Assessment of Land Suitability for Surface Irrigation Using GIS and WEAP Model in Sibilu Watershed (Upper Abbay Basin in Ethiopia)

Sisay Getachew Araga

A thesis submitted to

The department of water resources engineering,

School of Civil Engineering and Architecture

Presented in partial fulfilment of the requirement for the degree of mater'

In water resources engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies

Adama science and Technology University

January, 2024

Adama, Ethiopia

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Advisor

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DECLARATION

I, declare that this Master Thesis entitled "**Assessment of Land suitability for Surface Irrigation using GIS and WEAP Model in Sibilu Watershed (Upper Abbay Basin in Ethiopia)"**is my own work and has not been submitted to any university for similar purpose. The references used in this thesis are duly recognized by correct citations.

__________________________ ___________________ ___________________

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RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled **"Assessment of Land suitability for Surface Irrigation using GIS and WEAP Model in Sibilu Watershed (Upper Abbay Basin in Ethiopia)."**Prepared under my guidance by **Sisay Getachew** submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resource Engineering (Irrigation Engineering).

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Mesfin Benti (Ph.D.)	__________________	__________________
Major Advisor	Signature	Date

APPROVAL SHEET FOR MSC THESIS

I hereby certify that all the corrections and recommendations suggested by the board of examiners are incorporated into the final thesis entitled "**Assessment of Land suitability for Surface Irrigation using GIS and WEAP Model in Sibilu Watershed (Upper Abbay Basin in Ethiopia).**" by Sisay Getachew.

Major Advisor/Supervisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by Sisay Getachew Araga have read and evaluated his - master thesis entitled. **"Assessment of Land suitability for Surface Irrigation using GIS and WEAP Model in Sibilu Watershed (Upper abbay basin in Ethiopia).**" and examined the candidate. This is, therefore, to certify that the master thesis has been accepted in partial fulfillment of the requirement of the degree of Master of Science in Water Resource Engineering (Specialization in Irrigation Engineering).

Chairperson	Signature	Date
Examiner 1	Signature	Date
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Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the office of postgraduate studies (OPGS) through the department graduate council (DGC) and School Graduate Committee (SGC)

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ABSTRACT

Assessing potential land and water availability for irrigation is an important factor to extent of irrigated agriculture in an area and improving food security by increasing agricultural production. This study assessed irrigation potential for surface irrigation in sibilu watershed by considering the irrigation suitability factors such as slope, soil type, texture, depth, drainage, proximity to river, and land use and land cover by using Arc GIS10.8.1.The suitability of each parameter was analyzed individually and then the weighted overlay analysis was to get the overall suitable land. The results showed that 36.2 %(23019.4ha) highly suitable, 51.6 %(32828ha) moderately suitable, 11.6 %(7351.2ha) of the land was marginally suitable for surface irrigation and 0.7 %(428.4ha) of the land was not suitable for surface irrigation. The crop water requirement of five commonly grown crops was identified by the CROPWAT8.0 model using climate data. Irrigation water requirements for dominant crops which include wheat, barley, bean, pepper and potato was calculated and founded as were 265.5, 297.2, 254.9, 300.6 and 324.5mm respectively. The stream flow was assessed with the WEAP model. The model calibration and validation using observed stream flow. The result showed that model performance evaluation statistics coefficient added determination, Nash-Sutcliffe model efficiency, and Percent bias for calibration were 0.77, 0.71, and 17.02 and for validation 0.74, 0.7, and 9.41 respectively. This shows that a good agreement between the simulated and observed values. The assessment of available stream flow, the total net irrigation water demand for all selected crops with identified land potential for surface irrigation were the land suitable and the available water in the study area was found 63199.4 ha and 88Mm^3 of the total suitable land in the study area. The annual water demand and supply of the catchment including losses reuse and demand side management shows increment at November, December, January, April and May, of supply requirement for irrigation.

Keywords: *Land Suitability; Assess water availability, Irrigation Potential and "ArcGIS, WEAP"*

LISTS OF ABBREVIATION

AEZ	Agro ecological Zone
AHP	Analytical Hierarchy process
DEM	Digital elevation model
DSS	Decision Support System
ECSA	Ethiopian central statistics Authority
ERDAS	Earth remote sensing data analysis center
FOA	Food and Agriculture Organization
GIWR	Gross Irrigation Water Requirement
IWR	Irrigation water requirement
LULC	Land Use and Land Cover
MWIE	Ministry of water Irrigation and Energy
MoWR	Ministry of water resources
NASA	National Aeronautics and Space Administration
PRMS	Precipitation runoff modeling system
RVA	Range of variability approach
SEI	Stockholm environment institute
UN	United Nation
WEAP	Water Evaluation and Planning Model

CHAPTER 1: INTRODUCTION

1.1 Back ground

Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation. The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure, and little to no access to agricultural markets and to technological innovations. These issues, combined with increasing degradation of the natural resource base, especially in the highlands, aggravate the incidence of poverty and food insecurity in rural areas. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity (Awulachew, 2010).

Irrigation is the provision of water to agricultural crops by artificial means, intended to permit farming in arid regions and to overcome the effect of drought in semi-arid regions. Even in areas where total seasonal rainfall is adequate on average, it may be unevenly distributed during the year and varies from year to year. Where traditional rain-fed farming is a high-risk enterprise, irrigation can help to safeguard stable agricultural production (FAO, 1997).

The global water demand primarily grow due to population and economic growth, rapid urbanization and the increasing demand for food and energy (Arranz & McCartney, 2007). Therefore, assessing water resource availability of relevant spatial and temporal scales is of importance(Gedefaw et al., 2019). As well as an ability to assess the availability of freshwater resources has been an issue of importance in most countries for many decades (Gomo, 2012).

Water is a basic necessity for sustaining life and development of society, with the Increasing of population including urbanization, economic growth, industrial production, agricultural and livestock production, demand for water has increased rapidly over the years (Gedefaw et al., 2019). Population growth and economic development put constant pressure on the eco-systems of water resources (Gao et al., 2017).There is also a strong positive relation between water demand and urbanization or population growth.

Ethiopia is estimated to have 3.7 M ha of potentially irrigable area with the available surface water resources and the land irrigated through the development of traditional and modern irrigation schemes are estimated to be about 386,603 hectares, which is about 10 percent of potentially irrigable land (Awulachew, 2011)

Assessment of irrigation potential in Ethiopia is of prime importance for planning of sustainable food production through proper use of land and water resources of the country. Considerable information on irrigation potential in terms of suitable land and water resources are prerequisites for irrigation development. Ethiopia has many river basins all of them are trans-regional in Ethiopia and trans-boundary in East Africa in nature which have significant upper, middle and lower stream repercussion. To consider the regional dimension of the Ethiopian water resources for irrigation basin approach is followed which ensure consistency both within the country and among countries within each river basin (FAO, 1997).

Land potential is a process of predicting land performance over time according to the specific types of use. Irrigation land suitability assessment is defined as the process of assessment of land performance when used for alternative kinds of irrigation.

The principal purpose of irrigation land suitability assessment is to predict the potential and limitations of the land for crop production. This process typically requires large sets of data as inputs. Information on land resources and possibilities for their sustained use is essential for the selection, planning and implementation of land uses to meet the increasing demands for basic human needs and welfare.

Water resources are increasingly under pressure from population growth, economic activity and intensifying competition for the water among users; Water withdrawals have increased more than twice as fast as population growth and currently one third of the world's population live in countries that experience medium to high water stress; Pollution is further enhancing water scarcity by reducing water usability downstream; Shortcomings in the management of water, a focus on developing new sources rather than managing existing ones better, and top-down sector approaches to water management result in uncoordinated development and management of the resource. More and more development means greater impacts on the environment. Concerns about climate variability and climate change demand improved management of water resources to manage with more intense floods and droughts.

The water demand assessments done earlier are those uneven studies done to know the demands of water for a specific project to meet the needs that the project aims. Therefore this research is very vital in providing information concerning the current and near future water demand of the study area at watershed level. Knowledge on the water demand and resource of the watershed is very crucial for planning and management of the water resource and allocation of the water resource with in the watershed. The demand for water joined with the supply of the watershed water resource would help the water resource managers to better manage the watershed water resource in an equitable, efficient and sustainable manner.

1.2 Statement of the Problem

It is estimated that the eight major river basins of Ethiopia can irrigate about 5.3 M hectares of land (Awulachew et al., 2010).However, there is no consistent and reliable inventory and well-studied document in water and irrigation related potentials in the Ethiopian context (Haile and Kasa,2015).

The agricultural practice in the country in general and in the study area in particular is rain-fed agriculture and seasonal. The rainfall agriculture is at high degree of rainfall variability and unreliability. Irrigation is necessary to minimize the impact of rainfall variability and to increase a number of annual crops, perennial and commercial crops with control regulated water supply throughout the year (Abraham et al., 2015).

Irrigation is an essential activity within the country that tolerates human life. It is also the foremost sector in the Ethiopian economy. Yet, the country's irrigation sector is extremely dependent on the rains. Environment alteration limits the productivity of the region. To supply food to the growing population, irrigation has been playing a crucial role to ensure food security.

The Sibilu watershed, there is an unwise use of water in the watershed. In view of this, the water resource of the river is not well studied to address water potential assessment in the watershed and limited irrigation. Therefore, this study was intended to assess potential suitability of Sibilu watershed for irrigation using GIS and WEAP model.

1.3. Objectives of the Study

1.3.1 General objective

The general objective of the study was to assess the surface irrigation potential and suitability of the land using GIS and WEAP models in Sibilu watershed.

1.3.2.Specific objectives

- To assess land that is suitable for surface irrigation in the study area.
- To assess surface water availability for surface irrigation.
- To estimate the overall surface irrigation potential in the Sibilu watershed.

1.4. Research Questions

In this study, the following research questions would address:

- What is the amount of land that is suitable for surface irrigation in the watershed?
- What is the extent of surface water available for surface irrigation?
- What is the extent of surface irrigation potential in the watershed?

1.5. Significance of the Study

Assessment of the land for irrigation use plays a great role in the use of resources in an extremely sustainable way, and for its possible use to support the livelihood of the community and economy of the country. Thus, in addressing the problem of land resource application and minimizing the risk of dependence on rain-fed agriculture, this study may help to identify surface irrigation potential land and effective planning of land resources for the cultivators.

1.6. Scope of the Study

The scope of the study mainly focuses on to assess land suitable, water availability and irrigation potential area. Therefore, the study only studies slope, soil type, land use/cover, land slope, and river proximity for determining irrigation potential for surface irrigation and evaluates available water for surface irrigation to match with irrigation water demand for the selected crop.

1.7. Limitations of the Study

The recorded data by different organization were not recorded correctly. Some of metrological data for the study area in the station were missing (Bekele, 2020).Certain limitations are defined to set the compass of this thesis were land management, soil performance of implementing an irrigation system indicates shortage of data on some properties of soils such as infiltration rate, chemical characteristics of the land under the study area were not evaluated ,even stream flow recorded data was old data and the limitation of metrological gauge station was the main problem in the study area.

CHAPTER TWO: LITERATURE REVIEW

2.1. Land Suitability Evaluation for Surface Irrigation

Land suitability is the fitness of a given type of land for a defined use with the availability of water. The land can be classified in its present condition or after improvements for its specified 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(FAO, 1985).

Arranz et al.,(2007)reported that soil types, with their corresponding physical and chemical characteristics and slope layer, is being the most limiting factor for the realization of, especially for surface irrigation methods.

Land suitability assessment plays an important role in maintaining and developing land use on a spatial basis. It identifies the levels and geographical patterns of biophysical constraints and evaluates potential capacity of land and its sustainable use (Demelash, 2017).

2.1.1. Land Suitability class

According to (FAO, 2002), Land Suitability indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders Suitable and not suitable represented in maps, tables, etc. by the symbols S and N respectively.

S suitable: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

N not suitable: Land which has qualities that appear to preclude Sustained use of the kind under consideration.

Table 2.1:Land suitability classes and order (FAO, 1997)

Order	Class	Description
Suitable (S)	S1 (Highly suitable)	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.
	S2 (Moderately suitable)	Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.
	S3 (Marginally suitable)	Land having limitations in which aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increases required inputs that this expenditure will be only marginally justified.
Unsuitable (N)	N1 (Currently not suitable)	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.
	N2 (Permanently not suitable	Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner.

2.1.2. Irrigation Land Suitability Evaluation Criteria

According to Mamo et al.(2022) the available water resources may not be able to meet various demands in near future that will inevitably result in the irrigation of additional lands in order to achieve a sustainable productivity. To develop sustainable use, one has to know the limitations and potentials of the land. The best uses for land depend on soil characteristics and their response to the use such as texture, rooting depth, stoniness, nutrient status, structures, drainage conditions, slope, etc.

2.1.2.1. Soils

Assessment of land resource, with particular regard to soil survey is necessary prerequisite for all agricultural developments, particularly where irrigation is concerned. Soil act, as a storehouse of water, supplying plant needs during dry periods when rain was inadequate (Ganole, 2010).

The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed. Such properties include drainage, texture, depth, salinity, and alkalinity. Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997).

The assessment or evaluation of soils for irrigation involves using properties that are permanent in nature 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. State that soil properties including drainage, texture, depth, salinity, and alkalinity are the most determinant factors for the selection of irrigation methods. Identifying soil type means identifying the method of irrigation depending on soil properties in addition to the slope of the watershed.

2.1.2.2. Slope

The slope was the inclination or gradient of a surface and is commonly expressed as a percent. The slope is important for soil formation and management because of its influence on runoff, drainage, erosion, and choice of irrigation types. The slope gradient of the land has a great influence on the selection of irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2% are very suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended(USDA, 1999)

2.1.2.3. Land use land cover

Land-use planning was the systematic assessment of land and water potential, alternatives for land use and economic and social conditions in order to select and adopt the best land-use options. Its purpose was too selected and put into practice those land uses that will best meet the needs of the people while safe guarding resources for the future. The driving force in planning was the needed for change, the needed for improved management or the need for a quite different pattern of land use dictated by changing circumstances(Ganole, 2010).

The major land use and land cover types of the sibilu watershed are agriculture land, forest, and open bush grassland, settlement, and water bodies. Forests and woodlands occur on the better-drained soils of mountains and sides of the valleys, and grasslands occupy areas of heavy clay soil of the valley bottom (Gebeyehu, 2015) . Land use land cover of the study area is one of the factors used to evaluate the land suitability for surface irrigation. Land use land cover provides a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land cover/use with topographic and soil characteristics to evaluate land suitability for surface irrigation with land suitability classes, present possible lands for new agricultural production.

2.1.2.4. Drainage

Drainage can be defined as the removal of excess water and salt from the soil at a rate and to a depth that will permit normal plant growth. Prediction of the drainage requirement is a critical element in selecting land for irrigation, particularly with diversified upland crop production(FAO, 1997). Arable land must be drainable land. The selection of arable lands will, therefore, encompass drainage evaluations. These evaluations include investigating the substrata as well as the root zone. Some lands are endowed with adequate natural drainage to sustain irrigation. However, this must be confirmed by investigations. Adequate drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. Under irrigation, consideration must be given to additional facilities to permit adequate removal of the excess water and salts added by irrigation. Because of the difference in the quality and volume of water applied through irrigation when compared to a natural rainfall situation, the current drainage condition often is not a valid indication of what the drainage conditions would been under project irrigation conditions(FAO, 1998).

2.2. Irrigation Potential

The area which can potentially be irrigated depends on the physical resource 'soil' and 'water, combined with the irrigation water requirements as determined by the cropping patterns and climate. It is called physical irrigation(FAO, 2002).

Rainfall is the ultimate source of water in Ethiopia, with surface water, ground water, and other water sources fed by rain. To understand the country's irrigation potential, it is important to understand its water sources(Management & Manuals, 1992).Increasing irrigation and water management can help tackle some of the nation's significant development challenges. These challenges are overpopulation, climate variability, land degradation, farmer productivity, etc.

Land evaluation is primarily the analysis of data about the land its soils, climate, vegetation, and 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 to the terrain conditions in relation to methods of irrigation considered (Girma et al., 2020). In addition to these factors,Slope,land use and land cover, soil properties(drainage,depth,texture), soil types and river proximity were considered as limiting factors in evaluating suitability of land for irrigation).

2.2.1. Irrigation Development in Ethiopia

In Ethiopia, traditional irrigation was practiced before centuries. Moreover, in the high-lands of Ethiopia, irrigation practices have long been in use since ancient times for producing subsistence food Crops (Awulachew et al., 2007). Different authors stressed that supplementary irrigation has been practiced by smallholder farmers of Ethiopia for centuries to solve their livelihood challenges. The traditional irrigation systems were developed and managed through forming a water user's association for functions of construction, water allocation, operation and maintenance and were headed by individuals.

This association comprises up to 200 users grouped into 20 to 30 groups of farmers who share a common main canal or its branches (MoA, 2011).

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility in Ethiopia. Irrigation can contribute to the national economy in several ways. At the micro level, irrigation leads to an increase in yield per hectare and subsequent increases in income, consumption and food security. Irrigation enables smallholders to diversify cropping patterns, and to switch from low-value subsistence production to high-value market- water and energy oriented production, minimizing crop failure due to dry spells (Hagos et al., 2009).

Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources, while ground water uses has just been started on a pilot basis in the East Amhara region (MoA, 2011).Modern agriculture irrigation was started in Ethiopia in the upper Awash Valley with the objective of producing industrial Crops as sugarcane, cotton and horticultural Crops on a large-scale basis, explained in a remarkable emergence of irrigation development and establishment of agro-industrial centers.

Ethiopia has an irrigation eventuality of 5.3 million ha of which 3.7Mha can be developed using surface water sources, and 1.6 million ha using groundwater and rainwater operation. Irrigation contributes to the rapid-fire metamorphosis of agriculture as present day agriculture is dominated by rain-fed single crops.

Ethiopia has an important occasion in water- led development, but it needs to address critical challenges in the planning, design, delivery, and conservation of its irrigation systems if it's to capture its full eventuality. Irrigation schemes cover about 640,000ha across the 8 country. These irrigation schemes vary extensively in size and structure, from micro-irrigation to river diversion, pumping, small or large dams, etc.(IWMI, 2007)

2.3. Weighting Overlay Analaysis For Surface Irrigation

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Geographic problems often require the analysis of many different factors using GIS. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Yang, 2003).

The weighted overlay analysis uses a rating scale of 1 to 5 (from the most inappropriate factor to the most appropriate factor) to prioritize the influence of the values of these factors. The weighted overlay only accepts integer raster as components, such as LULC, soil type, and slope (from the center of the source cell to the straight line from the center of each surrounding cell) the output raster to find the suitable land for the irrigation (Janssen, 1990).

The MCE technique, along with the geographic system (GIS), can help properly categorize, examine, and organize accessible information regarding spatial planning choices(Gedefaw et al., 2019).

The Analytic Hierarchy Process (AHP) was the decision aiding method introduced by (Saaty, 1980) based on the use of relatively judgment matrices and may aid the decision maker to line priorities and make the best decision. By reducing difficult choices to a series of pairwise comparisons, then synthesizing the results, the AHP helps to capture every subjective and objective aspect of a selection. In addition, the AHP incorporates an effective technique for checking the consistency of the decision maker’s evaluations, therefore reducing the bias with in the process.

The AHP incorporates an effective technique for checking the consistency of the evaluations when building each of the pair wise comparison matrices involved in the process. For checking the consistency of matrix, calculate the Consistency Index (CI) as

$$\mathrm{CI} = \frac{\lambda \mathrm{max} - \mathrm{m}}{m - 1} \qquad 2.1$$

The pair-wise comparison matrix each factor was matched head-to-head (one-to-one) with each other, and a pairwise or comparison matrix was prepared to express the relative importance. A scale of importance was divided from a value of 1 to 9.The highest value 9 corresponds to absolute importance and the reciprocal of all scaled ratios was en-tired in the transpose position (1/9) and shows an absolute triviality. The accuracy of weights used is subjective as it depends on opinion; however, the results of the relative weights were used in land suitability evaluation because the Consistency Ratios were within the established acceptable limits (0.1).The preference scale and reference scale were shown in Table 2.2 and Table 2.3 respectively according to (Saaty, 1980).

Table 2.2: Saaty's pair wise comparison scale

Numerical	Description	Explanation
1	Equal importance	Two factors contribute equally to the objective
3	Somewhat important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgment strongly favor one over the other
7	Very much more important	Experience and judgment very strongly favor one over the other. Its importance demonstrated in practice
9	Absolutely more important	The evidence favoring one over the other is of the highest possibility of validity
2,4,6,8	Intermediate Values	When compromise is needed

Table 2.3: Contesistecy indices a randomly generated matrix

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Scanning the consistency of the paired comparison matrix to evaluate the decision-makers comparisons were consistent or not. If the consistency ratio (CR) is 0.10 or less was acceptable and continues the AHP analysis. If the consistency ratio is greater than 0.10 or 10%, it is necessary to revise the judgments to locate the cause of the inconsistency and correct it.

In AHP, there was a consistency index, called the consistency ratio (CR), which was used to express the probability that the matrix judgment is randomly generated (Saaty, 1980).

$$\mathrm{CR} = \frac{CI}{RI} \qquad 2.2$$

Consistency ratio (CR), which can be calculated as the ratio of the consistency index (CI) of the matrix to the consistency index of a random-like matrix (RI).The value of RI takes from the Consistency indices for a randomly generated matrix.

2.4. Assessment of Water Availability

Water resource was available in multiple forms that can be used for irrigation. Surface water, renewable groundwater, wetland, soil moisture and rainwater are some forms. However, these water sources are underdeveloped and under-utilized in Ethiopia, implying that there was significant potential to increase water usage from these sources (Sintayehu et al., 2022).

Identifying which portion of the freshwater resource is available for human use was always a complex issue, because water was not a static resource, but exists in very dynamic cycles of rain, runoff, and evaporation (Jariwala & Vadher, 2016). Therefore, to describe "available water resource," we need to draw a system boundary. For blue water, most studies define available blue water resource as "renewable surface water" such as runoff and stream flow, with groundwater recharge as an optional component. Spatially, "renewable surface water "resources defined in previous studies may include runoff generated within the watershed only, or more commonly with inflows from upstream(Gedefaw et al., 2019).Because river discharge will be reduced by upstream water consumption, upstream input is the "unused" part of blue water accumulated along the river network. This "unused upstream input" was subject to changes in upstream consumption. This was not a problem for describing the current demand-to-supply relationship, but the problem interdependency can be a challenge for future scenario analysis, since any change in an upstream watershed will affect upstream input of all downstream watersheds. For green water analysis, interdependency is not a concern, since soil moisture can only be utilized locally for plant growth.

2.4.1. Assessment of Surface Water Potential

Until recently, the water potential of the country wasn't accurately associated even nowadays this is often still an issue. Water system (water amount and seasonality) is a crucial issue to gauge the land's quality for irrigation consistent with the amount of water throughout the amount of the year during which it's accessible (FAO, 1985). If water is in brief offer throughout some a part of the irrigation season, crop production can suffer, re-turns can decline and a part of the scheme's investment can lay idle or valuable wherever potential, the supply of water is preferred to be settled higher than the commented space to irrigate the command space through the free surface flow while not the necessity of power generation.

The eradication of poverty and hunger in rural areas is closely related to a fair and equitable access for the most vulnerable people to basic livelihood assets (including land and water) for most domestic and productive uses. Therefore, water resource management is one of the most important challenges the world is facing today. In order to meet the demands of different users, efforts should be intensified on the efficient use of all water resources(surface water, ground water, and rainfall) and also on water allocation plans that maximize the resultant economic returns to limited water resources and, at the same time, protect the fragile ecosystem(Gedefaw et al., 2019).

Surface water is water that is on the Earth's surface, such as in a stream, river, lake, or reservoir. Surface water is a valuable resource which can be used for public, industrial and agricultural supply purposes. Surface water courses also provide important natural habitats and environmental and leisure resources. Therefore, understanding surface water resources is a key aspect of water resource assessment and evaluation (Girma et al., 2020).

Ganole, (2010)conducted a study of stream construction surface irrigation potential as-assessment in Dale Woredas. It absolutely was GIS-based and concerns had taken the potential of irrigable land, irrigation demand, and water availably. He identifies that distance from water sources to the command space is a crucial issue that is that the shorter the irrigation canal length the gap is additional economical associated helpful to develop an irrigation project effectively. Knowing the amount of the water system is equally as necessary as land associated alternative factors to the success and development of an irrigation project.

There is wide variability in their characteristics and potential applications, for example, spatial and temporal scale, processes modeled and the basis of relationships and algorithm used. With this increasing number of availability, wide ranging characteristics and potential applications of the models, it is becoming challenging job for the potential model users to choose a particular model best suited for the given problem. In addition, modifications are made to existing models and new models are available each year. Therefore, updated, consistent and comprehensive evaluations of hydrological models are a continuous need (Hosseini & Khaleghi, 2020) .

2.4.2. Water Demand Assessment

The factors that determine development potential in a given geographic area, the availability of water for residential, commercial, and industrial purposes is a primary indication of prospective growth. Governmental bodies at the regional, state and federal levels often need to identify water supply availability in order to identify growth potential According to (Gao et al., 2017) the demand for water resources of sufficient quantity and quality. For human consumption, sanitation, agriculture, and industrial uses will continue to intensify as the population increases and global urbanization, industrialization, and commercial development accelerate.

According to (Ayele, 2016) with supply and demand data in a base year, projections of Future water supply availability can then be made. Detailed projection of future water demand must account for changes in the amount of water use activities and the rates of water use within those activities, but a simplified procedure was applied here. Total off stream water use was averaged over the population in the base year to determine per-capita off stream use, which is assumed to remain constant in the future in this preliminary assessment procedure .Population was then projected and demand was forecasted as a function of the projected population. The supply quantity was projected assuming each flow parameter derived from the historical record will remain constant in the future year. By comparing projected supply and demand estimates, water supply availability in future years can be anticipated in the planning area.

2.5. Land suitability Evaluation

Land suitability analysis is a prerequisite to achieve optimum utilization of the available land resources for sustainable agricultural production. Access the potential of surface irrigation was studied to make the fragmented land more profitable. Therefore, assessing surface irrigation in terms of suitable land is a very important option for solving the problem (Hailemichae, 2020).

Irrigation planning process requires integration of information about the suitability of the land, water and climatic conditions. Irrigation water supplies and their requirements are important physical factors in matching the available supply to the requirements. The physical and chemical land resources that have great contribution on evaluation of land suitability for specific use must also be evaluated on condition that water can be supplied to it. Land evaluation is related with the selection of suitable land, and suitable cropping, irrigation and management alternatives that are physically and financially practicable and economically viable (FAO, 1985).

Proper use of land depends on the suitability or capability of land for specific purposes. The suitability of a given piece of land is its natural ability or the biological productivity of land to support a specific purpose. (FAO, 1977) analyze suitability mainly based on the land qualities, such as erosion resistance, water availability, and flood hazard that are not measurable. These land qualities, however derives from land characteristics that can be quantified. Some of land characteristics are slope angle and length, rainfall and soil texture and others.

The common way of determination of land quality from land characteristics is mainly by assessing and grouping the land types in orders and classes according to their aptitude. The order of suitability ranges from suitable (S), that characterizes a land were sustainable use and will give good benefits; to not suitable (N) which indicates a land qualities do not allow the considered type of use, or are not enough for sustainable outcomes. Gedefaw et al., (2019)in agricultural development strategy, the development of irrigation and agricultural water management holds a significant potential to improve productivity and reduce vulnerability to climatic volatility in the country. Accordingly, improvement and expansion of irrigated agriculture is playing an essential role to bring food security at national as well as household level particularly in food insecure dry lands of Ethiopia.

Demelash, (2017) revealed that, irrigation land suitability assessment and mapping play an imperative role for sustainable utilization of scarce physical land resources. Sound information on soils, water and other land characteristics provide a basis for decision making on proper utilization and management of natural resources. The importance of land evaluation points to opportunities for influencing future developments of soils in the region using management techniques that are tailored to the characteristics of the landscape elements.

Gebeyehu,(2015)conducted a study on GIS based land suitability evaluation for main irrigated vegetables in Semaz dam, northern Ethiopia. In this study the area was classified into six land mapping units and samples were taken from the representative sites of these land mapping units. The parametric evaluation system and Inverse Distance Weighted (IDW) interpolation provided in Arc GIS 10.1 software were used to perform the land suitability classification. The result of the study depicted that the study area was moderately suitable for any irrigated vegetable purposes. Soil texture was the only limiting factor and the cause for the area to be moderately suitable (S2).

2.6. Assessment of Water Availability in Ethiopia

Assessment of water resources can only be done at river basin level(FAO, 1997). Water resource is available in multiple forms that can be used for agriculture and irrigation. Surface water, renewable groundwater, wetland, soil moisture and rainwater are some forms. However, these water sources are severely underdeveloped and under-utilized in Ethiopia, implying that there is significant potential to increase water usage from these and other sources (IWMI, 2010).

A sense of the economic value of water implies the attachment of different values to different uses of water. These values will vary from setting as decided by the community, although it is invariably the case that survival and public health uses will be high value uses; whereas recreational uses will be comparatively lower-value Drc, (2011). For instance, “the physical features of the country of Ethiopia are composed of highlands, plateaus and lowlands; the highlands are mostly associated with high rainfall, several springs, lakes, streams and rivers”. Because there is plenty of water in the highlands, people do not value water very much. In the lowland areas, where water is scarce; people give more value to water. According to (Keflemariam, 1967) .where water is becoming scarce; it is desirable to discourage low-value uses.

Girma et al.,(2020) assessed surface irrigation potential and optimization of cropping pattern: case study of danse watershed, Oromia region. The availability of water was determined from surface runoff using curve number method. As a result, the weighted curve number of the watershed was estimated as 84. Using the mean annual precipitation of Ejere station from 1987-2016, the annual volume of surface runoff generated in the watershed was 18.64 MCM.

Gurara,(2020) surface water quality is critical issue since used in domestic, agricultural, and industrial purpose. The aim of this study was to assess surface water quality and suitability for drinking and irrigation purpose in the case of Amen River, Dangila Town, and Amhara national regional state. Ethiopia’s water resources, as in many other regions of the world, are facing many challenges especially from climate change, which is one of the dynamic processes impacting water resources. Other processes such as population growth, increasing water demand, overexploitation of natural resources and environmental degradation have also significantly degraded the world’s freshwater resources.

CHAPTER THREE: MATERIALS AND METHODS

3.1. Description of the Study Area.

3.1.1. Location

Sibilu watershed is found in the Sululta district, Shegar city, Oromia Regional National State, to the North of Addis Ababa to Fitche highway. It was one of the tributary of Muger River, which was the main tributary of Abay Basin. It is found between geographical coordinates of 10°48'58"N-10°17'49"N latitude, 46°10'12"E-48°24'50"E longitude. The study area consists of flat and undulated landmass with an altitude 3354 m above sea level. The economy of the study area was mainly dominated by agriculture. It was located about 20 km east of Addis Ababa. The study area covers about 63627.8ha.

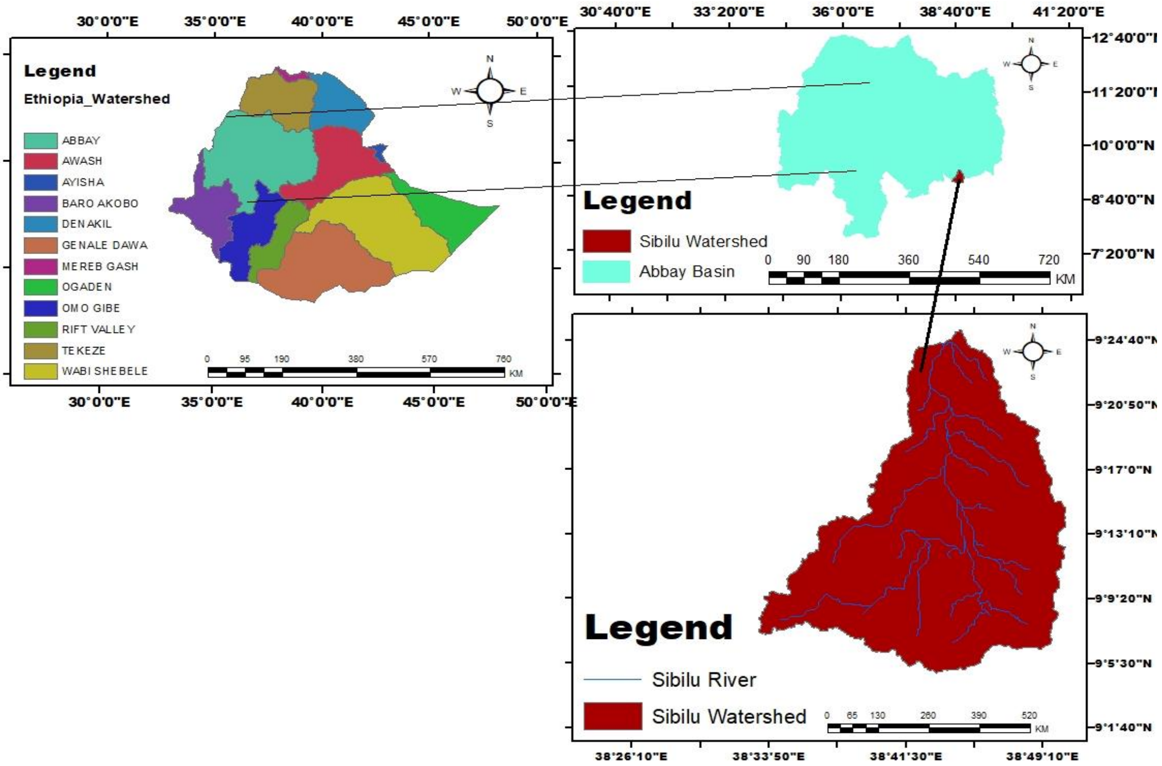


Figure 3.1: Location of study area

3.1.2 Topography

The altitude of the watershed boundary extends from 2255 to 3354 m above mean sea level. The maximum elevation of Sibilu watershed was located in the east part of the watershed and the minimum elevation of this watershed was located in the northeast part of this watershed.

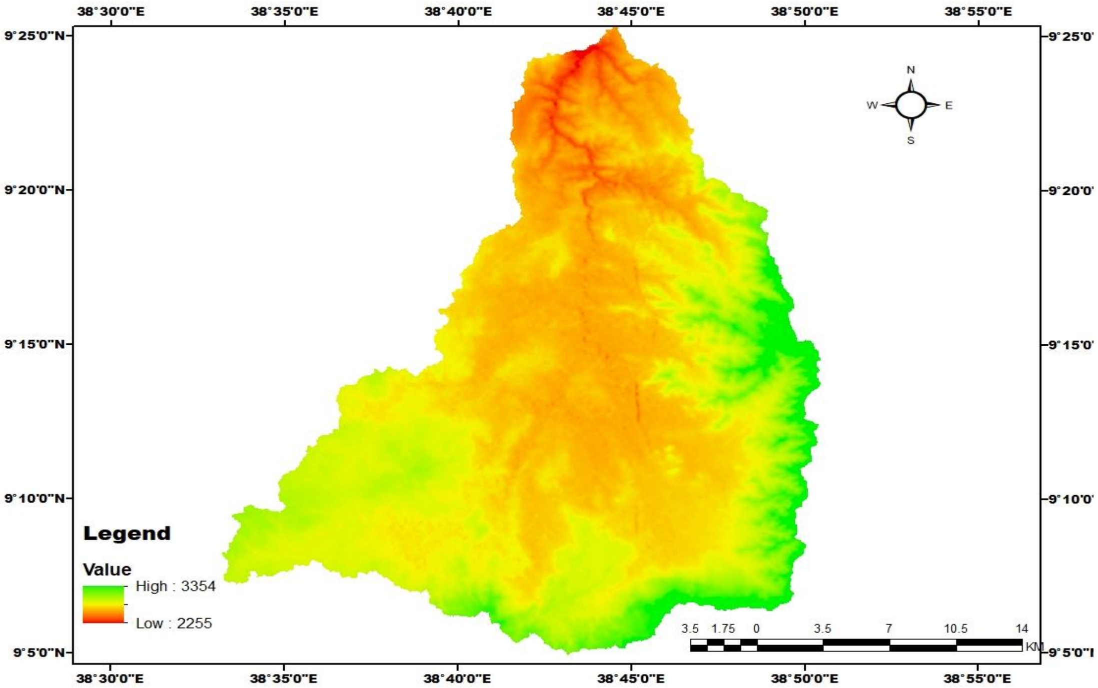


Figure 3.2: Topography of study area.

3.1.3. Soil Type

Soils were key parameters in watershed management. It was significant characteristics that influences the process within watershed were soil permeability, soil erodibility and compositions of nutrients that help vegetative growth. These characteristics were influenced mainly by soil properties such as soil texture, structure, depth, organic matter content, soil fertility, soil reaction, soil color and stoniness. These properties of soils were highly important parameters in watershed development planning. There were four different soil types' Luvisol, Cambisols, Leptosol, vertisol. Most of the study areas were mostly covered by Luvisol and Cambisols (ECO, 2018).

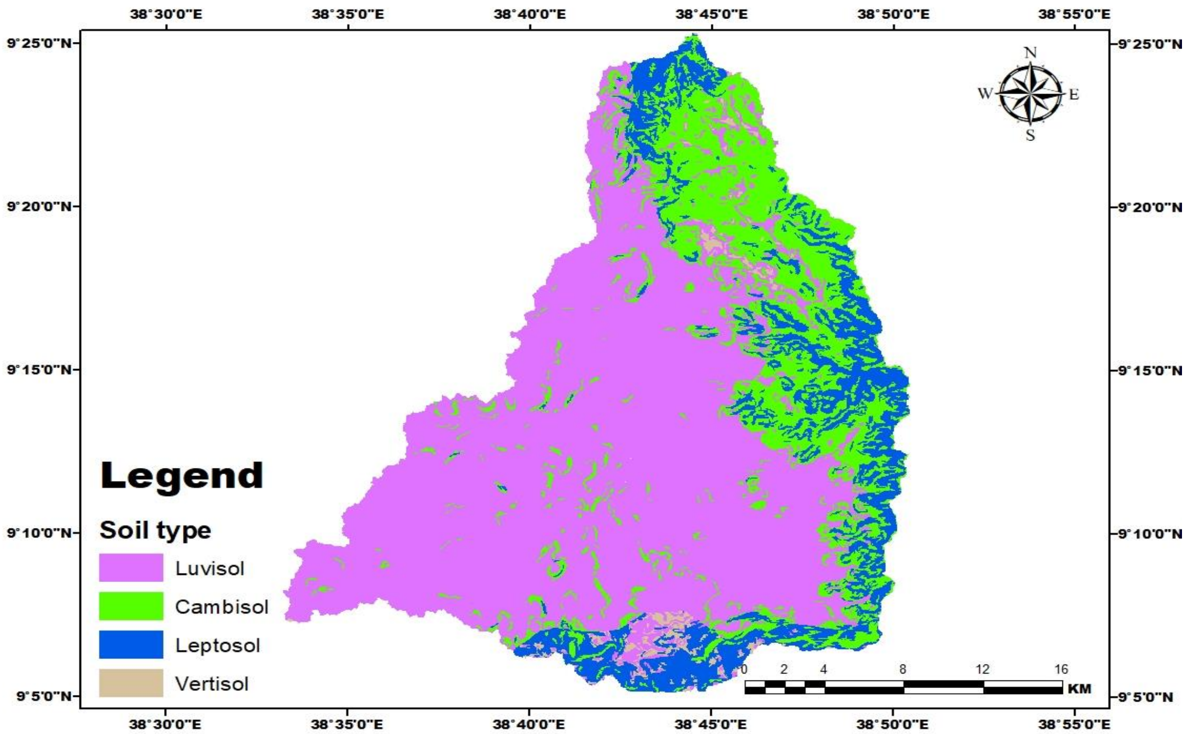


Figure 3.3: Soil type of the study area

3.1.4. Climate.

The temperature data were taken from five stations, Sululta, Derba, Intoto, Chancho and Addis Ababa Observatory. Generally, months of February, March, April and May had the highest temperature while July, August and September had the lowest temperature.

The annual maximum and minimum temperatures in the basin vary between 21.7-26℃ and 6.5-9.3℃, respectively. The monthly maximum temperature and minimum temperature of the various stations were shown below figure 3.4.

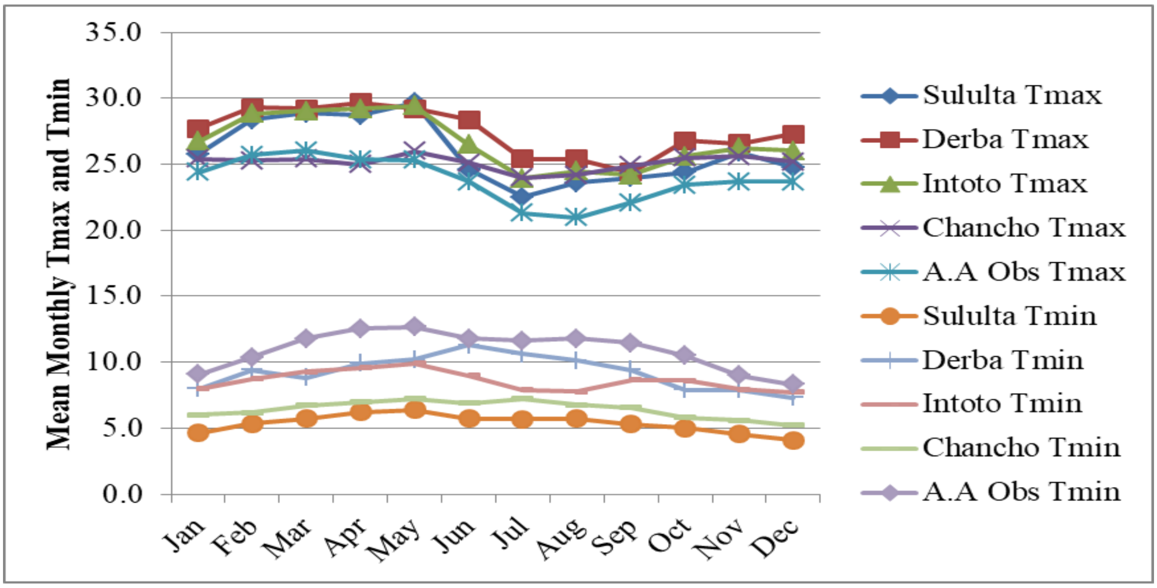


Figure 3.4: Average Monthly Temperature of study area.

3.1.4.1. Rainfall (mm)

Rainfalls in the study area generally exhibit a Mono modal rainfall pattern. The light/short and less reliable rains comes down from October to May, while the more reliable highest Rainfall which account much percent of the annual precipitation, comes down from June to September. Rainfall data was available from 1990 to 2021 and recorded from five stations, such as: from Sululta, Intoto, and Addis Ababa Observatory, Derba and Chancho. Annual Average rainfall for Sululta, Intoto, Derba, Chancho and A.A observatory were 1179.4mm, 1127.8mm 1223.5mm, 1214mm and1127.8mm respectively. The mean monthly rainfalls of different stations in the study area were given graphically shows in bellow Figure 3.5

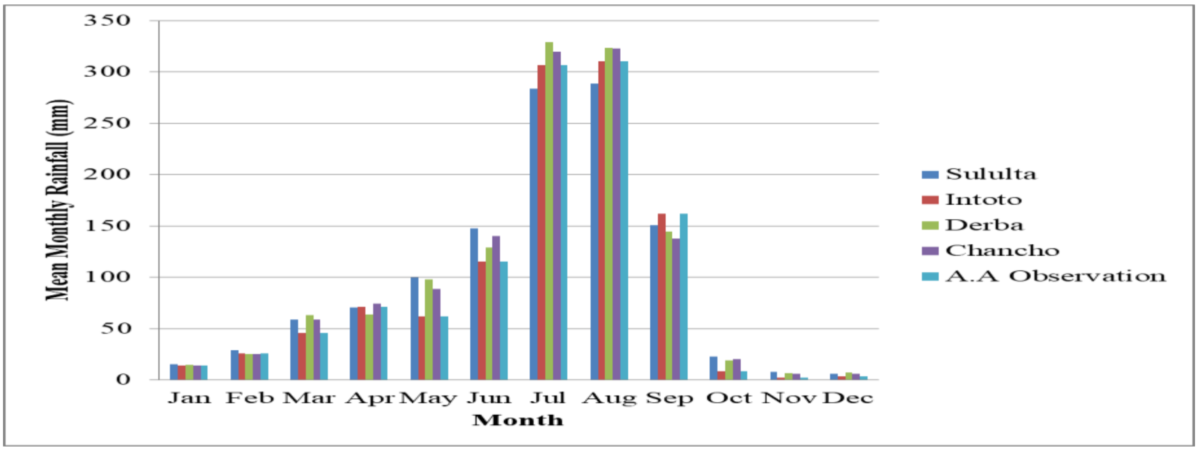


Figure 3.5: Mean monthly rainfall of study area.

3.1.4.2. Relative Humidity

The relative humidity in the study area was different from time to time, depending on climate. The mean monthly of relative humidity the maximum value occurs at when rainfall season from June to September and the minimum value relative humidity occur at dry season January to march.

Table 3.1: Monthly relative humidity of study area

Month	Jan	Feb	Ma	Apr	May	Jun	Jul	Au	Sep	Oct	Nov	Dec
Sululta	57	53	57	65	63	69	81	84	81	72	65	61
Intoto	57	53	57	65	63	69	81	84	81	72	65	61
Derba	57	52	55	62	60	66	81	83	79	71	65	60
Chancho	57	52	55	62	60	66	81	83	79	71	65	60
A.A Obs	57	53	57	65	63	69	81	84	81	72	65	61

3.1.4.3. Sunshine Hour

As the major factor affecting sunshine hour was cloud cover, this leads to high sunshine level in dry season and low sunshine levels in the wet season of the watershed. As the elevation of the study area increases, the sunshine value decreases. Since most area of the watershed relatively found at high to medium elevation area, it has relatively medium value of sunshine hour. Similarly, during the rainy season, the value of sunshine hour decreases (June to September) where as it increases during the dry season (October to May).

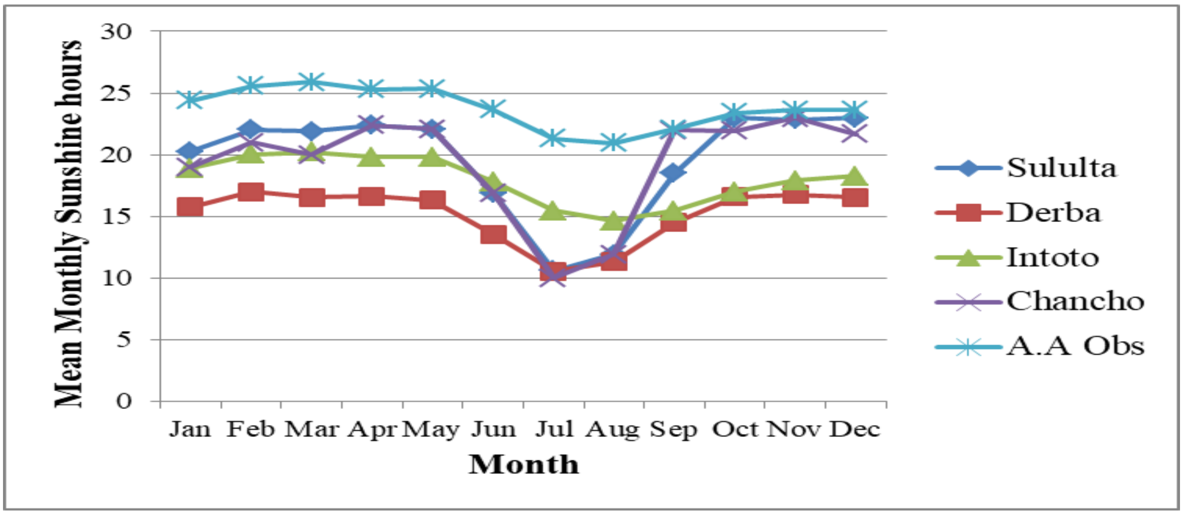


Figure 3.6: mean monthly sunshine hours of study area.

3.1.4.4. Wind Speed

The mean wind speed varies little over the study area. High wind speed was relatively occurred at high altitude, while there was a decreased in wind speed in low altitude. On the other hand, there was an interested variation in seasonal values of wind speed. During rainy season the wind speed was slightly decreased and during the dry season it was slightly increased around the study area. The wind speed of watershed minimum to maximum value was 1.7 to 2.5m/s.

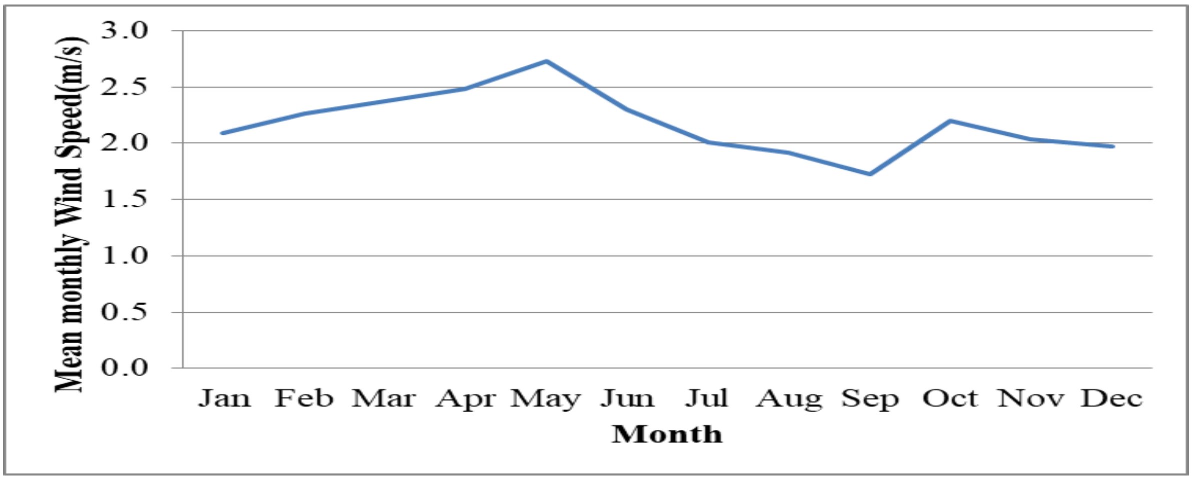


Figure 3.7: Mean monthly wind speed of study area

3.1.5. Land use and Land cover

Land use and land cover was an important aspect for modeling and understanding the earth as a system and was a key input for planning and management activities. It goes without saying that informed development planning promotes sustainable development and use of the natural resources. Land use/Land cover, developing with the remote sensing technology, has become a crucial item of basic tasks in order to carry through a series of important works, such as the prediction of land use change, prevention of natural disaster, land use management and plan, protection of the environment, and the like. With the more thorough development of remote sensing technology and Geo-Analysis model, using remotely sensed data to monitor the status and dynamic change of land use/land cover was come one of the most rapid, credible and effective method.

Land use land cover of the sibilu watershed includes the cultivated land, forest, bare land, bush shrub land, grass land and settlement land. The cultivation land dominated in the different types of the study area. The land use land cover of the study area was highly dominated by cultivated land and the land sat image of October 2023.

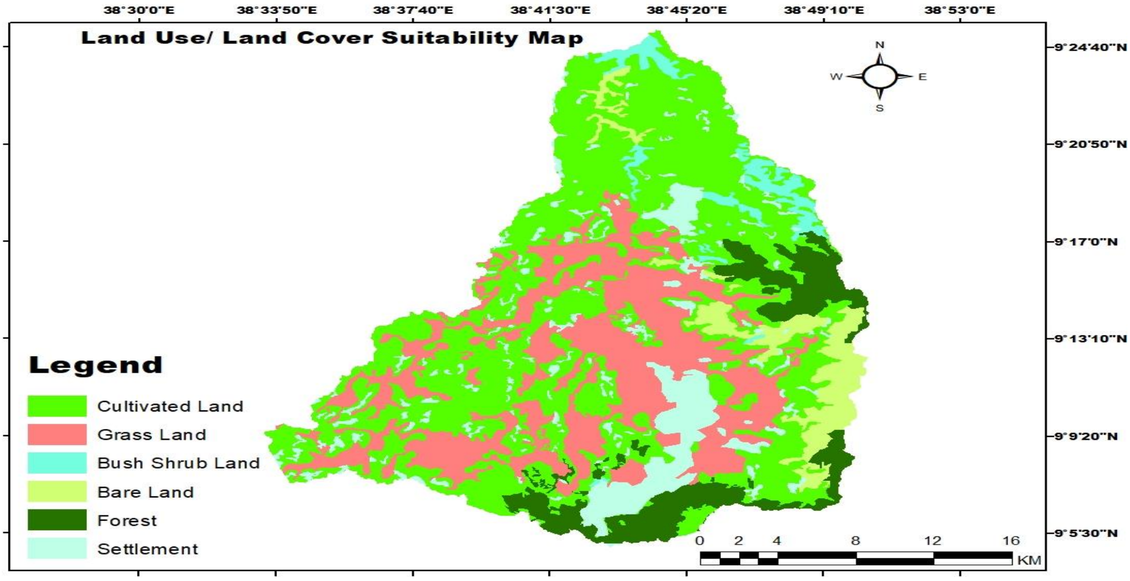


Figure 3.8: Land use and Land cover map of study area (Land sat image October, 2023).

3.1.6. Population

Sibilu watershed is the one where high rate of population growth is observed as a result of different pushing factors. Now a day there were high population growth and the total population estimated 426787.Of which 213245 were male and 211520 were female.

However, this population data was reliable source, because they were not estimated from various data sources of the study area. The estimated population sizes of the study area and the population size of study area was taken from Engineering Corporation of Oromia (ECO, 2023)

3.2. Data collection

Collected data can contain errors due to failures of measuring instrument or the recorded. So, before using the data for specific purpose, the data were checked and errors were removed. Analysis of raw data was made for data quality checking and filling of missing records. Sibilu watershed was characterized by slope, land use and land cover, rainfall, temperature, wind speed, sunshine hours and relative humidity.

Table 3.2: Secondary data sets for modeling work

S.No.	Data Type	Source of data
1	Hydrological data; stream flow	Ministry of water, irrigation and energy
2	Meteorological data; -Rainfall -Temperature -relative humidity, -sunshine hour and wind speed	National Metrological Service agency (NMSA) of Ethiopia
3	Water demand data -Domestic -Livestock -Agricultural	Engineering Corporation of Oromia
4	Population data	Engineering Corporation of Oromia
5	LULC data	Landsat image
6	Soil Data	Ministry of water, irrigation and energy, engineering corporation of Oromia, FAO Soil classification used
7	Slope data	DEM spatial resolution by using Arc GIS spatial analyst tool.

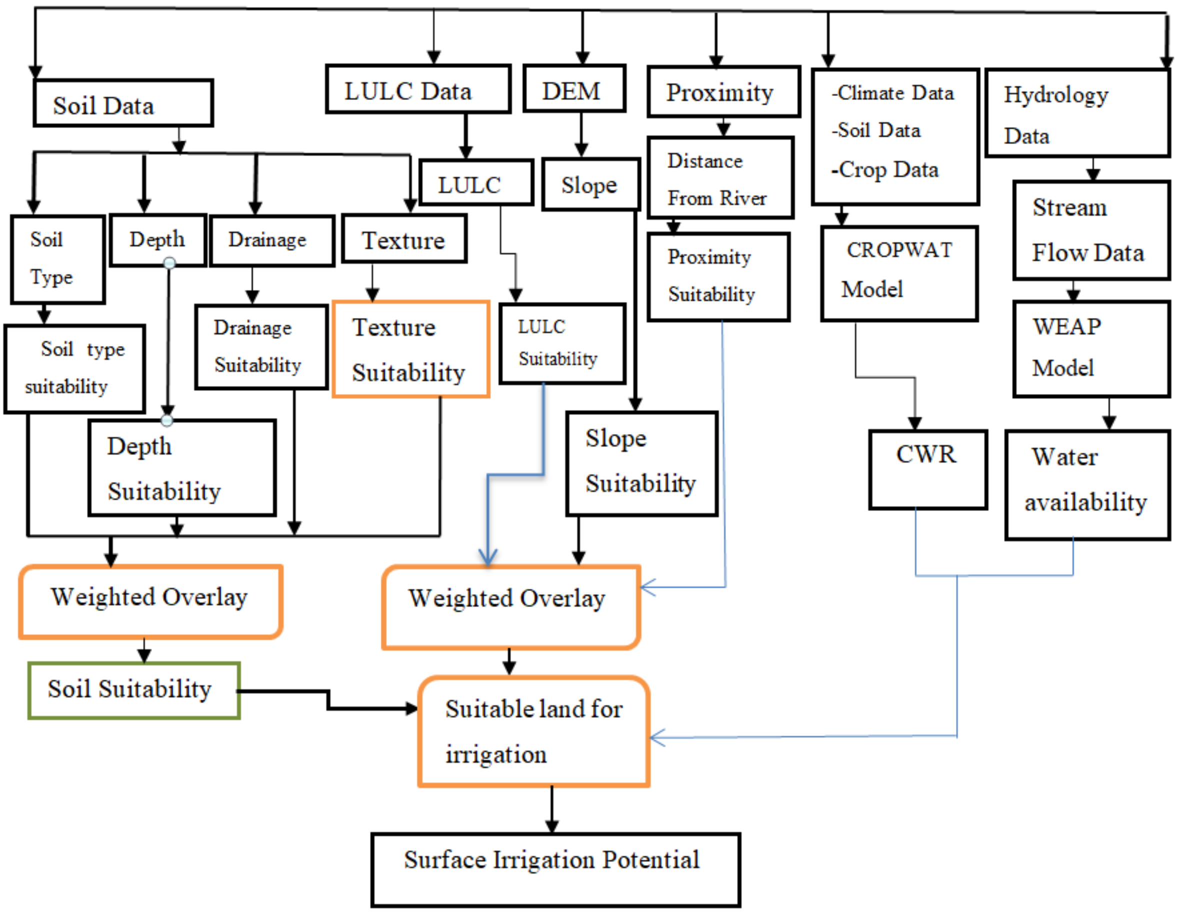


Figure3.9: Methodological framework of land suitability for surface irrigation and developing water availability

3.2.1. Data pre-processing and checking

Collected data can contain errors due to failures of measuring device or the recorder. So, before using the data for specific purpose, the data have to be checked and errors have to be removed**.** The analysis was extended to hydrological and meteorological data to prepare input data for water resources assessment and irrigation water requirement estimation using the CROPWAT model**.**

3.2.1.1. Filling missing rainfall data

Missing data was a common problem in hydrology. To perform hydrological analysis and simulation using data of long time series, filling in missing data was very important. The missing data can be completed using metrological and/or hydrological stations located in the nearby, provided that the stations were located in hydrological homogenous region.

A number of methods exist to conduct estimation of missing rainfall, the arithmetic mean methods used for filling missing rainfall data.

The arithmetic mean method

The Arithmetic mean method was usually applied for preliminary evaluation of precipitation depth within a basin. Preferably, dense meteorological stations evenly distributed over a sub basin, especially in plain areas highlight acceptable results. The mean precipitation depth was the averaged value of the stations. The arithmetic mean was simply the statistical averaging of the series/stations. The arithmetic mean method was given by:

$$P\,\mathrm{x} = \frac{1}{\mathrm{n}}\sum_{n=1}^{i=x}\left(\frac{1}{n}(P1 + P2 + P3 + \cdots + Pn\right) \qquad 3.1$$

Where, n is the number of nearby stations

Pi is precipitation at ith station and

PX is missing precipitation

Based on the arithmetic averaging, precipitation depth would be the sum of recorded rainfall in each meteorological station divided by the number of rain gauges within and outside of the sub basin. In practice, this method is used very rarely.

In and out of the project area, there were a total of 5 rain gauges periodically located in the thematic map. Two of them were located within the Upper Awash area while three of them were in the Muger sub basin. The meteorological stations located within & out of the targeted area and the amount of precipitation with their locations are presented in a tabular form as shown in Table 3.3.

Table 3.3: Recording rainfall data of different study area

S/No	Station Name	Longitude	Latitude	Elevation
1	Sululta	470700	1015036	2650
2	Chancho	472545	1030146	2480
3	Intoto	469377	1004023	2903
4	Derba	461741	1042561	2385
5	A.A.Observatory	472243	996862	2408

The simplest and the most commonly used method, especially in the relatively flat region, was the Arithmetic Mean Method. It gives fairly accurate results if the network of the rain gauge stations in the region under study is uniformly distributed.

3.2.2. Consistency of rainfall data

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. The checking for inconsistency of a record is done by double mass curve technique (Subramanya, 1983).

The accumulated total of the individual gauge was compared with the corresponding totals for a representative group of nearby gauge. If a decided change in the regime of the curve was observed it should be corrected. However, as all the selected stations in this study were consistent, there was no need of further correction. The rainfall data of Sululta, Chancho, Intoto, Addis Ababa Observatory and Derba stations from the year of 1990-2021 were collected for consistency checking.

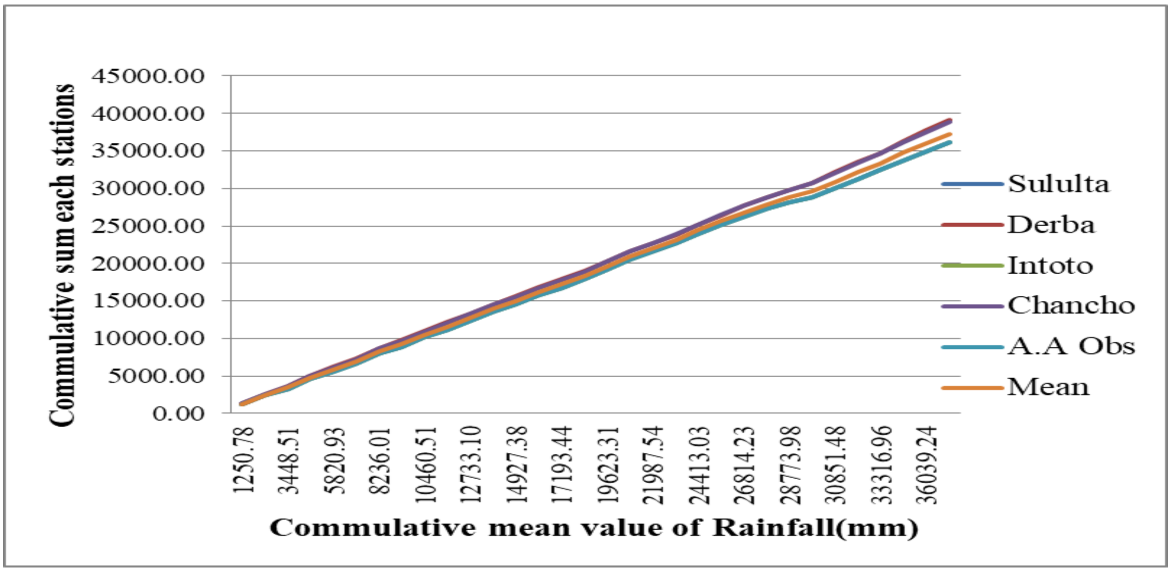


Figure 3.10: Double mass curve rainfall of study area

The relationship of variables for each station Sululta, Derba, Intoto, Chancho, and A.A observation were 0.9997, 0.9995, 0.9971, 0.9974 and A.A observation respectively. The results of the double-mass curve analysis of the rainfall stations shown that the rainfall recorded at the five gauging stations (Sululta, Derba, Intoto, Chancho and A.A Observation) were consistent with no significant change of slope on their respective plots as presented in figure 3.11. This also suggests that the rainfall data recorded at these five stations can be used directly for further analysis.

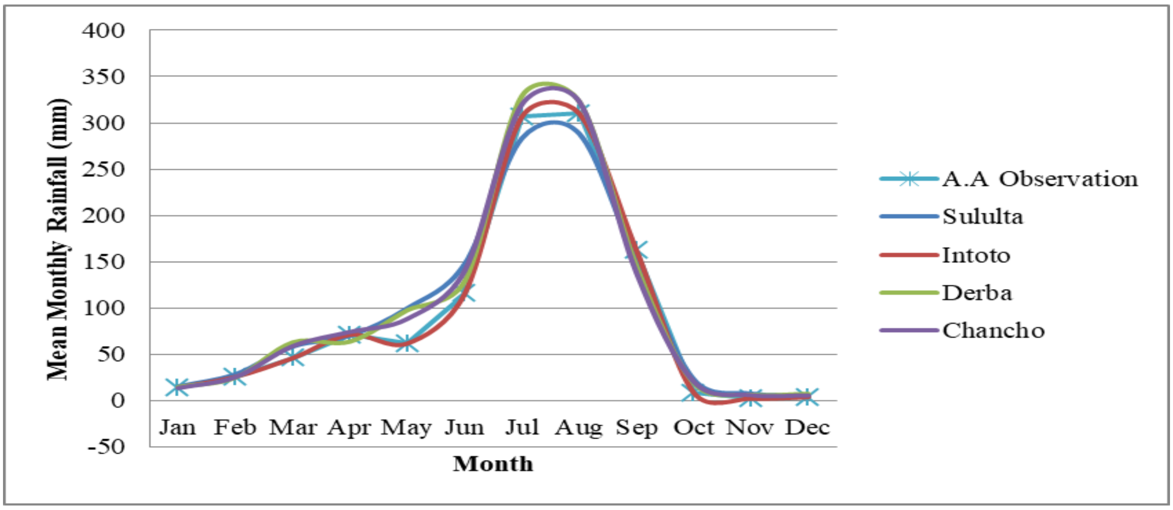


Figure 3.11: Homogeneity of Study area

As it is shown in the above figure the result of homogeneity analysis for climate stations have homogeneous characteristics and had been similar. Using all these stations for hydrological analysis of study area has no problem in hydrological result.

3.3. Material and software used

Table 3.4: Material and Software needed

S.No	Software Name	Purposes
1	ArcGIS	For delineating watershed and Land Suitability analysis
2	Global Mapper19	For generating digital elevation model (DEM).
3	AHP	Method calculates the required weights associated with the respective criterion map layers with the help of a preference matrix, in which all relevant criteria identified are compared against each other on the basis of preference factors.
4	CROPWAT8.0	Determine the crop water requirements of selected crops in the watershed.
5	WEAP	To evaluate the existing and planned water resources development in a given watershed.

3.4. Methods

3.4.1. Identification of Potential land for surface irrigation

Identification of suitable sites for irrigation was carried out by considering the slope, soil and land cover/use. The individual suitability of each factor was first analyzed and finally weighted to get potential irrigable sites.

3.4.1.1. Soil suitability

The soil suitability for irrigation was evaluated based on their soil type, texture, depth, and drainage class. Using overlay tool in Arc GIS spatial analyst, weighted overlay analysis of these factors were performed to determine their suitability for surface irrigation(Belete, 2021). Soil suitability for irrigation was made based on the common evaluation scale from S1-N available in weighted overlay analysis for land evaluation to the factor classes. A value (S1) represent highly suitable factor in evaluation, while value (N) represent not suitable factor in evaluation. The following soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1982).

Table 3.5: Soil properties rating suitability for surface irrigation evaluation (FAO, 2006)

Factor	Rating			
	S1	S2	S3	N
Soil depth(cm)	>100	50-100	25-50	<25
Drainage	W	M	I	P
Texture class	CL,SCL,L	SC,SL,C	SL	Coarse sand

CL=Clay Loam, SL, and SL=Sandy Loam, W=well drained, M=moderately well drained, I=Imperfectly, P=poor Source: (FAO, 2006) guideline for land evaluation team based on practical observation.

3.4.1.2. Slope suitability

Land slope was the most important topographical factor influencing land suitability for irrigation. The Slope derived from the DEM was classified based on the classification system of (FAO, 1996) using the "Reclassification "tool, which was an attributed generalization technique in ArcGIS. Four suitable ranges (S1, S2, S3, and N) were classified as follows.

Table 3.6: Slope suitability classification for surface irrigation

S/No.	Slope %	Class code	Class Description
1	0-2	S1	Highly Suitable
2	2-5	S2	Moderately Suitable
3	5-8	S3	Marginally Suitable
4	>8	N	Not Suitable

3.4.1.3. Land use and land cover suitability

The land cover and land use in the study area was also a factor in assessed whether the land is suitable for irrigation. The watershed land use and land cover includes cultivated land, forest, bare land, bush shrub land, grass land, settlement and town land. The rasterized land use/cover maps of these LULC classes were distributed into four suitability classes (S1, S2. S3 and N) were shown in table 3.7.

Table 3.7: FAO land use and land cover rating suitability standard for surface irrigation

LULC	Class code	Class Description
Cultivated Land, Forest	S1	Highly Suitable
Grass Land	S2	Moderately Suitable
Bush and Shrub land	S3	Marginally Suitable
Constraints(Settlement, water, wetland)	N	Not Suitable

3.4.1.4. River Proximity

In Ethiopia, most communities practice their irrigation activities near rivers or lakes. Cultivation lands near the water resources can easily get water for agricultural production and were highly favorable to surface irrigation. River/water resources proximity is one of the main criteria that almost certainly influence the site location of surface irrigation. So, based on streamlines equal distance, river proximity map was generated using a multiple-ring buffer of ArcGIS (Seneshaw et al., 2023). The distance to the major River Sibilu was categorized into four various classes, in such a way that land areas located within distance up to less than 1km from the river are grouped as highly suitable, whereas areas located within 1-2km distance from the river are classified as moderately suitable for surface irrigation. Areas located within 2-3km distance from the river classified marginally suitable and more than 3km distance from rivers unsuitable for surface irrigation (Hagos et al., 2022; Paul et al., 2020).The river proximity suitability for surface irrigation was shown in Table.3.8

Table 3.8: river proximity rating suitability standard for surface irrigation evaluation

Euclidean Distance(KM)	Class code	Class Description
<1	S1	Highly Suitable
1-2	S2	Moderately Suitable
2-3	S3	Marginally Suitable
>3	N	Not Suitable

3.5. Pair wise comparison matrix factor for surface irrigation

A pair wise comparison was the process of comparing in pairs to judge which of each criterion was preferred overall. Each criterion was matched one on one with each of the other criteria. Pairwise comparison is a great way to help make decisions when there were many options to think it.Pairwise comparison has been done for factors used in land suitability analysis for surface irrigation of the study area.

The analytical hierarchy processing method with GIS was used to evaluate the connection between soil parameter such as slope, soil factor, land-use and land cover factors and proximity/distance to water on the suitability of lands for surface irrigation. For this study, seven governing factors like Land use/cover, slope, soil type, texture, drainage, depth, and distance to water source were considered as input parameters. The pairwise comparison matrix was performed for seven major factors compared one to at least one and scored. For all the seven parameters the relative significance is deduced. Therefore, a common scale (0 to 100%) is attained from the AHP procedure.

After the pairwise comparison matrices were filled, the weight value was used to identify the consistency rate and develop the best-fit weights. The criteria weighted were added up using weighted overlay methods in ArcGIS to get a land suitable value.

Table 3.9: Pair wise comparison matric criteria of all factors

Criteria	LULC	Slope	Soil type	Texture	Drainage	Proximity	Depth	Weight (%)
LULC	1	3	5	7	7	9	9	43
Slope	0.333	1	3	5	5	7	7	24
Soil type	0.2	0.333	1	3	5	5	7	15
Texture	0.143	0.2	0.333	1	2	3	5	7
Drainage	0.143	0.2	0.2	0.5	1	3	5	6
Proximity	0.111	0.143	0.2	0.333	0.333	1	3	3
Depth	0.111	0.143	0.143	0.2	0.2	0.333	1	2

Consistency Ratio (CR) = 0.081

After the pairwise comparison matrices were filled, the weight value was used to identify the consistency rate and develop the best-fit weights. The consistency rate (CR) was 0.081, which was respectable for weighting the factors to estimate the land capability of the irrigation suitability maps.

3.6. Crop Water Requirement (CWR)

The water requirement of a crop depends on the climate. Under the same condition different crops require different amount of water and the quantities of water used by particular crop vary with its stage of growth. Initially during seeding, germination and early growth a crop uses water at a relative slow rate. The rate would increase with growth of crop reaching the maximum in most crops as it approaches flowering and then declined towards maturity.

For the purpose of calculating ET_O, Chancho meteorological station had been used. There were different formulas to calculate ET_O, but Penman-Montheith method is considered to be the most accurate method for estimating ET_O though it requires relatively more data than others. The method was considered to offer the best results with minimum possible error in relation to a living grass reference.

3.6.1. Calculation of Reference Evapotranspiration (ET_O)

CROPWAT 8.0 for Windows is a computer program for calculating the water requirements of plant-based on existing plant and climate data. In addition, the program enables the development of an irrigation plan for different management conditions and the calculation of the planned water supply for different crops. The software uses the FAO Penman-Montheith model to estimate reference evapotranspiration (FAO, 1998).

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad 3.2$$

Where, ET_o = reference evapotranspiration [mm day^{-1}],

R_n = 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 vapor pressure [kPa],

e_a = actual vapor pressure [kPa],

[e_s – e_a] = saturation vapor pressure deficit [kPa],

Δ = slope vapor pressure curve [kPa $°C_{-1}$],

γ = psychometric constant [kPa $°C^{-1}$].

The equation uses standard climatological records of solar radiation (sun), air temperature, humidity, and wind speed. The climate data used for the calculations were obtained from a meteorological station.

3.6.2. Crop evapotranspiration (ETc)

Crop water requirement refers to the amount of water required to compensate the evapotranspiration loss from the cropped field also synonymously known as crop evapotranspiration (ETc). CWR refers specially to the amount of water to be supplied whereas ETc refers to the amount of water that crop has lost through evapotranspiration. ETc is determined by multiplying the crop coefficient with the reference crop evapotranspiration. “ETc is referred to evapotranspiration from disease free, well fertilized crop grown under optimum or standard conditions.

Crop evapotranspiration (ETc) = kc*ETo 3.3

Where, ETc = Crop Evapotranspiration,

ETo = Reference Evapotranspiration and

Kc = crop coefficient.

3.6.3. Gross and Net Irrigation Requirements

3.6.3.1. Net irrigation requirements

The net irrigation requirement (net water depth application) was the depth of irrigation water needed to replenish the soil water deficit at the effective root zone to field capacity. The net irrigation requirement for a crop maintained without water stress for any time period could be determined through the following relationship. Net irrigation water requirement (NIWR) is the depth of water, exclusive of effective precipitation, stored soil moisture or ground water that is required for meeting crop evapotranspiration for optimum crop production and other related uses.

Therefore, net irrigation requirement may be expressed as:

NIR = ETc - Pef 3.4

NIR = Net irrigation requirement (mm)

ETc = Reference crop evapotranspiration (mm/day)

Pef = Effective precipitation (mm/day)

3.6.3.2 Effective Precipitation (Rainfall)

Effective precipitation is defined as the portion of precipitation that is effectively used by the crop after losses from surface runoff and deep seepage have been taken into account. Effective precipitation is the precipitation that is ultimately used to determine the crop's irrigation needs.

Monthly rainfall data are required to calculate the effective precipitation (on monthly basis) P_{ef}, which can be calculated depending on the USDA Soil Conservation Service method provided in the CROPWAT model (FAO, 1998).

When total rainfall is < 250 mm, effective rainfall (P_{ef}) is given by the following equation;

$$\text{Pef} = \frac{TR * (125 - 0.2 * TR)}{125} \qquad 3.5$$

When total rainfall is > 250 mm, effective rainfall is given by the following equation;

$$P_{ef} = 125 + 0.1 \times TR \qquad 3.6$$

Where TR is Total rainfall

3.6.3.3. Gross irrigation Water requirement (GIWR)

Gross irrigation water requirement is the net irrigation requirement divided by irrigation efficiency. It is described according to (FAO, 2002).

$$\text{GIWR} = \frac{NIWR}{E * T} \qquad 3.7$$

Where, GIWR = the gross irrigation requirement of crops (m^3/s) and

E = overall Efficiency of irrigation in percentage.

T= time of irrigation

Irrigation efficiencies: Efficiency is the ratio of the water output to the water input, and is usually expressed as a percentage. Input minus output is nothing but losses, and hence, if losses are more, the output is less, and therefore, efficiency is less. According to (FAO, 1997) recommendations on the irrigation schemes, irrigation efficiency for Ethiopian highlands is given as 50%.

3.7. Assessment of water availability

WEAP model was used to evaluate and analyses the surface water resources available in Sibilu watershed based on the observed river flow (1990-2011) at near Chancho station. The flow data was input to WEAP system in order to know the available water resources in monthly and annual bases.

3.7.1. Meteorology data

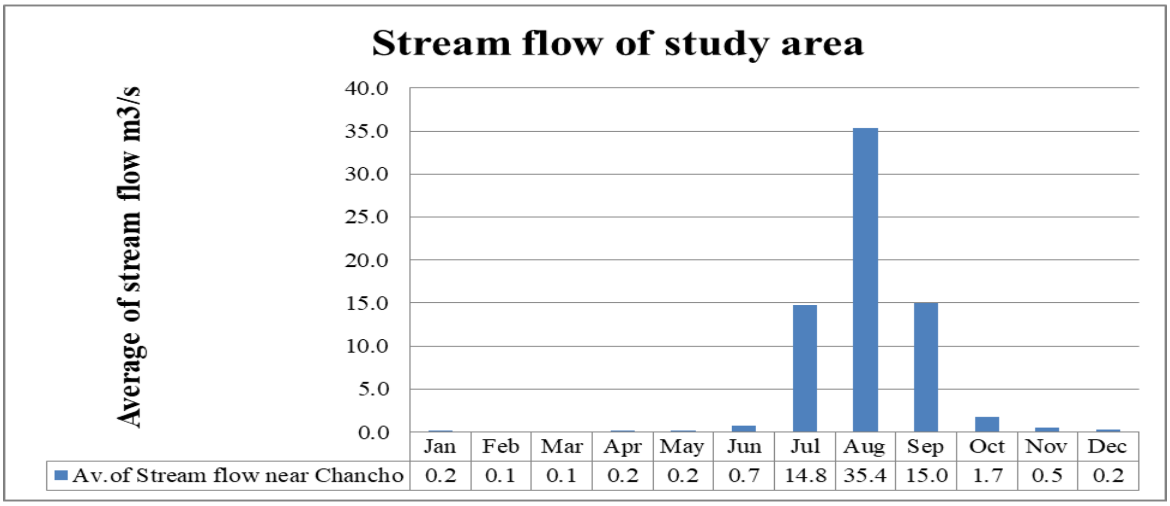
The metrological data in Sibilu watershed were: precipitation, maximum and minimum temperature, solar radiation, wind speed, and relative humidity on monthly basis were analysis. There were thirty one years (1990-2021) Monthly meteorological data taken from Sululta, Intoto, Addis Ababa observatory, Derba and Chancho stations were collected from National Meteorology Agency.

3.7.2. Hydrological data

The main objective of the hydrological data was estimation of water availability and its reliability, for performing sensitivity analysis, calibration and validation of the model. The monthly observed data is required for (WEAP) input as a head flow of the stream in the study area and this data was taken from Ministry of Water and Energy Hydrological Department for the period 1990-2011.Flow data was collected and arranged as per the requirement for WEAP model.

3.7.2.1. Stream flow of data

Stream flow records are important to make accurate surface water availability assessment. Available stream flow data of gauged perennial rivers in the sub basin was obtained from Ministry of water, Irrigation and energy. From the available flow data the sequence of the rivers would be carefully checked for homogeneity in order to have discharged series as long as possible for the necessary base flow analysis.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Av.of Stream flow near Chancho	0.2	0.1	0.1	0.2	0.2	0.7	14.8	35.4	15.0	1.7	0.5	0.2

Figure 3.12: Average stream flow of study area at Chancho station

3.8. Water Demand

Water demand was defined as the volume of water requested by users to satisfy their needs. In general water demand projections and calculations were done by estimating the irrigation water demand in the watershed.

3.8.1. The WEAP Model

The WEAP System model was developed by the SEI to enable evaluation of planning and Management issues associated with water resources development. The WEAP model can be applied to agricultural systems and can address a wide range of issues including sectorial demand analyses, water conservation, water rights and allocation priorities, stream flow simulation, reservoir operation, ecosystem requirements and project cost-benefit analyses (Sieber, 2015).

3.8.2. Model Calibration

The model calibration is to adjust the parameters so that the model solutions fit the observations in an optimal fashion (Jariwala & Vadher, 2016).

WEAP model was calibrated using observed stream flow data obtained from Ministry of water, Irrigation and Energy for the period of 1990-2000.

WEAP simulation results entirely depend on the quality of the input data like hydrological and meteorological data.

3.8.3. Model Validation

Model validation entails assessing the performance of the calibrated model using a segment of historical records not utilized during the calibration process. In this phase, diverse validation criteria, formulated from a comparison between observed and computed output records, are employed.

In this particular study, measured stream flow data from the Sibilu River near Chancho spanning the period of 2001-2011 were integrated for validation purposes. These data serve as an independent dataset, allowing for an objective evaluation of the model's accuracy and reliability in representing real-world hydrological processes.

Model Evaluation

Results of the calibration and validation were evaluated graphically and statistical procedures with that of quality criteria. The statistical parameters employed in measure of model quality are coefficient of determination (R^2), Nash-Sutcliffe modeling efficiency (NSE), Root mean square error observation standard deviation ratio (RSR) and percent bias (PBIAS) have been used. Some of the model performance indicators used in this study are described below

Coefficient of determination (R^2): the index of correlation of measured and simulated values. The value of R^2 ranges from 0 to 1. The more the value of R^2 approaches 1, the better was the performance of the model and the values of R^2 less than 0.5 indicate a poor performance of the model.

$$\boldsymbol{R^2} = \left[\frac{\sum_{i=1}^{n}(O_i-\bar{O})(S_i-\bar{S})}{\sqrt{\sum_{i=1}^{n}(O_i-\bar{O})^2}\sqrt{(S_i-\bar{S})^2}}\right] \qquad 3.8$$

Where, $\boldsymbol{n}$ is number of observations, $\bar{\boldsymbol{S}}$ is mean simulated value, $\bar{\boldsymbol{O}}$ is mean observed value,

$\boldsymbol{S_i}$is simulated value and $\boldsymbol{O_i}$is observed value.

Nash-Sutcliffe Efficiency (NSE): Nash-Sutcliffe defines the extents of variation between simulated to observed data discrepancy and Nash-Sutcliffe coefficient measures the efficiency of the model by relating the goodness-of- fit of the model to the variance of the measured data, which can range from −∞ to 1. An efficiency of 1 corresponds to a perfect match of simulated discharge to the observed data. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero ($-\infty < NSE < 0$) occurs when the observed mean is a better predictor than the model. Besides, due to frequent use of this coefficient, it is known that when values between 0.6 and 0.8 are generated, the model performs reasonably. A value between 0.8 and 0.9 tells that the model performs well and a value between 0.9 and 1 indicates that the model performs extremely well (Zeybek, 2018). The formula for Nash Sutcliffe (NSE) was the normalized statistics which measures the relative magnitude of the residual variance as compared to measured data variance. Similar to R^2, the more the NSE approaches 1, the better will be the model performance and vice versa.

$$NSE = 1 - \left[\frac{\sum_{i=1}^{n}(Q_{m,i} - Q_{s,i})^2}{\sum_{i=1}^{n}(Q_{m,i} - \overline{Q})^2}\right] \quad 3.9$$

Where Q_m is observed flow at ith period, Q_s is simulated flow at the i_{th} period and $\overline{Q}$ was mean of the observed flow.

Percent bias (PBIAS): This measures the average tendency of the simulated data to be larger or smaller than the observed values. PBIAS was expressed in percentage; the lower the absolute value of the PBIAS was the better would be the model performance.

$$\mathbf{PBIAS} = \left[\frac{\sum_{i=1}^{n}(O_i - S_i) * 100}{\sum_{i=1}^{n}(O_i)}\right] \quad \mathbf{3.10}$$

The evaluation of the model accuracy has been based on performance ratings: very good, good, satisfactory and unsatisfactory based on (Moriasi et al., 2007) suggestion of model performance evaluation criteria.

Table 3.10: General performance rating criteria (Moriasi et al., 2007).

Rating	RMSE	NSE	PBIAS	
			Flow	Sediment
Very good	$0.0 \leq$ RMSE ≤ 0.5	$0.75 <$ NSE ≤ 1	$\leq \pm 10$	$\leq \pm 15$
Good	$0.5 <$ RMSE ≤ 0.6	$0.65 <$ NSE ≤ 0.75	± 10 to ± 15	± 15 to ± 30
Satisfactory	$0.6 <$ RMSE ≤ 0.7	$0.5 <$ NSE ≤ 0.65	± 15 to ± 25	± 30 to ± 55
Unsatisfactory	RMSE ≥ 0.7	NSE ≤ 0.5	$> \pm 25$	>55

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1. Irrigation Potential for Surface Irrigation

The process of irrigation potential for surface irrigation suitability classification was the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 2007).The study results of surface irrigation suitability were defined by considering; Slope, Land use and land cover, soil type, river proximity.

4.1.1. Slope suitability

The Slope was classified based on the suitability classification system of (FAO, 1996) using the Reclassify tool, which was an attribute spatial analysis tool in ArcGIS software. Slope suitability class of the watershed was identified for irrigation development. Slope class, expressed as percentage of the configuration of land has been considered as one of the land unit factor used for land suitability evaluation for irrigation. Slope of the area were classified as four suitability classification in terms of irrigation development. These were highly suitable (S1), moderately suitable (S2), Marginally Suitable (S3) and Non suitable (N) of the study area for the development of irrigation system of an area. The study area was predominately by slope class of 0-8% covering about 39.2% and >8 % occupying 60.8 %. The following table 4.1 shows that suitability classes with area coverage of slope of the study area for irrigation development.

Table 4.1: Slope suitability for surface irrigation

S/No.	Slope Class	Suitability	Area (ha)	Area (%)
1	0-2	S1	2341.7	3.7
2	2-5	S2	11149.1	17.4
3	5-8	S3	11595.6	18.1
4	>8	N	38888.5	60.8

The result of slope suitability was 2341.7ha (3.7%) highly suitable, 11149.1ha (17.4%) was moderately suitable, 11595.6ha (18.1 %) was marginally suitable and 38888.5 ha

(60.8 %) was currently not suitable for surface irrigation in the study area based on the slope classification. The slope 0-2% was small in the study area, indicating that the highly suitability result was small.

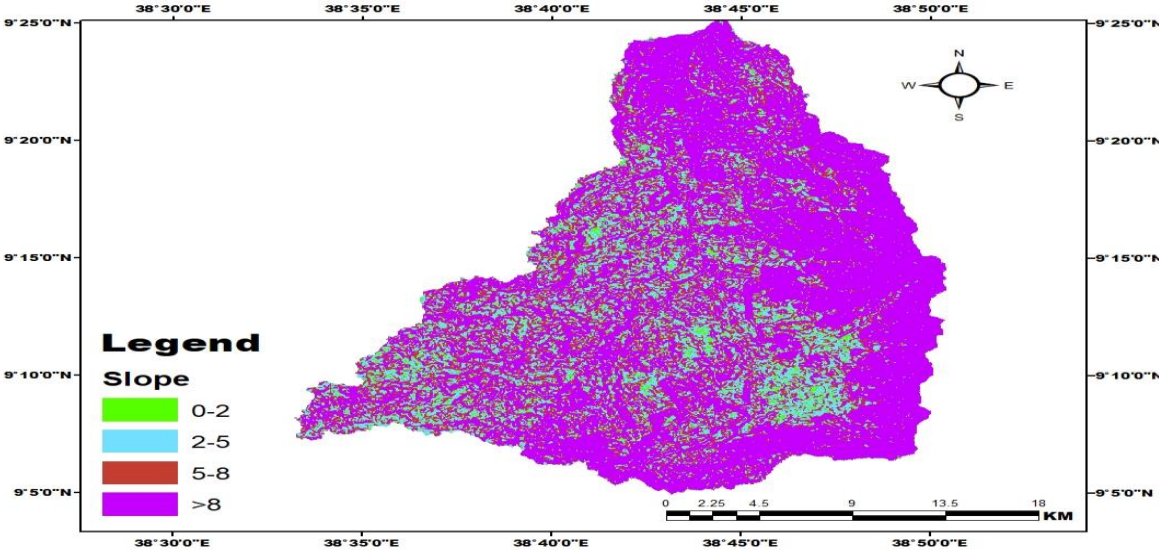


Figure 4.1: Slope suitability map of study area

4.1.2. Land use and land cover suitability

The major land use/land covers of the study area are cultivated land, grass land, bush shrub land and settlement, forest, bare land. The suitability results of land use and land cover of the study area shows that 37536ha (58.6%) is classified as highly suitable, 16214.5ha (25.3%) moderately suitable, 1871.9ha (2.9%) marginally suitable and 10832ha (13.4%) is not suitable for irrigation development. The table 4.2 below shows the area coverage and their suitability for irrigation development of different land use land cover of the study area.

Table 4.2: Land use and Land cover suitability for surface irrigation

S/No.	LULC Class	Area (ha)	Area (%)	Suitability
1	Cultivated land, Forest	37536	58.6	Highly Suitable
2	Grass land	16214.5	25.3	Moderate Suitable
3	Bush Shrub land	1871.9	2.9	Marginal Suitable
4	Settlement, bare land	10832	13.4	None suitable

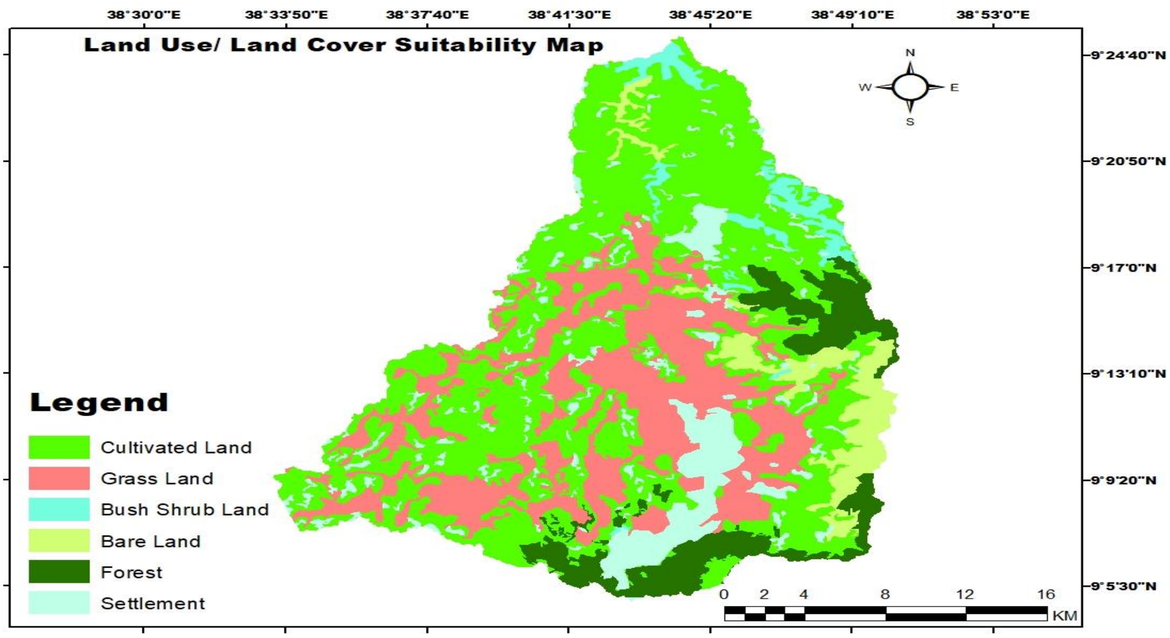


Figure 4.2: Land use and land cover suitability of study area

4.1.3. Soil suitability

The soil suitable for surface irrigation was obtained by making weighted overlay analysis that encompasses sets of soil properties such as soil texture, soil depth, and soil drainage to evaluate soil suitability for irrigation. Generally, suitability is classified into four suitability classes; S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable).

4.1.3.1. Soil texture suitability

The texture of surface soil layers of the fine earth fractions indicated that clay, sandy clay, clay loam, loam, sandy clay loam and sandy loam. The surface soil textures identified in the basin are conducive for irrigated agriculture from the perspective of aeration, drainage and water management.

Table 4.3: Soil texture suitability for surface irrigation

No.	Soil Texture Class	Area (ha)	Area (%)	Suitability
1	Clay loam(CL),Loam (L)	30349.4	47.2	S1
2	Sandy Clay Loam(SCL),Clay(C)	31165.2	48.4	S2
3	Sandy Loam(SL)	2817.9	4.4	S3

The soil texture suitability result for surface irrigation of the study area were 30349.4 ha (47.2 %) of the soil texture in the watershed highly suitable (S1), 31165.2 ha (48.4 %) of the soil texture moderately suitable (S2), and 2817.9 ha (4.4%) of the soil texture in the watershed marginally suitable (S3) class.

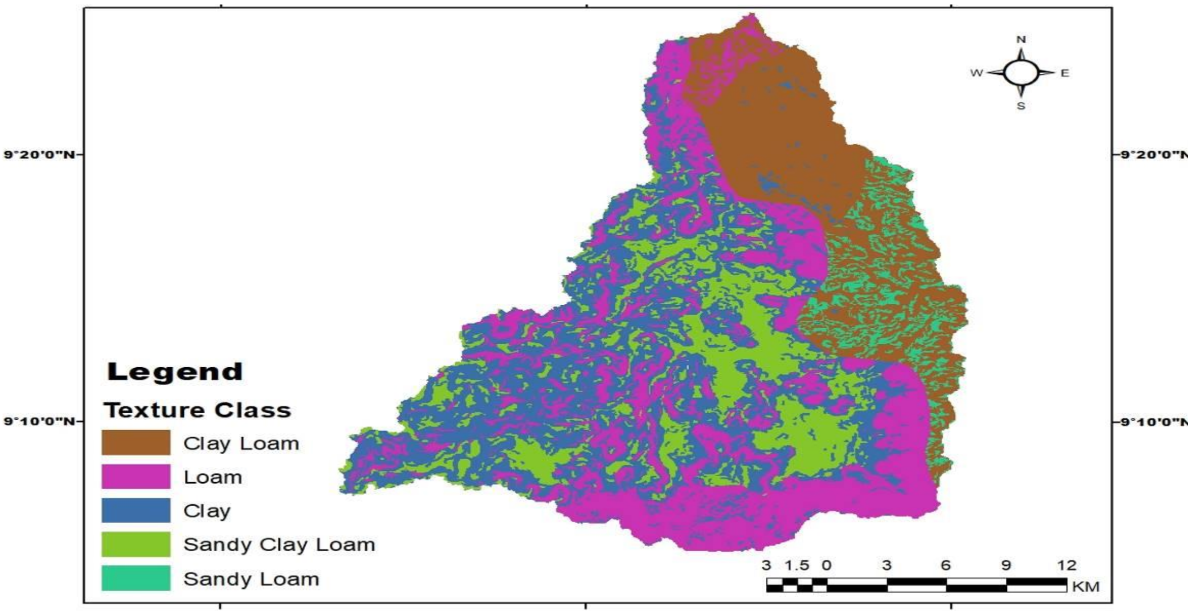


Figure 4.3: Texture suitability for surface irrigation

4.1.3.2. Soil depth suitability

Soil depth refers to the thickness of the soil materials which provide structural support, nutrients and water for plants. The depth of soil that can be effectively exploited by plant roots was an important criterion in the selection of land for irrigation. A soil depth variation from place to place determines the growth of plants and also affects the growth of plant roots. The thickness of the soil materials, that provide structural support, nutrients, and water for crops, was referred to as soil depth.

The soil depth of the study area was divided into four: >120, 100-120, 50-100 and < 50cm with a suitability class S1, S2, S3, N according to(FAO, 1996) respectively. Soil depth in sibilu watershed was evaluated for surface irrigation in terms of highly suitable, moderate suitable, marginally suitable and not suitable class with the area coverage of 66.7%, 5.7%, 8.3% and 19.2% respectively. Based on the soil depth assessment most of the study area was dominantly suitable for surface irrigation development. As the result shows, 66.7% of the total area was highly suitable for surface irrigation development concerning soil depth suitability. They were shown on the table 4.4 and figure 4.4 below.

Table 4.4: Depth suitability for surface irrigation

No.	Soil Depth Class	Area (ha)	Area (%)	Suitability
1	>120	42941.4	66.7	S1
2	100-120	3657.8	5.7	S2
3	50-100	5358.7	8.3	S3
4	<50	12374.5	19.2	N

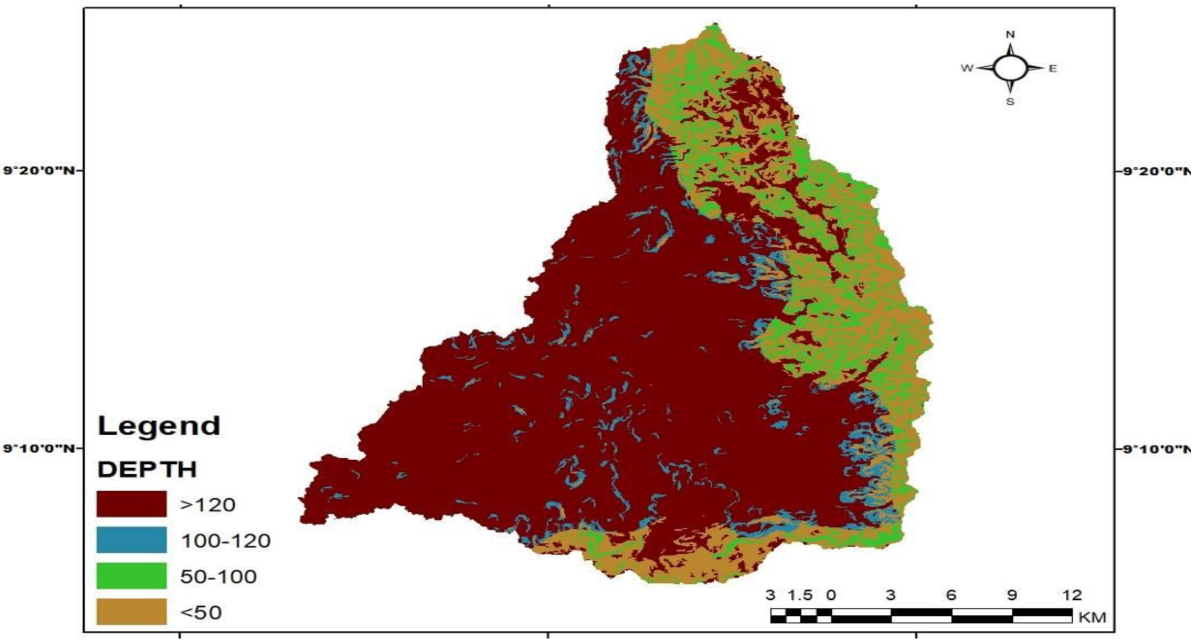


Figure 4.4: Depth suitability map of study area.

4.1.3.3. Soil drainage suitability

Soil drainage condition reflects the combined effects of climate, landscape, and soil. Soil permeability, surface infiltration rate internal vertical and lateral movement of water, and external surface run-off and run on may all affect the drainage. Drainage was an important criterion in crop suitability evaluation as it determines the availability of oxygen to roots.

(FAO, 1997) suggested that the soil drainage condition of a specific area be classified into; well-drained, moderately well-drained, imperfectly drained, poorly drained, and very poorly drained.

Table 4.5: Drain age suitability for surface irrigation.

S/No.	Soil Drainage Class	Area (ha)	Area (%)	Suitability
1	Well drained	28466.7	44.2	S1
2	Moderately Well drained	19984.4	31.1	S2
3	Excessively	4799.7	7.5	S3
4	Poor drainage	11081.6	17.2	N

From the above table well-drained class 44.2% (28466.7 ha) was distributed under highly suitable, 31.1% (19984.4ha), moderately suitable, 7.5% (4799.7 ha) was classified as marginally suitable and were as 17.2 %(11081.6 ha) poor suitable class were not suitable for surface irrigation according to FAO guidelines.

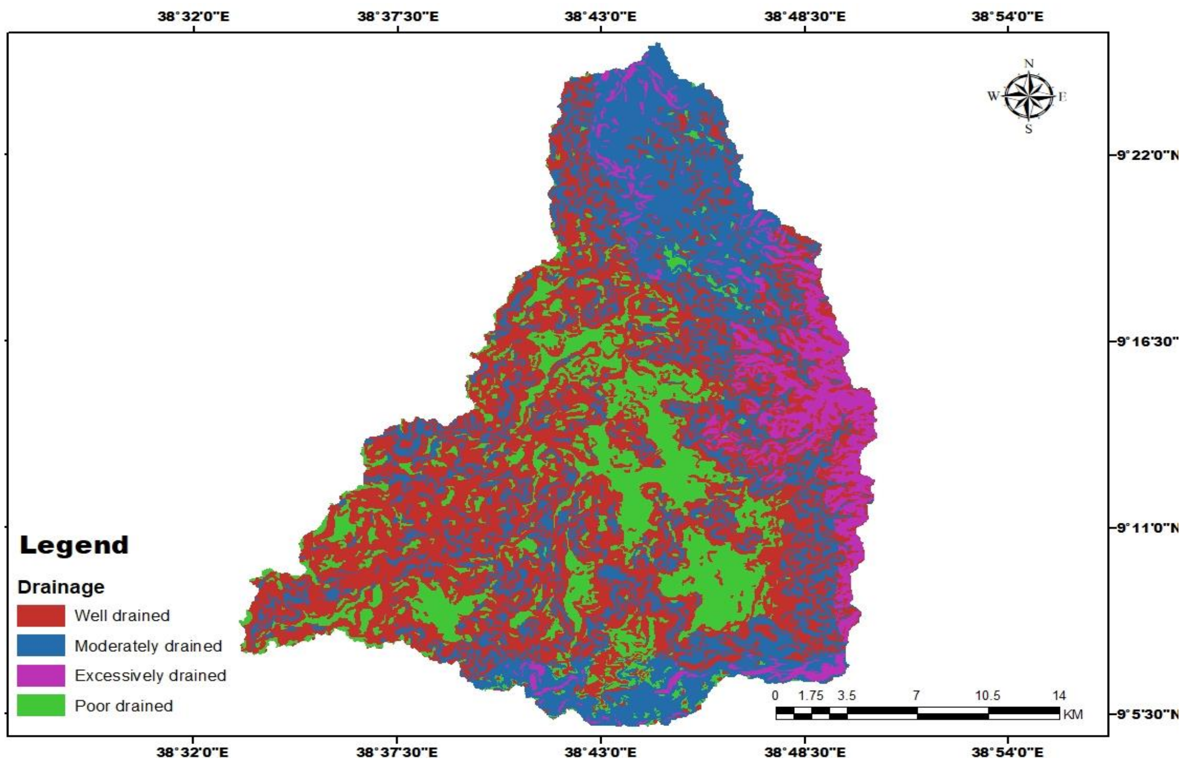


Figure 4.5: Drainage suitability map of study area.

4.1.4. Soil type suitability

The soil type suitability described in the study area was Luvisols,vertisols,cambisols and leptosol.When considering soil suitability of potential irrigation assessment attentions were given only for those soil properties that cannot improved and/or modified through soil management. Accordingly soil suitability of the study area was relay depends on permanent soil physical properties of effective root depth, soil texture and soil drainage of basin.

Table 4.6: Soil type suitability for surface irrigation

S/ No.	Soil type Class	Area (ha)	Area (%)	Suitability
1	Luvisol	40874.5	63.5	S1
2	Vertisol	822	1.3	S2
3	Cambisols	14039.5	21.8	S3
4	Leptosol	8596.5	13.4	N

The results of soil suitability analysis shown from the above table the study area can be generally classified into four soil suitability classes for irrigation development: S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable) and N (not suitable). Then the soil suitability result were 40874.5 (63.5%) were classified as highly suitable, 822ha (1.3%) classified as moderately suitable, 14039.5 ha (21.8%) classified as marginally suitable and the rest of the area 8596.5 ha (13.4%) were classified as non-suitable for irrigation development.

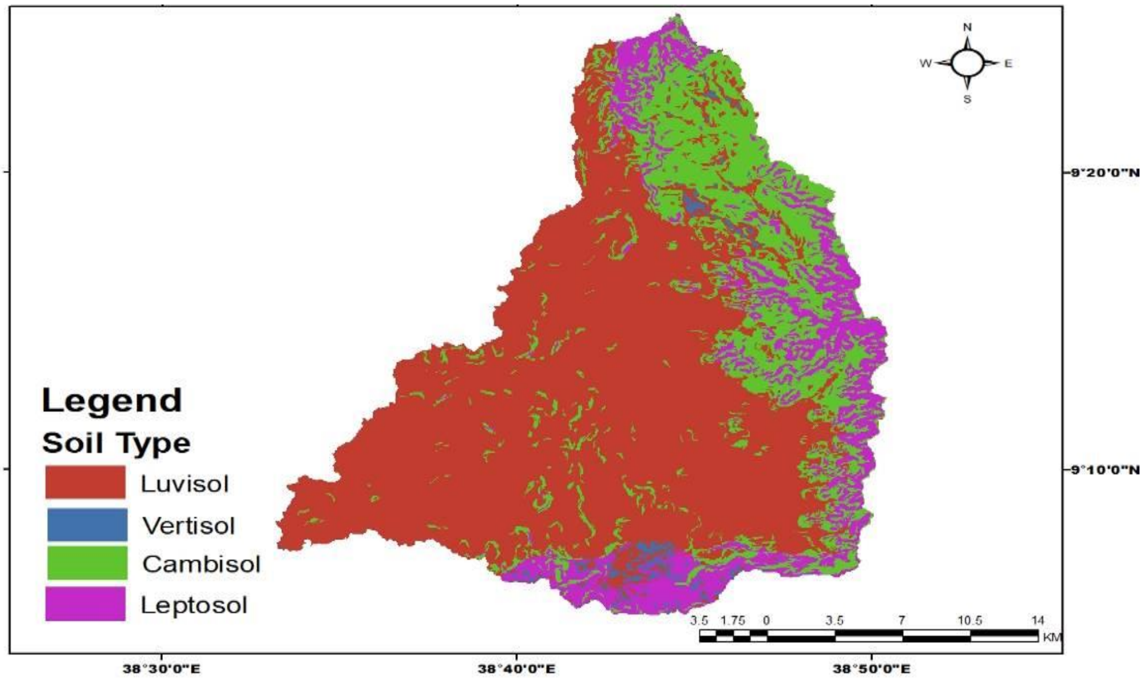


Figure 4.6: Soil type suitability map of study area.

4.1.5. River proximity/ Distance to the Water

The river proximity/distance to the water were used as a basis for the present study and completed with more detailed information on the variation in water discharges in space and time. This information was compared with surface runoff estimates, calculated for each of the outlets (in GIS) and based on the surface runoff map of Basin. Knowing Potential yield which was defined as the amount of water resources, be it surface water, which was generated on a yearly basis in a given area and base flow are crucial. Based on the distance from the water source, was shown in Table 4.7 and Figure 4.7.

Table 4.7: River proximity suitability for surface irrigation

S/ No.	River proximity Class	Area (ha)	Area (%)	Suitability
1	<1	10070.2	15.6	S1
2	1-2	9453.6	14.7	S2
3	2-3	8420.1	13.0	S3
4	>3	36429.6	56.6	N

The results of river proximity for surface irrigation were 10070.2 ha (15.6%) highly suitable, 9453.6 ha (14.7%), moderately suitable, 8420.1 (13.0%) marginally suitable and 36429.6 (56.6%) not suitable for irrigation.

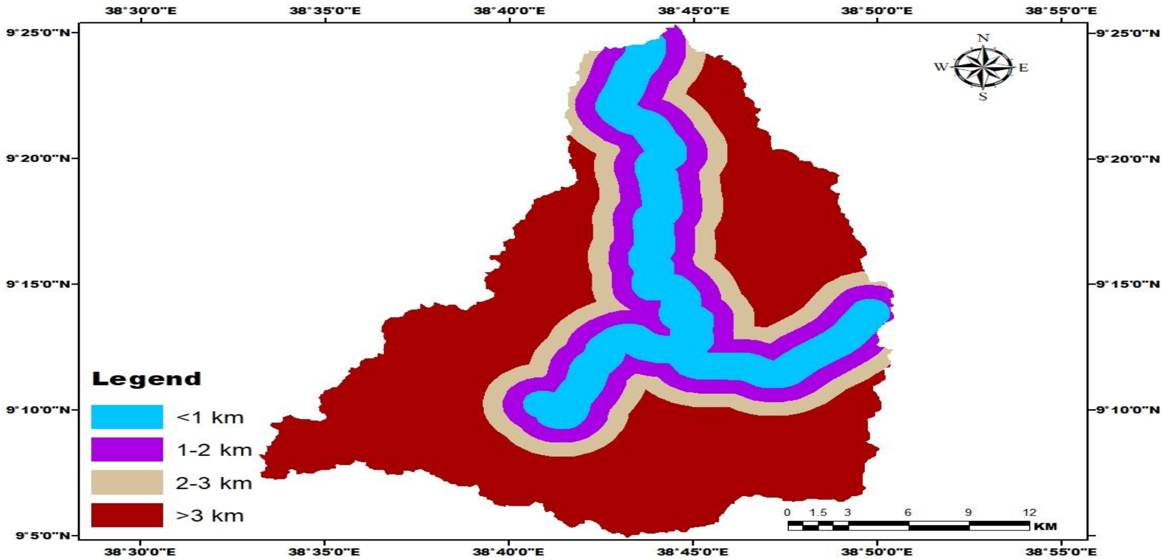


Figure 4.7: River proximity suitability of map study area

4.2. An overall suitable land for surface irrigation

Irrigation potential is the land area, which is potentially irrigable. Country/regional studies assess this value according to different methods, for example some consider only land resources suitable for irrigation, others consider land resources plus water availability, others include in their assessment economic aspects (such as distance and/or difference in elevation between the suitable land and the available water) or environmental aspects, etc.

Accordingly, this study refers to irrigation suitability model analysis which involved weighting of values of all suitability factors such as slope, soil type, land use and land cover, depth, drainage, texture and river proximity suitability. The seven suitability parameters used (Slope suitability, soil suitability, land use and land cover suitability, depth suitability, drainage suitability, texture suitability and proximity or distance to river suitability) were weighted overlay potentially irrigable sites in the study area.

The Result of the weighted overlay analysis of the irrigation suitability model was presented in table 4.8 and figure 4.10 as shown in the following.

Table 4.8: Over all suitable classification for surface irrigation

S/No.	Suitability class	Description	Area (ha)	Area coverage (%)
1	S1	Highly suitable	23019.4	36.2
2	S2	Moderately Suitable	32828.8	51.6
3	S3	Marginally suitable	7351.2	11.6
4	N	Not Suitable	428.4	0.7

The final result of the suitability analysis was categorized according to their weighted overlay analysis suitable level with respect to their area as shown in (Table 4.9). From the total area coverage 36.2% (23019.4 ha) was classified as high suitable, 51.6% (32828.8 ha) moderately suitable, 11.6% (7351.2ha) marginally suitable, whereas 0.7% (428.4ha) currently not suitable for surface irrigation. To determine the net irrigated area by considering slope, soil, depth, land use land cover and the existing land features, the corresponding irrigable in the study area was 63199.4ha.

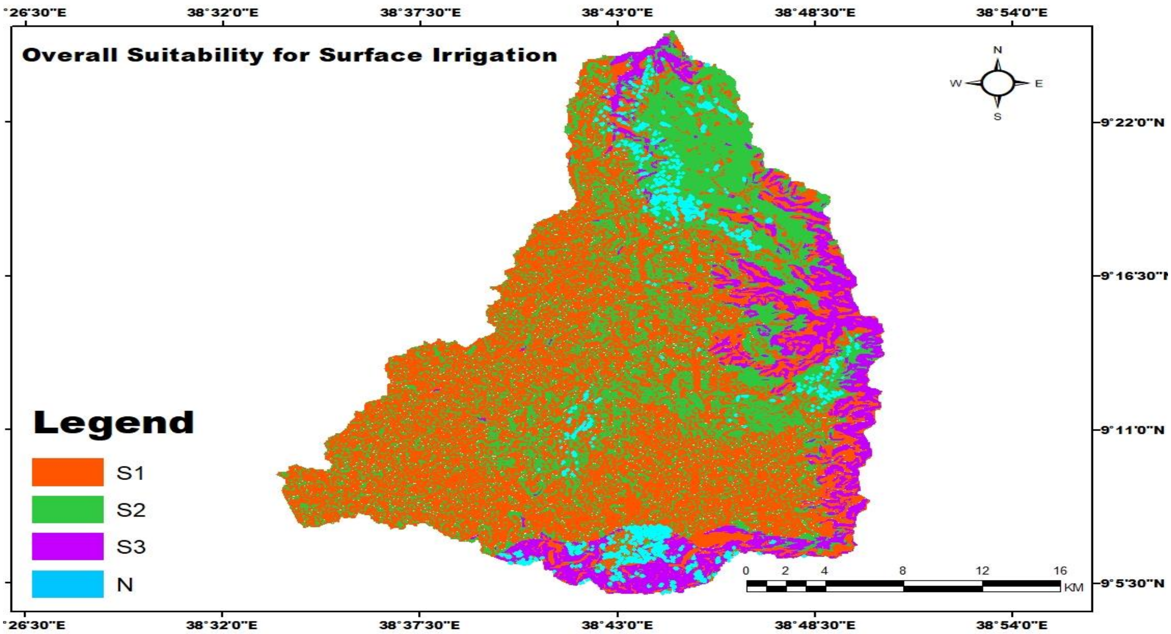


Figure 4.8: Overall land suitable for surface irrigation map of study area

4.3. Irrigation Water Requirements of the study area

Irrigation water requirement of a crop refers to the amount of water needed to be applied or supplied by irrigation in order to meet the water requirement of the crop for optimum growth and yield. The irrigation water requirement of selected crops was done using reference evapotranspiration, crop coefficient, crop water requirement or consumptive use. The effective rain fall, ETo and net and gross irrigation water requirements were calculated using the CROPWAT 8.0 software.

Table 4.9: Rainfall and Monthly Evapotranspiration of the study area

Mon	Jan	Feb	Mar	Apr	May	Jul	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rain mm	14	25	59	74	88	140	320	323	138	20	6	6	1213
ETo mm/day	2.7	3.0	3.3	3.36	3.32	3.18	3.01	3.07	3.21	3.1	2.87	2.63	36.7

Table 4.10: Rainfall and effective rainfall of the study area

Mon	Jan	Feb	Mar	Apr	May	Jul	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rain mm	14	25	59	74	88	140	320	323	138	20	6	6	1213
Eff rain mm	0	5	25.4	35.2	46.4	88	232	234.4	86.4	2	0	0	754.8

The average annual rainfall for the study area is 1213mm and the effective rainfall used by the crops is 754.8 mm which is 62.2 % of the average annual rainfall.

Operational Calendar for Crop pattern

Selected crops to be grown in the area were calculated assuming double-cropping practice in the area. After crops of the first phase, cultivation was harvested; land preparation was overtaken and the second phase cultivation was lead using the intended irrigation method. According to the crop calendar of the area, the first phase of land preparation and second land preparation finished the planting of crops were followed. The planting and harvesting phase for double cultivation has shown in Table 4.11.

Table 4.11: Crops cultivation calendar

Crop name	Sowing date	Harvesting date	Sowing date	Harvesting date
Wheat	Oct-01	Jan-28	Mar-01	July-07
Barley	Oct-01	Jan-18	Mar-02	Jun-28
Bean	Oct-01	Feb-02	Mar-03	Jun-19
Pepper	Oct-01	Feb-02	Mar-04	May-05
Potato	Oct-01	Feb-02	Mar-05	July-11

ET_C or CWR was estimated using climate data for the CROPWAT 8.0 model.

Table 4.12: Seasonal Net and Gross water requirements

Crop name	Net irrigation water requirement(mm)	Gross irrigation water requirement(mm)	Gross water required(m^3/ha)
Wheat	265.5	531.0	5310
Barley	279.2	558.4	5584
Bean	254.9	509.8	5098
Pepper	300.6	601.2	6012
Potato	324.5	649.0	6490

The final results of Irrigation water requirements at the identified potential irrigable area under surface irrigation methods were estimated. The total net and gross irrigation water requirements are 265.5 mm and 531.0 mm for wheat,279.2 mm and 558.4 mm for barley,254.9 mm and 509.8 mm for bean,300.6 mm and 601.2 mm for pepper and 324.5 mm and 649.0 mm for potato respectively.

4.4. WEAP Model Calibration

The Calibration was achieved by estimating the historic pattern of water demand and simulating the resultant flows (Arranz & McCartney, 2007).The WEAP model was calibrated using observed flow data obtained from Sibilu river gauging stations located on the Chancho station. The stream flow data from the Chancho station gauging stations have been recorded from 1990-2011, respectively. The model was calibrated using observed stream flow data obtained from MoWIE for Sibilu watershed. Naturalized stream flows for a period of the years (1990 to 2000) were used to calibrate WEAP model.

The quantitative statistics (coefficient of determination, R^2; Nash-Sutcliffe efficiency, NSE and Percent Bias, PBIAS) were computed for each set of simulated and historical observed stream flow over the period 1990-2000, the result which is R^2 =0.77,NSE=0.71 and PBIAS=17.02. The value of simulated and observed flows provides a good estimate and shows on the table below.

Table 4.13: Results of stream flow and performance evaluation during calibrated period (1990-2000)

	Monthly observed	Monthly simulated	Objective function	Calculated value	Acceptable limits	Decision criteria
Mean	7.7	9.02	NSE	0.71	0.65<NSE,≤0.75	Good
Min	0.03	0.15	PBIAS	17.02	±15 to ±25	Satisfactory
stdev	15.15	9.93	R^2	0.77	Close to 1	Better
Obs	132	132				

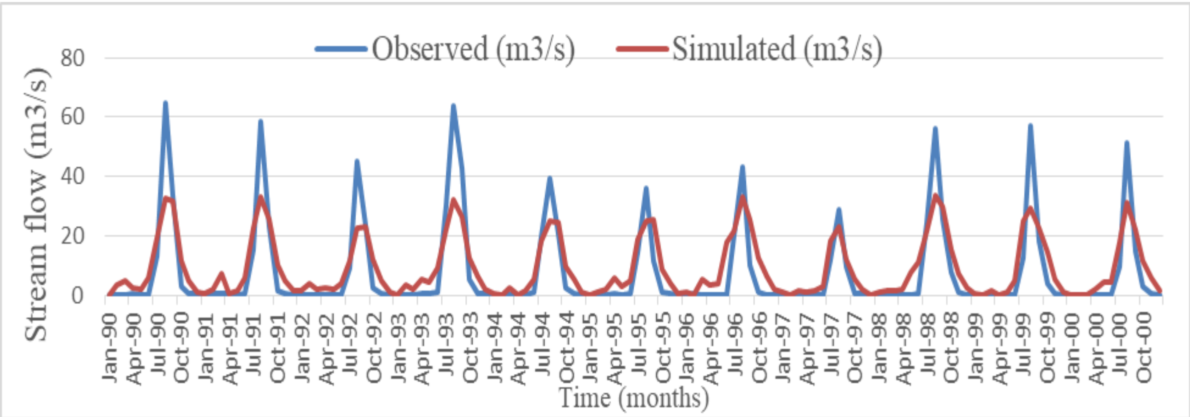


Figure 4.9: Comparison of simulated and observed monthly stream flow for the calibration period (1990-2000)

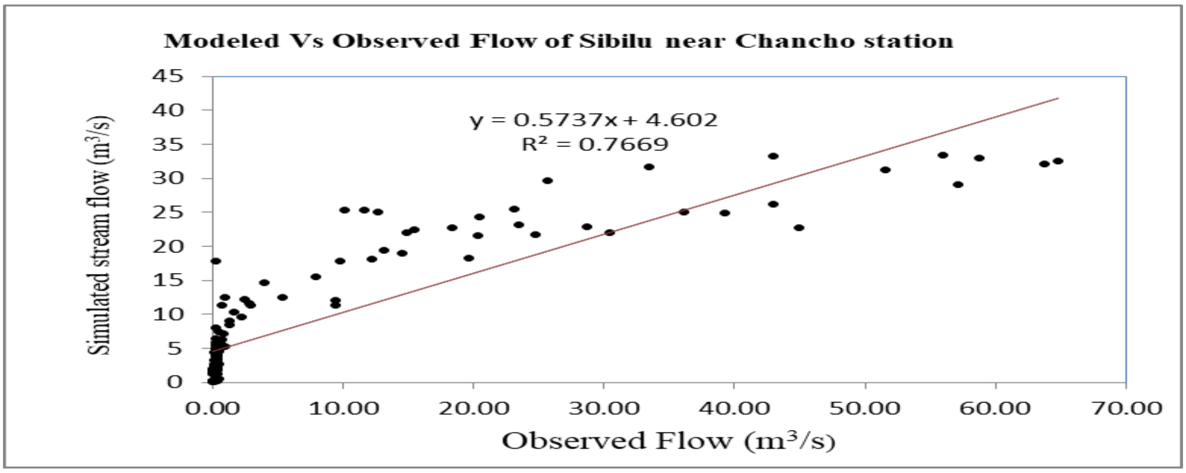


Figure 4.10: R square of observed and modeled flow calibration

4.5. Model Validation

The validation of watershed was evaluated from the period (2001-2011) which identified from calibration period. The objective functions that were used for evaluation like coefficient of determination, Nash Sutcliff efficiency, and percent of baize were in the acceptable range for the validation time of model in the monthly time step and R^2=0.74, NSE=0.7 and PBIAS=9.41 shows on the bellows figure 4.11 and table 4.14: for the validation period which shows good agreement between the simulated and observed flows of the watershed shown on table below.

Table 4.14: Results of stream flow and performance evaluation for validation periods 2001-2011)

	Monthly observed	Monthly simulated	Objective function	Calculated value	Acceptable limits	Decision criteria
Mean	8.42	9.43	NSE	0.7	0.65<NSE,$\leq$0.75	Good
Min	0.03	0.15	PBIAS	9.41	$\pm$15 to $\pm$25	Very good
stdev	15.15	9.93	R^2	0.74	Close to 1	Better
Obs	132	132				

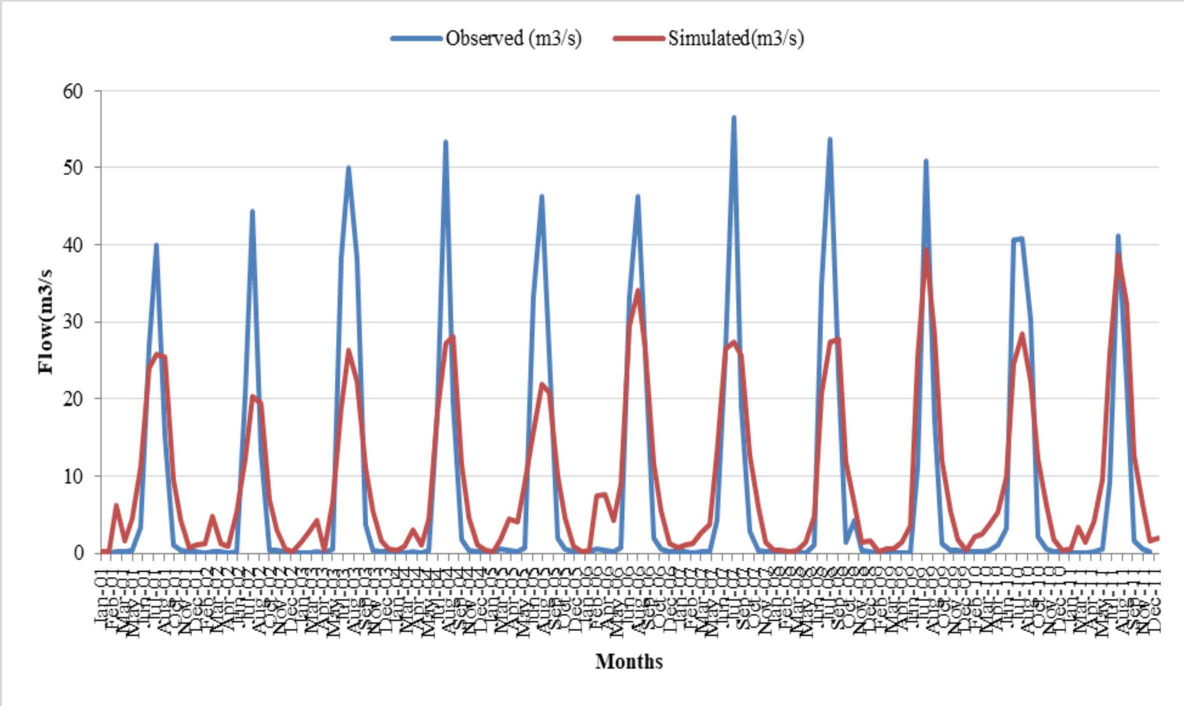


Figure 4.11: Simulated monthly flow for the validation period (2001-2011)

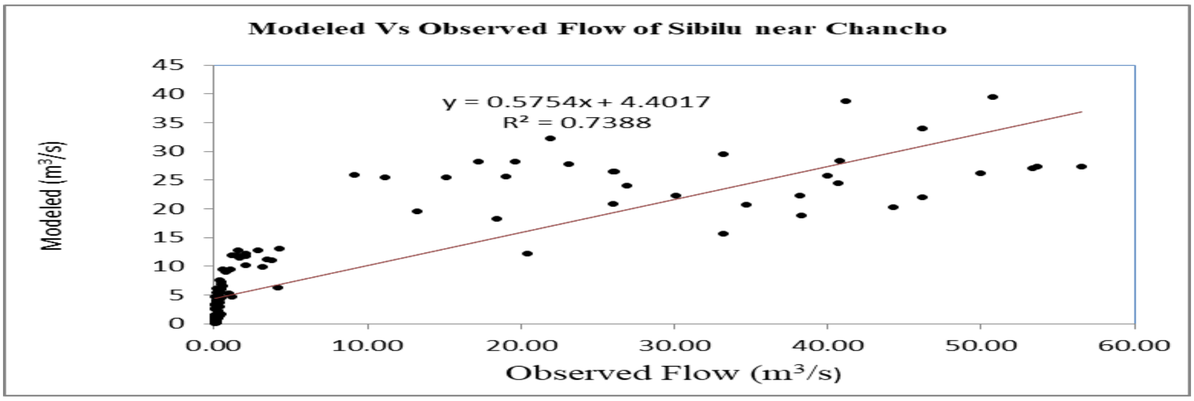


Figure 4.12: R square of observed and modeled flow validation

4.6. Assessment of water availability

4.6.1. Stream flow

The annual stream flow volume of Sibilu watershed was estimated and at the base year flow is 183.9Mm^{3}and the total net irrigation water demand for all selected crops wheat, barley, bean, pepper and potato irrigable land was 88Mm^3, but from available stream flow can irrigate 131426.2 ha of irrigable land. The remained whole irrigable area 63199.4 ha of land requires 88Mm^3 of irrigation water throughout the growing period. The mean monthly flow of the river as shown on the Figure 4.15 indicates that there is high seasonality where 92% of the annual flow is contributed on the 3 months (July, August, September) due to high rainfall occurs in those months. The values of highest monthly average are 39.7Mm^3, 94.8Mm^3 and 38.9Mm^3 respectively. Due to high flow of river at rain season storage structure is required within the study area, because the irrigation was carried out at dry season. The graph which represents by reference is shows the flow volume of the river result from 1990-2011 year and it uses to compare with the scenarios. The annual graph Figure 4.13 shows the volume of stream flow under reference scenarios.

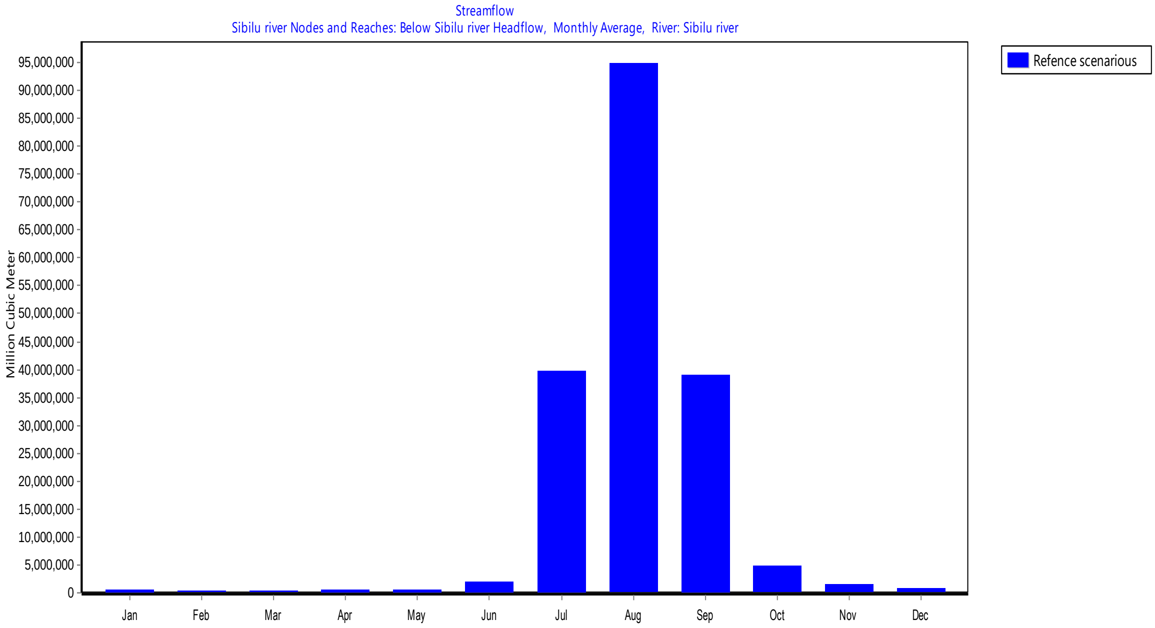


Figure 4.13: Mean monthly stream flow of sibilu watershed under Reference scenarios

4.7. Measures of Assessment of Water Availability

A flow-duration of the Sibilu River was modeled using WEAP on a water per year basis according to data obtained from the flow gauging stations. When the flows are ordered according to frequency of accompaniment and a flow-duration shows by graph. Figure 4.14 shows the flow duration graph of the rivers in the study area which shows the availability of water.

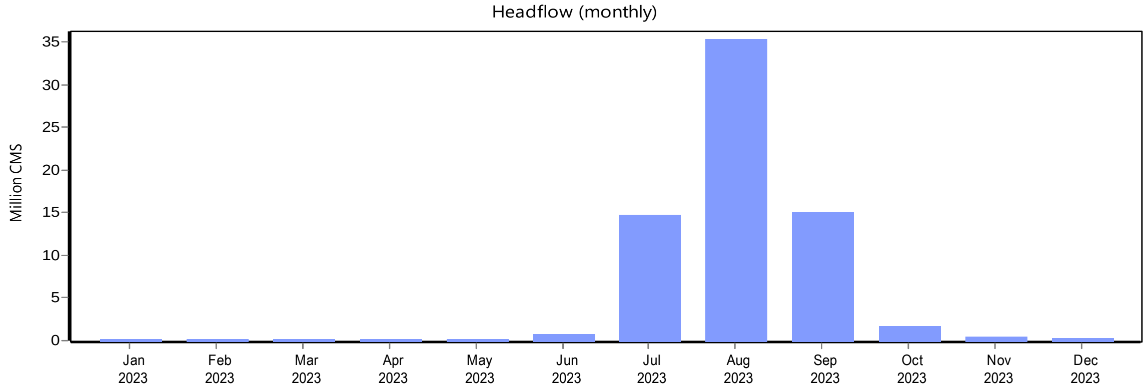


Figure 4.14: Flow duration Sibilu River of study area

4.8. Demand and supply Requirement

The annual total water demand and supply of the catchment including losses reuse and demand side management shows increment at November, December, January, April and May, of supply requirement for irrigation. The total annual water demand for the baseline is estimated as 49Mm^3.

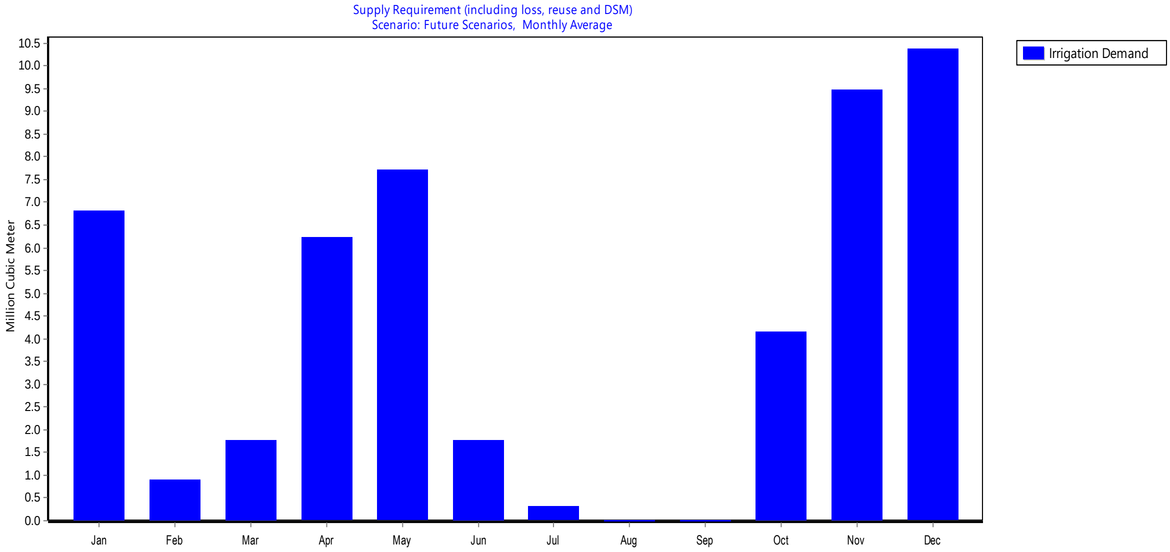


Figure 4.15: Demand and supply water requirements for Irrigation

4.9. Water Demand Sibilu Watershed

4.9.1 Water Demand Results in the Current Account

The Current Accounts consumption represent the basic definition of the water system as it currently exists was developed using demand data and the stream flow data 183.923 Mm^3

in the current account. In the study area there was irrigation water demand. Hence, it was important to look at the nature of the demand in the current account year as it was the base for scenarios demands. The annual water demands for the selected demand sites for the current account year is shown in figure 4.16.

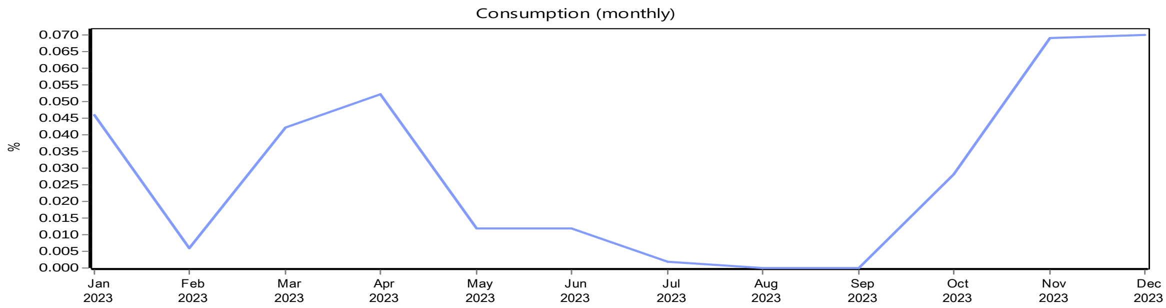


Figure 4.16: Average monthly consumption in current accounts year (2023)

The result shows that the total annual water a demand was consumed by the irrigation demand sites was high. The irrigation demand sites consumed very at October, November, January, April and may in study area sites.

4.10. Unmet Demands under Different Scenarios

Unmet demand was defined as the quantity of water that cannot be physically delivered from the river during a certain period of the year. The results of WEAP shows only irrigation water demand was unmet in the month February, March, June and July. Therefore, the analysis showed that the main water demand sites which get water scarcity problem or high unmet demand are due to increasing of irrigation area.

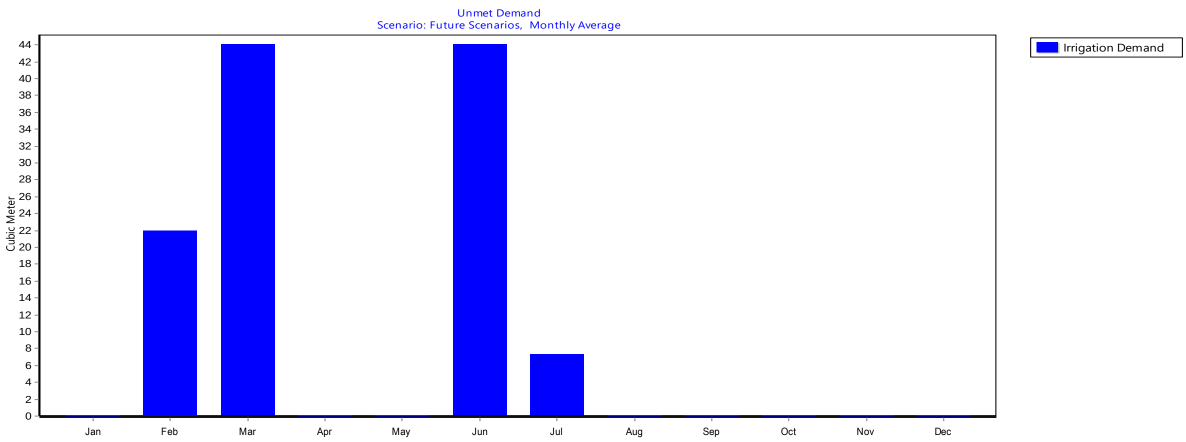


Figure 4.17: The monthly unmet demand of all demand sites, for irrigation demand

CHAPTER FIVE: CONCLCUSION AND RECOMMENDATIONS

5.1 Conclusion

To assess irrigation potential for surface irrigation was carried out through group use of ArcGIS, WEAP and CROPWAT 8.0 Model. Potential suitable land for surface irrigation was assessed using slope; soil type, land use and land cover, and river proximity were in the study area.

The soil types were found to be Vertisols, Luvisols, Cambisols, Leptosol, were the results of soil suitability analysis 40874.5 (63.5%) were classified as highly suitable, 822ha (1.3%) classified as moderately suitable, 14039.5 ha (21.8%) classified as marginally suitable and the rest of the area 8596.5 ha(13.4%) were classified as non-suitable for surface irrigation.

The overall suitable site for surface irrigation result analysis was categorized according to their weighted overlay analysis suitable level with respect the total area coverage of the study area 11.6% (7351.2 ha) was classified as high suitable, 51.6% (32828 ha) moderately suitable, 36% (23019.5 ha) marginally suitable, whereas 0.7% (428.4 ha) currently not suitable for surface irrigation.

Irrigation water requirements of wheat, barley, bean, and pepper and Potato crops were selected for surface irrigation and were the results assessed by using CropWat 8.0 software. The value of irrigation water requirements for above crops were 531mm, 558.4mm, 509.8mm, 601.2mm and 649mm respectively.

The Water availability assessments have been done using WEAP model for simulation of stream flow. The WEAP model was calibrated using data from 1990 to 2000 and validated from 2001 to 2011 monthly data. The quantitative statistics (coefficient of determination, R2; Nash-Sutcliffe efficiency, NSE and Percent Bias, PBIAS) during both the calibration and validation periods were found to be the result which is R2 =0.77, NSE=0.71 and PBIAS=17.02 respectively in calibration. R2=0.74, NSE=0.7 and PBIAS=9.41 for the validation period which shows good agreement between the simulated and observed flows of the watershed.

The annual stream flow volume of Sibilu watershed was estimated and at the base year flow is 183.9Mm^{3}and the total net irrigation water demand for all selected crops was 88Mm^3, but from available stream flow can irrigate 131426.2 ha of irrigable land. The remained whole irrigable area 63199.4 ha of land requires 88Mm^3 of irrigation water throughout the growing period. The mean monthly flow of the river was high seasonality on the 3 months (July, August, September) due to high rainfall occurs in those months. The values of highest monthly average are 39.7Mm^3, 94.8Mm^3 and 38.9Mm^3 respectively. Due to high flow of river at rain season storage structure is required within the study area, because the irrigation was carried out at dry season.

Unmet demand is defined as the quantity of water that cannot be physically delivered from the river during a certain period of the year. The result of WEAP shows irrigation water demand was unmet in the month February, March, June and July. For future if the natural recourse and environmental not protected the scarcity of water supply has been occurred.

5.2 Recommendation

To identify Irrigation potential is an essential asset for successful rural income through improved agricultural production. However, this can be achieved, by assessing land potential and water available for irrigation. Therefore, the assessed surface irrigation potential of the Sibilu watershed supports representatives in the progress of irrigation projects. From the result obtained about 63119.5ha irrigable land could be irrigated within the available water 88Mm^3. Therefore, most of water is highly flow at rain season in order to increase the irrigation potential for surface irrigation storage construction necessary at dry season.

The assessment of irrigation water requirement of identified command areas was carried out by selecting some crops types only. But the future research should select several crops to calculate irrigation requirements of identified potential irrigable land in the study area.

The irrigation potential for surface irrigation was carried out in this research by considering only slope, soil type, land use land cover and proximity of water resource. But the effect of other factors such stones, soil PH, and should be assessed to get consistent result.

Most of the potential of land has been used for grass land than irrigation special at dry season. So community should be awareness how to use surface irrigation.

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LIST OF APPENDINCES

Appendix Table 1; Meteorological station and their location

S/No	Station Name	Longitude	Latitude	Elevation
1	A.A.Observaton	472243	996862	2408
2	Sululta	470700	1015036	2650
3	Chancho	472545	1030146	2480
4	Intoto	469377	1004023	2903
5	Derba	461741	1042561	2385

Appendix Table 2: Location of Stream flow gauge

S/ No.	Site	Catchment Area(km^2)	Location		Period
			Lat. (N)	Long. (E)	
1.	Muger	481	9° 18'00"	38° 44'00"	1990-2011
2.	Sibilu	375	9° 14'00"	38° 45'00"	1990-2011
3.	Deneba	86	9° 16'00"	38° 43'00"	1990-2011

Appendix Table 3: Chancho meteorological station

Country Ethiopia Station Chancho
Altitude 2480 m. Latitude 9.32 °N Longitude 38.75 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.0	25.4	56	2	6.0	16.5	2.70
February	6.2	25.3	52	2	6.4	18.2	3.01
March	6.7	25.4	55	2	6.5	19.3	3.30
April	7.0	25.0	61	2	6.3	19.2	3.36
May	7.2	26.0	59	2	6.3	18.8	3.32
June	6.9	25.1	65	2	5.9	17.8	3.18
July	7.2	24.0	80	2	4.9	16.5	3.01
August	6.8	24.2	83	1	4.9	16.8	3.07
September	6.5	24.9	79	1	5.6	17.9	3.21
October	5.8	25.5	71	2	6.2	18.0	3.13
November	5.6	26.6	65	2	6.1	16.8	2.87
December	5.2	25.2	60	2	6.0	16.1	2.63
Average	6.4	25.2	66	2	5.9	17.6	3.07

Appendix Table 4: Rainfall and effective rain fall study area.

Station: Chancho Eff. rain method: FAO/AGLW formula

	Rain	Eff rain
	mm	mm
January	14.0	0.0
February	25.0	5.0
March	59.0	25.4
April	74.0	35.2
May	88.0	46.4
June	140.0	88.0
July	320.0	232.0
August	323.0	234.4
September	138.0	86.4
October	20.0	2.0
November	6.0	0.0
December	6.0	0.0
Total	1213.0	754.8

Appendix Table 5: Irrigation Water requirement for barley

Crop Water Requirements

ETo station: Chancho Crop: Barley

Rain station: Chancho Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Rec
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.30	0.95	9.5	2.1	7.4
Oct	2	Deve	0.35	1.10	11.0	0.0	11.0
Oct	3	Deve	0.67	2.04	22.5	0.0	22.5
Nov	1	Mid	1.02	3.02	30.2	0.1	30.1
Nov	2	Mid	1.14	3.28	32.8	0.0	32.8
Nov	3	Mid	1.14	3.19	31.9	0.0	31.9
Dec	1	Mid	1.14	3.10	31.0	0.0	31.0
Dec	2	Mid	1.14	3.01	30.1	0.0	30.1
Dec	3	Late	1.14	3.01	33.2	0.0	33.2
Jan	1	Late	0.92	2.47	24.7	0.0	24.7
Jan	2	Late	0.62	1.68	16.8	0.0	16.8
Jan	3	Late	0.35	0.99	8.0	0.1	7.8
					281.6	2.3	279.2

Appendix Table 6: Irrigation Water requirement for dry beans

Crop Water Requirements

ETo station: Chancho | Crop: Dry beans

Rain station: Chancho | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.40	1.26	12.6	2.1	10.5
Oct	2	Init	0.40	1.25	12.5	0.0	12.5
Oct	3	Deve	0.55	1.67	18.4	0.0	18.4
Nov	1	Deve	0.81	2.39	23.9	0.1	23.8
Nov	2	Mid	1.06	3.03	30.3	0.0	30.3
Nov	3	Mid	1.15	3.19	31.9	0.0	31.9
Dec	1	Mid	1.15	3.10	31.0	0.0	31.0
Dec	2	Mid	1.15	3.01	30.1	0.0	30.1
Dec	3	Late	1.13	3.01	33.1	0.0	33.1
Jan	1	Late	0.85	2.27	22.7	0.0	22.7
Jan	2	Late	0.49	1.32	10.6	0.0	10.6
					257.1	**2.2**	**254.9**

Appendix Table 7: Irrigation Water requirement for wheat

ETo station: Chancho | Crop: Wheat

Rain station: Chancho | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.30	0.95	9.5	2.1	7.4
Oct	2	Init	0.30	0.94	9.4	0.0	9.4
Oct	3	Deve	0.35	1.08	11.8	0.0	11.8
Nov	1	Deve	0.62	1.84	18.4	0.1	18.3
Nov	2	Deve	0.90	2.60	26.0	0.0	26.0
Nov	3	Mid	1.13	3.14	31.4	0.0	31.4
Dec	1	Mid	1.14	3.10	31.0	0.0	31.0
Dec	2	Mid	1.14	3.00	30.0	0.0	30.0
Dec	3	Mid	1.14	3.03	33.3	0.0	33.3
Jan	1	Late	1.06	2.85	28.5	0.0	28.5
Jan	2	Late	0.79	2.14	21.4	0.0	21.4
Jan	3	Late	0.50	1.39	15.3	0.1	15.2
Feb	1	Late	0.31	0.91	1.8	0.1	1.8
					267.9	**2.5**	**265.5**

Appendix Table 8: Irrigation Water requirement for Pepper

ETo station: Chancho | Crop: G.Pepper
Rain station: Chancho | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.60	1.89	18.9	2.1	16.8
Oct	2	Init	0.60	1.88	18.8	0.0	18.8
Oct	3	Deve	0.60	1.83	20.1	0.0	20.1
Nov	1	Deve	0.68	2.02	20.2	0.1	20.0
Nov	2	Deve	0.81	2.32	23.2	0.0	23.2
Nov	3	Deve	0.94	2.61	26.1	0.0	26.1
Dec	1	Mid	1.04	2.80	28.0	0.0	28.0
Dec	2	Mid	1.04	2.74	27.4	0.0	27.4
Dec	3	Mid	1.04	2.76	30.4	0.0	30.4
Jan	1	Mid	1.04	2.79	27.9	0.0	27.9
Jan	2	Late	1.02	2.76	27.6	0.0	27.6
Jan	3	Late	0.94	2.65	29.1	0.1	29.0
Feb	1	Late	0.89	2.60	5.2	0.1	5.2
					302.9	**2.5**	**300.6**

Appendix Table 9: Irrigation Water requirement for potato

ETo station: Chancho | Crop: Potato
Rain station: Chancho | Planting date: 01/10

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.50	1.58	15.8	2.1	13.7
Oct	2	Init	0.50	1.56	15.6	0.0	15.6
Oct	3	Deve	0.54	1.65	18.1	0.0	18.1
Nov	1	Deve	0.75	2.21	22.1	0.1	22.0
Nov	2	Deve	0.96	2.76	27.6	0.0	27.6
Nov	3	Mid	1.13	3.15	31.5	0.0	31.5
Dec	1	Mid	1.14	3.10	31.0	0.0	31.0
Dec	2	Mid	1.14	3.00	30.0	0.0	30.0
Dec	3	Mid	1.14	3.03	33.4	0.0	33.4
Jan	1	Late	1.14	3.05	30.5	0.0	30.5
Jan	2	Late	1.04	2.82	28.2	0.0	28.2
Jan	3	Late	0.90	2.53	27.8	0.1	27.7
Feb	1	Late	0.78	2.27	15.9	0.5	15.3
					327.5	**2.8**	**324.5**

Appendix Table 10: Observed flow (1990-2000)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.Mean
1990	0.23	0.32	0.24	0.47	0.22	0.28	13.12	64.85	33.47	2.98	0.60	0.36	9.76
1991	0.22	0.43	0.47	0.20	0.14	0.49	15.51	58.73	23.07	1.67	0.43	0.31	8.47
1992	0.24	0.23	0.14	0.16	0.19	0.41	9.70	45.35	22.81	2.33	0.51	0.28	6.86
1993	0.20	0.17	0.11	0.36	0.47	1.25	30.44	63.75	42.93	5.32	0.76	0.35	12.18
1994	0.23	0.11	0.14	0.19	0.16	0.91	19.61	39.31	20.50	2.28	0.53	0.30	7.02
1995	0.16	0.19	0.15	0.38	0.33	0.36	14.56	36.13	11.63	1.28	0.39	0.27	5.49
1996	0.17	0.21	0.22	0.29	0.25	0.36	24.24	39.29	9.91	0.84	0.27	0.16	6.35
1997	0.11	0.07	0.06	0.11	0.06	0.19	12.26	28.64	9.45	0.78	0.39	0.19	4.36
1998	0.20	0.10	0.08	0.07	0.20	0.71	24.71	55.92	25.67	7.96	0.83	0.29	9.73
1999	0.18	0.05	0.07	0.05	0.06	0.29	12.67	57.18	18.35	3.91	0.56	0.23	7.80
2000	0.17	0.05	0.03	0.07	0.13	0.23	10.34	52.14	14.02	2.51	0.55	0.26	6.71
Mean	**0.19**	**0.18**	**0.16**	**0.22**	**0.20**	**0.50**	**17.01**	**49.21**	**21.07**	**2.90**	**0.53**	**0.27**	**7.70**

Simulated Flow During Calibration Period													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.Mean
1990	0.2791	3.46	4.868	2.715	2.049	5.832	19.44	32.47	31.62	11.39	5.076	1.284	**10.04**
1991	0.4989	1.912	7.423	0.5214	1.751	5.615	22.43	33.01	25.53	10.28	5.019	1.563	**9.63**
1992	1.537	3.996	1.793	2.403	2.185	4.098	11.41	22.75	23.19	12.18	5.084	1.24	**7.66**
1993	0.2565	3.334	1.799	5.203	4.594	8.973	22.04	32.11	26.21	12.43	6.307	1.861	**10.43**
1994	0.3529	0.1668	2.352	0.3148	1.485	5.281	18.22	24.96	24.36	9.589	5.245	1.279	**7.80**
1995	0.232	1.261	2.077	5.737	2.927	4.77	19	25.03	25.31	8.495	3.881	0.6684	**8.28**
1996	1.018	0.1992	5.501	3.326	3.906	17.78	21.64	33.31	25.38	12.47	6.391	1.853	**11.06**
1997	1.218	0.199	1.396	1.279	1.386	2.747	18.17	22.86	12.1	5.255	2.093	0.3017	**5.75**
1998	1.028	1.692	1.41	2.041	7.973	11.33	21.7	33.46	29.7	15.55	7.197	2.287	**11.28**
1999	0.4338	0.1893	1.72	0.1559	1.265	4.987	25.09	29.14	22.76	14.65	5.213	1.174	**8.90**
2000	0.24	0.1489	0.2112	1.948	4.397	4.286	17.86	31.28	21.96	11.66	5.68	1.639	**8.44**
Mean	**0.645**	**1.505**	**2.777**	**2.331**	**3.083**	**6.882**	**19.727**	**29.125**	**24.375**	**11.268**	**5.199**	**1.377**	**9.02**

Appendix Table 11: Observed flow (2001-2001)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.Mean
2001	0.16	0.08	0.18	0.13	0.33	3.41	26.88	39.98	15.17	1.06	0.32	0.18	7.32
2002	0.16	0.08	0.11	0.11	0.07	0.19	20.45	44.30	13.24	0.43	0.39	0.20	6.64
2003	0.12	0.06	0.08	0.15	0.07	0.62	41.40	48.84	36.42	3.43	0.29	0.17	10.97
2004	0.10	0.06	0.03	0.22	0.09	0.56	19.88	52.70	18.76	1.64	0.32	0.63	7.92
2006	0.13	0.11	0.48	0.41	0.26	0.75	33.21	46.20	26.04	2.04	0.50	0.25	9.20
2007	0.17	0.13	0.07	0.13	0.14	4.21	26.13	56.51	19.07	2.81	0.45	0.22	9.17
2008	0.10	0.05	0.04	0.05	0.05	1.14	34.71	53.65	23.08	1.43	4.17	0.33	9.90
2009	0.26	0.09	0.05	0.05	0.07	0.09	11.16	50.78	17.25	1.17	0.32	0.32	6.80
2010	0.21	0.25	0.12	0.38	1.01	3.31	41.89	40.91	28.74	1.93	0.45	0.25	9.95
2011	0.15	0.07	0.07	0.06	0.15	0.59	10.08	41.98	20.19	1.49	0.48	0.23	6.30
Mean	**0.16**	**0.10**	**0.12**	**0.17**	**0.22**	**1.49**	**26.58**	**47.59**	**21.80**	**1.74**	**0.77**	**0.28**	**8.42**

Simulated flow during Validation Period													
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.Mean
2001	0.2535	0.1927	6.166	1.557	4.345	11.14	24.02	25.71	25.47	9.525	4.32	0.7268	**9.45**
2002	0.9881	1.221	4.693	1.315	0.9032	5.37	12.22	20.26	19.51	6.865	2.936	0.4626	**6.40**
2003	0.2307	1.48	2.632	4.165	0.3792	6.655	18.88	26.27	22.28	11.13	5.553	1.594	**8.44**
2004	0.4652	0.4237	0.812	3.034	1.084	4.512	18.2	27.13	28.16	11.46	4.636	0.9986	**8.41**
2006	0.1948	0.4523	7.37	7.638	4.241	9.075	29.45	34.02	26.52	11.73	5.492	1.32	**11.46**
2007	0.7785	1.143	1.235	2.664	3.674	13.1	26.42	27.4	25.67	12.8	6.066	1.433	**10.20**
2008	0.3126	0.4485	0.1207	0.3715	1.474	4.754	20.67	27.32	27.79	11.91	6.326	1.439	**8.58**
2009	1.541	0.2279	0.4944	0.6031	1.472	3.486	25.52	39.45	28.23	11.94	5.48	1.852	**10.02**
2010	0.307	2.195	2.52	3.666	5.251	9.888	24.51	28.39	22.29	12.23	6.224	1.745	**9.93**
2011	0.4426	0.5149	3.339	1.473	4.042	9.504	25.95	38.75	32.26	12.73	6.355	1.677	**11.42**
Mean	**0.55**	**0.83**	**2.94**	**2.65**	**2.69**	**7.75**	**22.58**	**29.47**	**25.82**	**11.23**	**5.34**	**1.32**	**9.43**