	2.2
2000	0.5	2.7	1.6	9.9	6.2	4.6	8.7	16.5	34.6	21.5	5.1	3.8
2001	1.8	1.3	4.8	2.0	6.5	12.6	26.2	40.9	31.0	7.4	2.5	1.6
2002	1.9	1.0	2.3	1.3	1.3	2.2	3.9	13.8	15.7	4.3	1.4	3.4
2003	1.9	1.2	1.0	6.7	1.9	2.8	8.6	12.4	20.5	10.8	1.7	2.2
2004	1.9	1.9	1.5	8.0	2.0	1.4	9.0	17.3	17.1	14.7	2.0	1.0
2005	1.1	0.5	2.1	9.8	19.1	5.3	14.9	26.7	50.4	30.0	14.7	10.1
2006	7.9	7.9	21.2	39.7	28.0	30.6	52.3	86.1	67.3	32.2	17.6	13.0
2007	11.5	19.8	14.0	23.6	36.0	44.9	69.3	83.8	83.5	59.4	26.6	21.5
2008	19.3	17.5	15.0	19.3	32.1	31.4	54.7	76.6	79.1	44.0	69.5	30.3
2009	23.6	19.8	24.4	31.7	51.2	29.3	36.8	73.9	55.6	62.4	33.0	25.9
2010	22.4	24.8	40.0	44.0	70.3	47.2	66.9	73.5	79.6	43.4	25.7	21.5
2011	19.3	16.9	21.3	19.2	33.4	44.9	53.8	83.2	80.3	45.1	29.1	21.9
2012	15.0	9.7	8.0	26.5	26.7	32.5	61.7	72.6	92.0	52.8	29.0	21.2
2013	14.4	10.2	18.0	23.5	31.6	42.4	65.6	84.5	87.5	73.1	35.6	20.3
2014	12.7	20.2	18.3	23.6	46.1	38.2	47.7	77.1	93.0	98.8	43.6	26.0
2015	17.7	14.1	9.4	13.4	23.2	37.7	58.3	39.8	90.8	74.9	36.1	22.5
Mean	7.3	7.2	9.1	14.1	19.2	20.2	30.8	45.6	48.9	33.6	17.2	10.4

Max	23.6	24.8	40.0	44.0	70.3	47.2	69.3	86.1	93.0	98.8	69.5	30.3
Min	0.4	0.5	0.6	0.5	1.0	1.4	3.9	11.3	13.8	4.3	1.4	0.8
STDEV	7.9	7.9	9.8	11.9	18.3	17.2	22.5	26.9	28.3	24.5	17.0	10.2

Meteorological data

Table in Appendix 2: Average Monthly precipipitation at Bilate station(mm)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	0.28	4.98	3.19	3.24	3.12	2.56	2.42	0.99	0.75	0.71	0.74	0.27
1991	0.96	2.94	2.93	1.93	3.74	3.33	2.35	4.05	1.87	1.08	0.00	1.62
1992	0.78	3.26	2.38	4.72	3.43	1.94	2.11	2.90	2.81	4.48	3.79	0.82
1993	2.97	2.53	0.34	3.99	6.16	3.46	1.32	1.27	1.93	3.02	0.72	0.09
1994	0.00	0.52	1.61	5.88	1.73	2.94	8.49	0.86	1.21	1.84	1.37	1.13
1995	0.00	0.50	3.70	4.46	2.28	1.43	2.58	0.70	3.08	1.67	0.52	1.25
1996	3.84	0.04	3.12	4.60	2.66	8.42	4.29	3.48	2.54	1.27	0.62	0.82
1997	0.36	0.00	0.27	4.88	2.46	1.91	2.32	1.41	2.97	5.30	5.00	1.33
1998	2.85	1.37	1.38	2.20	2.72	2.02	1.99	2.84	1.14	2.26	0.06	0.00
1999	0.28	0.00	1.19	0.76	1.60	1.17	3.15	2.74	1.40	2.60	0.66	0.24
2000	0.00	0.00	0.24	1.97	3.80	2.31	2.39	1.68	3.32	2.48	1.67	0.34
2001	0.35	0.62	1.13	1.31	3.26	2.67	1.73	1.48	1.62	2.95	0.14	0.29
2002	1.48	0.04	2.04	2.42	1.58	0.57	1.07	1.52	0.93	1.72	0.00	3.98
2003	0.39	0.57	1.28	9.24	1.89	2.53	2.15	3.86	2.43	1.71	1.50	0.82
2004	2.87	1.50	0.51	7.58	2.96	0.91	2.50	2.34	2.88	1.91	1.30	0.36
2005	1.12	0.35	1.88	5.15	7.60	1.47	5.99	1.33	3.05	2.31	2.38	0.48
2006	0.15	1.50	4.77	4.29	4.66	1.33	2.81	4.44	2.74	4.81	0.63	2.19
2007	1.34	0.83	2.61	4.05	4.62	6.29	1.89	2.39	6.33	1.54	0.97	0.00
2008	0.34	0.15	0.03	2.88	2.86	1.28	3.55	2.83	2.36	5.20	4.26	0.09
2009	1.68	0.71	1.00	4.04	2.75	2.13	1.54	2.02	1.43	3.23	1.15	1.72
2010	1.19	2.91	4.57	6.27	4.61	5.22	2.36	2.97	3.79	1.59	1.40	0.25
2011	0.11	0.60	1.25	2.12	6.75	1.20	3.00	5.31	1.20	1.73	5.41	0.00
2012	0.00	0.14	0.31	0.03	1.40	2.24	6.35	1.70	2.76	1.45	0.50	0.19
2013	1.57	0.21	2.12	7.94	3.05	3.07	6.09	4.60	0.85	7.50	2.18	0.00
2014	0.01	1.00	3.14	3.81	3.93	2.63	1.59	1.98	3.15	3.73	0.47	0.13
2015	0.07	0.03	1.55	2.91	4.08	5.26	2.05	0.89	1.68	1.31	1.30	1.65
2016	0.89	0.45	1.60	5.17	1.04	3.12	2.65	1.46	0.98	2.80	2.51	0.21
2017	0.00	1.29	1.15	0.78	4.23	1.22	0.97	3.07	4.20	3.35	0.59	0.00
2018	0.00	2.42	3.48	9.18	8.02	5.75	0.65	4.45	0.71	1.75	3.05	0.23
2019	0.00	0.42	0.90	2.96	2.36	4.54	2.64	3.90	0.91	3.42	3.74	0.95

Table in Appendix 3: Average Monthly precipipitation at Dintu station (mm)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	3.39	2.80	3.57	4.63	3.74	1.63	2.22	1.39	2.77	1.40	0.06	0.13

1991	0.87	2.20	1.63	0.91	2.10	7.74	4.82	4.31	3.50	0.41	0.16	2.21
1992	0.35	0.00	1.43	1.79	1.67	2.79	2.28	3.22	3.09	3.84	4.29	0.96
1993	3.91	3.33	0.73	3.46	7.03	2.72	1.20	1.71	1.41	4.09	0.01	0.09
1994	0.01	0.60	1.84	7.02	4.44	1.70	4.38	3.62	2.38	0.98	0.64	0.72
1995	0.00	1.38	4.39	10.92	2.15	2.36	2.82	0.71	5.06	1.08	0.00	1.58
1996	2.06	1.17	7.16	2.54	4.25	7.40	0.75	8.63	4.49	2.99	1.31	1.18
1997	0.30	0.12	2.12	7.62	2.35	2.05	3.38	3.26	3.24	7.69	8.14	0.60
1998	2.77	2.45	2.46	4.75	3.73	4.20	3.16	3.61	3.20	9.44	0.23	0.10
1999	2.61	0.00	4.23	3.07	3.94	1.48	5.20	4.20	2.93	5.11	0.30	0.51
2000	0.00	0.00	0.85	3.50	4.56	1.64	4.29	2.74	2.47	5.95	2.85	2.04
2001	0.20	1.35	2.89	3.10	6.95	3.72	2.89	4.08	2.13	2.82	0.40	0.15
2002	0.00	1.03	4.32	4.25	2.69	1.57	1.33	4.73	2.62	1.96	0.00	1.72
2003	1.87	0.31	5.39	7.85	0.79	3.03	3.04	2.68	1.63	1.58	0.36	1.43
2004	3.27	2.45	0.73	6.77	2.88	1.85	1.49	2.40	2.62	2.89	0.87	0.78
2005	1.41	0.84	2.13	4.63	5.61	1.95	4.27	1.34	3.37	4.54	2.28	0.26
2006	0.35	1.36	2.15	5.08	2.05	2.18	2.31	8.13	2.63	3.71	3.07	2.09
2007	0.86	2.56	3.18	4.30	6.13	4.20	4.17	2.60	4.53	1.14	0.43	0.00
2008	0.22	0.25	0.03	4.55	2.95	2.11	4.70	4.25	3.71	8.28	2.72	0.44
2009	0.85	0.31	2.34	1.74	1.16	0.97	2.02	1.16	1.55	3.66	1.87	1.26
2010	1.67	3.44	3.81	5.86	7.40	3.77	3.16	2.48	3.36	1.06	0.56	0.27
2011	0.00	0.49	2.49	2.20	6.27	0.70	3.51	5.05	0.94	1.77	4.00	3.35
2012	0.00	0.30	0.57	4.69	1.80	4.46	5.35	0.61	3.72	1.68	3.65	0.27
2013	0.63	0.00	2.16	6.85	1.96	6.22	4.33	3.39	6.54	5.44	1.76	0.00
2014	0.03	0.65	5.55	2.88	0.71	2.11	2.75	6.66	5.04	2.54	1.84	0.00
2015	0.03	0.00	0.33	0.94	1.02	2.16	1.20	1.09	3.10	0.88	1.09	0.50
2016	2.10	0.66	3.26	8.17	9.21	1.40	1.10	1.47	1.92	3.43	2.74	0.00
2017	0.01	0.98	0.28	0.44	5.17	1.19	2.42	3.51	6.00	6.58	1.20	0.00
2018	0.00	3.25	3.72	10.61	3.84	9.12	0.39	3.76	4.31	2.97	7.54	0.00
2019	1.42	0.89	1.46	5.72	5.58	12.06	6.98	9.10	5.06	8.00	9.16	3.37

Table in Appendix 4: Average Monthly precipitation at Bodity station (mm)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	1.10	7.42	6.26	4.57	3.74	3.63	3.94	5.42	5.07	2.45	0.50	0.86
1991	1.08	3.82	4.69	2.88	7.21	5.54	4.10	4.46	5.05	0.20	0.19	4.12
1992	0.86	5.08	3.71	3.51	4.68	3.53	4.86	7.53	4.95	4.83	2.89	1.76
1993	2.05	3.10	2.08	7.62	9.48	3.65	4.56	4.27	3.96	1.82	0.39	0.12
1994	0.05	1.03	4.42	5.49	5.11	6.40	7.48	6.27	2.77	0.91	1.12	0.27
1995	0.00	2.26	4.04	9.05	3.77	4.43	3.45	3.76	3.73	1.83	0.13	0.88
1996	2.32	0.98	3.52	6.73	4.09	8.49	5.43	7.43	4.97	0.51	0.68	0.03
1997	0.11	0.36	2.76	8.92	6.66	3.58	4.32	4.44	2.46	7.49	9.78	0.47
1998	2.58	4.75	5.31	7.68	9.37	6.05	4.87	5.21	2.34	4.30	0.67	0.19
1999	1.04	0.00	1.40	3.72	3.21	3.14	9.34	6.61	1.35	5.99	0.63	0.49

2000	0.00	0.00	0.85	3.09	6.61	3.33	3.21	4.60	2.43	4.53	2.72	0.75
2001	0.33	2.40	3.49	4.07	8.36	5.37	8.16	6.87	4.85	3.44	1.33	0.92
2002	0.22	0.39	5.43	3.90	4.48	2.03	4.45	5.58	4.48	1.73	0.05	3.91
2003	1.91	0.73	2.62	6.08	2.07	4.77	6.87	5.76	4.30	2.50	0.99	1.10
2004	2.53	1.42	1.39	5.40	3.23	2.74	8.53	3.39	6.84	2.32	0.80	1.79
2005	0.81	0.80	4.10	10.24	7.10	5.23	4.70	3.35	6.87	1.56	3.03	0.24
2006	0.39	2.43	4.83	7.89	4.64	3.29	7.33	5.15	1.74	3.83	1.39	4.38
2007	1.37	2.36	3.57	5.53	7.60	7.43	7.52	8.04	8.98	0.72	0.36	0.00
2008	0.33	0.12	0.44	2.47	3.51	3.71	5.36	6.40	4.40	5.19	2.75	0.04
2009	1.03	1.12	1.76	2.28	4.54	1.97	3.39	6.11	3.68	2.69	1.05	3.60
2010	0.59	3.76	2.42	7.79	9.05	4.05	3.15	3.81	3.52	1.07	0.65	0.85
2011	0.42	0.73	1.40	2.11	13.12	6.20	5.09	5.66	2.38	0.59	4.57	0.11
2012	0.00	0.00	1.44	6.03	2.33	6.40	6.71	6.06	4.51	0.42	1.10	0.54
2013	0.82	0.95	3.53	8.73	3.13	4.21	6.44	7.99	7.80	4.83	2.74	0.00
2014	0.38	1.46	5.01	4.76	6.18	5.64	5.22	5.63	6.84	3.68	0.93	0.07
2015	0.72	0.51	0.84	2.50	4.47	3.78	3.46	1.98	3.56	0.58	3.45	0.85
2016	1.99	0.20	3.26	9.83	5.60	4.97	3.19	2.69	4.67	2.61	2.43	0.81
2017	0.00	1.67	0.78	1.02	6.44	1.29	4.86	3.75	6.37	2.94	2.49	0.00
2018	0.13	2.10	2.49	10.82	5.58	6.78	4.51	8.92	0.86	1.64	4.92	0.76
2019	0.00	0.56	1.63	2.84	4.27	8.39	4.84	4.94	4.25	3.09	4.80	1.11

Table in Appendix 5: Average Monthly precipipitation at Hossana station (mm)

YEARS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1990	0.00	5.17	4.94	3.19	3.71	3.57	4.32	5.05	4.51	1.31	0.23	0.038
1991	0.24	1.63	3.03	1.05	4.15	4.62	6.79	5.90	3.67	0.31	0.00	2.14
1992	1.91	3.04	3.86	5.82	3.43	5.72	3.92	9.04	3.48	3.43	1.76	0.12
1993	2.52	3.82	0.66	8.51	5.65	2.52	3.77	6.42	3.09	5.72	0.00	0.00
1994	0.00	0.00	4.73	2.80	4.16	2.92	4.82	4.15	6.43	0.00	0.29	0.00
1995	0.02	2.20	2.26	7.32	3.53	2.75	6.48	5.05	5.35	0.10	0.00	3.19
1996	2.93	0.64	4.90	5.68	5.25	3.84	6.02	4.17	4.19	0.21	0.54	0.00
1997	0.71	0.00	2.72	5.92	4.20	5.72	3.65	6.01	4.67	10.28	2.84	0.00
1998	2.38	2.26	3.47	6.79	4.61	5.34	6.62	6.06	2.23	5.11	0.00	0.00
1999	0.03	0.00	1.82	2.57	3.95	4.78	5.86	3.48	4.26	6.00	0.00	0.00
2000	0.00	0.00	0.50	6.86	3.39	4.85	2.99	4.11	5.93	2.09	0.70	1.47
2001	0.15	2.50	6.49	3.65	6.23	4.20	5.89	6.23	4.01	2.09	0.16	0.18
2002	2.92	1.69	5.21	3.78	4.84	3.39	3.76	8.24	5.16	0.09	0.01	4.08
2003	1.69	2.10	3.84	7.05	2.60	5.14	6.01	7.28	6.61	0.38	0.45	0.00
2004	3.74	0.67	3.01	6.46	3.09	4.11	5.21	5.18	6.86	3.35	0.58	0.56
2005	1.32	0.67	6.46	5.40	7.47	2.59	6.37	3.99	6.64	1.48	2.26	0.00
2006	0.93	2.21	4.39	5.33	2.45	5.66	5.93	7.64	2.96	1.62	0.20	0.88
2007	1.03	1.81	4.07	5.90	3.98	6.00	6.09	5.43	7.16	0.62	0.00	0.00
2008	0.00	0.05	1.39	2.48	8.97	5.06	6.71	4.39	4.62	4.07	3.92	0.02

2009	1.39	0.20	3.21	3.02	3.99	4.19	6.43	7.32	6.13	5.46	0.17	2.19
2010	0.38	4.14	4.82	4.06	6.40	3.15	3.74	4.68	4.62	0.61	0.64	1.09
2011	0.50	0.40	3.28	3.86	7.51	2.70	5.28	6.24	3.98	0.00	1.64	0.00
2012	0.00	0.00	2.17	4.61	2.20	5.01	7.52	5.03	5.45	0.05	1.75	0.23
2013	0.03	0.62	4.15	2.26	4.25	6.07	6.48	6.81	5.77	1.50	0.01	0.00
2014	0.81	4.21	2.47	4.50	8.12	2.54	6.07	8.74	6.43	4.78	0.47	0.07
2015	0.00	0.11	1.45	0.64	4.42	7.10	4.60	1.32	4.74	0.00	1.04	0.37
2016	3.63	0.00	3.27	9.30	6.91	5.85	2.31	4.09	5.13	2.22	3.71	0.34
2017	0.02	2.52	2.57	1.85	7.08	7.04	5.30	3.09	9.22	0.40	0.04	0.00
2018	0.39	3.79	1.79	9.62	4.89	3.89	4.28	6.82	6.70	4.51	4.92	0.17
2019	0.00	0.36	2.98	11.50	5.34	5.11	5.85	10.85	6.17	1.25	2.75	0.79

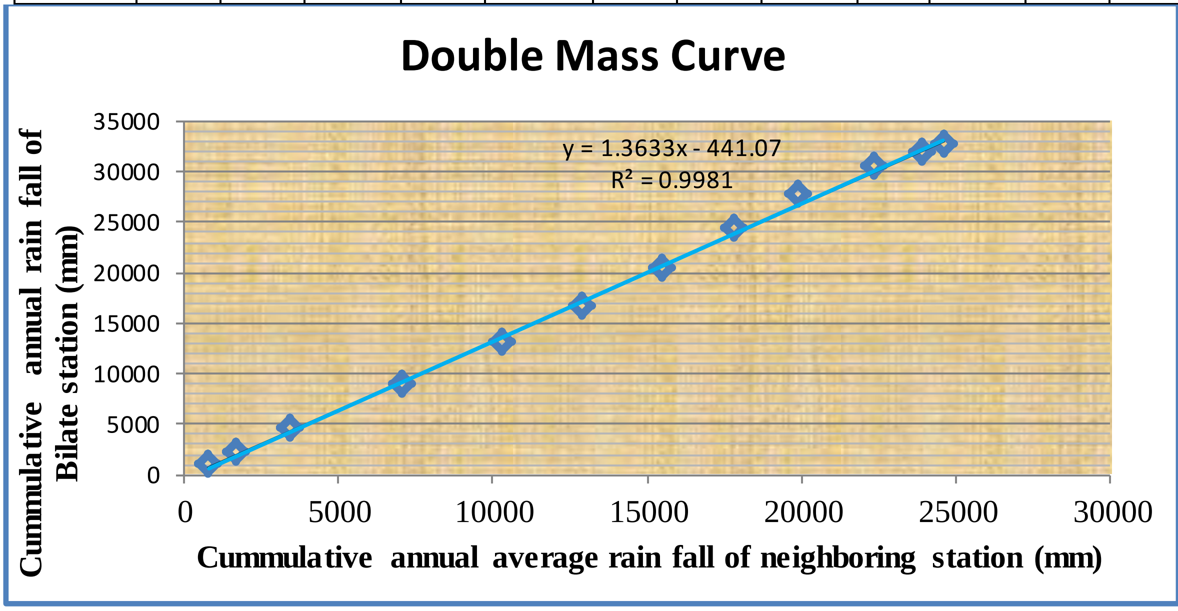

Figure in Appendix 1: Double mass curve of Bilate station

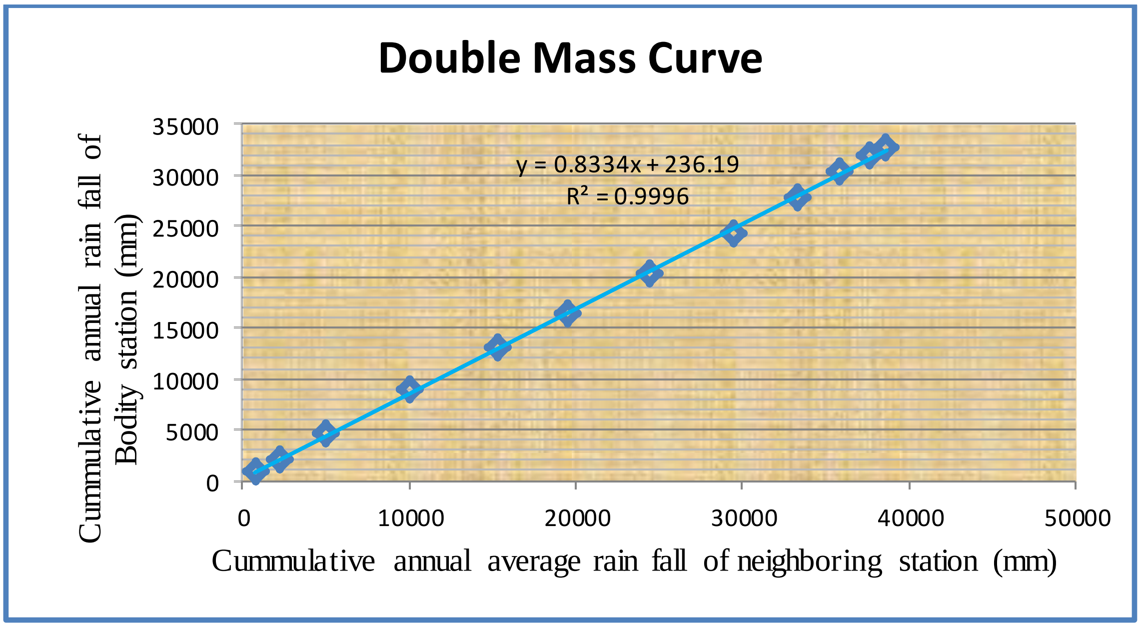

Figure in Appendix 2: Double mass curve of Bodity station

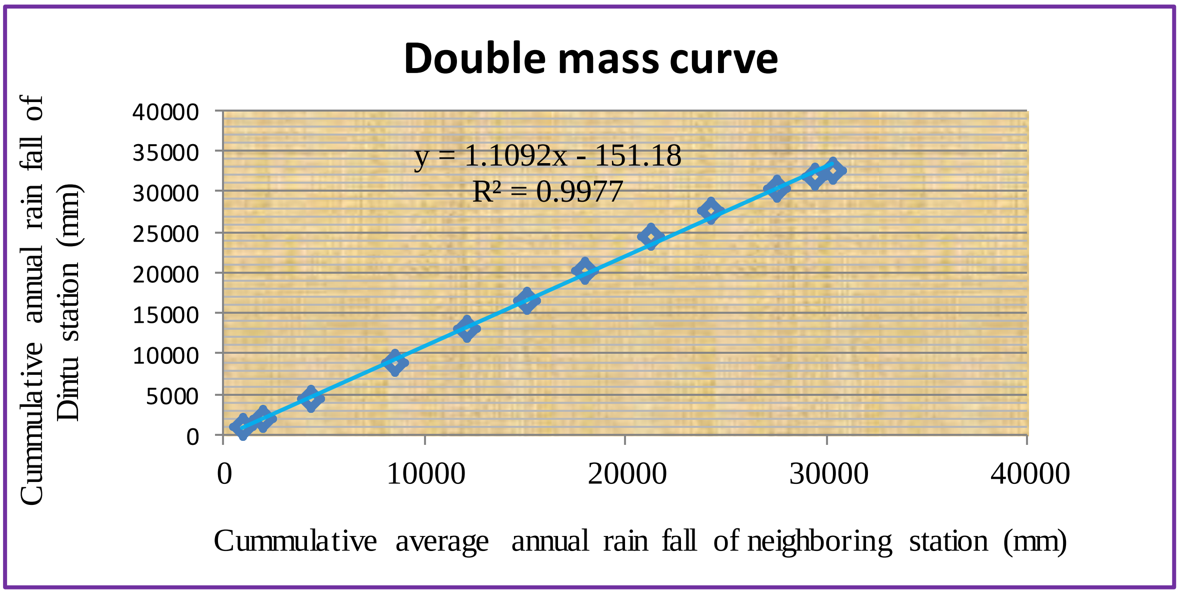

Figure in Appendix 3: Double mass curve of Dintu station

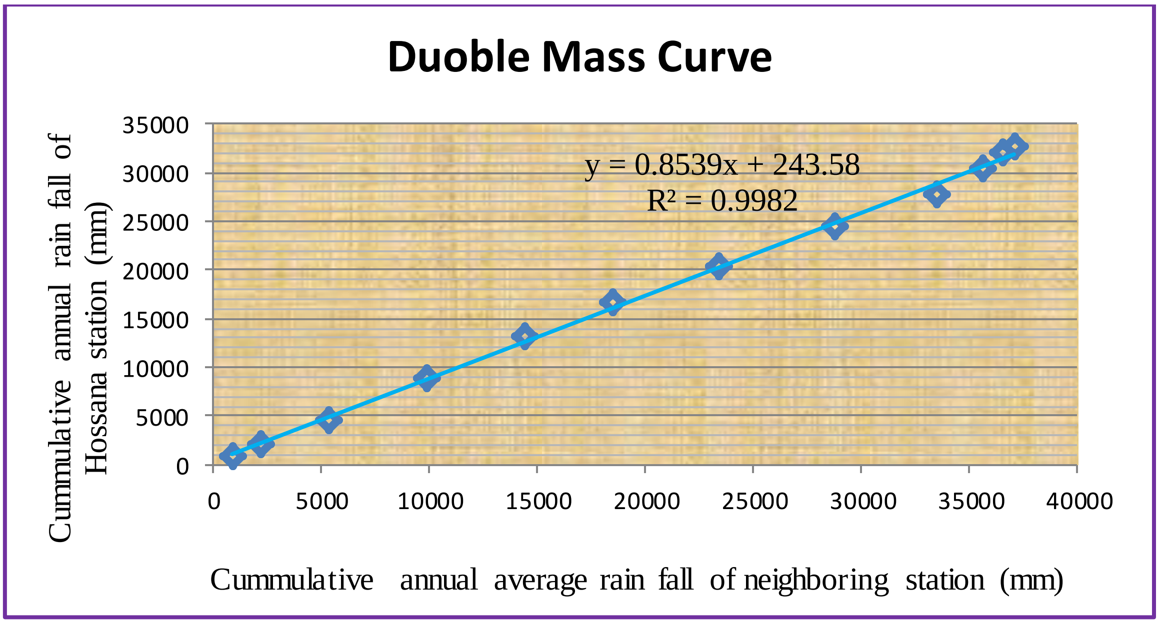

Figure in Appendix 4: Double mass curve of Hossana station

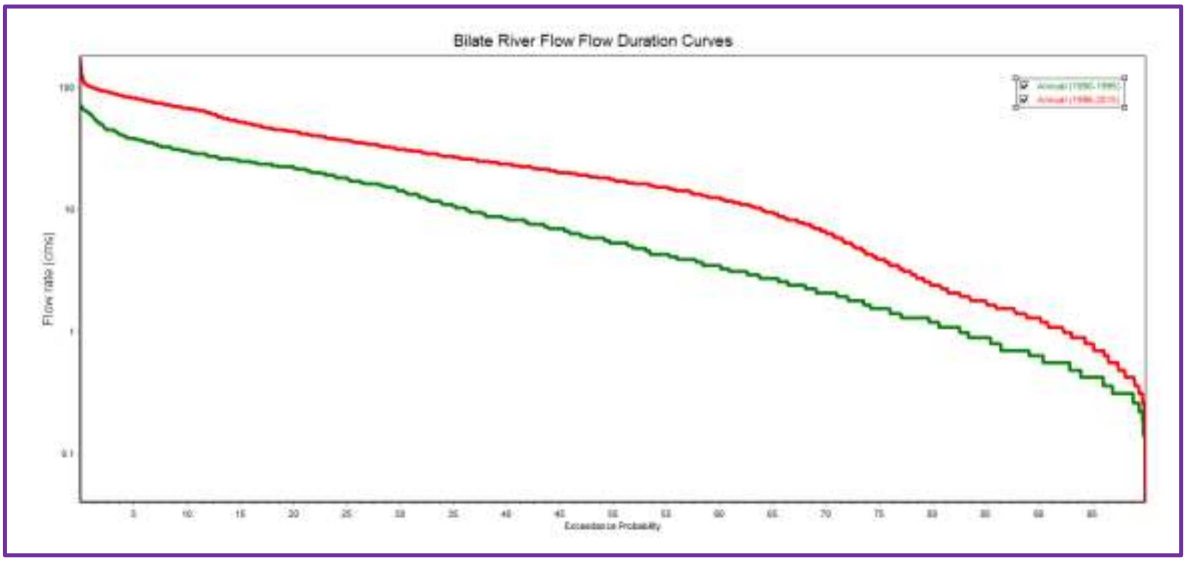

Figure in Appendix 5: Flow Duration Curve (FDC) for Bilate River

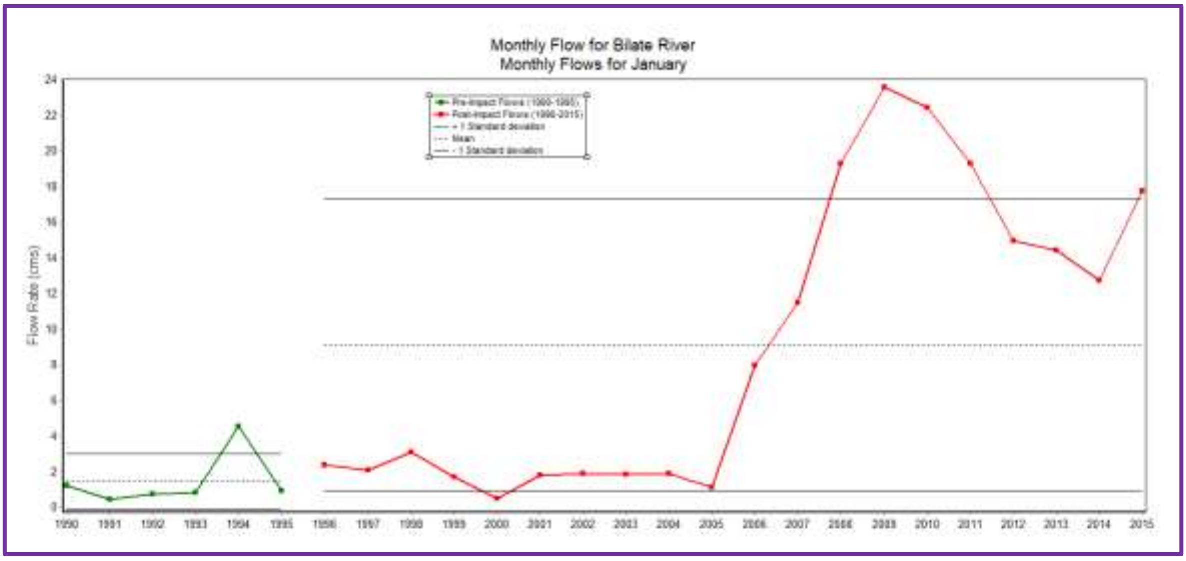

Figure in Appendix 6: Monthly Flows for Bilate River

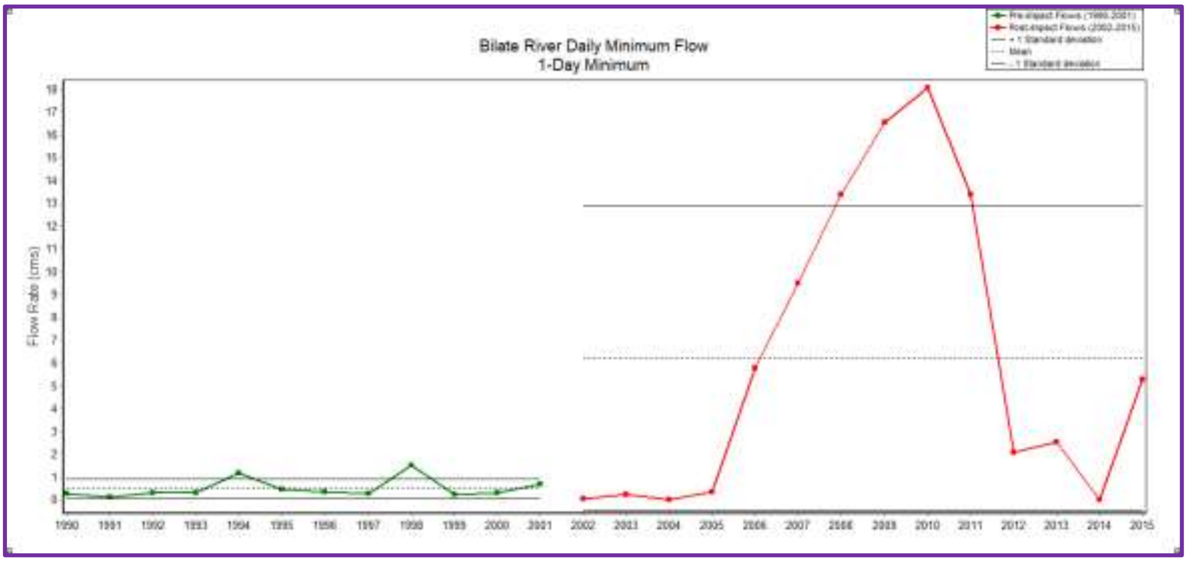

Figure in Appendix 7: Daily Minimum Flows for Bilate River

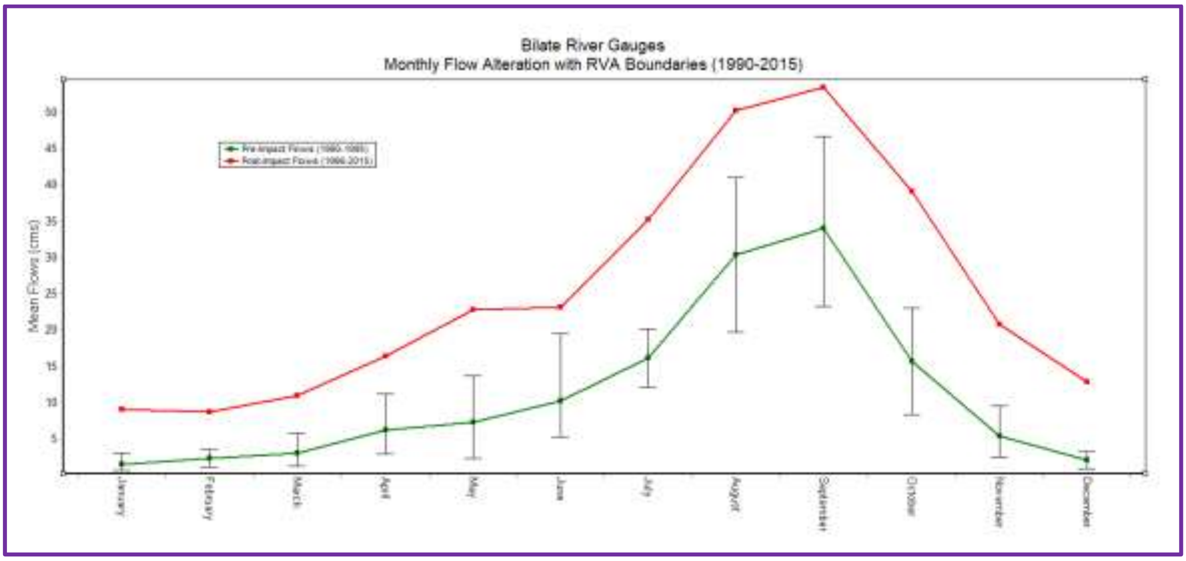

Figure in Appendix 8: Bilate River Gauges

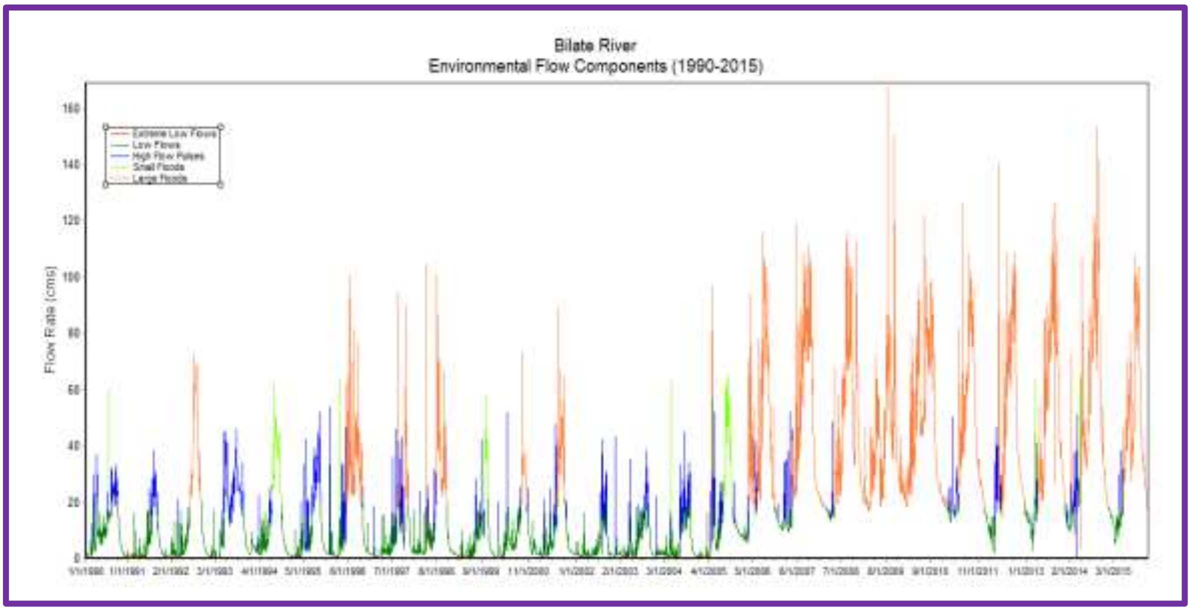

Figure in Appendix 9: Environmental Flow components for Bilate River

Table in Appendix 6: Annual average Maximum and Minimum Temperature of selected stations (°C)

Stations	Bilate		Boditiy		Dintu		Hossana	
Years	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin	Tmax	Tmin
1990	29.73	16.44	23.47	8.03	26.67	12.24	21.85	10.48
1991	29.88	16.25	24.02	7.25	26.93	11.58	22.50	10.92
1992	29.74	16.34	23.53	6.91	26.87	11.79	23.46	10.34
1993	29.94	15.84	23.60	12.86	26.67	14.41	27.55	8.23
1994	30.01	15.87	24.40	12.74	27.19	14.28	27.31	13.20
1995	30.93	16.11	24.75	13.45	28.00	14.84	24.39	11.80
1996	29.93	15.59	24.27	13.17	27.02	14.36	22.17	10.67
1997	30.23	16.48	25.08	13.52	27.53	15.18	22.80	11.12
1998	30.20	16.88	24.74	13.72	27.55	15.16	22.34	11.34
1999	30.07	16.62	25.13	13.07	27.69	14.97	22.65	10.41
2000	30.44	16.87	25.37	13.25	27.92	15.03	22.75	10.18
2001	30.13	16.66	24.71	13.39	27.45	15.12	22.28	11.31
2002	30.42	14.90	24.86	12.39	27.78	13.86	22.78	10.70
2003	30.16	13.80	24.64	13.57	27.48	13.69	22.81	11.14
2004	30.04	16.40	24.55	13.55	27.30	15.05	22.56	10.68
2005	30.27	16.73	24.64	13.55	27.41	15.17	22.82	11.05
2006	29.89	16.80	24.35	13.70	27.05	15.35	22.79	11.26
2007	29.78	16.63	24.69	13.26	27.41	15.17	22.93	11.15
2008	30.24	16.64	24.89	13.10	27.71	15.14	22.98	10.43
2009	31.22	16.88	25.87	13.63	28.63	15.40	24.49	10.64

2010	29.69	17.14	24.57	13.63	27.05	15.62	24.80	10.94
2011	30.52	16.94	25.47	13.59	28.02	15.37	24.00	11.02
2012	31.15	16.92	25.52	13.48	28.44	15.33	23.46	10.64
2013	30.25	16.83	24.49	13.49	27.60	15.31	23.07	10.57
2014	30.77	16.89	24.63	13.64	27.75	15.46	23.00	10.75
2015	31.91	17.61	25.70	14.00	28.76	15.92	24.23	11.53
2016	31.12	18.10	24.84	14.03	28.11	16.13	23.34	11.69
2017	31.39	17.84	25.00	13.88	27.93	16.03	23.76	11.42
2018	29.94	17.03	24.15	13.38	27.34	15.28	22.99	11.34
2019	31.05	17.34	24.93	14.03	28.20	15.81	23.73	11.90

Table in Appendix 7: Average Annual Relative humidity, Sunshine and Wind speed at Bilate and Hossana station

Station	Bilate			Station	Hossana	
Years	Relative Humidity (%)	Sunshine (hr)	Wind speed at 2m(m/s)	Relative Humidity (%)	Sunshine (hr)	Wind speed at 2m(m/s)
1990	61.38	7.84	1.06		7.31	1.71
1991	61.20	7.22	0.74		6.76	1.87
1992	64.02	7.52	0.35		7.03	1.71
1993	61.37	7.64	0.51		6.88	1.71
1994	61.95	7.64	0.57		7.22	1.78
1995	60.55	8.14	0.62		6.74	1.56
1996	67.11	7.80	0.48		7.05	1.49
1997	70.97	7.89	0.77		7.11	1.52
1998	67.65	7.49	0.87		7.20	1.33
1999	65.24	8.21	1.40	62.15	7.37	1.56
2000	64.53	8.50	1.39	67.17	7.46	1.43
2001	66.53	7.60	1.04	64.89	6.89	1.39
2002	58.17	7.81	1.19	66.39	7.37	1.33
2003	58.23	7.48	1.05	60.47	7.29	1.27
2004	59.24	7.63	1.01	66.03	6.97	1.16
2005	61.45	7.97	0.98	65.44	7.35	1.22
2006	65.01	7.46	0.83	67.56	6.82	1.08
2007	61.08	7.65	0.85	65.11	7.33	1.04
2008	58.36	7.63	0.92	60.05	7.74	1.00
2009	57.27	7.87	0.92	60.56	8.02	0.88
2010	64.21	6.98	0.73	68.69	6.21	0.66
2011	63.76	7.43	0.79	64.86	5.89	0.76
2012	59.82	6.88	0.73	63.70	6.33	0.82
2013	61.23	6.66	0.74	66.26	5.50	0.80
2014	59.38	7.09	0.86	67.16	5.98	0.66

2015	57.78	8.08	0.92	60.11	6.21	0.78
2016	59.87	7.41	1.02	64.41	6.16	0.70
2017	52.82	7.56	1.18	56.83	6.99	0.74
2018	60.99	6.78	1.00	55.22	6.45	0.68
2019	55.66	5.77	0.96	53.56	6.98	0.76

CWR and IWR of selected major crops of Bilate station

Table in Appendix 8: ETO and Climatic data of Bilate station

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	17	32.3	50	111	8.6	20.8	4.7
February	17.4	33.2	48	102	8.3	21.4	4.93
March	17.3	32.9	55	86	8.1	22	4.9
April	17	31.1	65	65	7.7	21.3	4.49
May	16.9	29.7	70	64	8	21.1	4.29
June	16.7	28.3	69	73	6.9	19	3.89
July	16.7	27.4	71	63	5.5	17.1	3.49
August	16.6	28	70	61	6	18.3	3.72
September	16.3	29.1	69	58	6.8	19.8	3.99
October	15.7	30.1	63	53	7.5	20.3	4.05
November	15.3	31	53	74	8.4	20.6	4.22
December	16.1	31.6	49	101	8.6	20.3	4.43
Average	**16.6**	**30.4**	**61**	**76**	**7.5**	**20.2**	**4.26**

Table in Appendix 9: Average Monthly and Effective ran fall of Bilate station (mm)

Moth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Rain (mm)	26.7	29.9	29.9	120.7	108.8	84.9	87.8	78	67	83.4	49	22.2	**787.9**
Eff. Rain (mm)	25.6	28.5	28.5	97.4	89.9	73.4	75.5	68.3	59.8	72.3	45	21.4	**685.2**

Table in Appendix 10: CWR and IWR estimation of Maize crops

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.3	1.31	11.8	8	2.9
Dec	2	Init	0.3	1.33	13.3	5.9	7.4
Dec	3	Deve	0.43	1.93	21.2	6.8	14.5
Jan	1	Deve	0.69	3.2	32	8.1	23.9
Jan	2	Deve	0.95	4.46	44.6	8.5	36
Jan	3	Mid	1.17	5.57	61.3	8.8	52.5
Feb	1	Mid	1.19	5.78	57.8	9.2	48.5

Feb	2	Mid	1.19	5.87	58.7	9.6	49.1
Feb	3	Mid	1.19	5.86	46.9	9.6	37.3
Mar	1	Late	1.16	5.71	57.1	7.3	49.8
Mar	2	Late	0.92	4.53	45.3	6.2	39.1
Mar	3	Late	0.63	3	33	15	18
Apr	1	Late	0.41	1.88	9.4	13.6	0
Total					**492.3**	**116.6**	**379**

Table in Appendix 11: CWR and IWR estimation of Onion crops

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.6	2.62	20.9	7.1	12
Dec	2	Init	0.6	2.66	26.6	5.9	20.7
Dec	3	Deve	0.62	2.81	31	6.8	24.2
Jan	1	Deve	0.68	3.14	31.4	8.1	23.3
Jan	2	Deve	0.74	3.46	34.6	8.5	26.1
Jan	3	Mid	0.79	3.76	41.3	8.8	32.5
Feb	1	Mid	0.79	3.86	38.6	9.2	29.3
Feb	2	Mid	0.79	3.92	39.2	9.6	29.6
Feb	3	Mid	0.79	3.91	31.3	9.6	21.7
Mar	1	Mid	0.79	3.9	39	7.3	31.7
Mar	2	Late	0.83	4.06	40.6	6.2	34.3
Mar	3	Late	0.84	3.98	43.8	15	28.8
Apr	1	Late	0.84	3.87	38.7	27.2	11.5
Apr	2	Late	0.84	3.75	37.5	36.1	1.5
Apr	3	Late	0.84	3.7	22.2	20.4	5.2
Total					**516.5**	**185.8**	**332.3**

Table in Appendix 12: CWR and IWR estimation of Tomato crops

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.6	2.62	18.3	6.2	13.9
Dec	2	Init	0.6	2.66	26.6	5.9	20.7
Dec	3	Init	0.6	2.71	29.8	6.8	23.1
Jan	1	Deve	0.65	2.99	29.9	8.1	21.8
Jan	2	Deve	0.78	3.67	36.7	8.5	28.2
Jan	3	Deve	0.92	4.41	48.5	8.8	39.7
Feb	1	Deve	1.07	5.17	51.7	9.2	42.5
Feb	2	Mid	1.14	5.62	56.2	9.6	46.6
Feb	3	Mid	1.14	5.61	44.9	9.6	35.3
Mar	1	Mid	1.14	5.6	56	7.3	48.7
Mar	2	Mid	1.14	5.59	55.9	6.2	49.7

Mar	3	Late	1.13	5.4	59.4	15	44.4
Apr	1	Late	1.04	4.8	48	27.2	20.8
Apr	2	Late	0.92	4.11	41.1	36.1	5
Apr	3	Late	0.81	3.59	25.1	23.8	0
Total					**628.3**	**188.3**	**440.5**

Table in Appendix 13: CWR and IWR estimation of Potato crops

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.5	2.18	13.1	5.3	8.6
Dec	2	Init	0.5	2.22	22.2	5.9	16.3
Dec	3	Deve	0.51	2.29	25.1	6.8	18.4
Jan	1	Deve	0.66	3.04	30.4	8.1	22.4
Jan	2	Deve	0.87	4.11	41.1	8.5	32.6
Jan	3	Mid	1.09	5.19	57.1	8.8	48.3
Feb	1	Mid	1.14	5.54	55.4	9.2	46.2
Feb	2	Mid	1.14	5.63	56.3	9.6	46.7
Feb	3	Mid	1.14	5.62	45	9.6	35.4
Mar	1	Mid	1.14	5.61	56.1	7.3	48.8
Mar	2	Late	1.11	5.46	54.6	6.2	48.3
Mar	3	Late	0.98	4.66	51.3	15	36.3
Apr	1	Late	0.84	3.86	38.6	27.2	11.4
Apr	2	Late	0.75	3.35	10	10.8	0
Total					**556.4**	**138.4**	**419.7**

Table in Appendix 14: CWR and IWR estimation of Tobacco crops

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.5	2.18	8.7	3.6	4.3
Dec	2	Init	0.5	2.22	22.2	5.9	16.3
Dec	3	Deve	0.53	2.39	26.3	6.8	19.5
Jan	1	Deve	0.73	3.34	33.4	8.1	25.3
Jan	2	Deve	0.94	4.41	44.1	8.5	35.6
Jan	3	Mid	1.12	5.36	59	8.8	50.1
Feb	1	Mid	1.14	5.54	55.4	9.2	46.2
Feb	2	Mid	1.14	5.63	56.3	9.6	46.7
Feb	3	Late	1.13	5.55	44.4	9.6	34.8
Mar	1	Late	1.03	5.06	50.6	7.3	43.3
Mar	2	Late	0.91	4.47	44.7	6.2	38.4
Mar	3	Late	0.82	3.89	23.3	8.2	15.9
Total					**468.5**	**91.7**	**376.5**

CWR and GIR of selected major crops of Hossana station

Table in Appendix 15: ETO and Climatic data of Hossana station

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	9.8	25	52	104	8.5	20.4	3.94
February	11.1	25.7	49	111	8.6	21.7	4.37
March	12	25.4	54	113	7.7	21.3	4.39
April	12.3	24.4	62	109	6.7	19.8	4.05
May	11.6	23.5	69	94	6.7	19.2	3.74
June	11.3	21.7	76	100	5	16.3	3.15
July	11.3	20.3	80	104	3.7	14.5	2.78
August	11.4	20.5	80	92	3.9	15.2	2.86
September	10.9	22	76	72	5.5	17.8	3.28
October	10.6	23.5	58	107	8.3	21.4	4.07
November	10.1	24.4	51	109	9	21.3	4.09
December	9.1	24.7	50	107	9.1	20.8	3.96
Average	11	23.4	63	102	6.9	19.2	3.72

Table in Appendix 16: Average Monthly and Effective ran fall of Hossana station (mm)

Moth	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	**Total**
Rain (mm)	30.6	43.8	103	151.8	151.7	135	164	179	156	71.4	31	18.5	**1237**
Eff. Rain (mm)	29.1	40.7	86.2	114.9	114.9	106	121	128	117	63.2	30	18	**968.4**

Table in Appendix 17: CWR and IWR estimation of Winter Wheat crops of Hossana station

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.7	2.8	28	6.6	21.5
Dec	2	Init	0.7	2.77	27.7	4.9	22.8
Dec	3	Deve	0.7	2.77	30.5	6.5	24
Jan	1	Deve	0.72	2.84	28.4	8.5	19.9
Jan	2	Deve	0.75	2.95	29.5	9.7	19.8
Jan	3	Deve	0.78	3.18	35	11	24
Feb	1	Deve	0.81	3.42	34.2	11.3	23
Feb	2	Deve	0.84	3.67	36.7	12	24.6
Feb	3	Deve	0.87	3.79	30.3	17.6	12.7
Mar	1	Deve	0.89	3.91	39.1	24.2	14.9
Mar	2	Deve	0.92	4.04	40.4	29.5	10.9
Mar	3	Deve	0.95	4.07	44.8	32.4	12.3

Apr	1	Deve	0.98	4.09	40.9	36	4.9
Apr	2	Deve	1.01	4.1	41	39.7	1.3
Apr	3	Deve	1.04	4.11	41.1	39.2	1.9
May	1	Deve	1.07	4.12	41.2	38.6	2.6
May	2	Mid	1.1	4.12	41.2	38.7	2.5
May	3	Mid	1.11	3.94	43.3	37.6	5.7
Jun	1	Mid	1.11	3.72	37.2	35.6	1.6
Jun	2	Mid	1.11	3.5	35	34.3	0.7
Jun	3	Late	1.1	3.33	33.3	36.3	0
Jul	1	Late	0.9	2.6	26	38.9	0
Jul	2	Late	0.61	1.69	16.9	40.7	0
Jul	3	Late	0.35	0.98	7.9	30.1	0
Total					**809.5**	**619.7**	**251.7**

Table in Appendix 18: CWR and IWR estimation of Maize crops of Hossana station

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.3	1.2	10.8	5.9	4.2
Dec	2	Init	0.3	1.19	11.9	4.9	7
Dec	3	Deve	0.43	1.69	18.6	6.5	12.1
Jan	1	Deve	0.69	2.74	27.4	8.5	19
Jan	2	Deve	0.95	3.74	37.4	9.7	27.7
Jan	3	Mid	1.17	4.77	52.5	11	41.5
Feb	1	Mid	1.19	5.04	50.4	11.3	39.1
Feb	2	Mid	1.19	5.2	52	12	40
Feb	3	Mid	1.19	5.21	41.7	17.6	24.1
Mar	1	Late	1.16	5.1	51	24.2	26.8
Mar	2	Late	0.92	4.06	40.6	29.5	11.1
Mar	3	Late	0.63	2.69	29.6	32.4	0
Apr	1	Late	0.41	1.69	8.5	18	0
Total					**432.4**	**191.5**	**252.6**

Table in Appendix 19: CWR and IWR estimation of Potato crops of Hossana station

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.5	2	16	5.3	9.5
Dec	2	Init	0.5	1.98	19.8	4.9	14.9
Dec	3	Deve	0.52	2.06	22.6	6.5	16.1
Jan	1	Deve	0.7	2.78	27.8	8.5	19.3
Jan	2	Deve	0.92	3.62	36.2	9.7	26.5
Jan	3	Mid	1.11	4.55	50.1	11	39.1

Feb	1	Mid	1.14	4.83	48.3	11.3	37.1
Feb	2	Mid	1.14	4.99	49.9	12	37.9
Feb	3	Mid	1.14	5	40	17.6	22.4
Mar	1	Mid	1.14	5.01	50.1	24.2	25.9
Mar	2	Late	1.09	4.8	48	29.5	18.5
Mar	3	Late	0.95	4.07	44.8	32.4	12.3
Apr	1	Late	0.81	3.37	33.7	36	0
Apr	2	Late	0.73	2.97	3	4	3
Total					**490.2**	**212.8**	**282.4**

Table in Appendix 20: CWR and IWR estimation of Tomato crops of Hossana station

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.6	2.4	16.8	4.6	13.5
Dec	2	Init	0.6	2.38	23.8	4.9	18.8
Dec	3	Init	0.6	2.37	26.1	6.5	19.6
Jan	1	Deve	0.65	2.56	25.6	8.5	17.2
Jan	2	Deve	0.78	3.09	30.9	9.7	21.2
Jan	3	Deve	0.92	3.78	41.5	11	30.5
Feb	1	Deve	1.07	4.51	45.1	11.3	33.8
Feb	2	Mid	1.14	4.98	49.8	12	37.8
Feb	3	Mid	1.14	4.99	39.9	17.6	22.3
Mar	1	Mid	1.14	4.99	49.9	24.2	25.8
Mar	2	Mid	1.14	5	50	29.5	20.5
Mar	3	Late	1.13	4.84	53.3	32.4	20.9
Apr	1	Late	1.04	4.32	43.2	36	7.2
Apr	2	Late	0.92	3.71	37.1	39.7	0
Apr	3	Late	0.81	3.22	22.5	27.4	0
Total					**555.5**	**275.3**	**289**

Table in Appendix 21: CWR and IWR estimation of Onion crops of Hossana station

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Dec	1	Init	0.6	2.4	14.4	3.9	11.1
Dec	2	Init	0.6	2.38	23.8	4.9	18.8
Dec	3	Init	0.6	2.37	26.1	6.5	19.6
Jan	1	Deve	0.64	2.52	25.2	8.5	16.7
Jan	2	Deve	0.77	3.03	30.3	9.7	20.6
Jan	3	Deve	0.91	3.72	40.9	11	29.9

Feb	1	Deve	1.05	4.45	44.5	11.3	33.2
Feb	2	Mid	1.14	4.97	49.7	12	37.7
Feb	3	Mid	1.14	4.99	39.9	17.6	22.3
Mar	1	Mid	1.14	4.99	49.9	24.2	25.8
Mar	2	Mid	1.14	5	50	29.5	20.5
Mar	3	Late	1.14	4.86	53.4	32.4	21
Apr	1	Late	1.05	4.37	43.7	36	7.7
Apr	2	Late	0.93	3.76	37.6	39.7	0
Apr	3	Late	0.82	3.24	25.9	31.4	0
Total					**555.4**	**278.5**	**285**