GIS-BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT OF MEKI RIVER WATERSHED, CENTRAL RIFTVALLEY OF ETHIOPIA.

MSc THESIS

KUFA KAFU MILO

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

MAY, 2023

GIS-BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT OF MEKI RIVER WATERSHED, CENTRAL RIFT VALLEY OF ETHIOPIA.

KUFA KAFU MILO

MAJOR ADVISOR: SHIMELLIS ASSEFA (PhD)

CO-ADVISOR: TESHALE TADDESSE (MSc)

A THESIS SUBMITTED TO THE

FACULTY OF BIO-SYSTEMS AND WATER RESOURCE ENGINEERING

DEPARTMENT OF WATER RESOURCE AND IRRIGATION ENGINEERING

HAWASSA UNIVERSITY INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN IRRIGATION AND DRAINAGE ENGINEERING

MAY, 2023

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

ADVISORS' APPROVAL SHEET

(Submission Sheet-1)

This is to certify that the thesis entitled "GIS-based surface irrigation potential assessment of Meki river watershed, Central Rift Valley of Ethiopia" submitted in partial fulfillment of the requirements for the degree of **Master's** with specialization in **Irrigation and Drainage Engineering** and the Graduate Program of the Department of Water resources and Irrigation Engineering, and has been carried out by **kufa kafu** ID.No **GpIDrI/012/12,** under my/our supervision. Therefore, I/we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

Shimellis Assefa (PhD)	____________	______________
Name of major advisor	Signature	Date
Teshale Taddese(MSc)	______________	__________________
Name of co-advisor	Signature	Date

SCHOOL OF GRADUATE STUDIES

HAWASSA UNIVERSITY

EXAMINERS' APPROVAL SHEET-1

(Submission Sheet-2)

We, the undersigned, members of the Board of Examiners of the final open defense by Kufa Kafu Milo have read and evaluated his/her thesis entitled **"**GIS-based surface irrigation potential assessment of Meki river watershed, Central Rift Valley of Ethiopia**"** and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree Master of Science in Irrigation and Drainage Engineering.

______________________	______________	_________________
Name of the chair person	signature	Date
_____________________	_________________	_______________
Name of the major advisor	signature	Date
______________________	___________________	____________
Name of internal examiner	signature	Date
________________________	___________________	____________
Name of external examiner	signature	Date
______________________	__________________	__________
SGS Approval	signature	Date

Final approval and acceptance of the thesis is contingent upon the submission of the final copy of the thesis to the School of Graduate Studies (SGS) through the Department/School Graduate committee (DGC/SGC) of the candidate's department.

Stamp of SGS

Date: ____________

DEDICATION

I dedicate my thesis work to my wife Meserat Merga, who has encouraged me attentively with her fullest and truest attention.

STATEMENT OF AUTHOR

I hereby declare that this MSc thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted and presented to any other institution anywhere for the award of any academic degree, diploma, or certificate

Name: kufa kafu   Signature: ___________________________

Place: Institute of Technology, Hawassa University, Hawassa

Date of Submission**:** ______________________________

ACKNOWLEDGMENT

I am grateful to the Almighty God for His unfailing grace shared upon me throughout the period of my studies. I would like to express my heart felt gratitude to my major advisor Dr. Shimellis Assefa and co-advisor Mr.Teshale Taddese. Without their involvement, the completion of this thesis would have been impossible.

My special appreciation also goes to Ethiopian Institute of Agricultural Research, Land and Water Resource Research Directorate for providing the scholarship to undertake graduate study, financial support for the research and for all technical and material support. My appreciation also goes to Chiro National Sorghum Research and Training Center and its entire staff members for their assistance during my works.

Special thanks to my mother and my father for their continuous, blessing, moral support and love. It would not be possible for me to be at this stage without your care and encouragements during my childhood. I equally wish to extend my gratitude to my brothers and sisters particularly Mrs. Alemitu kafu and Dasso Kafu for all they had done for me.

Finally, my deepest grateful and thanks goes to my wife Meserat Merga and my son Oli for their love, care, moral support and patience.

LIST OF ABBREVATION AND ACRONYMS

CSA	Central statistical agency
ADLI	Agricultural development led industrialization
MOWR	Ministry of water resources
FAO	Food and agricultural organization
MOA	Ministry of agriculture
CRV	Central rift valley
GIS	Geographic information system
SPOT	Système pour observation de la terre
DEM	Digital elevation model
CNES	Centre national d'études spatiales
NIWR	Net irrigation water requirement
GIWR	Gross irrigation water requirement
NGA	National geospatial intelligence agency
NASA	National aeronautics and space administration
SRTM	Shuttle radar topography mission
GPS	Global positioning system
NMSA	National meteorological services agency
MoWE	Ministry of water and energy
SWAT	Soil and water assessment tool
UTM	Universal transverse Mercator
ESRI	Environmental systems research institute
DFID	Department for international development
UNESCO	United nation’s scientific and cultural organization

TABLES OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN APPENDIX

ABSTRACT

Irrigation can contribute to food security by increasing food availability and cash income of smallholder farmers. However, surface irrigation development in the study area is hindered due to lack of reliable data of suitable land and available water potential. Therefore, this study assessed the land and water resources of Meki River watershed in rift valley lakes basin in Ethiopia using Geographic information system to identify suitable land and available water potential for surface irrigation. Land suitability factors such as soil depth, soil texture, soil drainage, slope and land use/cover were considered and their suitability analyzed using ArcGis10.3. Water availability assessed using soil and water assessment tool and calibrated and validated with observed flow. Flow duration curve from monthly simulated flow was developed to obtain the reliable monthly flow at 80% probability. Irrigation water requirements estimated using CROPWAT8.0 for the Maize, Onion and Tomato and compared with dependable flow to compute the potential irrigable area. Regarding evaluation factors the results showed that 52.31 % of slope, 89.9% % of soil depth, 75.95% of soil drainage 99.65% of soil texture and 94.73 % of land use land cover were in the range of highly to marginally suitable, whereas 47.69 % of slope, 10.1% of soil depth, 24.1% of soil drainage, 0.35% of soil texture and 5.27 % of land use land cover restricted for surface irrigation. Further weighted overlay results showed that 177,199 *ha were in the range of highly to marginally suitable whereas 35798 ha were unsuitable. Besides, the results revealed that maximum and minimum dependable flow during crop growing period were 39.6 m^3/s and 0.05 m^3/s respectively. Moreover, the results showed that irrigation water demands vary from crop to crop, and 4126.04 ha were obtained to be potentially suitable for the development of surface irrigation project. This study concludes that there is huge suitable land and insufficient water availability in the watershed. Therefore, irrigation potential of the watershed can be increased through using water saving technology such as drip, sprinkler and selecting other less sensitive crops, also using other water sources such as Lake Water, ground water and rain water harvesting.*

Keywords: Arc GIS, rift valley lakes basin, Land Suitability, water availability, Meki River watershed, Surface Irrigation

1. INTRODUCTION

1.1. Background

Ethiopia has a total surface area of 110.43 million ha, out of which 0.7% is water surface and 15.7 million ha is cultivated (FAO, 2013). Source of income in the country mainly depends on Agriculture and constitutes almost half of the GDP (43%) and 85% of the total export revenue (UNDP, 2014 and IMF, 2015) and employs beyond 85% of the labor force in the country (CSA, 2008 & EEA, 2008). Traditional rain fed agriculture is mostly practiced in which the peasant farm households contribute the largest proportion of the total agricultural production (FAO, 2006). As suggested by Belete (2006) rainfall is the single most important factor for food supply and country's economy. However, in the country rainfall is characterized by both seasonal and inters annual spatial variability (Alhamshry et al., 2020).This suggests that the sustainability of rain fed agriculture not reliable in the country and due to this crops may not obtain the required amount of water at critical growth stage. Therefore, expanding irrigated agriculture is needed to compensate the reduction of crops yield due to rainfall variability.

Ethiopia has abundant surface water resources that can be used for different purposes. There are 12 major river/drainage basins seven of which are Trans boundary and total annual runoff from these basins is estimated to be about 125 billion m^3 (Awulachew, 2019) and about 12 million ha cultivable land existed (MoA, 2011a).Moreover, in the country irrigation potential estimated to be 5.3 million ha (Mha) of which 3.7 Mha can be developed using surface water sources, and 1.6 Mha using groundwater and rainwater management (Awulachew & Ayana, 2011). But, the potential and actual irrigated areas are not properly examined (Belay and Bewket, 2013) .This indicates that the gap of reliable inventory and well-studied in terms of water and land related potentials in the country. Therefore, proper assessment of land and water availability is required to use effectively the existing land and water resources.

According to Saymen (2005) more than 90% of the world uses surface irrigation, even if local irrigators have least knowledge of how to operate and maintain the system .Also surface irrigation development requires favorable topography and information of land and water resources for proper planning (FAO, 1995). Moreover, According to FAO (1997) planning process for surface irrigation needs integration information about the suitability of the land, water resources availability and water requirements of irrigable areas in time and place. From this one can understand that proper planning; designing and expanding surface irrigation project requires reliable data on land suitability, water availability, and irrigation water demand of crops.

Meki River watershed is one of the parts of rift valley lakes basins that located in Central Rift Valley of Ethiopia, and where large investments in irrigation development are taking place for the production of various crops. However, in the watershed irrigator's, investors, planner, and managers do not have reliable data on land suitability and available water potential for surface irrigation. This may bring misuse of land and water as well as improper planning of irrigation schemes. Improperly planned expansions of irrigation is often associated with low efficiency in water use and with environmental problems (McCornick et al., 2003).Several studies have been conducted in the watershed on different topics. Those studies, however, did not provide complete information of the current state of suitable land and available water resource for surface irrigation. Due to this developing and planning sustainable small and large irrigation schemes in the watershed is hindered. Therefore, to realize the reliable data on land and water at watershed level it is necessary to conduct research in assessment of surface irrigation potential.

1.2. Problem statement

The Ethiopian agriculture sector depends highly on rainfall .However, temporal and spatial variability of rainfall and its insufficiency are common phenomenon. With this problem ensuring food security is difficult. Therefore, to bring food security in the national level as well as the house hold level, improvement and expansion of irrigated agriculture must be increased (Negash, 2015).This helps in supplying crops with required amount of water for the whole growing season or supplement rainfall during insufficiency in order to maximize yield. Very few attempts have been made to assess surface water irrigation potential in Ethiopia mainly used as reference master plan studies and official reports (Awulachew et al., 2007; Awulachew et al., 2010; FAO, 2016). This may not provide reliable data regarding suitable land, available water and its potential based on demand of dominant crop at watershed level for proper planning, designing, and expansion of surface irrigation schemes. So, before planning, designing, and expansion of irrigation scheme proper assessment of surface irrigation potential is needed in order to know potential of land and water resource in the given watershed.

Further, in the study area water from the River is abstracted mainly by local investors and farmers for crop production during dry season. But, they do not have information about irrigation water demand for the dominant crops, available surface water, and it potential. This may bring the misuse of available water. Therefore, In order to provide the solution for the above problems the establishment of well-developed irrigation suitability data base system in terms of land and water found to be very essential.

1.3. Objectives of the study

1.3.1.General objective

- ✓ The general objective of this study was to assess surface irrigation potential of Meki River watershed using GIS.

1.3.2. Specific objectives

- ✓ To identify the suitable land for surface irrigation based on suitability parameters.
- ✓ To assess the available surface water resource for surface irrigation.
- ✓ To estimate irrigation water requirement for the dominant crops.
- ✓ To determine potential irrigable area of the watershed.

1.4 Research Questions

- ✓ How much is suitable area for surface irrigation development using the physical suitability parameters?
- ✓ How much is monthly flow available in sub basin level?
- ✓ How much is the irrigation water demand for dominant crops in the watershed?
- ✓ Is the demand of dominant crop satisfied by available surface water flow?

1.5. Significance of the study

Land suitability is one of the indicators of irrigation development as well as sustainability of land production, resource utilization and management, which gives a basis for selection of irrigation methods as well as planning of new irrigation project. The significance of such suitability study is to identify the constraints and potentials for sustainable development of irrigation in the area. It also helps policy makers as a tool for decision making on irrigation developmental projects in the watershed and gives the detail information for the local investor and foreign investors about land suitability. Further, the study helps to know the existing surface water available and its potential to select the appropriate irrigation methods and crop types.

1.6. Scope of the Study

Assessing irrigation potential is important to generate reliable information such as irrigation demand, available water and suitable land for developing new irrigation project at basin level. However, this research delimited to one selected watershed in rift valley lakes basin, namely Meki River watershed. Besides, regarding land suitability factors this study focuses only on slope, land use and land cover and physical soil properties such as soil depth, soil drainage and soil texture. In addition to that it also focuses on assessment of available surface water and its potential in terms of surface irrigation by comparing with gross irrigation water requirement for the dominant crops in the watershed.

1.7. Limitation of the study

Considering all land suitability factors are essential to generate reliable data during assessment of irrigation potential in the given watershed. However, due to budget, time, and lack of reliable data constraints this study did not consider the land suitability factors such as salinity, water quality and other irrigation methods other than surface.

2. REVIEW OF LITERATURE

2.1. Irrigation Potential

FAO (1997) explained that irrigation potential is the area which can be potentially irrigated depends on the physical resources of land, soil and water combined with the irrigation water requirements. This implies that during assessment of irrigation potential for the given watershed considering suitability factors such as land, water, and irrigation water requirement for crops is essential. Moreover, in countries like Ethiopia which has plenty water resources, the concept of irrigation potential also include some considerations of suitability and economic feasibility of irrigated lands (FAO, 2015). Therefore, knowing the characteristics of land, soil, and capacity of available water concerning irrigation as well as economic viability of irrigated land is vital during irrigation potential assessment.

2.2. Irrigation developments in Ethiopia

Irrigation development has power to boost economic growth and rural developments .Due to this it can be considered as a basis for food security and poverty reduction tool (Hagos et al., 2009). Moreover, as stated in (MoA, 2011b) Subsistence dominated smallholder farmers' economy can be improved through the use of irrigation in the Ethiopian agriculture. However, irrigation development trend seems very low even when compared with other African countries (Birhane, 2002).To conclude, these research findings suggest that in the country irrigation development play the great role to make sure food security and economy of smallholder farmers though it needs proper expansion to realize the food security. Therefore, increasing small and large irrigation schemes in proper way at watershed level is very important.

Currently estimates show that 15 million ha is under cultivation of which 4 to 5% is irrigated with existing equipped irrigation schemes covering about 640,000 ha across the country (Awulachew et al., 2010). Moreover, Gebremedhin and Pedon (2002) reported that only 10% of the estimated potential irrigable land is actually irrigated and 2% of cultivated lands are irrigated (MoWR, 2001). Also Bacha et al. (2011) reported that irrigated agriculture comprises only 3% of the total national food production. From the above justification even though land and water potential available in the country the role of irrigation regarding crop production is very low and needs to be improved.

2.3. The necessity for irrigation development in Ethiopia

According to World Bank (2006) increasing irrigation has long been seen as the most direct strategy to reduce the impact of drought and ensure food security and emphasizes without increased irrigation, the irregularity of rains in Ethiopia is hindrance to investments in agricultural improvements. Awulachew *et al*. (2010) also explained that well-managed irrigation development is key in helping Ethiopia to overcome major challenges of population pressure, soil and land degradation, high climate variability, and low agricultural productivity. This implies that irrigation able to compensate the loss of crop production due to climate variability.

The research result in the Lake Tana Basin by (IWMI, 2015) revealed that, on average, household incomes of those that practiced irrigation were 27% higher than those that did not. This shows that those who use irrigation will have more income. Moreover, study at Gubalafto District; North Wollo (Mengistie and Kidane, 2016) indicated that irrigation has a great impact on enhancing farmers' livelihoods through different dimensions, such as diversification of crops grown, as well as increased agricultural production, household income, employment opportunity and participation in community decisions.

Irrigated agriculture represents 20% of the total cultivated land but contributes 40 percent of the total food produced worldwide (FAO, 2015). This shows that irrigation is used as an input to increase the yield of the crop with in small land. Moreover, irrigation play a significant role in the substantial increase in food production for food security enhancement and economic development of Ethiopia with the efficient use of land and water resources (Haile and Kasa, 2015; Sultan, 2013). The production function analysis done by (Makombe *et al*., 2007) shows that irrigation could shift the agricultural production frontier to a higher level. However, its contribution to the national economy is not significant when compared with rain fed agriculture.

2.4. Land suitability evaluation factors for surface irrigation

land evaluation for irrigation suitability was concerned with total land performances such as landforms, climate, vegetation, and soils for assessing land productivity when the land is used for specified purposes under a specified management system (Sys et al.,1991; Davidson 1992; FAO 2007). Moreover, Sys et al. (1991) suggested that parametric evaluation system for irrigation methods which was mainly based up on physical and chemical soil properties. The above justification suggests that during assessing land suitability for irrigation methods considering both physical and chemical properties of soil is very essential.

As widely discussed in FAO land evaluation guidelines (FAO, 1976, 1983, 1985) there are two orders represented by the symbols S and N for suitable and not suitable respectively. Order 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, whereas Order N (Not Suitable) is the Land which has qualities that appear to prevent sustained use of the kind under consideration. The suitability of these factors for surface irrigation method and for the given land utilization types can be expressed corresponding to the following suitability classes.

Accordingly, S1 (highly suitable) is the land having no significant limitation to sustained application of a given use, S2 (moderately suitable) is the land having limitation which in aggregate are moderately severe for a sustained application of a given use, S3 (marginally suitable) is the land having limitation which in aggregate are severe for a Sustained application of a given use and will reduce productivity or benefits and N-(not suitable) is the Land having a limitation for surface irrigation development in both currencies and permanently due to topographic effect, soil type and land cover conditions.

A lot of researches have been conducted on land suitability assessment for surface irrigation by considering different suitability factors. For instance, Bayush (2020) investigated land suitability for surface irrigation in Danse watershed, Oromia region. The study was considered the irrigation suitability factors such as soil depth, soil texture, soil drainage, slope, and land use/cover. The weighted overlay analysis revealed that out of the total 2170 ha of land 85.36 ha were highly suitable(S1), 1475.68 ha moderately suitable(S2), 596.67 ha marginally suitable(S3) and 4.78 ha of the area were unsuitable(n) for surface irrigation development. Furthermore, Ganole (2010) Studied GIS-based surface irrigation potential assessment of river catchments for irrigation development in Dale woreda, Sidama zone. The study was considered irrigation suitability factors such as soil type, slope, land cover/use, and distance from water sources. The results of these factors indicate that 86 % of soil and 58 .5 % slopes in the study area are in the range of highly suitable to marginally suitable for surface irrigation system. In terms of land cover/use, 87.1% of land cover/use is highly suitable whereas 12.9% were restricted from irrigation development. In conclusion, the above research findings suggest that suitable land for surface irrigation vary based on the factors considered during land suitability assessment.

2.4.1. Soils

Land quality will be described by land characteristics associated with soil parameters (Abu-Hashim et al., 2021). According to Seelig and Franzen as cited in Dengiz (2006) determining the suitability of land for irrigation requires a thorough evaluation of soil properties, topography and quality of water to be used for irrigation. The assessment of soils for irrigation involves using soil properties such as drainage, texture, depth, salinity, and alkalinity (Fasina *et al*, 2008). 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). Soil Physical properties are the most dominant factors that determine the land suitability for irrigation (Tesfaye, 2014). These physical properties are discussed in the following sub-sections.

2.4.1.1 .Soil depth

Soil depth is the distance from soil surface to bedrock, a hardpan, a water table, a specific soil depth, or to a root growth restrictive layer. Soil depth refers to the thickness of the soil materials. In addition effective soil depth is the depth of the soil at which the root growth of crops is strongly inhibited. Soil depth plays a major role in influencing plant growth and yield. Deep soil provides for storage of large volumes of irrigation water in the soil, and consequently sustains satisfactory plant growth during relatively long periods between rain/irrigation. According to (Sys et al., 1991) the soil depth greater than 100cm is highly suitable for crop production using surface irrigation whereas soil depth less than 50cm is not suitable for surface irrigation. This implies that as depth increase the soil suitability for irrigation in terms of depth also increase. Study conducted in Danse watershed by Bayush (2020) revealed that land about 54.13 % highly suitable, 23.47 % marginally suitable and 22.40 % not suitable for surface irrigation in terms of soil depth. This research implies that in terms of soil depth most of the study area is dominantly suitable for surface irrigation development.

2.4.1.2. Soil drainage

Evaluation of the soil drainage requirement is crucial element in choosing land for irrigation, especially with varied upland crop production (FAO, 1997). Adequate soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. When the soil drainage poor it causes the runoff over the surface of the soil during irrigation and also aeration problem will be occurred. Due to this huge investment required for drainage system installation. Also excessive soil drainage cause the waterlogged condition by increasing ground water table as well as decrease the amount of water stored in the crop root zone. According to FAO (1997) and (Sys et al., 1991) evaluation techniques used for evaluation of permeability of soil properties of the land, soil drainage area may be categorized as well drained, moderately well drained, imperfectly drained, poorly drained and very poorly drained. In general, considering soil drainage as one factor during land suitability assessment is helpful to obtain land suitable for proposed irrigation method.

2.4.1.3. Soil texture

The term soil texture refers to the size range of mineral particles in the soil. These minerals particles are identified by the term clay, silt, and sand. The percentage of sand, silt, and clay is used to decide the texture of the soil. It helps to determine the capacity of the soil to retain moisture and air that necessary for plant growth. Soils with a greater proportion of larger particles are well aerated and allowed water to pass through the soil more quickly. Soil textures are categorized by the fractions of every soil separate (sand, silt and clay) found in a soil. Coarse textured soils contain a large proportion of sand medium textures are dominated by silt, and fine textures by clay (FAO, 2008).

The texture of a soil has a very important influence on the flow of soil water, circulation of air and the rate of chemical transformations that important to plant life. The irrigation methods determined based on soil texture of the area. For example, as recommended by (Sys et al., 1991) and (FAO, 1997) soil texture such as silt clay(SIC) ,silty clay loam(SCL), clay loam(CL), loam(L), and silty loam(SIL) are considered as highly suitable for surface irrigation and this might be vice versa for other types of irrigation. Therefore, considering soil texture during developing irrigation scheme is crucial.

2.4.2. Land cover / use

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

2.4.3. Slope

Slope, or field gradient, is the inclination of the soil surface from the horizontal, expressed as a percentage.it is the most important topographic factor to assess suitable land for surface irrigation because surface irrigation requires level type of land in order to maximize the distribution uniformity of water over an irrigated land**.** In planning irrigation systems, slope is important in determining the type of irrigation system best suited for the site. It is important in determining optimum and maximum water application rates as well as for soil formation and management because of its influence on runoff, drainage, erosion and choice of irrigation types. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are highly suitable for surface irrigation. But slopes, which are greater than 8%, are not generally recommended for surface irrigation (FAO, 1999, 1996 and Sys et al., 1991).

2.5. Water availability assessment for surface irrigation

Water is a critical input for agricultural production and plays an important role in food security. As suggested by (FAO, 2001) If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle. This implies that knowing available water potential before beginning irrigation in the given watershed is crucial to overcome crop water stress and design proper irrigation scheme. Further, FAO (1985) stated that water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available.

2.5.1. Hydrological models used for surface water assessment

According to Guug et al. (2020) hydrological models is the best method to quantify the water availability in the given watershed at spatial and temporal resolution with reliable data sets. Moreover, as stated by Bardossy and Singh (2008) hydrological models play a vital role to understand the watershed behavior and responses. However, for a specific watershed selecting the most suitable hydrological model with proper selection of model input parameters is necessary to gain good simulated result (Bredesen and Brown, 2018).

Recently, the most commonly used hydrological models are Hydrological Engineering Centre-Hydrologic Modeling System (HEC-HMS), Hydrological Simulation Program-Fortran (HSPF), Agricultural Non-Point Source (AGNPS), Soil and Water Assessment Tool (SWAT), and MIKE SHE (Khoi, 2016). Even though, some of them were reviewed in the sections below.

2.5.1.1. Hydrologic Simulation Program-Fortran

The model is a robust highly complex mathematically based computer code developed under United States Environmental Protection Agency (EPA) sponsorship to simulate water quantity and quality processes on a continuous basis in natural and man-made water systems. The model is capable of simulating both permanent and non-permanent flow types (Watts et al., 2006). Donigian et al. (1997) noted that the model is the only available model that can simulate the continuous dynamic event or steady-state behavior of both hydrologic/hydraulic and water quality processes in a watershed with an integrated linkage of surface soil, and stream processes.

Albeck et al. (2004) conducted study on hydrological modeling of SeydiSuyu watershed in Turkey. In this study Hydrologic Simulation Program-Fortran (HSPF) was used to model runoff of the watershed and the results revealed that the average simulation error during validation is 11% and concluded that the results obtained by the model represent the hydrology of the watershed sufficiently.

2.5.1.2. Hydrologic Engineering Center - Hydrologic Modeling System

The Hydrologic Modeling System (HEC-HMS) is designed to simulate the complete hydrologic processes of watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. A lot of study has been conducted on assessment of water resource in different basin and watershed using HEC-HMS. For instance, Teferaa (2017) conducted study on Water Resource Assessment and Management Options in Beles River Basin by using HEC-HMS Model. Hence, the simulated findings of water balance assessment by the model showed that 2004 for Gilgel Beles (129 mm) and Upper Beles (61.24 mm) found to be a water surplus year. Whereas, 2003 showed the deficit year in the basin but 2005 was found almost balanced soil moisture storage in the River Basin.

Moreover, Fanta and Feyissa, (2021) evaluated the performance of HEC-HMS model for continuous runoff simulation of Gilgel Gibe watershed, Southwest Ethiopia and the performance results indicate that the model well simulated the continuous runoff of the watershed. Similarly, Aliye et al. (2020) evaluated the Performance of HEC-HMS and SWAT Hydrological Models in Simulating the Rainfall-Runoff Process for the katar watershed in Ethiopian rift valley lakes basin and the results of calibration and validation indicated that both models could simulate fairly well the stream flow. To conclude, the above research findings suggested that using HEC-HMS model the water availability of the given watershed can be easily estimated. Therefore, one can use the model for water resource assessment.

2.5.1.3. Soil and Water Assessment Tool (SWAT)

Soil and Water Assessment Tool (SWAT) is a physically-based continuous-event hydrologic model developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large and complex watersheds with varying soils, land use and management conditions over long periods of time (Arnold *et al.*, 1998). A study comparing hydrological models for the assessment of water resources in a data-scarce region in the Upper Blue Nile River Basin deduced that the SWAT model was better for the simulation of midrange, dry, and low flows in the Ribb watershed (Tegegne et al., 2017). Moreover, Martine et al. (2013) selected SWAT model for its relatively low data input requirements, and its ability to generate missing weather records during simulation or fill in gaps in weather records. Further, the model is suitable for large-scale applications and it is easily applicable in data-scarce areas (Gassman et al., 2007). Also As stated by Mtibaa et al. (2018) the model was demonstrated as a capable of predicting flow and sediment yields and performing further analyses of hydrological responses. Further, Jayakrishnan et al. (2005) used swat model for water resources management in the United States of America and they suggested that the model has good potential for application in hydrologic/water quality studies in countries around the world and as a tool to develop time and cost-efficient analyses for watershed/water resources management and decision-making. From the above explanation one could understand that SWAT model mainly preferred to estimate the quantity of water, sediment and further analysis in the given watershed than other models.

2.5.1.3.1. Sensitivity analysis

The first step in the calibration and validation process in SWAT is the determination of the most sensitive parameters for a given watershed. As suggested by (Abbaspour et al., 2017) Sensitivity analysis supports to reduce the number of parameters in the calibration procedure by eliminating the parameters identified as not sensitive. There are two types of sensitivity analysis in SWAT_CUP namely local, by changing values one at a time, and global, by allowing all parameter values to change. As explained by (Arnold et al., 2012) the problem with one-at-a-time analysis is that the correct values of other parameters that are fixed are never known, whereas the disadvantage of the global sensitivity analysis is that it needs a large number of simulations.

Manaswi & Thawait (2014) Studied Runoff modeling for Karam River Basin in Madhya Pradesh using Soil and Water Assessment Tool and selected twenty eight parameters for sensitive analysis. However, the sensitivity analysis showed that only four parameters such as curve number (CN2), base flow Alfa factor (V_ALPHA_BF.gw), ground water delay time (V_GW_DELAY.gw), and threshold depth of water (V_GWQMN.gw) revealed meaningful effects on the flow simulation. This suggests that before calibration and validation of simulated flow knowing parameters that affect the flow in the given watershed is crucial.

2.5.1.3.2. Model calibration and validation

Calibration is systematic process of adjusting model parameters until model results match closely as possible as the behavior of the observed system measured, whereas validation is testing the calibrated model by comparing the field observations (the portion of data which was not used in calibration) against the model predictions without changing any input parameter values (Gupta et al., 1998). Moreover, model calibration is performed by carefully selecting values for model input parameters (within their respective uncertainty ranges) by comparing model predictions (output) for a given set of assumed conditions with observed data for the same conditions. Therefore, careful doing model calibration and validation is necessary in order to minimize the bias of the model.

2.5.1.3.3. Model performance evaluation

SWAT model (SWAT-SUFI-2) includes several objective functions used for evaluating the performance SWAT model such as R^2, NSE, and PBIAS etc. The R^2 statistic can range from 0 to 1, where 0 indicates no correlation and 1 represents perfect correlation, and it provides an estimate of how well the variance of observed values are replicated by the model predictions (Krause et al., 2005).

The Nash-Sutcliffe efficiency (NSE) is a normalized statistic widely used to determine the relative magnitude of the residual variance compared to the measured data variance of hydrologic models (Nash and Sutcliffe, 1970).NSE values can range between ($-\infty$ to 1) and provide a measure how well the simulated output matches the observed data and perfect fit between the simulated and observed data is indicated by value of 1, whereas values ≤ 0 indicate that the observed data mean is a more accurate predictor than the simulated output Gassman et al. (2007). Also,Guug et al.(2020) conducted study at the Sherigu catchment of Ghana and Southern Burkina Faso for assessing water availability using SWATmodel.in this study the performance of the model was evaluated using NSE and R^2 and the result revealed that the NSE were 0.74 and 0.79 for calibration and validation respectively, whereas R^2 values were 0.8 and 0.81 for calibration and validation respectively. Finally, based on the statistical value obtained the researchers concluded that the model is well performed. Moreover, Swain et al. (2018) conducted study Using SWAT Model for Stream flow Estimation and performance was evaluated using NSE and R^2.The result revealed that NSE and $R^2$are found to be 0.07 and 0.31 during calibration respectively. The result implies that the model does not produce satisfactory results for the basin. From this one can conclude, before using the simulated data for further application evaluating the performance of the model is very important.

2.5.2. Flow duration curve (FDC)

The flow duration curve (FDC) shows characteristics of the flow regime for the given river basin. It has been a useful tool for various water resources problems, irrigation, and/or hydroelectric power planning. A lot of researchers used flow duration curve in order to determine reliable flow at different probability for different purpose. For example, Dawit et al. (2020) conducted study at Dhidhessa River Basin in Ethiopia on Assessment of Surface Irrigation Potential. In this study flow duration curve is applied to evaluate monthly dependable flow at 70% and 80% probabilities for surface irrigation. The result indicated that the annual dependable flow values at 70% and 80% are 7.56 and 6.97 BCM respectively. Moreover, Negasa (2021) conducted study on Irrigation Potential Assessment for Surface Irrigation for the case of Birbir River Watershed in Oromia region. The study applied flow duration curve to obtain 80% monthly dependable flow of Birbir River for growing crop period. In conclusion, from the above study it can be concluded that flow duration curve is essential to know the dependable flow at different probability level.

2.6. Application of GIS

According to López Trigal (2015) GIS is a set of tools made up of hardware, software, data and users, which allow us to capture, store, manage and analyze digital information, as well as make graphs and maps, and represent alphanumeric data. Also, According to Burrough (1986) GIS is used to capture, store, manipulate, analyze and display spatial referenced information. Further, with an adequate database, GIS can serve as decision-making tool for irrigation development by overlaying the evaluation factors considered based on their importance.

As stated by (Howari et al. 2007) the software has capability to store, arrange, retrieve, classify, manipulate, analyze and present huge spatial data and information in clear way. This helps to obtain information and perform complex analyses easily within short period of time. The most common geographic analyses that can be performed with a GIS are explained separately in the subsequent sub-sections.

2.6.1. Watershed delineation

A watershed can be defined as the catchment area or a drainage basin that drains into a common outlet. Simply, watershed of a particular outlet is defined as an area, which collects the rainwater and drains through gullies, to a single outlet. GIS uses DEMs data as input to delineate watersheds with integration of Arc SWAT or by hydrology tool in Arc GIS spatial analysis (Winchell *et al*., 2008). Gopinath et al. (2014) used the DEM to determine the locations of the watersheds and the characteristics that possess through the aid of the GIS program, where the topographic and topological drainage network of the target area was deduced for a study. In generally, through the use of GIS watershed of the given area can be easily delineated.

2.6.2. Mapping

A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. According to klosterman as cited in malczewski (2004) one of the most useful applications of GIS for planning and management is the land use suitability mapping and analysis. Also Butt et al. (2015) used GIS to map land use change for simly watershed, islamabad, pakistan. Further, Blanco et al (2018) conducted research in Italy for mapping agricultural plastic waste by applying GIS tool Therefore, GIS is essential tool for mapping different things that used for different purpose.

2.6.3. Overlay

Overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create an integrated analysis. Feizizadeh and Blaschke (2013) conducted a research for agriculture suitability analysis with the help of Weighted Overlay Analysis (WOA) based on Geographical Information System (GIS) and Analytical Hierarchical Process (AHP) techniques. They considered for soil information soil fertility and soil pH data, for topographical information they used elevation, slope and aspect data, for climatic understanding they used temperature and rainfall data along with the groundwater data. This implies that overlay is essential to obtain representative information during land suitability analysis for different purpose. For instance, finding optimal site for irrigation requires weighting of factors such as land cover, slope, soil and distance from water supply (Yang, 2003).

2.6.4. GIS as a tool for irrigation potential assessment

In the past, several studies have been made to assess the irrigation potential and water resources by employing GIS tool. Negash (2004) conducted a study on irrigation suitability analysis in Ethiopia a case of Abaya-Chamo lake basin. It was a Geographical Information System (GIS) based and had taken into consideration soil, slope, and land use and water resource availability in perennial rivers in the basin to identify potential irrigable land.

In 1987 FAO conducted a study to assess land and water resources potential for irrigation in Africa on the basis of river basins of countries. It was one of the first GIS based studies of its kind at a continental level. Its main limitations were in the sensitivity of criteria for defining land suitability for irrigation and in water allocation scenarios needed for computation.

Hailegebriel (2007) conducted a study on Irrigation potential evaluation and crop suitability analysis using GIS and Remote sensing techniques in Beles sub basin, Beneshangul Gumuz Region. The study was considered slope, soil, land cover/use, water resources and climate factors in evaluating surface irrigation suitability. Therefore, from the above findings it can be concluded that GIS is very important tool during assessing irrigation potential of different watershed.

2.7. Satellite image classification

Remotely sensed data and the potential to distinguish between different characteristics of land features from this data gives great potential for rapidly creating accurate LULC maps (Homer et al., 2004).This suggests that with the aid of remote sensed data LULC information easily obtained by saving time and resource. Remote sensing imageries with variable resolutions in combination with the use of different descriptive models, offer an extraordinary prospect to obtain past, present and future land use and land cover patterns (Li et al., 2014).

The most popular satellite imagery is the LAND SAT and SPOT. Land sat imagery operated by the National Aeronautics and Space Administration (NASA) with the cooperation of the U.S. Geological Survey (USGS) since early 1970s till 2003 have produced the most widely used imagery worldwide with 60, 30, and 15m spatial resolutions (Blundell and Opitz, 2006).

During identifying land use or land cover for a given area of interest, two common methods to classify each pixel in an image are supervised and unsupervised classifications. In supervised classification, an analyst uses previously acquired knowledge of an area, or a priori knowledge, to locate specific areas, or training sites, which represent homogeneous samples of known land use and/or land cover types. Whereas, unsupervised classification is useful for scenes in which land cover is not well-known or undefined and also the groupings of pixels with common characteristics are based on the software analysis of an image without the user giving sample classes.

Shalaby and Tateishi (2007) utilized Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) images (with path/row 178/39) acquired on 20 May 2001 and 7 June 1987, respectively using a supervised classification method to study the land-use changes in the Northwestern coastal zone of Egypt. Further, Butt et al. (2015) applied supervised classification using maximum likelihood to detect the changes in LULC in the Simly watershed, Pakistan using Landsat 5 and SPOT 5 for the years 1992 and 2012, respectively. Therefore, from the above studies it can be concluded that by the aid of satellite image land use land cover of the given area can be easily classified.

2.8. Digital elevation model (DEM)

According to Balasubramanian (2017) Digital elevation model is 3D representation of a terrain's surface that created from terrain elevation data. DEM is used in water resources projects to identify drainage related features such as ridges, valley bottoms, channel networks and surface drainage patterns, and to quantify sub catchment and channel properties such as size, length, and slope (Garbrecht & Martz,2000). Also Padilla et.al (2015) used the 30m DEM to derive the characteristics of watersheds such as determining the locations of drainage points and catchment areas, watershed boundaries, slope of pathways in which the water flows, and the absorptive capacity of the pathways to carry water. Therefore, point elevation data are very useful as an input to the GIS to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature.

2.9. CROPWAT model description

In recent years as suggested by Ines et al. (2001) the role of simulation models in understanding the processes in the soil-plant-atmosphere system has increased significantly. CROPWAT is used as tools to assist irrigation engineers and agronomists in performing irrigation water requirement for irrigation water studies mainly in the management and design of irrigation schemes (Clarke D, 2001). Therefore, engineers and agronomist easily know crop water requirement and irrigation water requirement during design, planning and management of irrigation scheme without spending a lot of time with the aid of CROPWAT by feeding the required inputs.

As suggested by Smith (1992) the model is capable of predicting crop water and irrigation requirements for many different agro-ecological zones and climates due to its interoperability with the CLIMWAT 2.0 database. A lot of researchers used CROPWAT model during crop water requirement calculation and irrigation water determination. For instance, Fitsume et al. (2015) used CROPWAT model for determination of Crop water requirement for chickpea in the central vertisol areas of Ethiopia. Moreover, Thimme et al. (2013) determined Water Requirement of Maize in Northern Transitional Zone of Karnataka,India using CROPWAT model. Therefore one can use CROPWAT model to determine amount of water required by crop during irrigation application as well as during planning and design phase of irrigation schemes development.

2.10. Irrigation Water Requirement

Knowing irrigation water requirement is helpful to know the potential of available flow of the given watershed. For example, Dawit et al. (2020) conducted research on Assessment of Surface Irrigation Potential of the Dhidhessa River Basin and determined potential irrigable area by comparing irrigation water requirement with available flow of the river. As defined by FAO (1984) it is the volume of water required for normal crop production over the whole cropped area without including the water from effective rainfall. Therefore, irrigation water requirement of a certain crop is the difference between the crop water need and that part of the rainfall which can be used by the crop (the effective rainfall) .Mathematically it is given by:

$$\mathrm{NIWR} = \mathrm{ETc} - P_{eff} \quad \ldots\ldots (2.1)$$

Where:

ET_c=Crop evapotranspiration (mm)

P_{eff}= Effective rainfall (mm)

$NIWR$=Net irrigation water requirement (mm)

2.10.1. Reference evapotranspiration (ETo)

Reference evapotranspiration (ETo) represents theoretical, evapotranspiration from an extensive surface of green grass of uniform height, actively growing, completely shading the ground, and not short of water (Allen et al., 1998). It expresses the evaporative power of the atmosphere. Therefore, the only factors affecting reference evapotranspiration are climatic parameters. Penman-Monteith method given in FAO-56 considers all the climatic parameters to estimate the reference evapotranspiration .Due to this the result from the method could be more accurate than the others methods. Based on the comparative studies of the reference evapotranspiration methods and recommendations of a panel of experts and researchers organized in FAO, Rome, in 1990, the Penman Monteith equation has been adopted as the globally best performing method of estimating evapotranspiration (Smith *et al.*, 1991).Moreover, as suggested by (Allen et al.,1998) Penman-Monteith more acceptable than the others due to the method physically based that has been tested using several lays meters and does not need other parameters than those usually measured at most weather stations. It is given by:

$$\mathrm{ETo} = \frac{0.408\Delta\,(Rn - G)\; + \gamma(\frac{900}{T + 273})u2(es - ea)}{\Delta + \gamma(1 + 0.34u2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (2.2)$$

Where: ETo- reference evapotranspiration (mm/day), Rn-net radiation at the crop surface (MJ/m2/day), G-soil heat flux density (MJ/m2/day), T- mean daily air temperature at 2 m height (^{o}C), es- saturation vapor pressure (kPa), ea- actual vapor pressure (kPa), es – ea- saturation vapor pressure deficit (kPa), Δ- slope vapor pressure curve (kPa/^{o}C) and γ- psychometric constant (kPa/^{o}C).

2.10.2. Crop Water Requirement

Crop water requirements are defined as the depth of water (mm) needed to meet the water consumed through evapotranspiration (ETc).As suggested by (Doorenbos and Pruitt, 1977) for the determination of crop water requirement reference crop evapotranspiration (ETo) and crop characteristics (Kc) are important. Thus, knowing crop characteristic and climatic condition of the given area is very crucial. The accuracy of determination of crop water requirements area largely dependent on the type of the climatic data available and the accuracy of the method chosen to estimate the evapotranspiration (Nuha and Henery, 2000). Also as suggested by (Allen et al., 1998) crop water requirement (ETc) given by equation (2.3).

$$ETc = Kc \times ETo \quad (2.3)$$

Where: - ETc= crop evapotranspiration (mm/day), Kc= crop coefficient, which is a function of crop type and stage of growth (fraction) ,and ETo= reference evapotranspiration (mm/day).

2.10.3. Effective rainfall (Peff)

Rainfall is the main source of water for agricultural production. Effective rainfall is taken to mean the portion of total rainfall that assists in meeting the consumptive use requirements of growing crops (Patwardhan et al., 1990). This means not all rain is available to the crops as some is lost through runoff and deep Percolation. Therefore, considering effective rainfall during irrigation water requirement is essential to overcome the misuse of water. This portion of rainfall can be estimated by the aid of CROPWAT 8.0 model. The model used four methods such as fixed percentage of rainfall, dependable rainfall, empirical formula and USDA Soil Conservation Service in estimating effective rainfall for irrigation planning and design (Smith, 1991).

3. MATERIAL AND METHODS

3.1. Description of the study area

3.1.1. Location

The study was carried out at Meki River watershed that is located partly in Oromia and partly in Southern Nations, Nationality and peoples regions in the Central rift valley of Ethiopia. The watershed lies in the geographic extent of 38°20' 0'' and 38°55' 0'' E longitude and 7° 55' 0'' and 8° 33' 0'' N latitude (Figure 3.1). Based on the digital elevation 30 m*30 m resolution the watershed has an elevation ranging from 1653 m to 3614 meters above mean sea level. The total gauged area coverage of the watershed that obtained through watershed delineation is 2171.15 km^2.

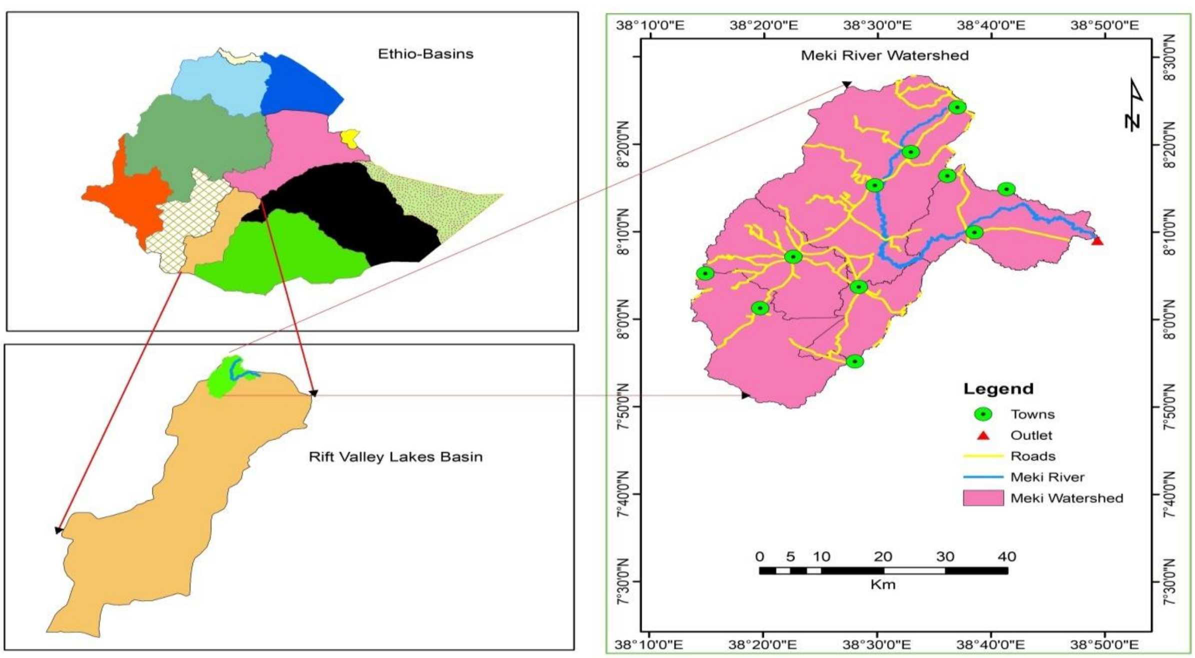

Figure 3. 1: Location map of the study area.

3.1.2. Agro-ecology

According to MoARD (2005) classification agro-ecology of Meki River watershed is classified as Tepid sub humid mid highland, cool moist mid highland, and cool sub humid

mid highland with area coverage of (74.6%), (19.6%) and (5.8%) respectively as shown in Figure 3.2. Accordingly, most part of the watershed is under the tepid sub humid mid highland.

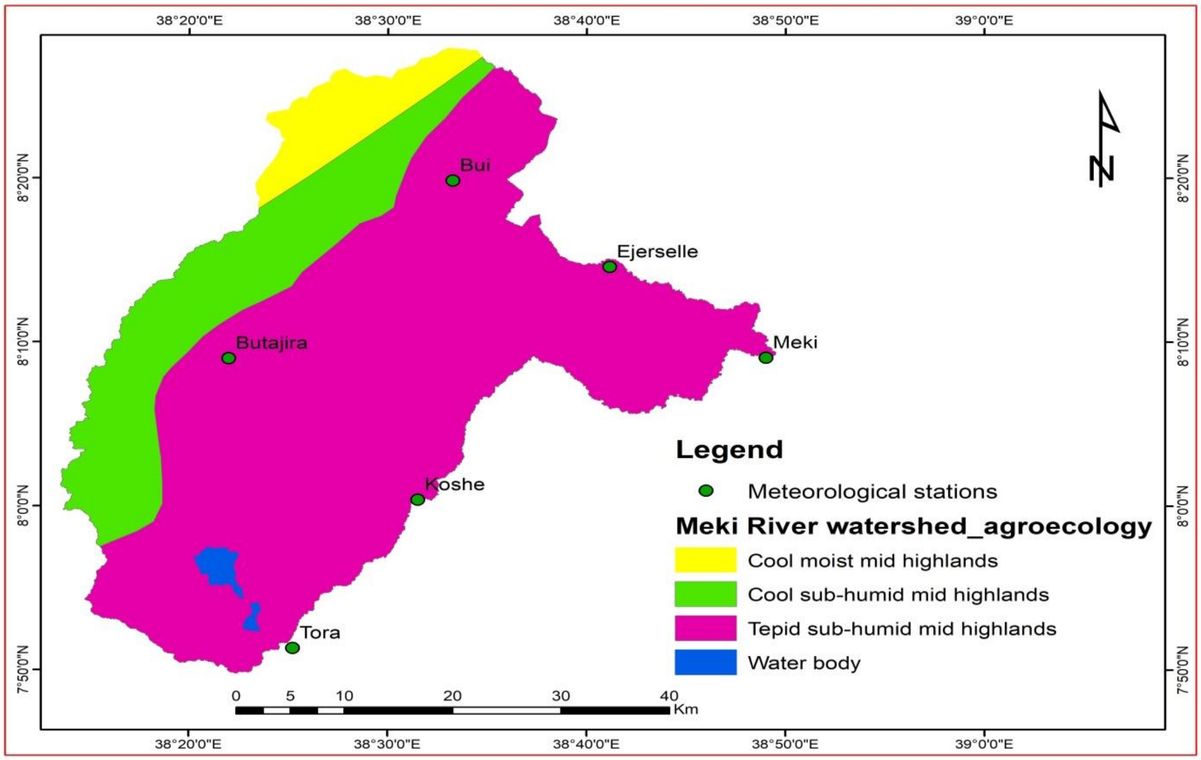

Figure 3. 2: Agro-ecological map of the study area.

3.1.3. Climate

Climate is the long-term pattern of weather in a particular area. Accordingly, Based on the time series data from 1995 to 2020 as shown in figure 3.3 in this watershed mean annual minimum temperature is about 11.15^{0}C, whereas the mean annual maximum temperature is around 25.6 ^{0}C. Further the watershed receives rainfall annually in average between 495.98 mm in the rift floor and 1065.1 mm at highland areas with an average of 929.18 mm. Also the average monthly rainfall is 198.4 mm for the wettest month (July), and 7.31 mm for the driest month (December).

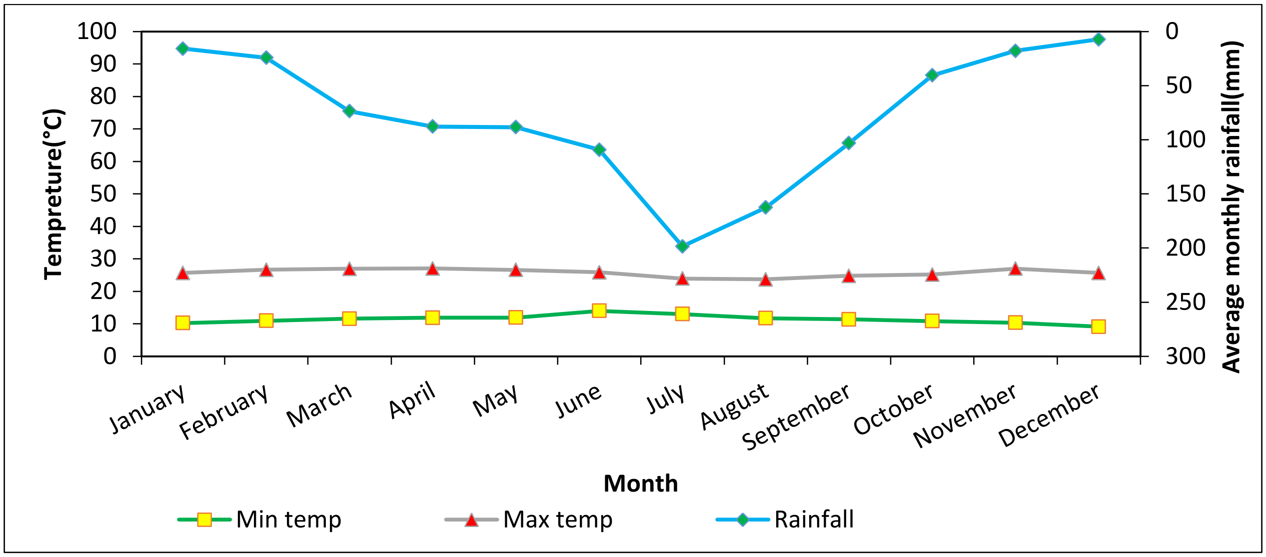

Figure 3. 3: Mean Monthly rainfall and Temperature of Meki Watershed for the period of (1995-2020)

3.1.4. Soil

Based on soil map obtained from Ministry of water resource the soil types of the study area are depicted below in figure 3.4.

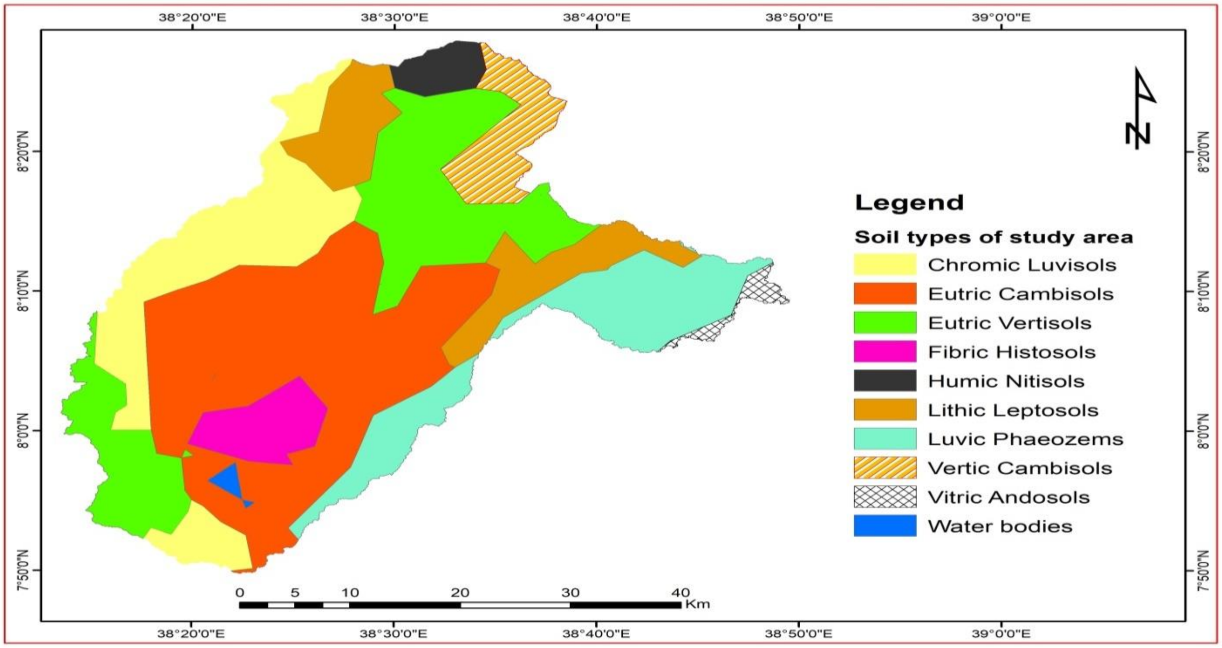

Figure 3. 4: Soil map of the study area

In terms of area coverage Lithic leptosols (9.71%), Eutric vertisols (19.74%),Chromic luvisols (15.6%), Eutric cambisols (31.3%),luvic phaeozems (11.5 %),Vitric Andosols (0.89%),Fibric histosols (3.98%), Humic nitisols (2.1%), Vertic cambisols (4.86%), and the rest (0.35%) was covered by water bodies. Accordingly, among these soil types, Eutric cambisols is the dominant soil in the watershed.

3.2. Data collection and analysis

A). Materials

In this study the materials depicted in table 3.1 were used to arrange data, full data scarcity, and analyze data.

Table 3. 1: Materials used in the study

No	Material	Version	Purpose
1	ARCGIS	10.3	Data processing and map preparation
2	ARCSWAT	2012	Flow simulation and delineation of watershed
3	ERDAS IMAGINE	2014	LULC classification and accuracy assessment.
4	CROPWAT	8.0	For estimating irrigation water demand
5	Google earth pro	7.3.1	Used as reference during image classification
6	New_LocClim	1.1	To obtain metrological data
7	Excel	2010	For Statistical analysis, table and graphs preparation
8	SWAT _CUP	5.2.1	For sensitivity analysis, calibration, and validation
9	Weather database	V01803	Weather generator preparation

B) Primary data

Agronomic data for the dominant crops such as planting date, harvesting date, and growth length were collected from local farmers by using informal survey (table 3.2).The data were used to obtain the length of growth stages of selected crops by comparing with recommended growth stage length by FAO irrigation and drainage paper. No.56 (Richard et al., 1998).

Table 3. 2: Agronomic data

Dominant Crop	Planting date	Growth length
Maize	1^{st}January	125
Onion	1^{st} October	100
Tomato	1^{st} October	130

C) Secondary data

For this study secondary data were collected from different sources and organizations as depicted in table 3.3, and 3.4 below.

Satellite images: The following satellite images listed below in the table 3.3 were obtained from the website (https://earthexplorer.usgs.gov/). They were used to acquire land use/cover of the study area.

Table 3. 3: Satellite images.

Satellite	Sensor ID	No of band	Path/row	Date of acquisition	Spatial resolution(m)	Source
Landsat 8	OLI-TIRS	7	168/054	1/21/2021	30	USGS
Landsat 8	OLI-TIRS	7	168/055	1/5/2021	30	USGS
Landsat 8	OLI-TIRS	7	169/054	1/28/2021	30	USGS

Moreover, for this study secondary data such as Stream flow from (1997-2012)(See in appendix table 1), meteorological data, soil data, and digital elevation model were obtained from different source and used for different purpose as shown in table 3.4

Table 3. 4: Stream flow, metrological, soil, and digital elevation model data with their sources.

No	Type of data	Source	purpose
1	Stream flow	MoWE	To calibrate and validate simulated flow of SWAT model
2	Meteorological data	ENMSA , New_LocClim	Input data for SWAT and CROPWAT model.
3	Soil data	MoWE & HWSD	For Soil suitability analysis and as usersol for SWAT model.
4	Digital elevation model	(https://earthexplorer.usgs.gov/)	For delineation and driving slope of the study area.

3.2.1. Data pre-processing and checking

The collected data may contain errors because of damaged measuring instruments, measurement errors, changes to instrumentation over time, a change in the measurement site, and a change in data collectors. Therefore, in this study before using the collected data for the wanted purpose, missed data was filled and the data consistency was checked to obtain the reliable result as presented below.

A). Filling missing rainfall data

In order to fill the missing rainfall data the percent of difference was computed to decide whether to use arithmetic mean or normal ratio method as cited in Bayush (2020).

$$\text{Percent difference} = \left(\frac{N_x - N_i}{N_x}\right) \times 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . (3.1)$$

Where:

$N_x =$ The normal annual rainfall amount from the missing data station.

$N_i =$ The normal annual rainfall amount from one of the nearby stations.

Accordingly, the missed rainfall data were filled by using the arithmetic mean and Normal ratio methods as explained below.

1. Normal ratio method

The method which is recommended to estimate missing data in regions where annual rainfall among stations differ by more than 10% (Dingman, 2002). This approach enables an estimation of missing rainfall data by weighting the observation at N gauges by their respective annual average rainfall values as expressed by equation 3.2 (Yemane, 2004).

$$P_i = \frac{1}{N}\left(\sum \frac{P_x}{P_{xa}} * P_{ia}\right) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.2)$$

Where: $P_i =$ missing data,

$P_x =$ The annual average precipitation at the gauge with perpendicular to the missing data,

$P_{xa} =$ Annual average values of neighboring stations

$P_{ia} =$ Monthly rain fall data in station for the same month of missing station

N = The total number of gauges under consideration

2. Arithmetic mean method

According to Chow 1964 as cited in Tang et al. (1996) the method is used if the normal annual rainfalls at surrounding gauges are within 10% of the normal annual precipitation at the stations concerned. Thus, missing data were estimated by the following equation (3.3).

$$P_X = \frac{1}{\mathrm{M}}(P_1 + P_2 + P_3 \ldots P_M) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.3)$$

Where:

P_X = Missing rainfall data at station X

P_1, P_2, P_3, and P_4 = Precipitation at surrounding gauges station.

M = the number of nearby gauge stations.

B). Consistency of rainfall data

After the missed data filled, their consistency was checked using double mass curve method. A plot of cumulated rainfall data at the site of interest against the cumulated average at the surrounding stations were used to check the consistency of rainfall data. Accordingly, the consistency rainfall data of Butajira, Ejerselle,Meki,Tora, Koshe, and Bui stations from the year of (1995 - 2020) were checked. The precipitation of station x (doubtful station) was corrected using equation (3.4) as stated by (Searcy & Hardison, 1960) and the corrected rainfall presented (See in Appendix table 8, 9, 10, 11, 12, and 13).

$$P_{cx} = P_x \frac{M_c}{M_a} \quad \ldots\ldots\ldots (3.4)$$

Where,

P_{cx} =Corrected precipitation at any time period (t) at station X

P_x = Original recorded precipitation at time period (t) at station X

M_c = Corrected slope of double mass curve

M_a =Original slope of the double mass curve

As suggested by Nemec (1973) the coefficient of correlation value was used to check the degree of consistence as indicated in table 3.5.Accordingly, the double mass curve shows that there is good direct correlation between the cumulative rainfall records for all rain gauge stations with the cumulative average rainfall at the five individual stations as depicted in figure 3.5.

Table 3. 5: Coefficient of correlation values

Correlation(r)	Correlation type
r=1	Direct linear correlation
o.6 ≤ r <1	Good direct correlation
-0.6 < r <0	Insufficient – reciprocal correlation
-1 < r <0.6	Good reciprocal correlation
r = -1	Reciprocal linear correlation

Therefore, the rainfall data of all rain gauge stations are consistent and can be used for further application as an input data.

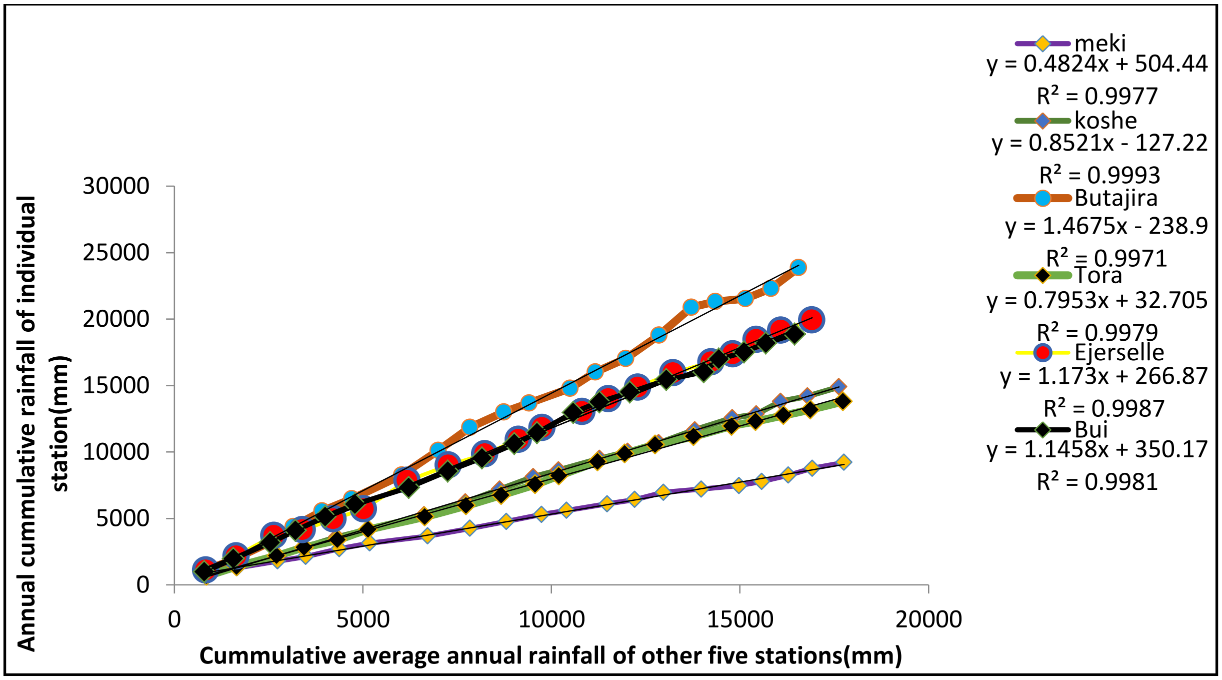

Figure 3. 5: Double mass curve of six stations (Meki, Koshe,Bui,Tora,Ejerselle and Butajira).

3.2.2. Assessment of land suitability for surface irrigation

In this study suitable land for surface irrigation was carried out by considering factors such as slope, soil depth, soil drainage, soil texture, and land use and land cover and rated based on FAO (1996, 1997) and (Sys et al., 1991**)**. The individual suitability of each factors were analyzed and overlaid based on their weight in order to obtain suitable land for surface irrigation as depicted in sub- sections below.

3.2.2.1. Slope suitability analysis

Slope suitability map of Meki River watershed was derived from digital elevation model (DEM) of 30 m×30 m spatial resolution Using ArcGIS 10.3 from spatial analysis tool-surface-slope. Accordingly, the slope of the study area was derived. In the watershed there is significant area occupied by water body and the area occupied by water body was classified under highly suitable during reclassification based on FAO (1996) and (Sys et al., 1991) guidelines recommendation .However, the water body do not used as land for irrigation purpose. Therefore, before reclassification the water body part was removed by their polygon using ERASE Command in Arcgis10.3. Then, the obtained slope from the DEM was reclassified using the “Reclassification” tool, in ArcGIS10.3 by giving the new value based on their suitability class. Hence, in this study the value 4, 3, 2 and 1 were given to highly suitable (S_1), moderately suitable (S_2), marginally suitable (S_3) and not suitable (N) respectively.

Table 3. 6: Standards for classification of Slope in the study area.

value	Slope (%)	Suitability class	Description
4	0-2	S_1	Highly suitable
3	2-5	S_2	Moderately suitable
2	5-8	S_3	Marginally suitable
1	>8	N	Not suitable

Source: FAO (1996) and (Sys et al., 1991) guidelines

Then, from the reclassified raster "Zonal statistics" as table tool of ArcGIS 10.3 platform was used to compute the areal extent of each category. Finally, the slope suitability map of the watershed was mapped.

3.2.2.2. Soil suitability analysis

The physical soil properties such as soil depth, soil texture, and soil drainage were considered for this study as factors for assessing land suitability for surface irrigation. The factors were clipped by shape file of Meki River watershed from soil map of Ethiopia that prepared according to FAO soil classification, and then each factor was rasterized for reclassification purpose by using conversion tool in ArcGIS 10.3.Finally, rasterized soil map of each soil factor was reclassified based on the suitability criteria rating suggested by (Sys et al., 1991) and (FAO, 1997) as shown in Table 3.7.

Table 3. 7: Standards for classification of soil (depth, texture and drainage) in the study area.

Factors	factor rating			
	S_1	S_2	S_3	N
Drainage class	Well	moderate	imperfect	poor/Very poor
Soil depth(cm)	>100	80-100	50-80	<50
Soil texture	SiC, SiCL, ,CL,L,SiL	C(light),SC,SCL,SL	LS,fS.LfS	Course sand

Source: (Sys et al., 1991) and (FAO, 1997)

C represent Clay, SC represents Sandy Clay, SiC represents Silty Clay, Si represents Silt, L represents Loam, CL represents Clay Loam, SiCL represents Silty Clay Loam, SCL represents Sandy Clay Loam, SL represents Sandy Loam. fS represents fine sandy,LS represents Loam sandy.

3.2.2.3. Land cover/use suitability analysis

Land cover/use also considered as factor for assessing land suitability for surface irrigation. In this study, land cover/use was obtained from LANDSAT 8 OLI/TIRS satellite image using supervised classification. During image selection cloud, and unwanted shade free imagery were set as criteria in order to increase accuracy of the classification work. Accordingly, three scenes of Satellite images of Landsat 8 sensor of 2021 OLI/TIRS with path/row (168 / 054, 168/055 and 169/054) acquired on January were used.

The pre-processing tasks such as layer stacking, image mosaicking, geometric correction and radiometric correction were accomplished by ERDAS Imagine 2014 as stated by Sekertekin & Marangoz, (2017). Finally, subset tool was applied to clip the study area from the mosaicked image in ERDAS 2014 (Figure 3.6).

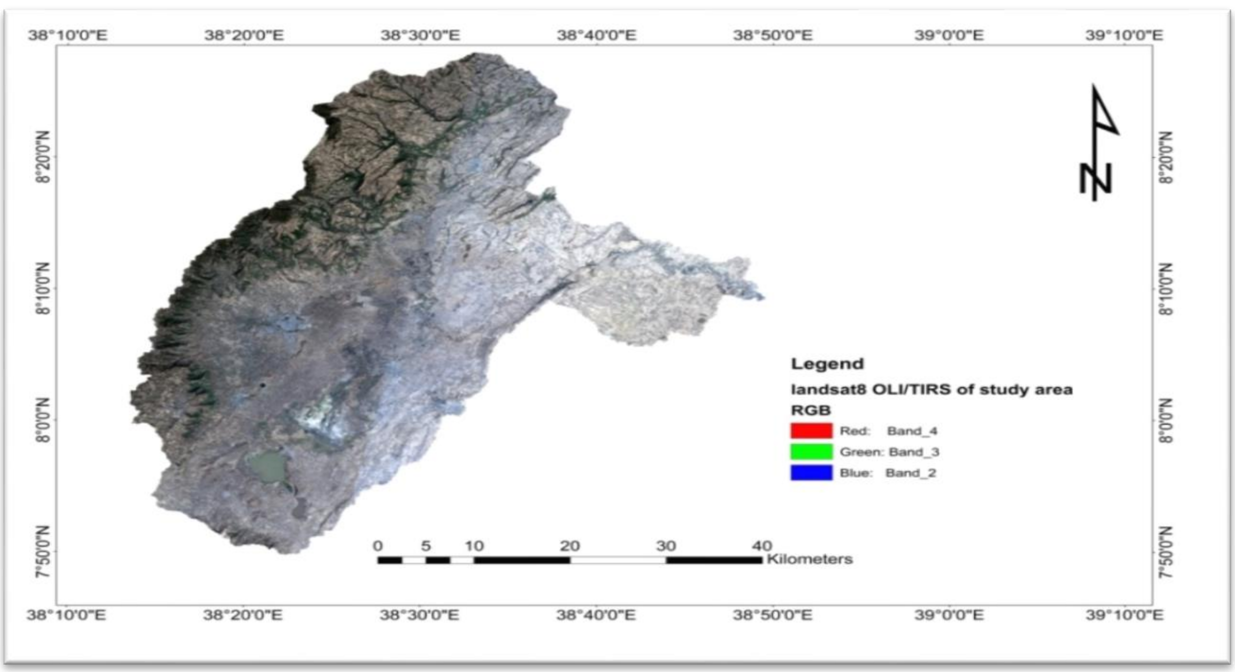

Figure 3. 6:Landdsat8 OLI/TIRS satellite image of the study area.

3.2.2.3.1. Image Classification

Classification of satellite image is necessary to extract information depending on application (Abburu & Golla, 2015). For this study supervised classification was done using ERDAS Imagine 2014 based on training manual suggested by (Hall et al., 2004). Moreover, during image classification since the area coverage of the watershed very large Google earth image were used to identify the doubt place during drawing area of interest. Hence, ERDAS Imagine 2014 was connected to Google earth pro and then the acquisition date was adjusted in the Google earth in order to make similarity with the acquisition date of landsat8 OLI/TIRS. Accordingly, an individual training site has selected as an area of interest and the pixels within the training site were used to generate a signature. This process has been repeated to collect several training sites for each class. Then, polygons with the same signatures were merged and given the class name. Finally, the supervised image classification using maximum likelihood algorithm method was done.

3.2.2.3.2. Accuracy assessment

Accuracy assessment is one of the most important classification processes that used to quantitatively assess how effectively the pixels sampled into the correct land use/cover classes. In this study accuracy assessment was done by ERDAS imagine using accuracy assessment tool. Thus, total of 200 points (See in appendix table 24) were generated randomly by the software in the classified image of the study area. Google earth and Google Map were used as reference source to verify the selected points. The Accuracy Assessment Cell Array Reference column was filled by inserting each point into the Google earth to check the mapped classes. accordingly, accuracy assessment was checked for the signature values of the classified images by calculating the confusion matrix which is a table with the columns representing the reference (observed) classes and the row the classified (mapped) classes (Rossiter, 2001). The agreement between classified land and observed land was checked using kappa value as suggested by (Rahman et al., 2006) that described as value greater than 0.8 represents strong agreement, between 0.4 and 0.8 represents moderate agreement and a value below 0.4 represents poor agreement and calculated using equation (3.5) as suggested by Cohen (1960).

$$Kappa = \frac{po - pe}{1 - pe} \quad \ldots \ldots (3.5)$$

Where: Po = is the proportion of correctly classified classes

Pe = is the proportion of correctly classified classes expected by chance

Moreover, overall accuracy was checked with the value suggested by Congalton, (1991) described as value greater than 70 % considered to be acceptable.

Accordingly, LULC were completed and then their suitability for surface irrigation was done based on suitability criteria shown in table 3.8.

Table 3. 8 :Land use/land covers suitability criteria

Category	Suitability	Description of LULC Types
S_1	Highly Suitable	Cultivated – dominantly, moderately Grassland – open, bushed, shrub bed Bush land – open, riparian
S_2	Moderately suitable	Woodland – open, riparian Bush land - dense
S_3	Marginally suitable	Forest - open Cultivated – Irrigation, state farm
N	Not suitable	Woodland – dense, Bamboo, urban area

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

3.2.2.4 .Weighted overlay analysis

Determining the weight of each factor during land evaluation is very essential in order to minimize bias and obtain representative suitable land .Therefore, for this study the weight of each factor was computed by using a pairwise comparison method as developed by Saaty (1980) in the context of Analytical Hierarchy Process (AHP). One of the benefits of using AHP method is that it allows the users to focus judgment separately on each of several properties essential for making a sound decision (Saaty & Vargas, 2012). A scale of importance from a value of 1 to 9 as suggested by (Saaty & Vargas,1991)(table 3.10) was used for the completion of pair wise comparison matrix .The completion of pair wise matrix was done based on related review literature, and on expert judgment.

The normalized comparison matrix was created by dividing each value in the matrix by the sum of its column. Then, from the normalized comparison matrix the weight of individual factors was calculated by finding the mean of each row of the factors. Finally, the consistence ratio was computed in order to check the acceptability of pair-wise comparison matrix. In this study the consistency was measured by consistent ratio (CR) suggested by (Ahamed et al., 2000; Saaty and Vargas, 1991).Accordingly, the consistence ratio was computed by the following formula.

$$\text{Consistence index (CI)} = \frac{l_{max} - n}{n-1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.6)$$

$$\text{Consistence Ratio (CR)} = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.7)$$

Where: n=Numbers of criteria.

l_{max}=maximum eigenvalue of the comparison.

RI= Random Consistency Index, which is depends on the number of criteria (table 3.9).

Table 3. 9: Random consistence index.

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.4	1.45

Source: (Saaty, 1994).

Table 3. 10: AHP method for pairwise comparison matrix

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

After the consistence ratio checked the weighted overlay analysis was applied by overlapping all thematic layers in GIS and by multiplying the weight value with the cell value of each raster in ArcGIS 10.3 based on equation (3.8).

$$Sx = \sum_{n=i}^{n} W_i X_i \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (3.8)$$

Where: S_X=Total suitability value, Wi=weight

X_i=Cell suitability value, and n=Number of factor considered.

Finally, land suitability for surface irrigation was done as shown in figure 3.7

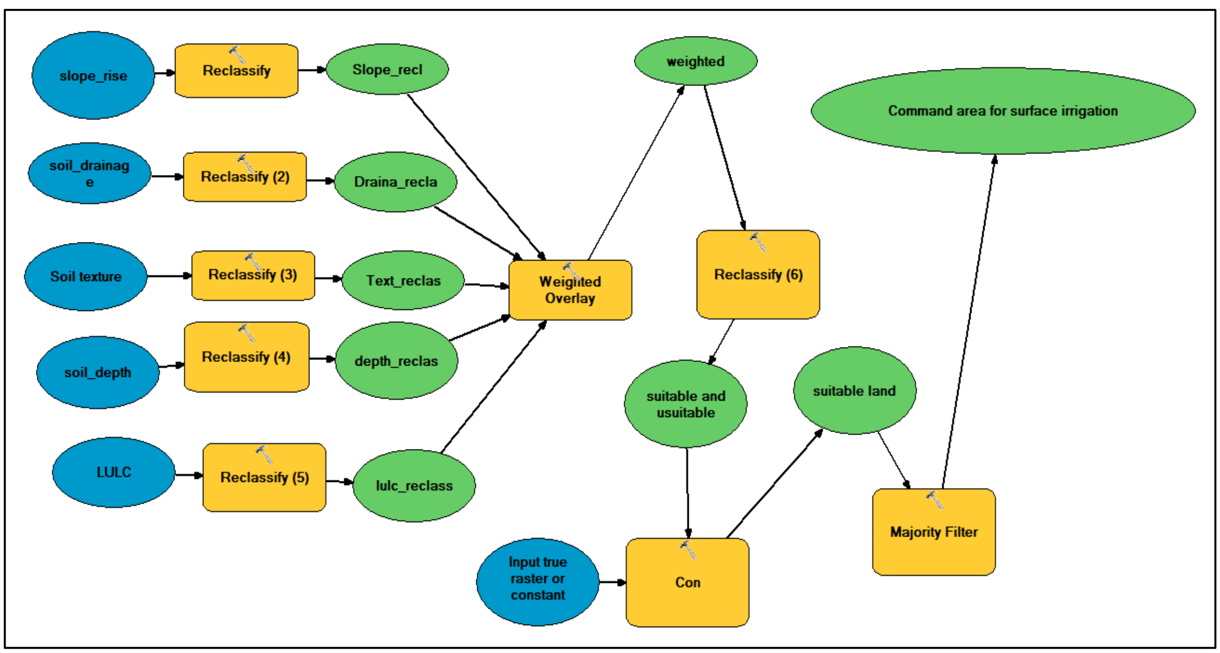

Figure 3. 7: Land suitability Model for surface irrigation.

3.2.3. Assessment of surface water using SWAT model

Runoff from a watershed produced by given precipitation estimated using various models. However, for this study surface water availability of the watershed was assessed by using

SWAT model due to the model advanced for hydrological drought forecasting in Africa in addition to its ability to be applied in a simpler way with few parameters, despite having high data requirements (Trambauer et al., 2013).Further, the model capable of predicting flow and sediment yields and performing further analyses at scale of hydrological responses (Mtibaa et al., 2018).

The metrological data of six stations (Meki, Butajira, Koshe, Bui Tora and Ejerselle), LULC data, LULC code, soil data, soil code, slope and DEM of Meki watershed were used for the simulation of stream flow using SWAT model 2012. The modeling technique was included SWAT project setup, Watershed delineation, HRU Analysis, Write Input Tables, Edit SWAT Input and SWAT simulation. All the above techniques were accomplished based on the user guide of SWAT that is prepared by Winchell et al. (2010).

3.2.3.1. Watershed delineation

Digital Elevation Model (DEM) with 30 meter pixel size which gives topographic information of the watershed was used. Watershed of the study area was delineated based on the procedures explained in the SWAT user's guideline prepared by Winchell et al,(2010).Accordingly, the DEM was imported to Arc SWAT to start automatic watershed delineation and its projection was defined. Hence, in order to reduce the number of sub-basin in the watershed twenty thousands (20000) hectares were taken as threshold area or minimum drainage area and then the flow direction and flow accumulation were automatically calculated. The location of the stream flow gauging station (Meki town) was manually added during the model set up process and the study area was delineated as shown in figure 3.9.

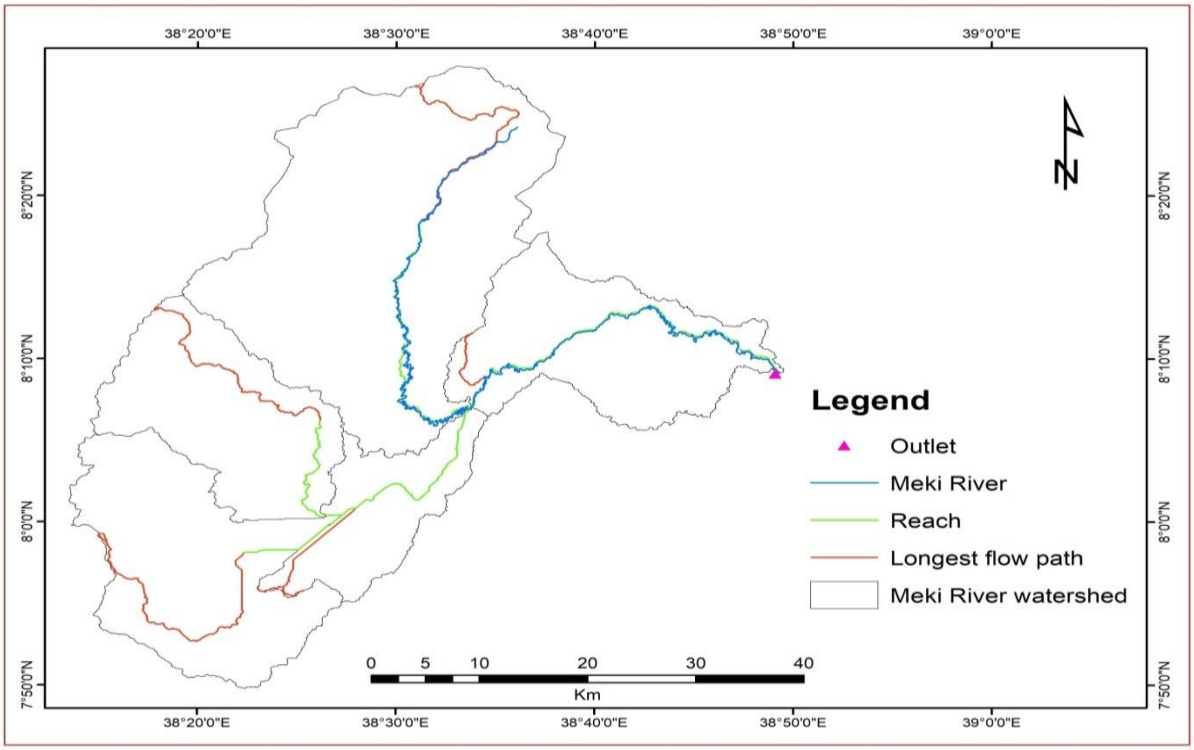

Figure 3. 8: Watershed of the study area

3.2.3.2. Hydraulic response unit (HRU) analysis.

Based on the user guide prepared by Winchell et al. (2010) hydraulic response analysis was done. Accordingly, the land use land cover and soil map of the study area were projected before loading into the model and defined using the look up table. Since the watershed has a wide range of slopes between them multiple slope discretization operation was selected over the single slope discretization. Based on the suggested minimum, maximum, mean and median slope statistics of the watershed four 4 slope classes (0-10, 10-15, 15-20 and >20) were applied. Hence, after land use /cover, slope and soil reclassified, overlay analysis was done to determine the land use/soil/slope class combinations.

3.2.3.3. Weather Data preparation

The six meteorological stations have precipitation data. However, only Bui station was synoptic station used for generating remaining weather data for others stations. The daily climate data were processed using SWAT-weatherdatabase-v01803. Accordingly, WGEN statistics, and text file for each weather parameter was prepared and used with SWAT project. Finally, the weather generator data file WGEN_user, rainfall data, temperature data, relative humidity data, solar radiation data, and wind speed data were selected and added to the SWAT model.

3.2.3.4. Sensitivity analysis

The sensitivity analysis was undertaken to identify the parameters that highly influence stream flow of the river .In this study Global sensitivity analysis technique was used using the algorithm for Sequential Uncertainty Fitting (SUFI-2) that included in the SWAT-CUP 2019 version 5.2.1. The parameters for sensitivity analysis were selected based up on different literature that have been done around the study area including from Desta & Lemma, (2017).Thus, seventeen parameters as shown in table 3.11 were selected.

The mean monthly stream flow data of 11 years (1997–2007) were used to determine the sensitivity of the parameters with 500 simulation numbers. Upon the completion of global sensitivity analysis the sensitive parameters was identified based on the t-stat values where the values are more sensitive for a larger in absolute t-stat values and if the P-values are close to zero (Abbaspour, 2015). Accordingly, sensitive parameters were selected for the study area.

Table 3. 11: Parameters used for sensitivity analysis.

Parameter Name	description
ESCO	Soil evaporation compensation factor
HRU_SLP	Average slope steepness
REVAPMN	Threshold depth of water in the shallow aquifer for “revap” to occur
SOL_BD	Moist bulk density.
ALPHA_BF	Base flow alpha factor
CANMX	Maximum canopy storage
CH_K2	Effective hydraulic conductivity in main channel
RCHRG_DP	Deep aquifer percolation fraction
EPCO	Plant uptake compensation factor
GW_REVAP	Groundwater “revap” coefficient
GWQMN	Shallow Aquifer Threshold (mm)
SLSUBBSN	Average slope length
SOL_K	Saturated hydraulic conductivity
OV_N	Manning's "n" value for overland flow
CN2	SCS runoff curve number
GW_DELAY	Ground water delay
SURLAG.bsn	Surface runoff lag time

3.2.3.5. SWAT model calibration and validation

For this study Model calibration and validation were performed using the algorithm for Sequential Uncertainty Fitting (SUFI-2) that included in the SWAT-CUP package (Abbaspour, 2015). The model was run monthly for the simulation period of January 1, 1995, up to December 2020, with the first two years (1995–1996) being used as a warm period. Hence, the model was calibrated from 1997 up to 2007 and validated from 2008 up to 2012 using sensitive parameters obtained from global sensitive analysis. In the calibration process the values of parameters were varied iteratively with in the allowable range until the measured and simulated flow agreed, whereas the validation was done using calibrated parameters without changing their value.

3.2.3.6. Model performance evaluation

In this study three mainly used indicators such as coefficient of determination (R^2), Nash-Sutcliffe coefficient efficiency (Nash and Sutcliff 1970), and percent bias (PBIAS) were used for calibration and validation of model to test the goodness of fit between simulated and observed values as recommended by (Moriasi et al., 2007).

$$\mathrm{NSE} = 1 - \left[\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}(O_i - P_i)^2}{\sum_{\mathrm{i}=1}^{\mathrm{N}}(o_i - \bar{o}_i)^2}\right] \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3.8)$$

$$\mathrm{PBIAS}(\%) = \left[\frac{\sum_{\mathrm{i}=1}^{\mathrm{N}}(O_i - P_i) * 100}{\sum_{\mathrm{i}=1}^{\mathrm{N}}(O_i)}\right] \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots (3.9)$$

$$R^2 = \left[\frac{\sum_{i=1}^{N}(O_i - \bar{O}_i)(P_i - \bar{p}_i)}{\sqrt{\sum_{i=1}^{N}(O_i - \bar{O}_i)^2}\ \sqrt{\sum_{i=1}^{N}(P_i - \bar{P}_i)^2}}\right] \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . \ldots \ldots (3.10)$$

Where P_i = predicted flow, O_i = observed flow, $\bar{o}$= the mean of observed data, $\bar{P}$, the mean predicted flow and the remaining variable is stated above and N is the total number of observations.

Moreover, in this study the general performance rating for the recommended statistics for monthly time step depicted below in table 3.12 were used.

Table 3. 12.General performance rating for monthly time step (Moriasi et al., 2007)

Performance rating	NS	PBIAS	R^2
Very good	0.75 < NS ≤ 1	PBIAS < ±10%	$0.75 < R^2 \leq 1$
Good	0.65 < NS ≤ 0.75	±10% ≤ PBIAS < ±15%	$0.65 < R^2 \leq 0.75$
Satisfactory	0.5 < NS ≤ 0.65	±15% ≤ PBIAS < ±25%	$0.5 < R^2 \leq 0.65$
Unsatisfactory	NS ≤ 0.5	PBIAS ≥ ±25%	$R^2 \leq 0.5$

3.2.3.7. Flow duration curve

After surface water assessed flow duration curve technique was applied in order to determine dependable flow. The FDC was developed by arranging monthly simulated flow values in decreasing magnitude order and assigning rank numbers to each stream flow value to determine the monthly dependable flow.

According to Kannan et al.(2018) as cited in Koteia et al.(2016) flow duration curve could be divided into five zones, representing high flows (0-10%), humid conditions (10-40%), medium-range flows (40-60%), dry conditions (60-90%), and low flows (90- 100%). Since irrigation mainly practiced during dry season it is better to evaluate the flow of the River for dry season. Therefore, for this study among the dry condition flow 80% dependable flow (Q_{80}) was used as supply during irrigation period. Using the relationship explained in equation (3.11) as suggested by (Awass, 2009; Koteia et al., 2016; Yahiaoui, 2019) the probability of exceedence was computed.

$$P = \left(\frac{m}{N+1}\right) \times 100 \qquad (3.11)$$

Where, P = the percentage of time a given flow is equaled or exceeded; N = the total number of records; m = the rank of the flow magnitude.

3.2.4. Determination of irrigation water requirement

Three dominant crops (Onion, Tomato and Maize) were selected for single growing season for estimating irrigation water requirement to evaluate the available surface water potential. To estimate irrigation water requirements of dominant crops in the watershed, the climatic data were taken from National Meteorological Service Agency of Ethiopia for six stations such as Butajira, Bui, koshe, Tora Meki,and Ejjerselle. However, except Bui station other stations did not have complete climatic parameters. Because of this, the climatic data such as Wind speed,Temprature (max and min), Sunshine hour and Humidity for Butajira, koshe Tora,Meki ,and Ejerselle stations were obtained from New_LocClim_1.10 software (See in Appendix table15) by using coordinate of each station (See in Appendix table 23).Accordingly, Irrigation water requirement was computed based on the following procedures.

3.2.4.1. Estimation of reference evapotranspiration (ETo)

For this study Penman-Monteith method was used due to all climatic parameters available and the method advantages over the other many methods as suggested by (Allen et al., 1998).Among the numerous models CROPWAT model was selected due to the model uses Penman–Monteith method as a base. Averaged climatic data of six stations were used as an input (See in appendix table 16). Accordingly, reference crop evapotranspiration was estimated using CROPWAT 8.0 based on equation (2.2) of section 2.10.1 as shown in table 3.13.

Table 3. 13: Reference crop evapotranspiration of Meki River watershed.

Month	Min temp (°c)	Max temp (°c)	Humidity (%)	Wind (m/s)	Sunshine hr.	Rad (MJ/m²/day)	Eto (mm/day)
January	10.2	25.7	77	1.3	8.2	19.8	3.63
February	11	26.7	73	1.3	8.3	21.2	4.05
March	11.6	27	74	1.5	8.3	22.2	4.36
April	11.9	27.1	83	1.2	8	21.8	4.18
May	11.9	26.6	86	1.2	7.7	20.8	3.95
June	11.9	25.8	88	1.2	6.8	19	3.6
July	11.9	24	89	1.1	5.8	17.7	3.28
August	11.7	23.7	88	0.8	5.8	18.1	3.32
September	11.4	24.8	90	0.7	5.5	17.7	3.3
October	10.9	25.2	82	1.2	8.1	21	3.83
November	10.4	25.2	80	1.5	8.8	20.9	3.77
December	9.1	25.7	74	1.5	8.6	19.9	3.71
Average	11.2	25.6	82	1.2	7.5	20	3.75

3.2.4.2. Determination of crop water requirement

Cropwat for windows (version 8.0) was used to compute crop water requirement by feeding all the necessary input data. The model was used equation (2.3) of section 2.10.2 as suggested by (Allen et al., 1998).In this study input data of Planting and harvesting date for the selected crops were collected from the study area through informal survey and then matched with the FAO's recommendation values to get the lengths of each crop stage. Moreover, the crop characteristics (Kc) values were obtained from reference texts in FAO Irrigation and Drainage Paper No. 33 and 56 (See in Appendix table 17, 18, and 19).Hence, crop water requirement for each selected crops were computed (See in Appendix table 20, 21 and 22).

3.2.4.3. Determination of Effective rainfall (Peff)

Effective rainfall is taken to mean the portion of total rainfall that assists in meeting the consumptive use requirements of growing crops (Patwardhan et al., 1990). In this study Effective rainfall was computed using CROPWAT for windows (version 8.0) based on USDA Soil Conservation service method. Long term mean monthly rainfall data (P_n) of six stations from (1995-2020) (See in Appendix table 14) were used as input for effective rainfall after averaged using Theissen Polygon method as depicted below in equation (3.12) as suggested by (Şen ,1998). An area of influence (A_n) for each station was obtained using Thiessen polygons method as suggested by (FAO, 1997) as indicated in Figure 3.7

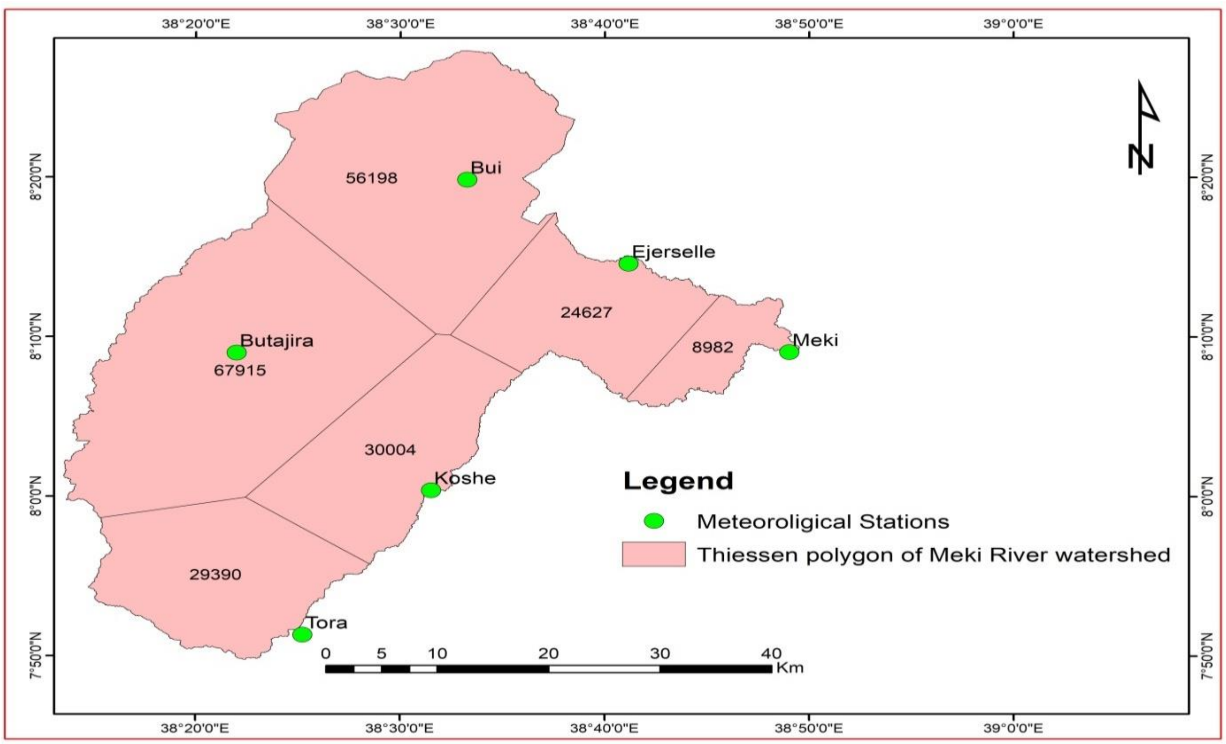

Figure 3. 9: Thiessen polygons showing area (ha) of influence of climatic stations.

$$P_{av} = \sum_{n=1}^{m} \frac{P_n * A_n}{A_n} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (3.12)$$

Where:

P_{av}=Areal mean precipitation

P_n=rainfall observed at each station, and

A_n= portion of the area of polygon

Then, the averaged aerial rainfall was inserted into the CROPWAT8.0.Thus; the effective rainfall (mm) of the watershed was computed as shown in table 3.14.

Table 3. 14: Effective rainfall (Eff) of Meki River watershed

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rain(mm)	16	24	74	88	88.4	109.2	198	162.5	103.1	40.5	18	7.3	929.2
Eff rain(mm)	16	23	65	76	75.9	90.1	135	120.3	86.1	37.9	18	7.2	749.7

3.2.4.4. Net and Gross irrigation water requirements

Net irrigation water requirement for the selected crops were computed using CROPWAT 8.0 based on equation (2.1) of section (2.10). Whereas, gross irrigation water requirement was computed using equation (3.9) below by considering the losses occurred from the canal during conveying water from the river and losses occurred on the field during application of irrigation water to field. According to Raine and Bakker (1996) irrigation application efficiencies normally vary from (45-60%). But In the watershed, water may not be applied with precise measurement, and there may be variation of length of furrow. Due to this the amount run-off and deep percolation might be high. Therefore, for this study lower value of application efficiency (45%) was adopted. Moreover, conveyance efficiency (Ec) was taken 90% as recommended by (FAO, 1992). Hence, the gross irrigation water requirements that must be diverted from the river to fulfill the demand required by the crops were calculated as below.

$$\text{GIWR} = \frac{\text{NIWR}}{\text{Ea} * \text{Ec}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (3.13)$$

Where:

E_a=Field application irrigation efficiency (%)

E_c=Conveyance efficiency (%)

GIWR=Gross Irrigation water requirements (mm)

NIWR=Net irrigation water requirements (mm)

3.2.5. Determination of potential Irrigable area (PIA).

In this study the irrigation potential area was computed by comparing gross irrigation water requirement and water supply from the source. Hence, using irrigation water requirement obtained based on cropping pattern and 80% dependable flow (Q_{80}) irrigation potential area of Meki River watershed was determined by the following relation.

$$\text{PIA} = Q_{80}/\text{GIWR} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots.. (3.14)$$

Where:

PIA=Potential irrigable area (ha).

Q_{80}= Dependable flow at 80% probability (l/s).

GIWR=Gross irrigation water requirement (l/s/ha).

4. RESULTS AND DISCUSSIONS

4.1. Assessment of land Suitability for surface irrigation.

Based on land evaluation factors considered the results of land suitability assessment for surface irrigation explained in the following sub-sections.

4.1.1. Slope suitability

The slope suitability classes and area coverage of the watershed is presented in table 4.1. The results showed that the area coverage of highly suitable class for surface irrigation was very small when compared with other suitability classes. This indicates that majority part of the watershed has slope above 2%. Also the results showed that about 102,804.03 ha (47.69 %) in the watershed was unsuitable area for surface irrigation in terms of slope.

Table 4. 1: Slope Suitability Classes and area coverage of the Watershed.

value	Slope	Suitability class	Description	Area(ha)	Area (%)
4	0-2	S_1	Highly suitable	16,897.41	7.84
3	2-5	S_2	Moderately suitable	53,067.61	24.62
2	5-8	S_3	Marginally suitable	42,792.75	19.85
1	>8	N	Not suitable	102,804.03	47.69
Total				215,561.79	100

To conclude the findings from table 4.1 the land about 112,757.8 ha (52.31 %) of the total area were in the range of highly to marginally suitable class in terms of slope for surface irrigation. Moreover, regarding location as indicated below in the figure 4.1 the suitable land for surface irrigation in terms of slope mainly located in the middle part and lower part of the watershed, whereas the non-suitable class mainly found on the upper part of the watershed.

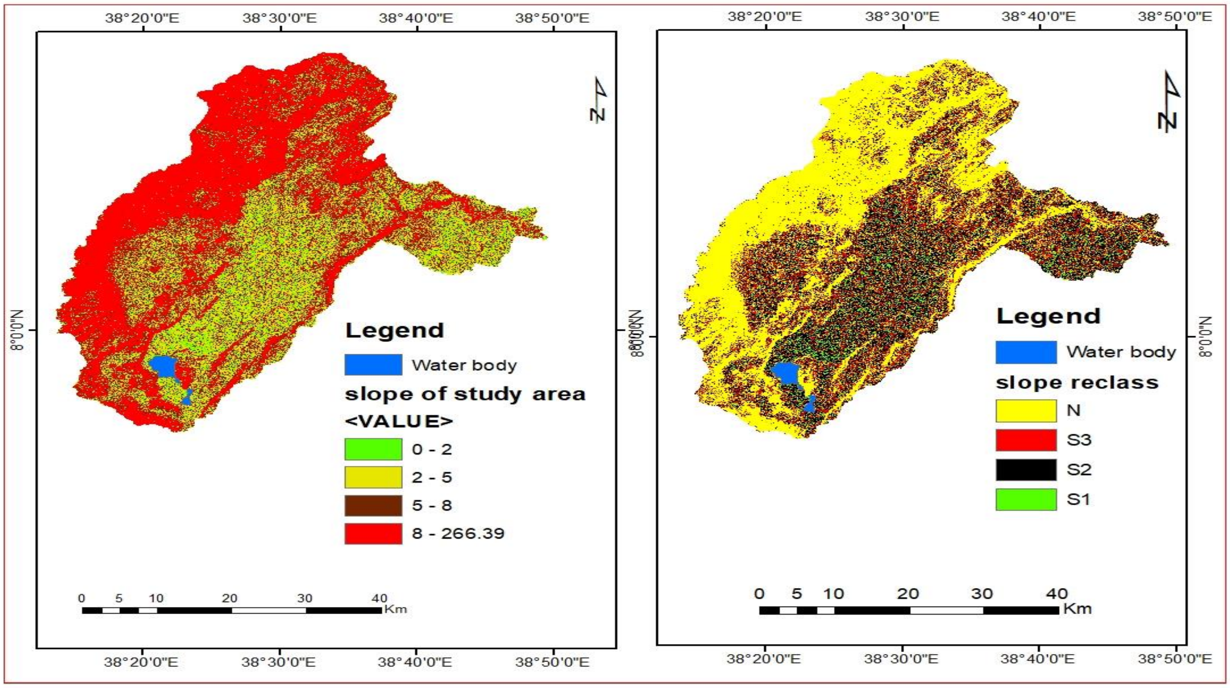

Figure 4. 1: Slope class and suitability map of Meki River watershed.

4.1.2. Soil suitability analysis

The soil suitability analysis for considered soil parameters in this study was presented in the following sub-sections.

4.1.2.1. Soil depth suitability

Table 4.2 and figure 4.2 shows the results of soil depth suitability classes and area coverage for surface irrigation in the study area. The results indicated that in the watershed highly suitable and marginal suitable classes do not exist for surface irrigation, and the majority (89.90%) of the total area was moderately suitable for surface irrigation. Generally, from the above findings it can be concluded that majority of the study area was suitable for surface irrigation, whereas about 21,950.19 ha (10.10%) of the total area was not suitable for surface irrigation because of depth limitation.

Table 4. 2: Soil depth suitability and area coverage of the watershed.

value	Soil depth class	Suitability class	Description	Area(ha)	Area (%)
3	80-100	S_2	Moderately suitable	195,164.19	89.90
1	<50	N	Not suitable	21,950.19	10.10
Total				217,114.38	100.00

Figure (4.2) shows the location of suitable land for surface irrigation in terms of soil depth.

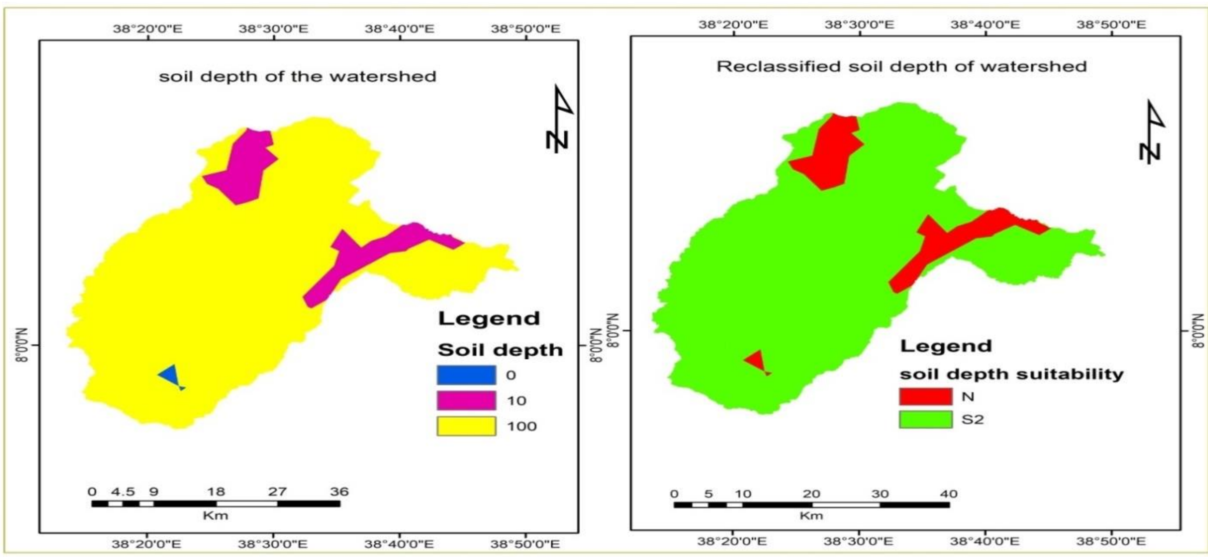

Figure 4. 2 : Soil depth class and soil depth suitability map of Meki River watershed.

4.1.2.2. Soil drainage suitability

As can be seen from table 4.3 and figure 4.3 regarding soil drainage except highly suitable class other classes such as moderately suitable, marginal suitable and unsuitable classes were existed in the watershed. This implies that the nonexistence of soil with well drainage in the watershed. Also the result reveals that in terms of area coverage moderately suitable cover about (66 %), followed by not suitable that cover about (24.05 %) and marginally suitable cover about (9.95 %) of the total area of the watershed. These results indicate that the soil of the watershed mostly moderately well in terms of drainage class. In conclusion, with regard to soil drainage of the total area about 164,895 ha was suitable for surface irrigation, whereas (52,220 ha) was not suitable for surface irrigation.

Table 4. 3: Soil drainage suitability and area coverage of the watershed.

value	Soil drainage rate	Suitability	Description	Area(ha)	Area (%)
3	Moderately well drain	S_2	Moderately suitable	143,303	66.00
2	Imperfectly drain	S_3	Marginally suitable	21,592	9.95
1	Water body/very poor/poor	N	Not suitable	52,220	24.05
Total				217,115	100

Figure (4.3) shows the location of suitable land for surface irrigation in terms of soil drainage.

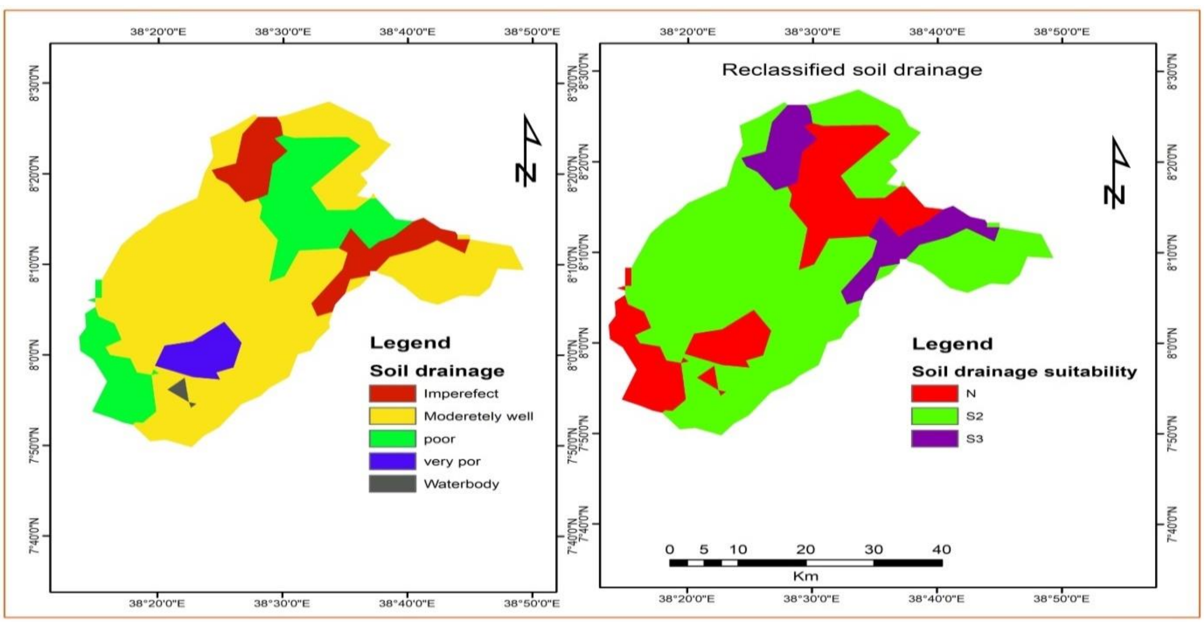

Figure 4. 3: Soil drainage and suitability map of Meki Watershed.

4.1.2.3 Soil texture suitability

Table 4.4 and figure 4.4 show that soil texture suitability and area coverage for surface irrigation. The results revealed that 29.17 % is highly suitable which is covered by loam soil texture and about 70.48 % is moderately suitable, and the rest 0.35 % is not suitable of the total area for surface irrigation. Generally, with regard to soil texture 216,348.8 ha of the study area were in the range of highly to moderately suitable for surface irrigation.

Table 4. 4: Soil texture suitablity classes and area coverage of the watershed.

value	Soil texture	Suitability	Description	Area(ha)	Area (%)
4	Loam	S1	Highly suitable	63,336.2	29.17
3	Sandy loam/clay	S2	Moderately suitable	153,012.6	70.48
1	Water	N	Not suitable	765.6	0.35
Total				217,114.5	100

Figure 4.4 depicts the location of soil texture and suitability area in terms of soil texture.

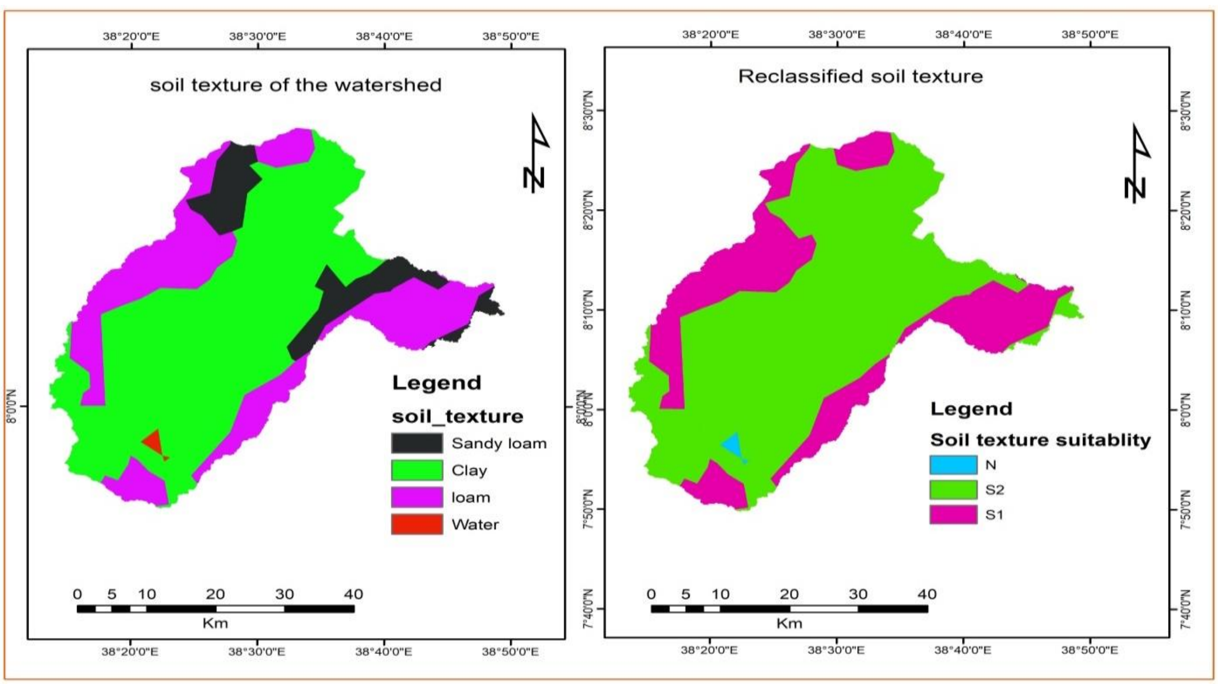

Figure 4. 4: Soil texture suitablity map of meki watershed.

4.1.3. Land Use / Land Cover suitability analysis

4.1.3.1. Land Use / Cover classification

The results of Land use land cover classification of the study area depicted in table 4.5 and figure 4.5.The results revealed that five LULC classes such as cultivated land, shrub land, forest, settlements (built up area), and water body were identified with the area coverage of 161,394.66 ha, 26,752.86 ha, 17,512.02 ha, 10,049.13 ha and 14,07.33 ha respectively. From the above area coverage it can be concluded that majority part of study area is covered by cultivated land, and followed by shrub land. Also the results revealed that in terms of land use and cover the class of water body was the smallest when compared with other land use land cover classes.

Generally, because of huge cultivated land in the watershed the land suitability for surface irrigation in terms of land use/ cover might be increased.

Table 4. 5 : Land use / cover and area coverage of the watershed.

No	Class name	Count	Area(ha)	Area (%)
1	Forest	194578	17,512.02	8.07
2	Cultivated land	1793274	161,394.66	74.34
3	Shrub land	297254	26,752.86	12.32
4	Built up area	111657	10,049.13	4.63
5	Water body	15637	1,407.33	0.65
Total			217,115.90	100

Figure (4.5) shows the location of LULC of Meki River watershed.

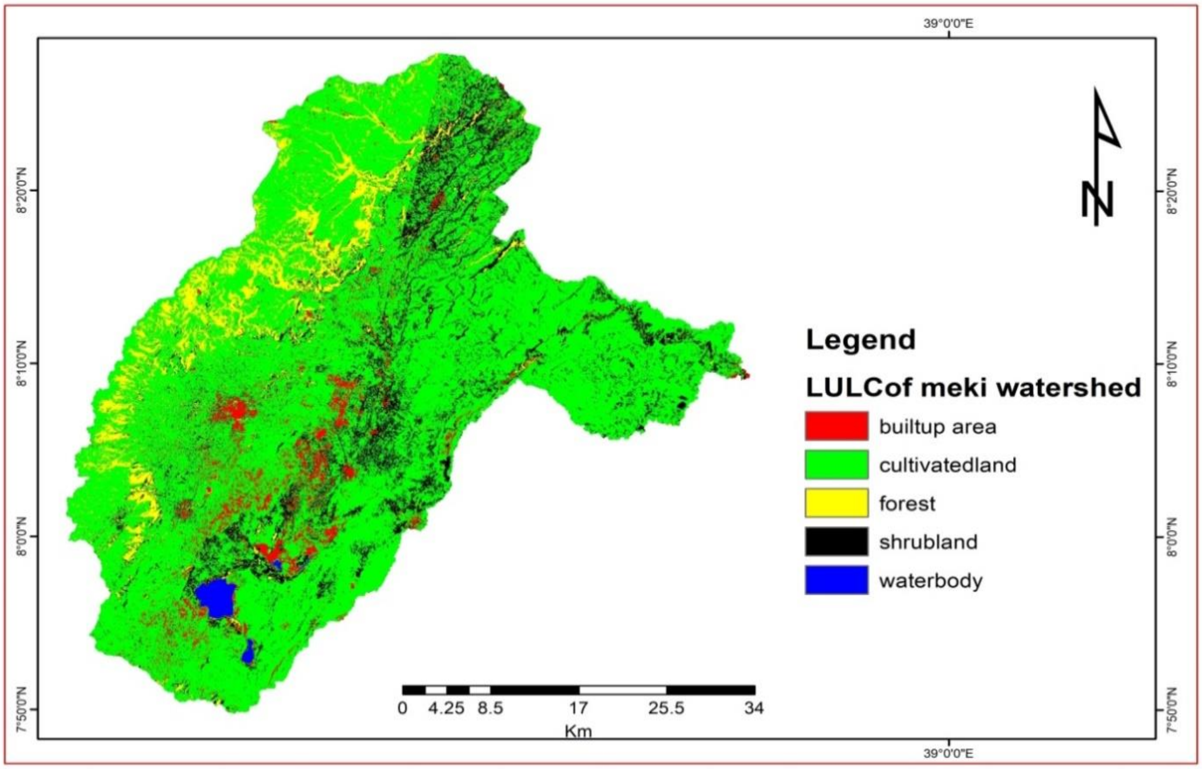

Figure 4. 5: Land use /cover map of Meki River watershed.

4.1.3.2. Accuracy assessment of supervised image classification.

The accuracy assessment results showed that overall accuracy was 73.5% and overall kappa statistics about 0.6687 as depicted in table 4.6. Overall accuracy is equal to number of pixels correctly classified (147) divided by total number of pixels (200) times one hundred that is equal to 73.5 %. This means that the land use /cover about 73.5% of the study area are classified accurately and the remaining area is not accurately classified.

Based on the kappa agreement suggested by (Rahman et al., 2006) and overall accuracy as recommended by Congalton, (1991) the classified land use land cover of the study area is acceptable. Therefore, the land use land covers classified above in table 4.5 can be used for further application.

Table 4. 6: LULC accuracy assessment report (error matrix, kappa statistics and total accuracy).

Error matrix						
	Reference data					
Classified data	Shrub land	Water body	Forest	Settlement	Cultivated	Row total
Unclassified	0	0	0	0	0	0
Shrub land	26	0	1	2	11	40
Water body	1	38	0	0	1	40
Forest	1	0	39	0	0	40
Settlement	5	2	2	9	22	40
Cultivated	3	1	0	0	35	39
Column total	36	41	42	11	69	200

KAPPA (K^) STATISTICS	Class name	kappa
Overall Kappa Statistics = 0.6687	Unclassified	0
	Shrub land	0.57
	Water body	0.94
	Forest	0.97
	Settlement	0.18
	Cultivated	0.81

Accuracy totals

Class name	Reference Totals	Classified Totals	Number Correct	Producers Accuracy (%)	Users Accuracy (%)
Unclassified	0	0	0	---	---
Shrub land	36	40	26	72.2	65.0
Water body	41	40	38	92.7	95.0
Forest	43	40	39	90.7	97.5
Settlement	11	40	9	81.8	22.5
Cultivated	69	40	35	50.7	87.5
Totals	200	200	147		

4.1.3.3. Land use/cover suitability

As shown in Table 4.7 and figure 4.6 according to land use/land cover suitability classification, most of the watershed area was under highly suitable for surface irrigation. Further, the results show that highly suitable class covers 74.34%, moderately suitable covers

12.32%, and marginally suitable covers 8.07% of the total area, whereas about 5.27 % area of watershed is not suitable for surface irrigation. In generally, regarding land use land cover about 94.73% of the total area was found in the range of highly to marginal suitable.

Table 4. 7: Land use/ cover Suitability Class and area coverage of the Watershed.

Value	Land use type	Suitability classes	Description	Area(ha)	Area (%)
4	Cultivated land	S_1	Highly suitable	161,395	74.34
3	Shrub land	S_2	Moderately suitable	26,753	12.32
2	Forest	S_3	Marginally suitable	17,512	8.07
1	Settlement /water body	N	Not suitable	11,456	5.27
Total				217,115	100

Figure 4.6 shows the location of the land use land cover suitability class in the watershed

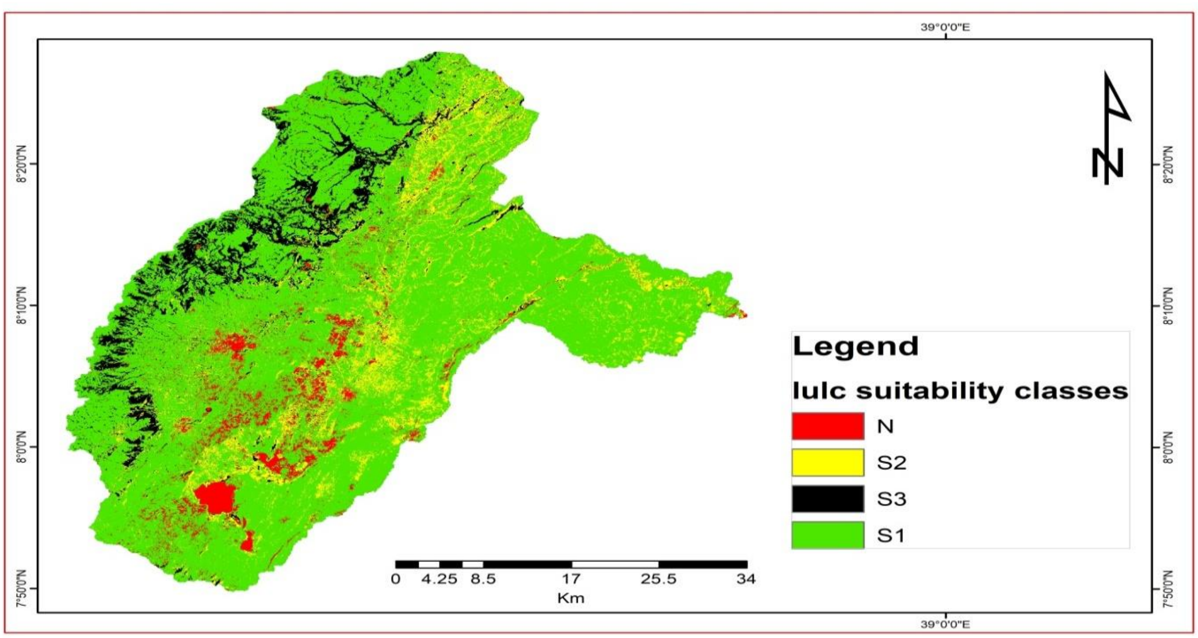

Figure 4. 6: Land use/land cover suitability map of the Meki Watershed.

4.1.4. Weighted overlay Analysis.

4.1.4.1. Assessment of Weights

The weights for considered factors were determined based on the importance of each factor for surface irrigation. Thus, based on the analytical hierarchy method results of importance for each factor presented in table 4.8 and 4.9.

Table 4. 8: Pairwise comparison matrix.

Factors	Slope	Soil drainage	Soil texture	Soil depth	Lulc
Slope	1.00	4.00	5.00	7.00	9.0
Soil drainage	0.25	1.00	3.00	4.00	4.0
Soil texture	0.20	0.33	1.00	3.00	3.0
Soil depth	0.14	0.25	0.33	1.00	3.0
Lulc	0.11	0.25	0.33	0.33	1.0
Sum	1.70	5.83	9.67	15.33	20

Table 4.9 shows the normalized matrix that obtained from each element of the matrix divided with the sum of its column (table 4.8) and the relative weight that obtained by averaging across the row of the normalized matrix.

Table 4. 9: Normalized matrix

Factors	Slope	Soil drainage	Soil texture	Soil depth	Lulc	Relative weight
Slope	0.59	0.69	0.52	0.46	0.45	0.54
Soil drainage	0.15	0.17	0.31	0.26	0.20	0.22
Soil texture	0.12	0.06	0.10	0.20	0.15	0.12
Soil depth	0.08	0.04	0.03	0.07	0.15	0.08
Lulc	0.07	0.04	0.03	0.02	0.05	0.04
Sum	1	1	1	1	1	1

In order to accept the above results the consistency of the pairwise matrix was checked using a consistency ratio and the result revealed that (CR=0.092) which was less than the maximum permitted value 0.1. This finding implies that the pair wise Comparison matrix is in acceptable range. Similarly, Nigussie et al. (2019) found the consistency ration of 0.067 which was acceptable for weighting the factors to evaluate the physical land in Jabitenan district to develop irrigation suitability maps. In conclusion, from these findings we conclude that the percentage of influence for each factor listed in table 4.10 can be used for further application.

Table 4. 10.Percentage of influence for each parameter

Factors	Percentage of influence (%)
Slope	53.9
Soil drainage	21.8
Soil texture	12.5
Soil depth	7.5
Lulc	4.3

4.1.4.2. Overall land suitability for surface Irrigation

Table 4.11 shows the results of overall land suitability for surface irrigation in the study area obtained by combining the evaluation factors such as slope, soil depth, soil drainage, soil texture, and LULC. Accordingly, as shown in table 4.11 and figure 4.7 the majority 100,377 ha (47.12 %) was under marginal suitable class, followed by moderately suitable class 65,025 ha (30.53%) of the total area of the study area. Further, the results reveal that in this watershed highly suitable land for surface irrigation due to the combined effect of the land suitability factors were very small that was about 11,797 ha (5.54 %), and the rest about 35,798 ha (16.81%) of the total area was under unsuitable land for surface irrigation. From the results it can be concluded that marginal suitable class is the largest class based on the combined effect of the selected factors when compared with other suitability classes

Table 4. 11: Overall land Suitability Classes and area coverage of the Watershed.

Weight	Suitability	Description	Area(ha)	Area (%)
4	S_1	Highly suitable	11,797	5.54
3	S_2	Moderately suitable	65,025	30.53
2	S_3	Marginal suitable	100,377	47.12
1	N	Not suitable	35,798	16.81
Total			212,997	100

Figure 4.7 shows Location Map of land suitability for surface irrigation.

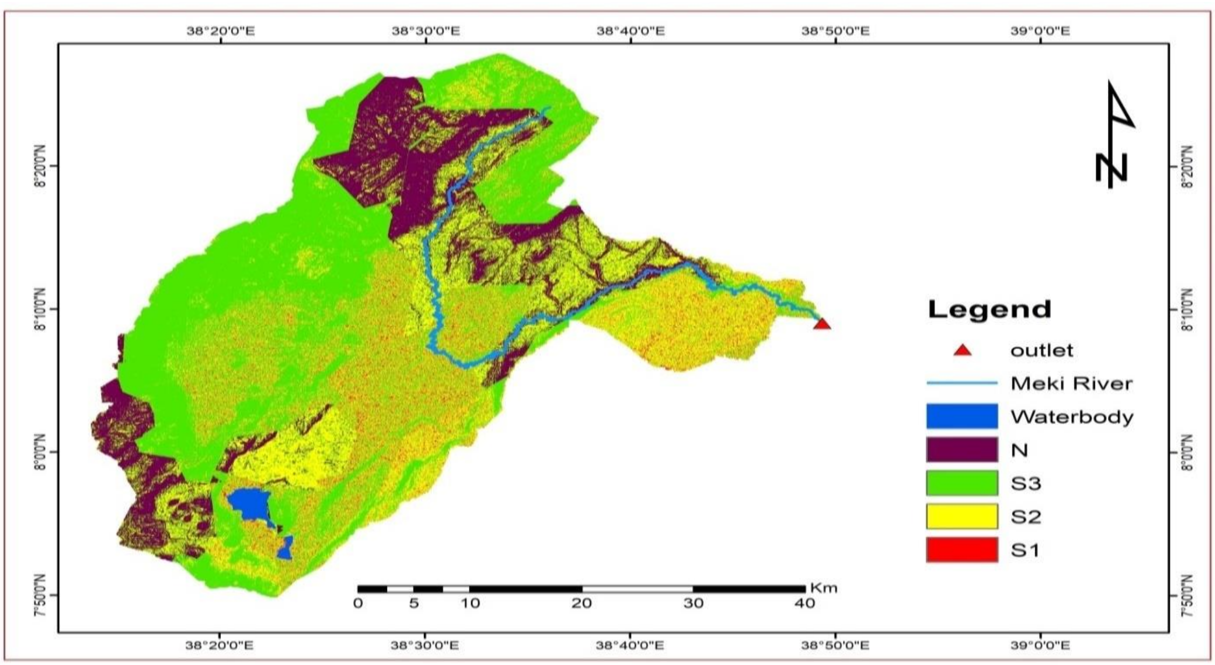

Figure 4. 7: Final land suitability map of the watershed

Also the results indicate that the area coverage of land suitability for surface irrigation in this watershed was 177,199 ha (83.2%) of the total area. This result implies that in the watershed due to the combined effect of soil depth, drainage, texture slope, and land use land cover the suitable area for surface irrigation is very large. However, this number might be changed if other properties of land considered during land suitability assessment for surface irrigation.

4.2. Assessment of Available surface water

Arc SWAT2012 model was run successfully and the mean monthly simulated available water for sub basins of Meki River watershed (figure 4.8) for the year 1995-2020 with two warm up periods were depicted in table 4.12. From ten sub basins outlets five outlets such as outlet of sub basin 1, outlet of sub basin 3, outlet of sub basin 5, outlet of sub basin 7, and outlet of sub basin 10 were considered as diversion site above the command area. Therefore, the flows at the diversion sites were used as supply during determining potential irrigable area by comparing with irrigation water requirement of the dominant crop in the watershed.

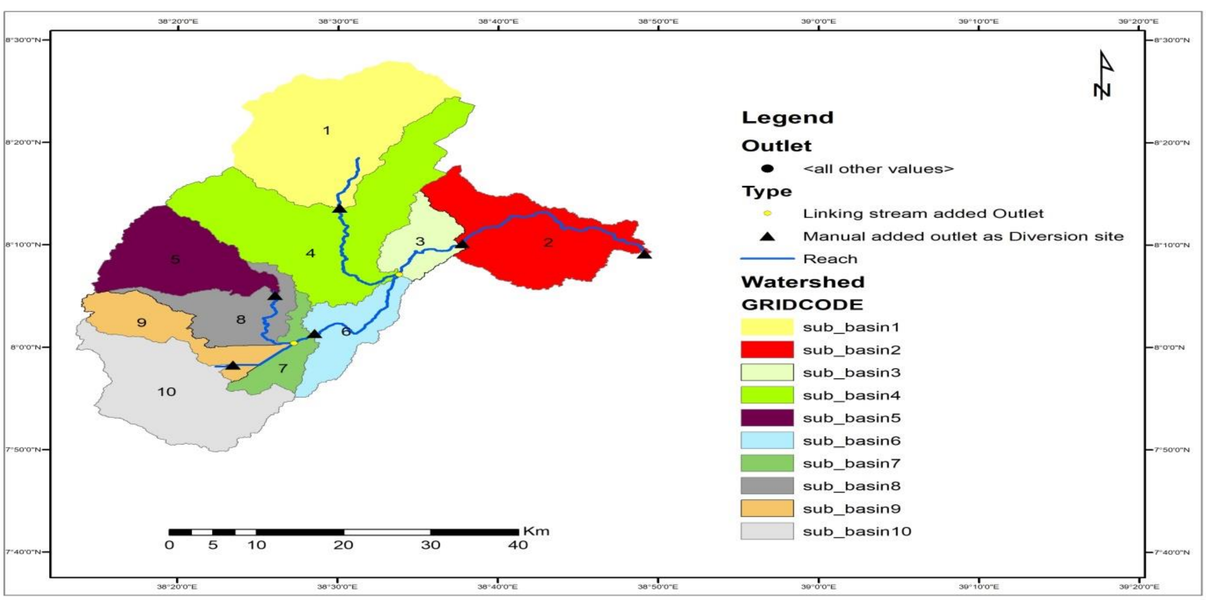

Figure 4. 8 :Sub-basins and outlets of Meki River watershed.

Table 4. 12: Mean monthly simulated flow for sub_basins of Meki River watershed (m^3 /s).

Subbasin	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Sub_basin1	1.5	2.0	6.2	8.5	8.0	11.7	22.2	22.4	17.6	10.3	5.7	2.3
Sub_basin2	9.0	9.8	24.0	36.1	40.7	52.8	92.1	101.3	90.8	62.9	37.8	18.3
Sub_basin3	8.4	8.8	21.1	31.8	36.3	46.8	79.5	89.0	80.7	56.6	33.9	16.7
Sub_basin4	3.6	4.2	11.5	16.6	17.0	23.2	43.2	47.4	40.4	26.2	15.0	6.7
Sub_basin5	1.0	1.1	2.1	3.5	4.1	5.2	8.2	9.4	8.8	6.2	3.9	2.1
Sub_basin6	4.6	4.3	8.7	13.8	17.8	21.6	32.4	37.4	36.8	28.1	17.5	9.4
Sub_basin7	4.0	3.9	7.9	12.4	15.6	19.4	28.9	33.5	32.9	25.0	15.7	8.4
Sub_basin8	1.8	1.8	3.3	5.3	6.0	8.2	12.9	14.1	13.8	11.0	6.9	3.9
Sub_basin9	1.9	1.9	4.3	6.4	7.8	9.8	12.7	15.9	15.7	12.0	7.5	3.9
Sub_basin10	1.3	1.2	3.0	4.4	5.4	6.6	9.2	10.2	10.3	8.1	5.0	2.5

The simulated flow was used for further application after the model calibrated and validated.

4.2.1. SWAT model sensitivity Analysis

Global sensitivity analysis result indicated that among seventeen model parameters that were selected for sensitivity analysis, twelve parameters were taken based on p- value and t-stat as shown in table 4.13. These twelve parameters were found to be more sensitive when compared with remain five parameters. This implies that those twelve sensitive parameters are highly affects the flow of water in the watershed than the others.

Table 4. 13: Sensitivity analysis of model parameters in Meki River watershed.

Parameter name	t-stat	P-value	Sensitivity rank
7:V__ALPHA_BF.gw	-48.18	0.00	1
13:V__SOL_K(..).sol	3.29	0.00	2
2: R__CN2.mgt	2.34	0.02	3
3:V__REVAPMN.gw	1.77	0.08	4
11:V__GW_REVAP.gw	1.63	0.10	5
12:V__RCHRG_DP.gw	1.45	0.15	6
14:V__OV_N.hru	1.05	0.29	7
17:V__CH_K2.rte	1.03	0.31	8
4:V__HRU_SLP.hru	-1.02	0.31	9
5:V__ESCO.hru	0.89	0.37	10
16:V__CANMX.hru	-0.70	0.48	11
6: V__SOL_BD(..).sol	-0.63	0.53	12
15:V__SLSUBBSN.hru	-0.30	0.76	13
1:V__SURLAG.bsn	0.23	0.82	14
8:V__GW_DELAY.gw	0.10	0.92	15
9:V__GWQMN.gw	-0.09	0.93	16
10:R__EPCO.bsn	-0.07	0.95	17

Moreover, among twelve selected parameters Base flow (V__ALPHA_BF.gw), Initial SCS CN II value (R__CN2.mgt), and Saturated Hydraulic Conductivity V_SOL_K(..).sol) were found to be the major sensitive Parameters than others and prioritized in the calibration process. This finding is consistent with Desta (2017) which obtained the major sensitivity parameters namely CN2, SOL_K(..).sol and RCHRG_DP.gw during hydrological assessment and characterization of Lake Ziway sub-watersheds.

Also the finding is agree with Leta et al (2022) that obtained the most sensitive parameters such as CN2, ALPHA_BF, and GW_DELAY for modeling Nash Watershed, Blue Nile River

Basin, Ethiopia. The consistence of the above findings might be due to slight similarity in terms of land use land cover, soil type, and slope of the study area with other study area.

4.2.2. Model calibration and Validation

The agreement between simulated and observed monthly discharge in the watershed was evaluated against R^2, NSE, and PBIAS, for calibration and validation of the SWAT model. The final calibration was obtained using the calibrated value shown in table 4.14.Thus; the results revealed that the performance evaluation statistics were 0.58, 0.75, and -18.3 for Nash–Sutcliffe simulation efficiency (NSE), correlation coefficient (R^2), and PBIAS for calibration respectively. Therefore, According to the goodness-of-fit measures recommended by (Moriasi et al. 2007) the results show that the agreement between simulated and observed monthly discharge during calibration was satisfactory to good correlation. Figure 4.9 below shows the trend of simulated and observed stream flow.

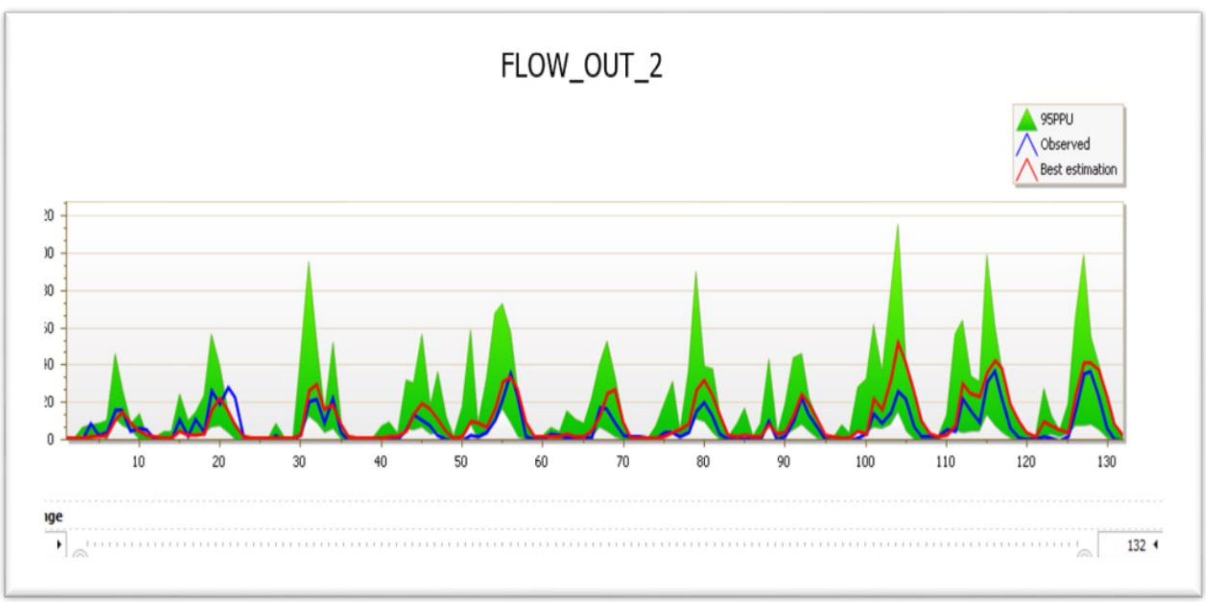

Figure 4. 9: Monthly mean Simulated and Observed Discharge for Calibration Period (1997-2007)

Table 4. 14: List of best fitted parameters with calibrated values for mean monthly flow.

	Calibrated range			Global range	
Parameter_Name	Fitted_Value	Min_value	Max_value	min_value	max_value
1:V__SOL_BD(..).sol	2.6	0.5	2.9	0.9	2.50
2:V__REVAPMN.gw	132.05	130.2	133.13	0	500.00
3:V__HRU_SLP.hru	0.34	0.33	0.35	0	1.00
4:V__ESCO.hru	0.693	0.6	0.75	0	1.00
5:R__CN2.mgt	-0.12	-0.199	0.17	-0.2	0.20
6:V__ALPHA_BF.gw	0.3	0.05	0.65	0	1.00
7:V__GW_REVAP.gw	0.102	0.02	0.192	0.02	0.20
8:V__RCHRG_DP.gw	0.54	0.36	0.65	0	1.00
9:V__SOL_K(..).sol	50	0	2000	0	2000.00
10:V__OV_N.hru	9.78	0.05	30	0.01	30.00
11:V__CANMX.hru	72.5	0	100	0	100.00
12:V__CH_K2.rte	12.5	-0.01	500	-0.01	500.00

Moreover, during validation based on the calibrated value depicted in table 4.14 the result indicates that the three statistical goodness (NSE, R^2, & PBIAS) were 0.6, 0.81, and 23.6 respectively. These statistics results imply that the relationships between simulated and observed flows are satisfactory to very good correlation during validation. In generally, from the result of validation and calibration it can be concluded that based on the goodness-of-fit measures the agreement between simulated and observed monthly discharge is in acceptable range. Therefore, the simulated flow obtained from the model can be used for further application.

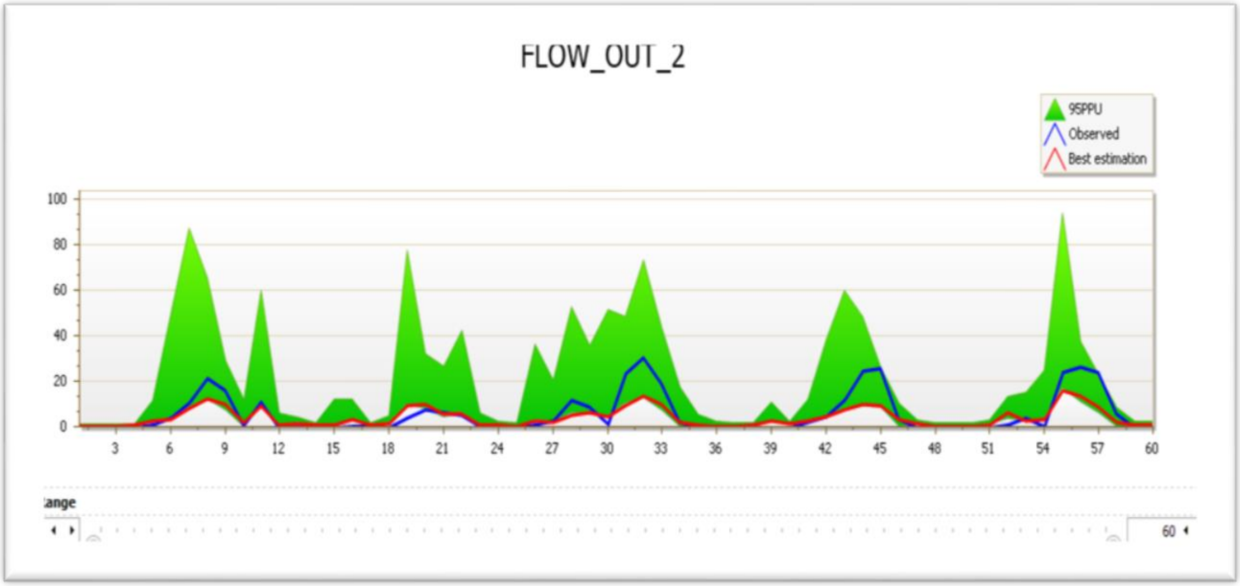

Figure 4. 10: Monthly mean Simulated and Observed Discharge for validation Period (2008-2012).

Table 4. 15: Summary of model performance.

Objective function	Calibration (1997-2007)	Validation (2008-2012)
NSE	0.58	0.6
R^2	0.75	0.81
PBIAS	-18.3	23.6

4.2.3. Flow duration curve analysis (FDC)

The flow duration curve gives a graphical representation of the frequency distribution of the flow of a catchment, and allows the estimation of the percentage of time that a specified stream flow is equaled or exceeded. Thus, table (4.16) shows the dependable flow for 80 % of the time for the month of growing period of selected crops at each proposed diversion sites that obtained from flow duration curve. The results indicate that dependable flow varied from month to month and from site to site during crop growing period. This might be due to climatic variability in the study area.

Table 4. 16: Dependable flow (m^3/s) for 80% of the time.

site	Command (ha)	flow	Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
Site1	21900.3	Q_{80}	0.38	0.15	1.18	2.14	2.58	6.47	3.38	1.30
Site2	17414.2	Q_{80}	3.73	1.30	3.63	7.11	16.22	39.68	21.25	9.56
Site3	6846.8	Q_{80}	0.07	0.05	0.06	0.11	0.32	3.33	1.69	0.72
Site4	6328.1	Q_{80}	1.55	0.60	0.98	1.50	6.02	15.89	9.67	2.85
Site5	10978.4	Q_{80}	0.28	0.14	0.86	0.97	1.66	4.34	2.51	1.05

4.3. Irrigation Water Requirements.

4.3.1 .Net and Gross Irrigation water requirement.

Table 4.17 shows monthly net and gross irrigation water requirements for the selected dominant crops such as Maize, Onion, and Tomato. The results showed that Maize requires maximum amount of net irrigation water in the month of March which was about 78.3 mm. This is equal to 783 m^3/ha with the conversion of (1mm=10m^3/ha). This finding implies that March is the critical month for maize crop in the watershed.

Also the result reveals that for Onion high amount of water from irrigation is required in the month of December which was 103.1 mm (1031 m^3/ha), and for Tomato the maximum irrigation water needed in the month of December which was 120 mm (1200 m^3/ha). From the results of Onion and Tomato it can be concluded that December is the critical month which requires conserving water practice during scarcity of water from the source, and also of the three crops Tomato requires high amount of irrigation water.

Table 4. 17: Monthly Irrigation water requirement of selected crops in the study area.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Maize crop	29.0	74.4	78.3	50.7	5.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
2. Onion	21.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	44.4	93.7	103.1
3. Tomato	106.6	19.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.7	82.6	120.0
Net scheme irr.req.												
In mm/day	1.6	1.5	1.3	0.8	0.1	0.0	0.0	0.0	0.0	0.5	1.5	1.8
In mm/month	50.8	42.9	39.2	25.3	2.7	0.0	0.0	0.0	0.0	14.8	43.5	56.6
In l/s/ha	0.2	0.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2
Irrigated area(%)	100.0	80.0	50.0	50.0	50.0	0.0	0.0	0.0	0.0	50.0	50.0	50.0
Net Irr.req for Actual area(l/s/ha)	0.19	0.22	0.29	0.20	0.02	0.00	0.00	0.00	0.00	0.11	0.34	0.42
Gross Irr.req. For Actual area (l/s/ha)	0.47	0.54	0.72	0.49	0.05	0.00	0.00	0.00	0.00	0.27	0.84	1.04

Moreover, the results from table (4.17) showed that based on the cropping patterns (proportion of land) maximum net irrigation requirement was obtained for the month of December that was (0.42 l/s/ha), whereas the minimum amount of irrigation water required for the month of April which was (0.02 l/s/ha).

Also the result reveals that by considering overall irrigation efficiency (40.5 %) the maximum and minimum gross irrigation water requirements were 1.04 l/s/ha, and 0.05 l/s/ha for the month of December ,and April respectively. This implies that December is critical month which requires maximum amount of irrigation water. Therefore, during developing irrigation scheme in the given watershed considering maximum demand is essential to overcome crop water stress during critical time.

4.4. Potential Irrigable area of Meki River watershed

Figure 4:10 shows the command area below proposed diversion site for surface irrigation

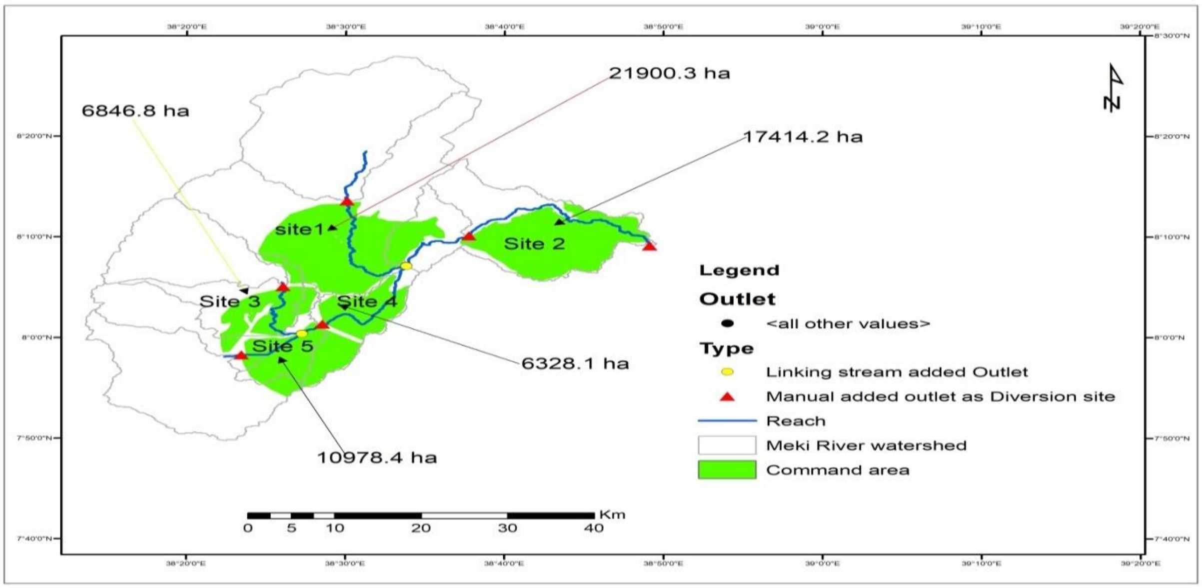

Figure 4. 11: Command area for surface irrigation development with diversion site.

Also table 4.18 below shows the area that can be irrigated by dependable flow (Q_{80}) based on irrigation water demand of selected crops (Maize, Onion, and Tomato). Hence, the results reveal that the maximum and minimum irrigable area from diversion site one were obtained 52305.8 ha, and 284.79 ha in the month of May and February respectively. This result implies that the demand is greater than supply in the month of February. So, February is the critical month during growing Maize, onion, and Tomato based on their cropping pattern with available dependable flow of diversion site one. Moreover, the results revealed that for diversion site two based on the 80% dependable flow February is the critical month that was about 2391.34 ha can be irrigated, whereas the largest irrigable area 328,455 ha was obtained for the month of May. Similarly, the results revealed that potential irrigable area from diversion site three, four, and five were 77.3 ha, 1109.5 ha, and 263.1 ha for the month of March, February, and February respectively.

Table 4. 18: potential irrigable area based on selected dominant crops and flow (Q_{80}).

site	CA(ha)		Jan	Feb	Mar	Apr	May	Oct	Nov	Dec
1	21900.3	GIWR(l/s/ha)	0.47	0.54	0.72	0.49	0.05	0.27	0.82	1.04
		Q80 (m3/s/)	0.4	0.2	1.2	2.1	2.6	6.5	3.4	1.3
		Q80(l/s)	379.8	154.7	1178.0	2144.0	2583.0	6471.0	3377.0	1302.0
		PIA(ha)	809.6	284.8	1645.1	4341.6	52305.8	23825.0	4022.6	1255.5
2	17414.2	GIWR(l/s/ha)	0.47	0.54	0.72	0.49	0.05	0.27	0.82	1.04
		Q80 (m3/s/)	3.7	1.3	3.6	7.1	16.2	39.7	21.3	9.6
		Q80(l/s)	3731.0	1299.0	3627.0	7110.0	16220.0	39680.0	21250.0	9564.0
		PIA(ha)	7952.9	2391.3	5065.3	14397.8	328455.0	146094.5	25312.5	9222.4
3	6846.8	GIWR(l/s/ha)	0.47	0.54	0.72	0.49	0.05	0.27	0.82	1.04
		Q80 (m3/s/)	0.1	0.1	0.1	0.1	0.3	3.3	1.7	0.7
		Q80(l/s)	74.9	50.8	55.4	105.2	319.2	3326.0	1691.0	717.0
		PIA(ha)	159.6	93.5	77.3	213.0	6463.8	12245.7	2014.3	691.4
4	6328.1	GIWR(l/s/ha)	0.47	0.54	0.72	0.49	0.05	0.27	0.82	1.04
		Q80 (m3/s/)	1.5	0.6	1.0	1.5	6.0	15.9	9.7	2.9
		Q80(l/s)	1547.0	602.7	977.6	1497.0	6018.0	15890.0	9669.0	2851.0
		PIA(ha)	3297.6	1109.5	1365.3	3031.4	121864.5	58504.1	11517.5	2749.2
5	10978.4	GIWR(l/s/ha)	0.47	0.54	0.72	0.49	0.05	0.27	0.82	1.04
		Q80 (m3/s/)	0.3	0.1	0.9	1.0	1.7	4.3	2.5	1.0
		Q80(l/s)	282.9	142.9	862.9	967.7	1664.0	4344.0	2505.0	1045.0
		PIA(ha)	603.0	263.1	1205.1	1959.6	33696.0	15993.8	2983.9	1007.7

Generally, from the results it can be concluded that with 80% dependable flow February is the critical month based on the demand of selected crops for all diversion sites except for diversion site three. Furthermore, the summary of potential irrigable area along tributaries of Meki River watershed for the proposed diversion sites are depicted in Table 4.19.The results reveal that the area to be irrigated with the dependable flow during the crop growing period was varies from site to site.

Table 4. 19: Summary of potential irrigable area of Meki River watershed.

River name	Potential Irrigable Area (ha)					
	Site1	site 2	Site 3	Site 4	Site 5	Total
Meki	284.8	2391.3	77.3	1109.5	263.1	4126.04

Therefore, the potential irrigable areas of Meki River watershed based on the demand of selected crops, and 80 % dependable flow was obtained 4126,04 ha.

In conclusion, from the results it can be concluded that the potential irrigable area obtained from 80% dependable flow and demand of the three crops are very small when compared with the total suitable land obtained for surface irrigation. This implies that the water available in the river is not enough to irrigate the entire suitable land for surface irrigation. Therefore, in order to irrigate the whole suitable land of the watershed other source of water is needed.

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary

Irrigation is used as an input to increase agricultural production and productivity. Therefore expanding small and large irrigation schemes are very important through assessing land suitability and water availability. The main purpose of this study was to assess land suitability and water availability of Meki River watershed for surface irrigation using GIS. To accomplish the objective different types of data such as metrological data, satellite image, stream flow, soil data and crop information were collected from different sources and used as an input.

In this study land evaluation factors such as soil texture, soil drainage, soil depth, land use/cover and slope were considered to identify suitable land for surface irrigation. First suitability analysis for each factor was done and overlaid using ArcGIS 10.3. In terms of slope the result reveals that majority 52.3 % was suitable, whereas about 47.7 % was not suitable of the total study area. Moreover, regarding soil depth the result indicates that the majority (89.9 %) of the total area is moderately suitable and 10.1% is not suitable. Also the soil texture suitability analysis showed that of the total area about 99.65% were under highly to marginal suitable classes. Further, soil drainage suitability analysis revealed that of the total area 75.95% were under moderately to marginal suitable classes. The land use land cover was done using ERDAS Imagine 2014. The results reveal that cultivated land is dominant in the watershed which was 74.34 % of the total area. Also regarding Suitability the results indicate that the majority 94.73 % were in the range of highly to marginally suitable, whereas 5.27 % of the total area were not suitable. Finally, the weighted overlay analysis result reveals that

177,199 ha of total area were in the range of highly to marginally suitable for surface irrigation development, whereas the rest 16.81 % were unsuitable for surface irrigation due to the combined effects of the considered factors.

The water availability for surface irrigation assessed by using SWAT model 2012 .The monthly simulated flow were calibrated for the period of (1997-2007) and validated for the period of (2008-2012) using SWAT cup 2019 version 5.2.1.The model performance was checked using NS, R^2, and PBIAS. The calibration results showed that 0.58, 0.75 and -18.3 for NSE, R^2, and PBIAS respectively, whereas for validation the results revealed that 0.6, 0.81, and 23.6 for NSE, R^2, and PBIAS respectively. Based on the performance evaluation parameter the correlation between observed and simulated flow showed that satisfactory to good during calibration, whereas, satisfactory to very good during validation.

Also flow duration curve was done using simulated discharge for five diversion sites to determine the monthly dependable flow at 80% probability. The results revealed that the maximum and minimum monthly dependable flow (Q_{80}) were 39.7 m^3/s and 0.051 m^3/s for the month of October at diversion site two and for the month of February at diversion site three respectively.

Irrigation water requirement for Onion, Tomato and Maize were computed by Cropwat8.0 by feeding all necessary input data. Some of the input data such as temperature wind speed sunshine hour humidity were collected from software called NeWLoclime 10.1 for stations not have complete climatic data. The result revealed that Tomato requires high amount of irrigation water when compared with Maize and Onion. Moreover, Based on the cropping pattern of selected crops the gross irrigation water requirement was found 0.47 l/s/ha, 0.54

l/s/ha ,0.72l/s/ha,0.49l/s/ha ,0.05 l/s/ha,0.27 l/s/ha,0.84l/s/ha and 1.04 l/s/ha for the month of January,February,March,April, May, October, and December respectively.

Moreover, by comparing 80% dependable flow and gross irrigation water requirement of selected crops the potential irrigable area at each diversion site was computed. The results revealed that the irrigable area 284.79 ha, 2391.34 ha, 77.3 ha, 1109.5 ha, and 263.1 were obtained from diversion site one, two three four and five respectively. Finally, the results concluded that the potential irrigation area of Meki river watershed was found to be 4126.04 ha.

5.2. Conclusions

Based on the findings of the research, the following conclusions were made.

- ✓ Due to the combined effect of the five factors huge suitable land for surface irrigation is obtained in the watershed.
- ✓ Also regarding available water there is scarcity of stream flow to irrigate the whole suitable land in the watershed.
- ✓ Regarding irrigation water requirement, of the selected crops (Maize Tomato and onion) Tomato requires high amount of irrigation water in the watershed.
- ✓ The irrigable area that can be irrigated with dependable flow is very small.

5.3. Recommendation

In view of the findings of the study, and conclusion drawn the following recommendations are forwarded to irrigators ,policymakers, development actors and researchers who have a strong interest in the development of irrigation projects in Meki river watershed.

- In addition to those factors considered in this study Irrigation suitability constraints such as water quality, environmental, economic and social as well as other soil physical and chemical properties may have their own influence to identify the suitable land for surface irrigation. So, future research should incorporated additional factors to assess land suitability in this study area.
- In order to maximize the irrigable area with the available supply from Meki River, crop those require less amount of water for growing should be selected. Also water saving irrigation techniques such as sprinkler and dripper should be practiced in the watershed to increase the land area to be irrigated.
- In addition to surface water from Meki River, to expand the irrigable area other water source such as water harvesting, lake water, and ground water must be seen as an alternative source.

6. REFERENCES

Abbaspour, K. C., Vaghefi, S. A., & Srinivasan, R. (2017). A guideline for successful calibration and uncertainty analysis for soil and water assessment: a review of papers from the 2016 international SWAT conference. Water, 10(1), 6.

Abbaspour, K. C. (2015). SWAT calibration and uncertainty programs. A user manual, 103, 17-66.

Abbaspour, K.C., 2011. Swat-Cup2: SWAT Calibration and Uncertainty Programs Manual Version 2, Department of Systems Analysis, Integrated Assessment and Modeling (SIAM).

Abburu, S., & Golla, S. B. (2015). Satellite image classification methods and techniques: A review. International journal of computer applications, 119(8).

Abu-Hashim, M., Sayed, A., Zelenakova, M., Vranayová, Z., & Khalil, M. (2021). Soil water erosion vulnerability and suitability under different irrigation systems using parametric approach and Gis, Ismailia, Egypt. Sustainability, 13(3), 1057.

Ahamed, T. N., Rao, K. G., & Murthy, J. S. R. (2000). GIS-based fuzzy membership model for crop-land suitability analysis. Agricultural systems, 63(2), 75-95.

Albek, M., Öğütveren, Ü. B., & Albek, E. (2004). Hydrological modeling of Seydi Suyu watershed (Turkey) with HSPF. Journal of Hydrology, 285(1-4), 260-271

Alhamshry, A., Fenta, A. A., Yasuda, H., Kimura, R., & Shimizu, K. (2020). Seasonal rainfall variability in Ethiopia and its long-term link to global sea surface temperatures. Water (Switzerland) 12 (1).

Aliye, M. A., Aga, A. O., Tadesse, T., & Yohannes, P. (2020). Evaluating the performance of HEC-HMS and SWAT hydrological models in simulating the rainfall-runoff process for data scarce Region of Ethiopian Rift Valley Lake Basin. Open Journal of Modern Hydrology, 10(04), 105.

Allen, R.G., L.S. Pereira, D. Raes and M.Smith. 1998. Crop evapotranspiration. Guidelines for computing crop water requirements. FAOIrrig.Drain. Paper No. 56. FAO, Rome, Italy

Arnold, J. G., Moriasi, D. N., Gassman, P. W., Abbaspour, K. C., White, M. J., Srinivasan, R., ... & Jha, M. K. (2012). SWAT: Model use, calibration, and validation. Transactions of the ASABE, 55(4), 1491-1508.

Arnold, J. G., Srinivasan, R., Muttiah, R. S. & Williams, J. R., 1998. Large area hydrologic modeling and assessment part I: Model development. Journal of The American Water Resources Association, 32(1), pp. 1752-1688.

Awass, A. A. (2009). Hydrological drought analysis-occurrence, severity, risks: The case of Wabi Shebele River Basin, Ethiopia.

Awulachew, S. B. (2019). Irrigation potential in Ethiopia: Constraints and opportunities for enhancing the system. Gates Open Res, 3(22), 22.

Awulachew, S. B., & Ayana, M. (2011). Performance of irrigation: An assessment at different scales in Ethiopia. Experimental Agriculture, 47(S1), 57-69.

Awulachew, S. B., Merry, D. J., Kamara, A. B., Koppen, B. V., Vries, F. P.D. & and Boelee, E. (2005) Experiences and opportunities for promoting small scale /Micro irrigation and rain water harvesting for food security in Ethiopia. Colombo: IWMI

Awulachew, S. B.; Yilma, A. D.; Loulseged, M.; Loiskandl, W., Ayana, M.; Alamirew, T. 2007. Water Resources and Irrigation Development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute. 78p. (Working Paper 123).

Awulachew, S.B.; Teklu Erkoss, Regassa E. Namara. 2010. Irrigation potential in Ethiopia constraints and opportunist for enhancing the system. International water management institute.

Ayalew, D. W. (2018). Theoretical and empirical review of Ethiopian water resource potentials, challenges and future development opportunities. International Journal of Waste Resources, 8(4).

Bacha, D., Namara, R., Bogale, A., & Tesfaye, A. (2011). Impact of small-scale irrigation on household poverty: empirical evidence from the Ambo district in Ethiopia. Irrigation and Drainage, 60(1), 1-10.

Balasubramanian, A. (2017). Digital elevation model (DEM) in GIS. University of Mysore.

Bárdossy, A., & Singh, S. K. (2008). Robust estimation of hydrological model parameters. Hydrology and earth system sciences, 12(6), 1273-1283.

Bayush, M. (2020). Assessment Of Surface Irrigation Potential And Optimization Of Cropping Pattern: Case Study Of Danse Watershed, Oromia Region (Doctoral dissertation, ASTU).

Belay Mihretie and Woldeamlak Bewket. 2013, Traditional Irrigation and Water Management Practices in Highland, Ethiopia: Case Study in Dangila Woreda, Irrigation and Drainage. 62: 435–448.

Belete Bantero, 2006. Across systems comparative assessment of Hare Community managed irrigation schemes performance. MSc thesis, Arba Minch University.

Birhane, G. (2002). Present and future water resources development in Ethiopia related to research and capacity building. Integrated water and land management research and capacity building priorities for Ethiopia, 11.

Blanco, I., Loisi, R. V., Sica, C., Schettini, E., & Vox, G. (2018). Agricultural plastic waste mapping using GIS. A case study in Italy. Resources, Conservation and Recycling, 137, 229-242.

Blundell, J.S., & Opitz, D.W. (2006). Object Recognition and Feature Extraction from Imagery : the Feature Analyst ® Approach

Bredesen, A., & Brown, C. J. (2018). Comparison of hydrologic model performance statistics using rain gauge and NEXRAD precipitation input at different watershed spatial scales and rainfall return frequencies for the Upper St. Johns River, Florida USA. Multidisciplinary Digital Publishing Institute Proceedings, 7(1), 11.

Burrough, P. A. (1986). Principles of geographical. Information systems for land resource assessment. Clarendon Press, Oxford.

Butt, A., Shabbir, R., Ahmad, S. S., & Aziz, N. (2015). Land use change mapping and analysis using Remote Sensing and GIS: A case study of Simly watershed, Islamabad, Pakistan. The Egyptian Journal of Remote Sensing and Space Science, 18(2), 251-259.

Central Statistical Agency (CSA), 2008. Agricultural Sample Survey 2007/08. Report on Land Utilization. Volume IV. Statistical Bulletin No. 417. Addis Ababa, Ethiopia.

Clarke, D.; Smith, M.; El-Askari, K. CropWat for Windows: User Guide; University of Southampton: Southampton, UK, 2001.

Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. Remote sensing of environment, 37(1), 35-46.

Davidson, D. A. (1992). The evaluation of land resources. Longman Scientific and Technical.

Dawit, M., Olika, B. D., Muluneh, F. B., Leta, O. T., & Dinka, M. O. (2020). Assessment of surface irrigation potential of the Dhidhessa River Basin, Ethiopia. Hydrology, 7(3), 68.

Dengiz, O. (2006). Comparison of different irrigation methods based on the parametric evaluation approach. Turkish Journal of Agriculture and Forestry, 30(1), 21-29.

Desta, H., & Lemma, B. (2017). SWAT based hydrological assessment and characterization of Lake Ziway sub-watersheds, Ethiopia. Journal of Hydrology: Regional Studies, 13, 122-137.

Dingman, S.L, 2002. Physical hydrology, Second edition printice, Hall New Jersey.

Doorenbos, I. and Pruitt, W. O. 1977: Crop water requirements, FAO Paper 24, Rome, Italy, 144 pp.

Droogers, Peter. 2002. Global Irrigated Area Mapping: Overview and Recommendations. Working Paper 36. Colombo, Sri Lanka: International Water Management Institute

EEA (Ethiopian Economics Association), 2007/08. Report on the Ethiopian Economy, Vol. VII, and Addis Ababa, Ethiopia.

Ephrem Haile, 2008. Land cover/ use dynamics and erosion susceptibility analysis: a case Ethiopia. MSc thesis, International Institute for Geo-Information Science and Earth

Food and Agriculture Organization (FAO), 2016. AQUASTAT Websit

FAO.2015.FAO’s Information System on Water and Agriculture.Aquastat.

FAO,2013. Ethiopia: Country fact sheet. Accessed 25 February 2013 and available at http://www.fao.org/nr/water/aquastat/data/factsheets/aquastat_fact_sheet_eth_en.pdf

FAO/IIASA/ISRIC/ISSCAS/JRC, 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

FAO, 2008.Harmonized World Soil Database.

FAO and IFAD, 2006. Water for food: agriculture and rural livelihoods. In: Water shared responsibility.

FAO, 2003. Unlocking the water potential of Agriculture, Rome, Italy.

FAO, 2001. Irrigation Water Management: Irrigation Methods, Rome, Italy.

FAO, 1999. The future of our land Facing the challenge. Guidelines for integrated planning for sustainable management of land resources. FAO, Rome. Land and Water Digital Media Series 8.

FAO, 1997. Irrigation potential in Africa: A basin approach FAO Land and Water Bulletin 4.

FAO, 1996. an interactive multi- criteria analysis for land resource appraisal. Italy, Rome

FAO, 1995. Irrigation in Africa in Figures. Rome, Italy

FAO,1995. FAO production yearbook 1994. Vol. 48. FAO Statistics Series No. 125.Rome.

FAO, 1992. Crop water requirements. FAO Irrigation and Drainage paper 24. Italy, Rome.

FAO, 1987. Irrigation and water resources potential for Africa, Report AGL/MISC/11/87, and Irrigated areas in Africa: Extent and distribution, Report AGL/MISC/13/87, Food and Agriculture Organization, Rome.

FAO, 1985. Guidelines Land Evaluation for Irrigated Agriculture.FAO Soils Bull 55, Rome, 290 pp.

FAO, 1983. Guidelines for the preparation of irrigation and drainage projects. Revised version.

FAO, 1976. A framework for land evaluation. FAO Soils Bulletin No. 32. FAO, Rome

FAO, 1976. A framework for land evaluation. FAO Soils Bulletin No. 32. FAO, Rome

Fasina, A. S., Awe, G. O., & Aruleba, J. O. (2008). Irrigation suitability evaluation and crop yield an example with Amaranthus cruentus in Southwestern Nigeria. African Journal of Plant Science, 2(7), 61-66.

Feizizadeh, B. and T. Blaschke.2013. Land suitability analysis for Tabriz County, Iran: A multi-criteria evaluation approach using GIS. J. Environ. Plan. Manag. 56:1-23

Fitsume, D., Michael, B., & Lijalem, K. (2015). Crop water requirement determination of chickpea in the central vertisol areas of Ethiopia using FAO CROPWAT model. African Journal of Agricultural Research, 10(7), 685-689.

Ganole, K. (2010). GIS-based surface irrigation potential: Assessment of river catchments for irrigation development in Dale Woreda, Sidama Zone, SNNP (Doctoral dissertation, Haramaya University).

Garbrecht, J., & Martz, L. W. (2000). Digital elevation model issues in water resources modeling. Hydrologic and hydraulic modeling support with geographic information systems, 1-28.

Gassman, P.; Reyes, M.; Green, C.; Arnold, J. The Soil and Water Assessment Tool: Historical Development, Applications, and Future Research Directions. Trans. ASAE 2007, 50, 1211–1250.

Gebremedhin, B., & Peden, D. (2002). Policies and institutions to enhance the impact of irrigation development in mixed crop–livestock systems. Integrated water and land management research and capacity building priorities for Ethiopia, 168.

GLCN, 2006. Land cover and Land use definitions. http://www.glcnlccs.org/index.php

Gopinath, G., Swetha, T. V., & Ashitha, M. K. (2014). Automated extraction of watershed boundary and drainage network from SRTM and comparison with Survey of India toposheet. Arabian Journal of Geosciences, 7(7), 2625-2632.

Guug, S. S., Abdul-Ganiyu, S., & Kasei, R. A. (2020). Application of SWAT hydrological model for assessing water availability at the Sherigu catchment of Ghana and Southern Burkina Faso. HydroResearch, 3, 124-133.

Hagos, F., Makombe, G., Namara, R. E., & Awulachew, S. B. (2009). Importance of irrigated agriculture to the Ethiopian economy: Capturing the direct net benefits of irrigation (Vol. 128). IWMI.

Haile, Gebremedhin Gebremeskel, and Asfaw Kebede Kasa. 2015. Irrigation in Ethiopia : A Review. Academia Journal of Agricultural Research 3 (10): 264–69.

Hailegebriel, S. (2007). Irrigation potential evaluation and crop suitability analysis using GIS and remote sensing technique in Beles Sub basin, Beneshangul Gumez Region. Unpublished Master's Thesis, Addis Ababa University, Addis Ababa, Ethiopia.

Hall, M., Bateson, L., & Jordan, C. (2004). ERDAS imagine 8.5 and 8.6 training manual.

Homer, C., Huang, C., Yang, L., Wylie, B., Coan, M., 2004. Development of a 2001 National Land Cover Database for the United States. Photogrametric Engineering and Remote Sensing 70 (7), 829–840

Howari, F. M., Sherif, M. M., Singh, V. P., & Asam, M. S. A. (2007). Application of GIS and remote sensing techniques in identification, assessment and development of groundwater resources. In Groundwater (pp. 1-25). Springer, Dordrecht.

Ines, A. V. M.; P. Droogers; I. W. Makin; and A. Das Gupta. 2001. Crop growth and soil water balance modeling to explore water management options. IWMI Working Paper 22. Colombo, Sri Lanka: International Water Management Institute.

IWMI. 2015. IWMI in Ethiopia: Addis Ababa. http://eastafrica.iwmi.org. Accessed on 2018-01-07

J. Cohen (1960). "A coefficient of agreement for nominal scales". Educational and Psychological Measurement 20(1):37-46. doi:10.1177/001316446002000104.

Jayakrishnan, R. S. R. S., Srinivasan, R., Santhi, C., & Arnold, J. G. (2005). Advances in the application of the SWAT model for water resources management. Hydrological Processes: An International Journal, 19(3), 749-762

Kannan, N., Anandhi, A., & Jeong, J. (2018). Estimation of stream health using flow-based indices. Hydrology, 5(1), 20.

Kareem, H. H., Alkatib, A. A., & Mahdi, W. H. (2021, August). Watershed basins delineation using GIS and Digital Elevation Model (DEM) to the region NI-38-14 Karbala-Al-Najaf Plateau, Iraq. In Journal of Physics: Conference Series (Vol. 1973, No. 1, p. 012188). IOP Publishing.

Khoi, D.N. (2016) Comparision of the HEC-HMS and SWAT Hydrological Models in Simulating the Stream Flow. Journal of Science and Technology, 53, 189-195.

Klosterman, R. E. (1997). Planning support systems: a new perspective on computer-aided planning. Journal of Planning education and research, 17(1), 45-54.

Kotei, R., Agyare, W. A., Kyei-Baffour, N., Atta-Darkwa, T., & Atakora, E. T. (2016). Estimation of flow-duration and low-flow frequency parameters for the Sumanpa stream at Mampong-Ashanti in Ghana for the 1985-2009 period.

Krause, P., Boyle, D. P., & Bäse, F. (2005). Comparison of different efficiency criteria for hydrological model assessment. Advances in geosciences, 5, 89-97

Leta, M. K., Ebsa, D. G., & Regasa, M. S. (2022). Parameter Uncertainty Analysis for Streamflow Simulation Using SWAT Model in Nashe Watershed, Blue Nile River Basin, Ethiopia. Applied and Environmental Soil Science, 2022.

Li, M., Zang, S., Zhang, B., Li, S., & Wu, C. (2014). A review of remote sensing image classification techniques: The role of spatio-contextual information. European Journal of Remote Sensing, 47(1), 389–411. https://doi.org/10.5721/EuJRS20144723

López Trigal, L. (2015). Diccionario de Geografía aplicada y profesional. Terminología de análisis, planificación y gestión del territorio. Universidad de León.

Makombe, g., kelemework, d. & aredo, d. (2007) A comparative analysis of rainfed and irrigated agricultural production in Ethiopia. Irrigation and Drainage Systems 21: 35–44.

Malczewski, J. (2004). GIS-based land-use suitability analysis: a critical overview. Progress in planning, 62(1), 3-65.

Manaswi, C. M., & Thawait, A. K. (2014). Application of soil and water assessment tool for runoff modeling of Karam River basin in Madhya Pradesh. International Journal of Scientific Engineering and Technology, 3(5), 529-532.

Mancebo, S., Ortega, E., Martín, L., & Valentín, A. (2008). LibroSIG: Aprendiendo a manejar los SIG en la gestión ambiental: ejercicios. Madrid, España.

Martine, N.; D'Urso, G.; Immerzeel, W.W. Adaptive Simulation of the Impact of Changes in Land Use on Water Resources in the Lower Aswa Basin. J. Agric. Eng. 2013, 43, 159–164.

Mccornick, P.G., kamara, A.B. & girma, T. (2003) Integrated water and land management research and capacity building priorities for Ethiopia. Proceedings of a MoWR/EARO/IWMI/ILRI international workshop held at ILRI, Addis Ababa.

Mengistie, Dereje, and Desale Kidane. 2016. Assessment of the Impact of Small-Scale Irrigation on Household Livelihood Improvement at Gubalafto District, NorthWollo, Ethiopia. Agriculture 6 (27): 1–22.

Michael, A. M. (2009). Irrigation Theory And Practice-2Nd Edn: Theory and Practice. Vikas publishing house.

MoA (Ministry of Agriculture), Natural Resources Management Directorates (2011a), Small Scale Irrigation Situation Analysis and Capacity Needs Assessment, Addis Ababa, Ethiopia.

MoA (Ministry of Agriculture) Natural Resources Sector, (2011b), Small-Scale Irrigation Capacity Building Strategy for Ethiopia, Addis Ababa, Ethiopia.

MoARD (Ministry of Agriculture and Rural Development). 2005. Major Agro-ecological Zones of Ethiopia. Forestry, Land Use and Soil Conservation Department. Addis Ababa, Ethiopia.

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model evaluation guidelines for systematic quantification of accuracy in watershed simulations. Transactions of the ASABE, 50(3), 885-900.

MoWR 2001. Irrigation Development Strategy (Component of the Water Sector Development Strategy). Draft Report. Addis Ababa, Ethiopia.

Mtibaa, S., Hotta, N., & Irie, M. (2018). Analysis of the efficacy and cost-effectiveness of best management practices for controlling sediment yield: a case study of the Joumine watershed, Tunisia. Science of the Total Environment, 616, 1-16.

Nachtergaele, F., Van, H. V., Verelst, L., Batjes, N., Dijkshoorn, K., van, V. E., Fischer, G., Jones, A., Montanarella, L., Petri, M., Prieler, S., Teixeira, E., Wiberg, D., and Shi, X. 2009. Harmonized World Soil Database (version 1.1). FAO, Rome, Italy and IIASA, Laxenburg, Austria.

Negasa, G. (2021). GIS-Based Irrigation Potential Assessment for Surface Irrigation: The Case of Birbir River Watershed, Oromia, Ethiopia. American Journal of Civil Engineering, 9(4), 127-137.

Negash, Wagesho. 2015. GIS based irrigation suitability Analysis: A case study in Abaya-Chamo basin in southern Rift valley of Ethiopia. MSc thesis, Arba-Minch University

Negash, W., & Seleshi, B. (2004). GIS based irrigation suitability analysis. Journal of Water Science and Technology, 8, p 55-61.

Nigussie, G., Moges, M. A., Moges, M. M., & Steenhuis, T. S. (2019). Assessment of suitable land for surface irrigation in ungauged catchments: Blue Nile Basin, Ethiopia. Water, 11(7), 1465.

Nuha, H. and F.M. Henery. 2000. Rain water harvesting for natural resource management.

Padilla, Ramon Francisco Q., Emeline S. Crisologo, Rodolfo A. Romarate II, and Sonnie A. Vedra. "Analysis of vegetation degradation using GIS and remote sensing at Lake Mainit watershed, Mindanao, Philippines." Advances in Environmental Sciences 7, no. 3 (2015): 409-414.

Patwardhan, A. S., Nieber, J. L., & Johns, E. L. (1990). Effective rainfall estimation methods. Journal of irrigation and Drainage Engineering, 116(2), 182-193.

Pereira, D. D. R., Martinez, M. A., Pruski, F. F., & da Silva, D. D. (2016). Hydrological simulation in a basin of typical tropical climate and soil using the SWAT model part I: Calibration and validation tests. Journal of Hydrology: Regional Studies, 7, 14-37

Podvezko, V., 2009. Application of AHP technique. J. Bus. Econ. Manag. 181–189. process. RWS publications.

Rahman, M.M, Csaolovics,E., Koch, B., & Kohl, M., 2006, "Interpretation of Tropical Vegetation Using Landsat ETM+ Imagery", Accessed from the Internet on Feb 15, 2010.

Raine, S.R. and D.M. Bakker. 1996. Increased furrow irrigation efficiency through better design and management of cane fields. Proceedings of Australian Society of Sugarcane Technologists.pp.119-124

Rossiter, D. G, 2001. Assessing the thematic accuracy of area-class soil maps.

Saaty, T. L. (1994). Fundamentals of decision making and priority theory with the analytic hierarchy

Saaty, T. L., & Vargas, L. G. (2012). The seven pillars of the analytic hierarchy process. In Models, methods, concepts & applications of the analytic hierarchy process (pp. 23-40). Springer, Boston, MA.

Saaty, T. L., & Vargas, L. G. (1991). Prediction, projection and forecasting: applications of the analytic hierarchy process in economics, finance, politics, games and sports (pp. 11-31). Boston: Kluwer Academic Publishers.

San Woldegebriel, S. (2005). Performance evaluation of furrow irrigation system and GIS-based gravity irrigation suitable area map development at Godino Mariam, Debrezeit (Doctoral dissertation, MSc thesis, Alemaya University).

Searcy, J. K., & Hardison, C. H. (1960). Double-mass curves (No. 1541). US Government Printing Office.

Sekertekin, A., & Marangoz, A. M. (2017). An Erdas imagine model to extract urban indices using Landsat 8 satellite imagery. International Journal of Scientific & Technology Research, 6(1), 62-67.

Seleshi Bekele Awulachew. 2010. Irrigation potential in Ethiopia Constraints and opportunities for enhancing the system, International Water Management Institute, Addis Abeba.

Şen, Z. (1998). Average areal precipitation by percentage weighted polygon method. Journal of Hydrologic Engineering, 3(1), 69-72.

Shalaby, A., & Tateishi, R. (2007). Remote sensing and GIS for mapping and monitoring land cover and land-use changes in the Northwestern coastal zone of Egypt. Applied geography, 27(1), 28-41.

Smith M. 1992. CLIMWAT for CROPWAT: A climatic database for irrigation planning and management. FAO Irrigation and Drainage Paper No 49. Rome, Italy: FAO.

Smith, M. (1992). CROPWAT: A computer program for irrigation planning and management (No. 46). Food & Agriculture Org.

Sultan, Dagnenet. 2013. Assessment of Irrigation Land Suitability and Development of Map for the Fogera Catchment Using GIS, South Gondar. Asian Journal of Agriculture and Rural Development 3. (1): 7–17.

Swain, S., Verma, M. K., & Verma, M. K. (2018). Streamflow estimation using SWAT model over Seonath river basin, Chhattisgarh, India. In Hydrologic Modeling: Select Proceedings of ICWEES-2016 (pp. 659-665). Springer Singapore.

Sys, C., Van Ranst, E., & Debaveye, J. (1991). Land evaluation, part II. Methods in land evaluation. Agricultural Publication, (7), 247.

Tang, W. Y., Kassim, A. H. M., & Abubakar, S. H. (1996). Comparative studies of various missing data treatment methods-Malaysian experience. Atmospheric Research, 42(1-4), 247-262.

Tegegne, G.; Park, D.K.; Kim, Y.-O. Comparison of Hydrological Models for the Assessment of Water Resources in a Data-Scarce Region, the Upper Blue Nile River Basin. J. Hydrol. Reg. Stud. 2017, 14, 49–66.

Tesfaye, Y. (2014). GIS-Based Land Suitability Assessment For Surface Irrigation And Mapping: The Case Of Azule Catchment, Arsi Zone, Oromia Region, Ethiopia. Irrigation Engineering. Haramaya University.

Thimme Gowda, P., Manjunaththa, S., Yogesh, T., & Satyareddi, S. A. (2013). Study on Water requirement of Maize (Zea mays L.) using CROPWAT model in northerntransitional zone of Karnataka. J. Environ. Sci. Comput. Sci. Eng. Technol, 2, 105-113.

Trambauer, P., Maskey, S., Winsemius, H., Werner, M., & Uhlenbrook, S. (2013). A review of continental scale hydrological models and their suitability for drought forecasting in (sub-Saharan) Africa. Physics and Chemistry of the Earth, Parts A/B/C, 66, 16-26.

UNDP (United Nations Development program), 2014. Country Economic Brief**.** Analysis Issue No. 1/Feb.2014.United World Water Development Report (2) pp. 244-273.Washington. Vegetation Using Landsat ETM+ Imagery. Accessed from the Internet on Feb 15, 2010.

Winchell, M. Srinivasan, R.,Di Luzio, M., and Arnold, J, 2008. ArcSWAT2.Interface for SWAT 2005, User manual.

Winchell, M., Srinivasan, R., DiLuzio, M., & Arnold, J. (2010). ArcSWAT interface for SWAT 2009 user'guide. Temple, Texas: Blackland research and extension center

World Bank. 2006. Ethiopia Managing Water Resources to Maximize Sustainable Growth. Country water Resources Assistant Strategy, Report No. 36000-ET the World Bank, Agriculture and Rural Development Department.

Yahiaoui, A. (2019). Frequency analysis of the extreme streamflow by the threshold level method in semi-arid region: Case study of Wadi Mekerra catchment in the North-West of Algeria. Journal of Water and Land Development.

Yang Yi .D.H.G, 2003. Application of GIS and Remote Sensing for Assessing Watershed Ponds for Aquaculture development in Thai Nguyen, Vietnam. School of Environment, Resources and Development Asian Institute of Technology

Yemane, G. (2004). Assessment of the water balance of Lake Awassa catchment. Ethiopia (Doctoral dissertation, M. Sc. thesis, International Institute for Geo-Information Science and Earth Observation, Enschede).

7. APPENDICES

Appendix table 1: Mean Monthly Flow of Meki River (m^3/s)

Year	Jan	Febr	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1997	0.32	0.27	0.99	9.95	2.89	4.36	16.59	16.60	5.40	6.56	6.18	0.92
1998	1.60	0.74	12.12	3.27	11.77	5.23	27.62	45.11	29.24	23.12	2.55	0.42
1999	0.09	0.07	2.84	0.12	0.51	2.84	20.64	22.42	10.16	23.55	4.73	0.28
2000	0.02	0.00	0.00	0.05	0.83	0.64	6.31	14.02	11.00	8.25	2.96	0.94
2001	0.01	0.18	3.06	1.91	4.61	10.89	23.95	38.99	23.97	2.55	0.94	0.52
2002	4.08	3.12	1.58	1.73	3.24	4.21	10.11	17.29	9.63	3.04	2.57	2.16
2003	1.47	0.87	4.23	4.84	2.56	4.48	16.37	20.99	13.68	3.99	0.56	1.00
2004	1.11	0.41	0.87	11.39	0.95	2.26	10.67	24.05	13.86	7.54	0.64	0.07
2005	0.48	0.04	1.49	3.62	14.82	9.76	14.84	27.43	22.43	7.79	2.61	1.91
2006	2.56	1.78	5.08	22.98	17.14	10.75	32.54	39.37	22.34	6.55	1.62	1.11
2007	0.71	2.49	1.30	0.35	2.09	16.17	36.29	37.80	23.80	6.83	0.58	0.31
2008	0.17	0.04	0.00	0.13	1.35	3.98	11.01	21.72	16.21	1.10	11.51	0.24
2009	0.80	0.04	0.15	0.63	0.56	0.10	4.01	8.04	6.68	5.72	0.66	0.00
2010	0.00	1.12	3.12	12.19	9.35	1.63	24.01	30.65	19.63	2.29	0.00	0.00
2011	0.00	0.00	0.28	0.00	2.41	4.86	12.03	25.18	26.50	3.36	0.00	0.09
2012	0.42	0.14	0.00	1.11	3.98	0.55	24.17	26.65	24.22	6.20	0.00	0.00
Mean	0.87	0.71	2.32	4.64	4.94	5.17	18.20	26.02	17.42	7.40	2.38	0.62

Appendix table 2: Mean monthly maximum temperature of Bui

Year	Jan	Feb	Mar	Apr	may	jun	jul	Aug	Sept	Oct	Nov	Dec
1995	25.4	28.1	28.1	28.8	27.7	26	25.8	25	25.7	26.6	26	25.7
1996	25.2	27.2	30.1	26.5	26.1	25.7	23.6	23.8	25.5	26	25.5	25.2
1997	26.1	26.9	28.5	28.1	26.9	27.6	24.1	23.5	24.5	25.4	25.4	24.7
1998	25.1	27.2	26	26.1	26.5	24.7	24	24.1	25.6	26.3	25.5	25.8
1999	26.9	28.6	30	29	28.9	25.9	24.6	24.1	26.6	25.7	24.8	23.9
2000	25.4	27	28.2	27.3	27.4	25.9	23.9	23.2	24.5	24.4	24.4	24.6
2001	24.7	26.4	25.4	26.6	26.2	25.2	23.2	23.5	25.3	25.6	26	26.1
2002	25.6	27.4	27.4	27.8	28.4	26.5	26.6	25.1	25.6	26.7	26.4	25.8
2003	26.3	28.8	28.3	26.8	28.4	26.8	24	23.8	24.5	26.2	26.1	25.2
2004	26.5	26.4	27.3	26.3	28.4	27.3	24.7	25.2	26.2	25.6	26.4	26.7
2005	27.1	29.6	28.4	29.5	27.2	27	25.8	26.3	26.5	27.2	26.8	26.3
2006	27.4	28.3	28.4	27.1	28.6	27.9	25.6	24.9	26	27.5	27.3	26.8
2007	28	29.2	30.5	29.1	30.5	26.8	25.6	26.3	26.7	27.1	27	26.8
2008	28.7	29.1	31.4	29.5	29.1	26.9	25.7	25.3	27.2	28.1	26.6	26.6
2009	27.8	29.4	31.1	30	30.3	31.1	25.9	25.8	27.6	26	27.2	27
2010	27.7	28.2	27.5	28.5	28.8	28.3	25.6	25.6	26.3	28	27.7	27.2
2011	28.1	30.2	29.3	31.5	29.1	28.6	26.5	25.3	26.4	28.1	27.3	24.6
2012	25.9	27.5	28.6	26	27.6	26.6	22.8	22.6	24.1	24.8	25.5	25
2013	25.5	27.2	28.8	27.6	26.5	25.8	22.1	23	25	24.7	24.7	24.3
2014	25.5	25.8	26.6	27.1	27.1	26.8	24.6	23.6	23.9	24	25	24.4
2015	25.4	28.1	28.1	28.8	27.7	26	25.8	25	25.7	26.6	26	25.7
2016	25.2	27.2	30.1	26.5	26.1	25.7	23.6	23.8	25.5	26	25.5	25.2
2017	26.1	26.9	28.5	28.1	26.9	27.6	24.1	23.5	24.5	25.4	25.4	24.7
2018	25.1	27.2	26	26.1	26.5	24.7	24	24.1	25.6	26.3	25.5	25.8
2019	26.9	28.6	30	29	28.9	25.9	24.6	24.1	26.6	25.7	24.8	23.9
2020	25.6	27.4	28.9	27.8	26.9	26.4	24.5	24.1	25.2	26.0	25.6	25.2
Mean	26.3	27.8	28.5	27.9	27.8	26.7	24.7	24.4	25.6	26.2	25.9	25.5

Appendix table 3: Mean monthly minimum temperature of Bui

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1995	12.5	10.7	12.5	12.3	12.7	13.2	13.3	13.9	12.8	12.2	10.1	13.6
1996	11.4	10.3	14.9	15.3	14	12.8	13.4	13	12.9	11.3	9.7	8.1
1997	14.5	12.2	13.4	14.3	15.8	15.3	15.2	14.5	14.3	13	11.2	12.9
1998	6	7.8	8.6	9.8	9.4	9	8.4	8.5	8.2	7.3	8	5.9
1999	6.2	5.8	9.4	9	10.1	11.6	6	5.7	5.1	5.1	3.5	3
2000	3.1	5.1	7.3	9.5	8.8	7.1	7.1	8.3	7.9	7.2	5.5	4.9
2001	5.2	6.6	8.6	7.4	7.9	7.9	8.4	8.3	7.5	7.1	4.4	5.2
2002	6.2	5.5	8.1	8	8.2	7.4	7.7	7.5	6.6	4.9	3.3	7.1
2003	6.2	7.9	8.8	9.2	8.7	8.5	8.9	9	8.7	6.4	5.6	4.8
2004	8.3	6	12.1	13.4	13.6	12.8	12.1	13.1	12.9	10.5	9.7	10
2005	9.4	10.4	13.6	13.5	13.8	12.4	12.4	12.5	12.9	9.7	9.2	7
2006	10.8	12.4	12.8	13.2	12.8	12.4	14	12.6	13.3	13	13	13.1
2007	9.9	12.3	8.3	11.5	9	12.5	12.1	12	11.6	9	8.6	6.5
2008	9	9.1	9.4	12	11.8	10.7	10.5	10.7	10.7	10.7	10.8	10.7
2009	13.9	11.3	13.5	14.3	13.6	13	12.8	13.2	12.9	11.2	9.4	11.7
2010	12.7	12.7	13.8	13.9	12.5	12.6	13.4	11.8	11	8.1	8.2	8.2
2011	9.6	10.1	11.4	13.2	13.2	11.4	11.6	11.6	11.1	8.6	9.4	7.5
2012	7.9	8.4	10.1	11.6	10.9	10	10.5	10.2	9.9	7.9	7.5	7.2
2013	7.6	8.5	10.7	11	10.4	9.8	8.9	8.2	8.9	8.2	8.4	5.5
2014	8	10.1	10.3	10.9	11	9.4	9.5	9.3	9.5	9.4	9.4	9.8
2015	12.5	10.7	12.5	12.3	12.7	13.2	13.3	13.9	12.8	12.2	10.1	13.6
2016	11.4	10.3	14.9	15.3	14	12.8	13.4	13	12.9	11.3	9.7	8.1
2017	14.5	12.2	13.4	14.3	15.8	15.3	15.2	14.5	14.3	13	11.2	12.9
2018	6	7.8	8.6	9.8	9.4	9	8.4	8.5	8.2	7.3	8	5.9
2019	12	10.5	13.7	13.8	13.35	13	13.4	13.45	12.85	11.75	9.9	10.85
2020	8.98	9.15	11.15	11.8	11.38	11	10.9	10.98	10.525	9.525	8.95	8.375
Mean	9.37	9.38	11.23	11.95	11.72	11.31	11.2	11.09	10.78	9.457	8.567	8.555

Appendix table 4: Average monthly wind speed of Bui

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1995	1.36	1.35	1.38	1.45	0.98	1.57	1.25	0.76	1.45	1.22	1.29	1.23
1996	1.04	1.25	1.28	0.92	0.75	0.82	0.7	0.64	1.11	1.34	1.4	1.22
1997	1.39	1.47	1.16	1.46	1.32	1.36	1.09	0.8	1.68	1.31	1.26	1.14
1998	1.21	1.36	1.22	1.19	1.03	1.09	0.9	0.72	1.4	1.32	1.33	1.18
1999	2.12	2.45	1.93	1.8	2.78	2.24	1.63	1.46	1.38	1.51	2.05	2.05
2000	2.25	2.47	2.53	2.27	1.82	1.73	1.49	1.45	1.2	1.55	1.71	1.79
2001	1.77	2.01	1.69	2.09	1.54	1.42	1.38	1.55	1.47	1.87	2.11	2.05
2002	2.09	2.07	1.82	2.2	1.5	1.5	1.43	1.25	1.33	2.01	2.22	2.05
2003	2.02	2.34	2.24	2.12	1.85	1.54	1.4	1.17	1.09	1.81	1.86	1.95
2004	1.72	2.06	1.87	1.64	1.78	1.43	1.31	1.18	1.18	1.63	1.88	1.86
2005	1.63	1.91	1.74	1.77	1.36	1.22	1.21	1.18	1.1	1.63	1.8	1.83
2006	1.82	1.75	1.94	1.52	1.55	1.23	1.23	1.1	1.15	1.63	1.79	1.92
2007	1.73	1.6	1.86	1.78	1.6	1.18	1.09	1.04	1.07	1.7	1.96	1.85
2008	1.84	1.99	1.98	2.05	1.47	1.18	1.16	0.97	1.07	1.33	1.4	1.38
2009	1.4	1.57	1.48	1.42	1.38	1.35	1.12	0.96	1.07	1.3	1.4	1.25
2010	1.36	1.08	1.33	1.1	0.85	0.89	0.98	0.73	0.9	1.31	1.3	1.22
2011	1.5	1.66	1.57	1.17	1.23	0.94	1.01	0.87	0.8	1.35	1.25	1.35
2012	1.49	1.65	1.57	1.16	1.44	1.12	0.88	0.89	0.91	1.41	1.31	1.33
2013	1.35	1.51	1.24	1.19	0.88	0.97	0.88	0.81	0.9	0.9	1.34	1.26
2014	1.25	1.19	1.28	1.32	1.05	1.41	1.04	1.4	1.06	1.48	1.18	1.17
2015	1.36	1.35	1.38	1.45	0.98	1.57	1.25	0.76	1.45	1.22	1.29	1.23
2016	1.04	1.25	1.28	0.92	0.75	0.82	0.7	0.64	1.11	1.34	1.4	1.22
2017	1.39	1.47	1.16	1.46	1.32	1.36	1.09	0.8	1.68	1.31	1.26	1.14
2018	1.44	1.5	1.479	1.358	1.16	1.18	1.04	0.92	1.02	1.288	1.309	1.274
2019	1.26	1.315	1.275	1.288	1.025	1.29	1.02	0.9	1.325	1.338	1.283	1.19
2020	1.3	1.39	1.35	1.208	1.02	1.18	0.95	0.9	1.086	1.27	1.304	1.242
Mean	1.54	1.654	1.578	1.512	1.324	1.29	1.12	0.99	1.192	1.438	1.526	1.476

Appendix table 5: Average monthly sunshine hours of Bui

Year	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1995	9.9	9.8	9.4	9	7.8	4.9	6.8	6.8	7.5	9.1	8.5	7.9
1996	7	8.9	8.6	6	7.3	5.3	4.6	5.9	6.7	9.1	8.6	9.8
1997	10.3	10.3	9	10.3	9.8	9.6	10.2	9.5	6.6	7.7	9.4	10.2
1998	9.1	7.7	7.1	6.2	7.5	3.8	4.3	5.3	8.3	8.7	8.3	8.6
1999	9	9.7	9	8.5	8.3	6.6	7.2	7.4	6.9	8.6	8.8	9.3
2000	8.6	9.6	8.8	8.2	8.5	7.4	7.4	7.7	6.7	8.4	9	10
2001	8.8	9.6	8.9	8.3	8.4	7	7.3	7.6	6.8	8.5	8.9	9.6
2002	8.7	9.6	8.9	8.3	8.5	7.2	7.4	7.6	6.7	8.5	8.9	9.8
2003	9	9.2	8.5	7.9	8.1	5.9	6.5	6.9	7.3	8.7	8.7	9.1
2004	7.6	7.4	7.3	7.1	7.1	6.8	7	7.4	8.2	9	9.4	9.2
2005	8.2	8	7.9	7.6	7.5	7.3	7.6	8.1	8.3	8.6	8.8	8
2006	9.6	8.9	7.7	7.4	8.8	7.2	5.2	4.1	5.8	7.7	9.9	7.8
2007	8.4	8.7	10.1	7.5	8.9	4.5	4	4.9	5.8	8.4	9.5	10.6
2008	9.9	9.4	10.6	9.3	8.7	4.1	5.8	5.3	6.8	8.1	9	9.9
2009	9.1	10.2	9.6	8.6	9.1	5.8	5	9.1	8.4	8.1	10.1	6.1
2010	8.4	6	7.1	7	7	7	4.7	6.9	6.1	10	10.4	8.8
2011	9.5	8.2	7.6	8.8	7.9	7.5	5.6	9	9.2	9.9	8.1	10.4
2012	10.4	9.8	9.3	5.3	9.4	3.8	3.4	4.5	6.3	8.5	9.7	9.4
2013	1.9	8.2	4.8	8.6	7.7	4.3	3.6	4.1	6.8	8.1	8.8	9.9
2014	8.9	7.6	9.1	8.5	7.7	6.2	4.6	6	6	7.4	6.8	9.9
2015	9.9	9.8	9.4	9	7.8	4.9	6.8	6.8	7.5	9.1	8.5	7.9
2016	7	8.9	8.6	6	7.3	5.3	4.6	5.9	6.7	9.1	8.6	9.8
2017	10.3	10.3	9	10.3	9.8	9.6	10.2	9.5	6.6	7.7	9.4	10.2
2018	9.1	7.7	7.1	6.2	7.5	3.8	4.3	5.3	8.3	8.7	8.3	8.6
2019	8.45	9.35	9	7.5	7.55	5.1	5.7	6.35	7.1	9.1	8.55	8.85
2020	5.4	7.9	6.95	8.55	7.7	5.25	4.1	5.05	6.4	7.75	7.8	9.9
Mean	8.6	8.87	8.4	7.9	8.14	6.0	5.9	6.7	7.1	8.6	8.8	9.2

Appendix table 6: Mean monthly maximum temperature of Butajira

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1995	30.3	30.9	30.5	32.4	27	27.1	22.2	26.3	25.9	28.1	29.6	30.6
1996	29.1	30.1	32	28.9	29	28.3	25.9	26.8	28.1	29.6	28.8	27.8
1997	27.6	27.8	31.2	30.6	28	28.4	26.5	27	29.7	31.2	30.5	28.8
1998	29.7	28.3	27	25.8	23	23.5	23.8	25.3	26.8	28.3	29.7	31.2
1999	23.9	24.2	24.4	24.6	24.9	26.3	24.1	23.8	24.4	24	25.8	25.8
2000	26.4	28	28.8	27.4	26.9	25.1	23	22.6	25.6	25.2	26.4	26.8
2001	25.5	27.4	24.4	27.7	25.5	24.5	23.8	24.2	26.5	27.6	26.5	27
2002	25.7	27.3	26.1	27	26.6	26.2	24.9	24.7	26.2	28.2	27.5	25.8
2003	25.6	28.5	28.7	26.6	28.1	25.9	23.1	22.5	24.9	26	26.3	25.8
2004	26.6	26.8	27.7	26.6	29	26.6	26.2	25.3	23.9	24.8	26.3	26.3
2005	26.6	27.6	27.4	27.4	25.4	26	24.3	25.3	26.6	27.6	26.3	26.9
2006	27.1	26.6	27.5	26.4	27.3	26.3	24.1	23.5	25.9	26.1	25.9	25.2
2007	27	27.6	28.6	26.3	26.4	24.4	20.7	16.9	18.8	23.8	22.1	27.4
2008	27.9	28.1	30.4	28.8	27.9	25	23	23	24.4	25.3	25.3	26.3
2009	26.4	27.8	30.1	28.3	28.7	29.1	24.4	23.9	25.8	25.5	26.9	25.7
2010	26.9	26.7	26.3	27.1	24.1	24.3	24.4	24.6	24.7	24.9	25	25.2
2011	25.3	25.5	25.6	25.8	26	26.1	26.3	26.4	26.6	26.7	26.9	27
2012	27.2	27.4	27.5	27.7	27.8	27.6	26	26.3	26.5	27.2	28.2	28.8
2013	24.8	17.8	19.5	20.5	31	27.8	23.1	24.9	28.4	31.6	35.3	28.1
2014	28.4	28.1	31	29.1	29.2	30.9	22.5	18.6	19.1	30.2	27.5	25.2
2015	30.3	30.9	30.5	32.4	27	27.1	22.2	26.3	25.9	28.1	29.6	30.6
2016	29.1	30.1	32	28.9	29	28.3	25.9	26.8	28.1	29.6	28.8	27.8
2017	27.6	27.8	31.2	30.6	28	28.4	26.5	27	29.7	31.2	30.5	28.8
2018	29.7	28.3	27	25.8	23	23.5	23.8	25.3	26.8	28.3	29.7	31.2
2019	29.35	29.5	30.75	30.75	28.1	29	22.35	22.45	22.5	29.15	28.55	27.9
2020	28.35	28.95	31.6	29.75	28.5	28.35	26.2	26.9	28.9	30.4	29.65	28.3
Mean	27.4	27.62	28.38	27.82	27.1	26.69	24.202	24.487	25.8	27.64	27.83	27.6

Appendix table 7: Mean monthly minimum temperature of Butajira.

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1995	4.3	12.8	14.2	15.2	10.6	9.7	8.6	11.8	10.3	10.4	10.8	11
1996	12	13.4	14.2	11.9	13.8	13.1	10.7	10.5	11.5	10.6	9.7	8.7
1997	8.8	10.6	13.8	13.7	14.3	10.8	11.6	13.8	14.6	12.8	9.7	6.2
1998	12	12	10.6	11.5	9.3	10.1	2.2	4.6	6.9	9.2	11.5	13.8
1999	10	10.8	11.3	11.8	12.6	12.2	12.8	12.3	12.3	12.1	10.3	9
2000	9	10	12.3	13.9	12.6	11.3	12.2	11.9	11.7	11.5	11.8	12
2001	11	11.2	12.4	12.3	11.8	12	12.5	12.4	11.8	12.1	9.9	10.7
2002	10	9.5	13	12.7	12.7	11.5	12.3	10.9	11	11	10.8	11.1
2003	12	11.2	12.7	14.1	12.2	12.1	10.9	11.6	11.7	8.9	8.4	7
2004	9.9	9.4	9.5	13.3	10.3	12.2	12	11.9	11.1	9.5	7.5	8.5
2005	6.9	6.2	10.6	11.6	11.9	11.5	11.5	10.2	10.9	10.9	10.8	7.8
2006	8.7	11.8	11.2	11.2	10.2	11.8	11.7	10.9	10.5	10.4	8.9	7.2
2007	11	10.6	11.6	11.2	11.8	12.1	12.3	12.5	12.7	12.9	13.1	13.3
2008	11	9.9	8.4	11.8	13.1	12	12	11.5	11.9	10.7	7.5	5.8
2009	8.6	8.6	11.1	13.3	12.6	11.9	12.6	12.7	12.4	10.1	6.6	10.7
2010	8.8	12.1	11	13.1	14.4	14.4	14.3	14.2	14.1	14.1	14	13.9
2011	14	13.8	13.7	13.6	13.5	13.4	13.4	13.3	13.2	13.1	13.1	13
2012	13	12.8	12.7	12.7	12.6	12.4	12	12.4	12.1	10.7	4.8	8.9
2013	9.1	10.2	11.4	12.5	11.7	6.8	5.6	10.7	11.2	13.3	12.3	9.9
2014	10	15	15.2	14.7	14.9	15.8	10.2	9.8	10.2	13.8	14	8.2
2015	4.3	12.8	14.2	15.2	10.6	9.7	8.6	11.8	10.3	10.4	10.8	11
2016	12	13.4	14.2	11.9	13.8	13.1	10.7	10.5	11.5	10.6	9.7	8.7
2017	8.8	10.6	13.8	13.7	14.3	10.8	11.6	13.8	14.6	12.8	9.7	6.2
2018	12	12	10.6	11.5	9.3	10.1	2.2	4.6	6.9	9.2	11.5	13.8
2019	12	7.7	7.3	7.3	6.9	23.5	22	20	18	16.1	14.2	12.2
2020	10.2	11.3	12.2	12.6	11.8	10.45	6.9	9.2	10.75	11	10.6	10
Mean	9.92	11.14	12.05	12.63	12.06	12.11	10.9	11.5	11.7	11.5	10.46	9.946

Appendix table 8: Corrected monthly rainfall data at koshe (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1995	0	0	12.5	0	110.9	6.3	40.5	42.5	69.7	0	0.2	0	283
1996	32.3	22.8	2.1	159	292.3	120.9	183.9	49.9	73.4	6.8	12.7	0	956
1997	0	7.2	22.1	0	70.6	19.8	90.6	39.6	144.1	0.5	0	0	395
1998	0	11.7	25.8	124.7	102.7	88.5	124.5	113.8	77.2	40.7	0	0	710
1999	0	0	60.8	31.2	10.7	109.6	171.2	110.2	77.5	127.5	0	0	699
2000	0	0	7.9	107.3	58	0.5	122.7	95.9	135.5	40	50.5	40.2	659
2001	0	68.3	141.4	34.5	170.9	79.3	183.1	135.9	82.5	15.9	0	1.5	913
2002	9.3	36	70.8	88.4	38.2	46.4	119.6	126.5	39.1	0	0	4.4	579
2003	53.3	1.3	23.5	104.8	0	55.8	158.4	127.2	175.8	0	0	50.5	751
2004	47.4	1.2	61.6	114.3	0.2	66.5	106.8	77.5	55.8	62.9	0	0	594
2005	121	0	92.5	139.7	124.9	61.5	231	163.3	110.9	25.7	5.6	0	1077
2006	3.3	34.9	105.8	149.9	146.4	76.4	234.2	104.8	50.2	46.5	0	1.2	954
2007	8.7	61.3	52	40.6	172.2	141.6	174.2	168.4	136.2	12.3	0	0	968
2008	0	0	0	7.9	140.5	197.1	166.2	171.4	66.6	49.1	140.7	0	940
2009	34.6	0	58.2	4.5	35.1	25.3	149.4	48.9	69	76.6	0	0	502
2010	0	86.3	173.7	104.8	139.7	56	84.1	131.6	70.8	16.5	0	11.6	875
2011	12.5	0	65.6	44.1	50	108.3	108.5	107.2	22.7	0	6.4	0	525
2012	0	0	61.8	95.1	0	80	239.6	156.6	16.9	0	0	0	650
2013	7.4	0	104.3	65.3	16.9	159.3	286.7	105.4	131.6	105.4	2.7	0	985
2014	1.3	37.9	104.1	25	50	30.7	172.5	200.4	93.7	176.2	6.5	0	898
2015	0	0	12.5	0	110.9	6.3	40.5	42.5	69.7	0	0.2	0	283
2016	32.3	22.8	2.1	159	292.3	120.9	183.9	49.9	73.4	6.8	12.7	0	956
2017	0	7.2	22.1	0	70.6	19.8	90.6	39.6	144.1	0.5	0	0	395
2018	0	11.7	25.8	124.7	102.7	88.5	124.5	113.8	77.2	40.7	0	0	710
2019	10.3	15.18	55.7	62.3	117.5	79.3	170.9	99.55	92.1	72.1	5.525	0	781
2020	3.7	0	83.05	80.2	8.45	119.65	263.2	131	74.25	52.7	1.35	0	818
Mean	14.5	16.38	55.6	71.8	93.5	75.5	154.7	105.9	85.7	37.5	9.4	4.2	725

Appendix table 9: Corrected monthly rainfall data at meki (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1995	0	28.8	68	141.3	21.6	49.5	79.9	132	28.5	3.1	0	11.6	564
1996	47.5	8.2	53.9	110.4	127.1	128.4	135	162	106	0	32.8	0	912.1
1997	20	0	70.4	229.5	4.7	150.4	162	57.4	45.8	108	0.3	0	848.6
1998	6.1	22.3	43.4	48.7	57.7	44.9	167	178	98	90.8	0	0	756.2
1999	0.8	2.8	88	8	9.4	76.9	221	139	57.3	184	0	0	787.7
2000	0	0	14.3	51.4	42	37.6	74.9	121	91.9	12	41.8	12.8	499.1
2001	0	29.3	98.1	10.2	75.4	33.4	120	103	34.9	0	0	0	504
2002	0	5.7	28	48	8.4	36.6	80.8	96.7	19.5	0	0	16.1	339.8
2003	35	20.3	96.8	194.4	10.9	49.8	106	17.6	0	0	0	62.1	592.6
2004	3.8	0	6.7	69.7	0	132.8	54.9	62.7	56.6	16.4	16.4	0	420
2005	36.5	22.1	65.3	13.8	52.8	27.2	120	88	110	0	0	0	535.7
2006	0	48.2	87.1	47.9	36.2	57.7	135	81.8	67.7	16.9	0	0	578.6
2007	8.4	16.3	26.4	74.5	79.6	103	118	86.3	0	0	0	0	512.8
2008	0	0	0	12.8	40.1	47.4	129	137	59.4	22	84.8	0	533
2009	7.5	0.8	28.3	15.5	9.6	15	87.8	51	31.9	50.2	0	5.6	303.2
2010	0	16.7	99.6	31.5	81.9	30.2	75.4	102	54.3	0	0	0	491.2
2011	0	0	38.7	12.9	20.6	58.6	55.5	68.6	52.8	0	10.1	0	317.9
2012	0	0	9.8	23.5	19.5	35.8	267	106	85.2	0	0	0	547.4
2013	0	0	30.3	23.9	3	39.6	75.5	29	30.4	14.3	0	0	245.8
2014	1.9	9.7	33.5	3.6	38.1	5.6	50.1	58.5	33.8	23.7	0	0	258.4
2015	0	0	8.4	0	58.3	71.4	76.7	58.3	39.1	0	0.1	0	312.2
2016	0	0	4.6	121.3	56.6	94.4	104	35.7	38.1	4.5	8.5	0	467.9
2017	0	15.8	42.2	1	120	61.7	133	71.8	82.1	0.4	0	0	527.8
2018	0	6.9	56.3	116.7	27	74.4	51.4	70.9	29.1	0	7.8	0	440.5
2019	0.95	4.85	31.9	13.75	20.55	22.6	62.8	43.8	32.1	19	0	0	252.25
2020	0.48	5.88	44.1	65.23	23.78	48.5	57.1	57.3	30.6	9.5	3.9	0	346.38
Mean	6.5	10.2	45.16	57.29	40.19	58.98	108	85.2	50.6	22.1	7.94	4.16	495.98

Appendix table 10: Corrected monthly rainfall data at Butajira (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1995	9.5	6.6	11.9	75.6	81.4	69	84.3	44.9	28.5	9	5.8	0	426.5
1996	0	10.3	17.4	24	20.3	30.7	71.9	31.7	14	0	0	0	220.3
1997	0	3.4	12.9	37.9	56.8	48.6	176.9	222	116	58.6	48.8	0	781.8
1998	0	6.9	25.9	75.8	113.6	97.2	353.7	445	231	117	97.6	0	1563.6
1999	3	15.2	91	35.3	69.4	92.5	205.9	215	112	216	0	0	1054.4
2000	0	0	6.1	122	75.4	57.8	150	133	55.5	57	90	118	865.6
2001	0	59	263	59.2	194.8	234	136.6	189	121	24	9.4	1.8	1291.5
2002	49.2	38.8	144	82.4	105	182	93.6	249	168	0	0	48.3	1159.9
2003	10.4	58.3	129	155	43.4	230	272	115	123	0.3	7.7	44	1187.8
2004	75.4	6.1	58.5	190	6.9	109	145.3	116	136	67.2	2.1	0.2	913.4
2005	27	7	94	221	266.9	166	394.8	169	275	134	29.8	0	1783.6
2006	3.5	62.8	207	382	116.3	270	257.3	206	270	62.7	0.5	11.6	1849.3
2007	7.4	245	88.5	121	153.3	260	366.1	238	211	43.8	1.8	0	1735
2008	0	2.2	0	49	186.8	173	191.7	261	117	85.9	101	0	1168.4
2009	46.9	5.9	31.4	41	55.9	34.7	247.1	90	44.9	69	0	0	666.8
2010	0	93.8	70.2	53.2	299.5	187	90.1	186	94.1	30.7	11.6	5.9	1121.7
2011	5.3	7.7	39.2	30.4	242.7	160	255.3	275	160	0	34.2	0	1210
2012	0	0	47.8	153	75.7	63.7	356.2	190	116	20.9	0	4.6	1028.4
2013	29	0	204	140	87.7	362	578.7	218	63.6	66.2	0	0	1749.3
2014	0	171	225	96.1	140.1	102	547	582	213	17.2	7.4	0	2099.6
2015	9.5	6.6	11.9	75.6	81.4	69	84.3	44.9	28.5	9	5.8	0	426.5
2016	0	10.3	17.4	24	20.3	30.7	71.9	31.7	14	0	0	0	220.3
2017	0	3.4	12.9	37.9	56.8	48.6	176.9	222	116	58.6	48.8	0	781.8
2018	0	6.9	25.9	75.8	113.6	97.2	353.7	445	231	117	97.6	0	1563.6
2019	4.75	8.45	14.7	49.8	50.85	49.9	78.1	38.3	21.3	4.5	2.9	0	323.4
2020	0	6.85	15.2	31	38.55	39.7	124.4	127	64.8	29.3	24.4	0	501
Mean	10.8	32.4	71.7	93.8	105.9	126	225.5	196	121	49.9	24.1	9.03	1065.1

Appendix table 11: Corrected monthly rainfall data at Bui (mm)

Year	Jan	Febr	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
1995	0	57.9	89.8	254.5	171	116.2	223	196.4	164.9	3.6	0	29.1	1306
1996	117	0	191.1	34.9	138.3	206.7	249	265.6	90.3	11.7	4.7	17.4	1327
1997	32.9	0	53.8	101.8	11.2	103.4	178	149.4	31.3	78.9	19.3	0	760
1998	46	57.4	117	53.2	85.4	134.3	260	152.3	65.6	74.8	0	0	1046
1999	1.2	0	54.3	10.2	48.2	198.5	342	154.4	43.4	131.8	0	0	984
2000	0	0	0	62.1	57.2	54.1	161	180.5	270.1	96.2	81.2	15.6	978
2001	26	62	201.1	49.5	162.3	210.9	254	194.8	44.6	10.4	0	5.2	1221
2002	52.8	39.9	44.9	49.8	101	117.7	161	198.6	111.8	0	0	23.8	901
2003	4	21.4	122.2	140.6	17.3	150.7	251	166.1	132	0	4.8	42.1	1052
2004	59.3	4.7	23.1	158.1	2.6	114.3	211	193.9	117.9	26.8	9.5	0	921
2005	56.2	17.4	143.9	103.3	158.9	122.8	147	353.9	90	34.8	36.7	0	1265
2006	14.5	33.7	206.2	161.8	95.9	76	299	221.7	74.6	33.2	0	12.5	1229
2007	17.7	33.4	31.5	70.2	97.3	174.2	287	154.4	98.2	21.2	3.5	0	988
2008	0	0	0	0	86.2	186.2	332	187.1	116.4	17.8	148	0	1074
2009	19.2	0	68.7	74.9	0	22.2	244	140.7	116.8	140.7	0	11	839
2010	0	152.3	141.1	262.4	114.4	209.1	206	269.4	154.4	0	9.2	0	1518
2011	0	0	50.6	49	44.7	149.4	218	179.9	85.5	0	14	0	791
2012	0	0	20.1	111.4	66.9	110.6	221	95	99.7	0	0	2.5	727
2013	0	0	136.2	88.5	54.1	156.9	211	190	57.4	47.5	0.6	0	942
2014	0	18.6	109	22.1	38.3	31.3	116	160	37.7	47.5	9.9	0	591
2015	0	18.6	116.4	22.1	106.4	94.4	176	260.3	99.8	47.5	9.9	0	951
2016	26.2	0.8	20.4	112.9	76.7	64.8	114	63.6	48.1	4.8	8.6	0	541
2017	0	24.3	53.8	1.5	201	40.4	138	109.5	112	1	0	0	682
2018	0	16.7	69	161.7	56.7	108.3	87.4	117.4	44.1	0	10.7	0	672
2019	0	0	25.9	120.6	61.5	185.6	299	128.5	238.5	52.76	149	82.1	1344
2020	13.1	12.55	37.1	57.2	138.85	52.6	126	86.55	80.05	2.9	4.3	0	612
Mean	22.3	24.9	90.2	92.9	77.6	132.3	229	190.2	100.1	38.8	17.1	8	1023

Appendix table 12: Corrected monthly rainfall data at Ejerselle (mm)

year	Jan	Feb	Mar	Apr	May	Jun	july	Aug	sept	Oct	Nov	Dec	Annual
1995	0	0	17.5	0	171.9	65.1	161	109	77.1	0	0	0	601.9
1996	12.1	0	10.5	269.3	103.8	104.3	312	127	132	0	0	3.7	1074.3
1997	0	18.5	64	1.2	118.3	3.5	265	128	115	0	0	0	713
1998	0	0	88.8	112	60.4	92.2	124	169	95.6	0	10.7	0	753.1
1999	0	0	68.8	26.2	34	123.2	378	221	96.6	164	0	0	1112.2
2000	0	0	16.7	89.6	80.4	100.1	240	189	185	70.6	87.3	0	1058.2
2001	0	62.1	314.6	12.5	109.6	299	464	235	39.8	0	0	0	1536.4
2002	14.4	0	29.6	45.7	33.3	11.4	188	59.5	30	0	0	19.3	431.4
2003	5.7	41.3	65.5	129.5	25.6	76.9	246	133	69.6	0	1.8	23.8	819.1
2004	67.1	0	59	210.2	2.2	64.8	102	138	84.3	18.7	0	0.8	747.4
2005	135	37.4	188.5	462.2	99.7	232	300	416	220	35.9	6.6	1.5	2135
2006	10.6	127	167.9	70.3	100	131	301	155	61.4	28.9	0	7.5	1160.9
2007	7.4	22.5	79	45.4	87.7	166.5	150	179	90.5	12.2	5.7	0	845.6
2008	0	0	2.2	28.3	101.7	118.2	209	287	150	5.5	195	0	1097.4
2009	56.7	0	49.1	39.7	17	61	248	176	78.3	129	0	18.5	872.7
2010	0	84.3	83.5	146.6	124	119.7	233	293	139	0	0	0	1222.1
2011	0	0	97.4	34.3	105.3	130.9	158	206	182	0	33.1	0	946.5
2012	0	0	54.2	111.8	35.3	111.9	301	169	104	0	0	0	887.4
2013	0	0	93.2	106.6	35.1	348.3	231	119	111	34.3	0	3.7	1082.2
2014	0	40.7	81.9	6.5	44.9	0	164	311	107	60.8	0	0	816.9
2015	0	0	17.5	0	171.9	65.1	161	109	77.1	0	0	0	601.9
2016	12.1	0	10.5	269.3	103.8	104.3	312	127	132	0	0	3.7	1074.3
2017	0	18.5	64	1.2	118.3	3.5	265	128	115	0	0	0	713
2018	0	0	88.8	112	60.4	92.2	124	169	95.6	0	10.7	0	753.1
2019	28.4	0	25.65	34	59.35	89.6	229	231	114	67.1	97.7	9.25	985.1
2020	6.05	0	14	134.7	137.9	84.7	237	118	104	0	0	1.85	838.1
Mean	13.7	17.4	71.24	96.12	82.38	107.7	235	181	108	24.1	17.3	3.6	956.89

Appendix table 13: Corrected monthly rainfall data at Tora (mm).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1995	0	71.7	208	303	51.5	64.3	150.7	105	143	25.6	0	38.6	1161.5
1996	96.7	1.2	188	71.6	172.3	159	147.9	166	152	3.4	1	0	1158.6
1997	35.4	0	109	160	32	146	142.4	80.2	51.8	153	3.3	0	913.5
1998	44.1	79.6	28.8	114	227.9	49	168.4	159	114	38.7	0	0	1022.3
1999	0	0	77.2	25.4	35.3	117	86.5	47.4	101	168	0	0	656.8
2000	0	0	0.4	104	73	42.5	41.4	74.7	138	59.4	130	55.4	717.8
2001	0	0	170	26.1	154.9	93.8	107.1	194	69	1.3	5.4	0	822.2
2002	20.3	10.6	52.4	118	31.3	59.6	85.8	117	111	0	0	8.6	614.4
2003	30	16.5	54	110	19.7	21	157	34.5	100	0	0	29.9	572.5
2004	103	0	121	13.2	70	76	119	96	97.2	42.9	20.9	9.3	768.5
2005	17.8	21.1	56.1	122	231.3	83.2	169.8	120	57.5	84	6.8	0	970
2006	0	39.1	130	119	132.9	121	118.2	68.9	77.4	27.8	0	2.7	837.3
2007	4.6	147	23.3	52	102.1	110	148.3	68.2	102	35.3	0	0	792.9
2008	15.5	0	4.6	14	91.7	114	119	184	100	12.7	146	0	801.1
2009	2.7	1.4	82.8	6.9	23.8	45.9	163.2	121	60.2	127	0	21	655.3
2010	6.6	54.3	96.6	141	124	114	103.1	135	208	46.7	0	21	1050.2
2011	15.5	5.7	53.9	64.8	73	69.3	126.2	111	88.6	0	0	0	608.4
2012	0	0	60.5	40.6	73	84.8	252.5	58.5	103	0	0	0	672.8
2013	51.3	0	96.5	90.6	21.4	69.3	95.7	66.8	88.6	39.2	0	8.5	627.9
2014	0	45.3	50	71	80.1	72.1	119	96	141	67	41.9	0	782.9
2015	0	0	10	71	64.7	29	60.2	53	28.9	1.3	21	9.3	348.5
2016	31	20	47	71	14.9	2.1	67	71	82.8	16	21	9.3	453.1
2017	33	17	33	32	75	33	73	52	57	19	0	9.3	433.3
2018	20	23	78	82	55.3	93	64.5	78.3	38	76	0	0	607.5
2019	25.7	22.7	73.3	80.8	50.75	70.7	107.4	81.4	115	53.1	21	4.25	705.4
2020	8.27	18.6	61.3	53.8	79.83	91.3	128.4	147	123	62	48.5	14	835.63
Mean	21.6	22.9	75.6	82.9	83.14	78.1	120.1	99.5	97.9	44.6	17.9	9.28	753.48

Appendix table 14: summary of Long term corrected mean monthly rainfall (1995-2020).

Area	stations	jan	feb	mar	apr	may	jun	july	aug	sept	Oct	Nov	Dec	Annual
29390	Tora	21.6	22.9	75.6	82.9	83.1	78.1	120.1	99.5	97.9	44.6	17.9	9.3	753.5
24627	Ejerssel	13.7	17.4	71.2	96.1	82.4	107.7	234.7	180.9	107.9	24.1	17.3	3.6	956.9
67915	Butajira	10.8	32.4	71.7	93.8	105.9	125.6	225.5	195.6	120.8	49.9	24.1	9.0	1065.1
30004	Koshe	14.5	16.4	55.7	71.8	93.6	75.5	154.7	105.9	85.8	37.5	9.4	4.2	725.0
56198	Bui	22.3	24.9	90.2	92.9	77.6	132.3	228.5	190.2	100.1	38.8	17.1	8.0	1022.9
8982	Meki	6.5	10.2	45.2	57.3	40.2	59.0	107.7	85.2	50.6	22.1	7.9	4.2	496.0
thiessen	Pav(mm)	15.9	24.3	73.6	87.8	88.4	109.2	198.4	162.5	103.1	40.5	18.0	7.3	929.2

Appendix table 15: summary of climatic data obtained from New_LocClim_1.10.

Station	Parametrs	Unit	Jan	Febr	Mar	Apr	May	Jun	July	aug	Sept	oct	Nov	Dec
Butajira	Humidity	%	81	74	75	91	91	96	95	90	95	86	84	71
	Wind	m/s	1.2	1.3	1.5	1.2	1.1	1	1	0.8	0.6	1.2	1.6	1.8
	Sun	hours	8.1	8.3	8.6	8.1	7.6	6.5	5.4	5.4	5.2	8.2	8.9	8.4
Tora	Tmax	°C	25	25.1	25	25.1	24.7	24	22.2	22	23.2	24	24	24
	Tmin	°C	9.3	10.1	11	11.3	12.3	11	10.8	10	10.1	9.8	9.3	8.3
	Humidity	%	80	73.8	73	91	90.5	95	95	90	96.1	86	84	72
	Wind	m/s	1.2	1.4	1.6	1.2	1.3	1.1	1.5	0.7	0.8	1.3	1.5	1.6
	Sun	hours	8.1	8.3	8.6	8.1	7.6	6.5	5.4	5.4	5.2	8.2	8.9	8.4
Koshe	Tmax	°C	25	25.3	25	25.1	24.7	23	22.5	22	23.8	22	24	26
	Tmin	°C	9.3	10.1	11	11.3	12.3	11	10.8	10	10.1	9.8	9.3	8.3
	Humidity	%	78	74	79	92	92	97	94	91	98	87	86	72
	Wind	m/s	1.2	1.3	1.5	1.1	1.3	1.4	1	0.8	0.6	1.3	1.5	1.6
	Sun	hours	8.1	8.3	8.6	8.1	7.6	6.5	5.4	5.4	5.2	8.2	8.9	8.4
Meki	Tmax	°C	25	27.1	28	28.2	27.7	27	25.1	25	25.1	26	25	25
	Tmin	°C	12	12.5	13	12.1	11.6	13	13.8	14	12.8	12	12	9.8
	Humidity	%	86	83	82	85	90	87	92	93	93	88	84	86
	Wind	m/s	1.2	1	1	0.8	0.8	1.5	1.1	1	0.6	0.8	1.2	0.8
	Sun	hours	8.1	8.1	7.8	8	7.7	7.7	6.4	6.1	5.1	7.8	8.6	8.5
Ejerselle	Tmax	°C	25	27.1	28	28.2	27.7	27	25.1	25	25.1	26	25	25
	Tmin	°C	12	12.5	13	12.1	11.6	13	13.8	14	12.8	12	12	9.8
	Humidity	%	86	83	82	85	90	87	92	93	93	88	84	86
	Wind	m/s	1.2	1.1	1.7	1.2	1.3	1	1	0.8	0.5	1.3	1.5	1.8
	Sun	hours	8.1	8.1	7.8	8	7.7	7.7	6.4	6.1	5.1	7.8	8.6	8.5

Appendix table 16: summarized Long term Averaged climatic data of six stations

Parameters	Unit	Jan	Febr	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec
Min temp	°C	10.2	11.0	11.6	11.9	11.9	11.9	11.9	11.7	11.4	10.9	10.4	9.1
Max temp	°C	25.7	26.7	27.0	27.1	26.6	25.8	24.0	23.7	24.8	25.2	25.2	25.7
Humidity	%	76.9	73.1	73.7	83.3	85.7	87.7	88.5	87.7	89.9	82.0	79.7	74.2
Wind	m/s	1.3	1.3	1.5	1.2	1.2	1.2	1.1	0.8	0.7	1.2	1.5	1.5
Sun	hours	8.2	8.3	8.3	8.0	7.7	6.8	5.8	5.8	5.5	8.1	8.8	8.6
Rainfall	mm	15.9	24.3	73.6	87.8	88.4	109.2	198.4	162.5	103.1	40.5	18.0	7.3

Appendix table 17: Maize Crop Characteristics

	Growth stage				
Maize crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	21	34	42	28	125
Crop coefficient(kc)	0.35	0.8	1.06	0.87	
Rooting depth(m)	0.3		1.0	1.0	
Depletion level(p)	0.55		0.55	0.8	
Yield response factor (ky)	0.4	1.5	0.5	0.2	1.25

Appendix table 18: Onion Crop Characteristics.

	Growth stage				
Onion crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	10	17	47	26	100
Crop coefficient(kc)	0.5	0.75	0.98	0.87	
Rooting depth(m)	0.25		0.6	0.6	
Depletion level(p)	0.3		0.45	0.5	
Yield response factor (ky)	0.45	0.5	0.8	0.3	1.1

Appendix table 19 : Tomato Crop Characteristics.

	Growth stage				
Tomato crop characteristics	Initial	Dev.t	Mid	Late	Total
Length of growing season(days)	25	33	50	22	130
Crop coefficient(kc)	0.48	0.79	1.1	0.88	
Rooting depth(m)	0.25		1.0	1.0	
Depletion level(p)	0.3		0.4	0.5	
Yield response factor (ky)	0.4	1.1	0.8	0.4	1.05

Appendix table 20: Daily and decadal ETc and irrigation water requirement of Maize

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.35	1.28	12.8	4.2	8.6
Jan	2	Init	0.35	1.27	12.7	5.2	7.5
Jan	3	Deve	0.45	1.72	18.9	6	12.8
Feb	1	Deve	0.67	2.64	26.4	5.9	20.5
Feb	2	Deve	0.88	3.58	35.8	6.2	29.6
Feb	3	Mid	1.05	4.35	34.8	11.4	23.4
Mar	1	Mid	1.06	4.52	45.2	18	27.2
Mar	2	Mid	1.06	4.63	46.3	23.1	23.2
Mar	3	Mid	1.06	4.57	50.3	23.8	26.5
Apr	1	Late	1.06	4.49	44.9	24.3	20.6
Apr	2	Late	1	4.19	41.9	25.6	16.2
Apr	3	Late	0.93	3.81	38.1	25.5	12.6
May	1	Late	0.88	3.53	17.6	12.4	5.2
Total					425.7	191.7	234

Appendix table 21: Daily and decadal ETc and irrigation water requirement of onion.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.5	1.83	18.3	17.1	1.2
Oct	2	Deve	0.66	2.52	25.2	11.3	13.8
Oct	3	Mid	0.93	3.54	39	9.5	29.5
Nov	1	Mid	0.98	3.73	37.3	7.8	29.5
Nov	2	Mid	0.98	3.71	37.1	5.4	31.7
Nov	3	Mid	0.98	3.69	36.9	4.4	32.5
Dec	1	Mid	0.98	3.67	36.7	3	33.7
Dec	2	Late	0.97	3.6	36	1.6	34.5
Dec	3	Late	0.93	3.43	37.7	2.8	34.9
Jan	1	Late	0.89	3.26	26.1	3.4	21.8
Total					330.1	66.2	263.1

Appendix table 22: Daily and decadal ETc and irrigation water requirement of Tomato.

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.48	1.75	17.5	17.1	0.4
Oct	2	Init	0.48	1.84	18.4	11.3	7.1
Oct	3	Deve	0.52	1.97	21.7	9.5	12.2
Nov	1	Deve	0.7	2.65	26.5	7.8	18.7
Nov	2	Deve	0.89	3.36	33.6	5.4	28.2
Nov	3	Mid	1.07	4.01	40.1	4.4	35.7
Dec	1	Mid	1.11	4.13	41.3	3	38.3
Dec	2	Mid	1.11	4.11	41.1	1.6	39.5
Dec	3	Mid	1.11	4.08	44.9	2.8	42.1
Jan	1	Mid	1.11	4.05	40.5	4.2	36.3
Jan	2	Late	1.1	3.98	39.8	5.2	34.7
Jan	3	Late	1	3.79	41.7	6	35.6
Feb	1	Late	0.91	3.56	24.9	4.1	19.1
Total					431.9	82.4	347.8

Appendix table 23: Stations coordinate

Stations	Lat	Long	Easting	Northing
Bui	8.330833	38.55444	450940	920899.9
Butajira	8.15	38.36667	430231.6	900935.3
Meki	8.151	38.817	479841	900995.8
Ejerselle	8.2432	38.686	465418.1	911197.7
Koshe	8.0065	38.5253	447688.7	885046.6
Tora	7.8555	38.42067	436134.6	868367.3

Appendix table 24: Random points

No	x	y	NO	X	Y	class value	class name
1	432323.8	910136.2	ID#36	457936.8	916047	6	shrub land
2	431808.7	910618.8	ID#37	457850.9	915881	6	shrub land
3	431924.3	910657.2	ID#167	476987.6	903321	6	shrub land
4	432057.8	910642.5	ID#170	476913.1	903368	6	shrub land
5	430460.7	909860	ID#171	476976.3	903472	6	shrub land
6	426807.7	909615.1	ID#172	476931.1	903375	6	shrub land
7	423194	887992.3	ID#176	476835.3	904405	6	shrub land
8	423043.4	887975	ID#177	476752.1	904486	6	shrub land
9	422941.5	887102.7	ID#178	476760.7	904426	6	shrub land
10	422721.8	886861.2	ID#179	476911.9	904469	6	shrub land
11	421679.1	883434.1	ID#180	476912.7	904289	6	shrub land
12	420908.9	882723.2	ID#181	476834.8	904248	6	shrub land
13	420691.1	882244.6	ID#182	476625.7	904871	6	shrub land
14	442186.8	923657.8	ID#183	476574.7	904792	6	shrub land
15	442158.9	923635.8	ID#184	476651.9	904776	6	shrub land
16	441125	922393.8	ID#185	476572.8	904858	6	shrub land
17	441101.5	922370.6	ID#186	476449	904742	6	shrub land
18	441098.5	922397.9	ID#187	476666.3	904939	6	shrub land
19	426830.8	909631.3	ID#188	472266.8	905262	6	shrub land
20	426771.4	909673.5	ID#189	472325.3	905156	6	shrub land
21	441255.9	923919.5	ID#190	472394	905224	6	shrub land
22	441157.7	923777.8	ID#191	472943.9	905634	6	shrub land
23	441151.6	923925.3	ID#192	472695.4	905731	6	shrub land
24	441368	924023.8	ID#193	472848.8	905505	6	shrub land

25	441462.2	924737	ID#194	471862.6	906154	6	shrub land
26	441454.3	924727.2	ID#195	472079.6	905132	6	shrub land
27	447968.5	932942.7	ID#196	472085.7	904978	6	shrub land
28	447924.3	932901	ID#197	472157.7	905029	6	shrub land
29	457986.2	915577	ID#198	472382.2	905009	6	shrub land
30	457877.9	915481.3	ID#199	472395.2	904873	6	shrub land
31	457891.4	915610.6	ID#200	472478.4	904788	6	shrub land
32	457906	915676.5	ID#201	470847.8	905695	6	shrub land
33	457910.8	915996.4	ID#42	429329.9	877240	11	water body
34	457869.1	915992.9	ID#43	429393.1	876983	11	water body
35	457936.8	916047.5	ID#44	429190.9	876701	11	Water body
36	457850.9	915880.8	ID#45	428931.8	875941	11	Water body
37	458635.4	915714.2	ID#46	430240	876242	11	Water body
38	458606.5	915699.3	ID#47	427907.9	877109	11	Water body
39	447928.5	932971.6	ID#48	430114.3	877140	11	Water body
40	447949.1	932970.1	ID#49	429667.9	879325	11	Water body
41	429329.9	877240.5	ID#50	430707.7	878975	11	Water body
42	429393.1	876983.1	ID#51	430556.5	876227	11	Water body
43	429190.9	876700.6	ID#52	429886	876326	11	Water body
44	428931.8	875940.9	ID#53	429684.7	877076	11	Water body
45	430240	876242.2	ID#54	432309.6	871618	11	Water body
46	427907.9	877108.7	ID#55	432292.8	871551	11	Water body
47	430114.3	877140.3	ID#56	432276	871601	11	Water body
48	429667.9	879325.2	ID#57	432232.6	871677	11	Water body
49	430707.7	878975.3	ID#58	432145.7	871913	11	Water body
50	430556.5	876226.6	ID#59	432156.8	871863	11	Water body
51	429886	876326.3	ID#60	432182.1	871841	11	Water body
52	429684.7	877076	ID#61	432636.8	872946	11	Water body
53	432309.6	871617.9	ID#62	432535.7	873272	11	Water body
54	432292.8	871551.2	ID#63	432257.7	871414	11	Water body
55	432276	871601.2	ID#64	432561.1	871062	11	Water body
56	432232.6	871677.4	ID#65	432333.5	871037	11	Water body
57	432145.7	871912.8	ID#66	432131.3	871087	11	Water body
58	432156.8	871862.6	ID#67	430613.8	876961	11	Water body
59	432182.1	871840.6	ID#68	430639.9	876384	11	Water body
60	432636.8	872945.5	ID#69	430057.7	876233	11	Water body
61	432535.7	873272	ID#70	429526.5	875906	11	Water body
62	432257.7	871413.7	ID#71	429071.3	875831	11	Water body
63	432561.1	871062.2	ID#72	430892.3	878971	11	Water body
64	432333.5	871037	ID#73	429855.4	879624	11	Water body
65	432131.3	871087.3	ID#74	429147.3	879498	11	Water body
66	430613.8	876961.5	ID#75	428034.3	879047	11	Water body

67	430639.9	876384.1	ID#76	427478.1	878645	11	Water body
68	430057.7	876233.1	ID#77	427730.8	877841	11	Water body
69	429526.5	875906.4	ID#78	428642	876007	11	Water body
70	429071.3	875831.1	ID#79	429526.5	875932	11	Water body
71	430892.3	878970.6	ID#80	430437	877464	11	Water body
72	429855.4	879623.9	ID#81	430665	878845	11	Water body
73	429147.3	879498.5	ID#2	432323.8	910136	12	forest
74	428034.3	879046.5	ID#3	431808.7	910619	12	forest
75	427478.1	878644.6	ID#4	431924.3	910657	12	forest
76	427730.8	877840.7	ID#5	432057.8	910642	12	forest
77	428642	876007.1	ID#6	430460.7	909860	12	forest
78	429526.5	875931.6	ID#7	426807.7	909615	12	forest
79	430437	877463.8	ID#8	423194	887992	12	forest
80	430665	878844.8	ID#9	423043.4	887975	12	forest
81	450234	901057.1	ID#10	422941.5	887103	12	forest
82	450126.7	901018	ID#11	422721.8	886861	12	forest
83	450186.4	901224.8	ID#12	421679.1	883434	12	forest
84	460863.6	908005.2	ID#13	420908.9	882723	12	forest
85	460837.1	908015.1	ID#14	420691.1	882245	12	forest
86	466673.4	902086.2	ID#15	442186.8	923658	12	forest
87	466557.4	901983.8	ID#16	442158.9	923636	12	forest
88	467151.1	901427.1	ID#17	441125	922394	12	forest
89	467786.7	901027.9	ID#18	441101.5	922371	12	forest
90	468436.6	901061.1	ID#19	441098.5	922398	12	forest
91	468468.3	900942.3	ID#20	426830.8	909631	12	forest
92	468970.8	900931.4	ID#21	426771.4	909674	12	forest
93	469779.8	900932.6	ID#22	441255.9	923920	12	forest
94	471002.2	900774.2	ID#23	441157.7	923778	12	forest
95	471051.1	900655.7	ID#24	441151.6	923925	12	forest
96	471679.6	900717.2	ID#25	441368	924024	12	forest
97	471734.7	900730.4	ID#26	441462.2	924737	12	forest
98	472392.2	900299.3	ID#27	441454.3	924727	12	forest
99	472429.1	900213.9	ID#28	447968.5	932943	12	forest
100	473299.1	899819.6	ID#29	447924.3	932901	12	forest
101	473803.7	899638.3	ID#30	457986.2	915577	12	forest
102	475424.6	900220.5	ID#31	457877.9	915481	12	forest
103	475603.5	900406.8	ID#32	457891.4	915611	12	forest
104	475544.1	900354.4	ID#33	457906	915677	12	forest
105	475483	900272.7	ID#34	457910.8	915996	12	forest
106	475428.7	900168	ID#35	457869.1	915993	12	forest
107	475492.7	899641.6	ID#38	458635.4	915714	12	forest
108	471598	899898.6	ID#39	458606.5	915699	12	forest

109	467095.3	904967.2	ID#40	447928.5	932972	12	forest
110	466862.6	904708.5	ID#41	447949.1	932970	12	forest
111	465617.8	905565.5	ID#122	431284.6	897206	14	Built up
112	461983.6	904781.4	ID#123	431179.1	897241	14	Built up
113	459592.6	904763.4	ID#124	431115.8	897121	14	Built up
114	458106.8	904818.4	ID#125	431060.6	897416	14	Built up
115	456723.7	904854.5	ID#126	431155.4	897692	14	Built up
116	456661.7	904695.7	ID#127	430929.2	897536	14	Built up
117	455213.7	904691.5	ID#128	430859.6	897580	14	Built up
118	455005.4	904633.7	ID#129	430929.6	897490	14	Built up
119	448537.7	906341.8	ID#130	431170.4	897471	14	Built up
120	446816.2	906299	ID#131	431502.8	897675	14	Built up
121	431284.6	897206.1	ID#132	431566.8	897799	14	Built up
122	431179.1	897240.8	ID#133	431891.8	897531	14	Built up
123	431115.8	897121.1	ID#134	431986.7	897402	14	Built up
124	431060.6	897416	ID#135	431925.8	897836	14	Built up
125	431155.4	897691.6	ID#136	431959.9	897937	14	Built up
126	430929.2	897535.8	ID#137	431835.3	898011	14	Built up
127	430859.6	897580.3	ID#138	432000.5	898051	14	Built up
128	430929.6	897489.9	ID#139	431863	897799	14	Built up
129	431170.4	897470.7	ID#141	432707.9	897717	14	Built up
130	431502.8	897674.8	ID#142	432490.8	897724	14	Built up
131	431566.8	897798.9	ID#143	432623.1	897649	14	Built up
132	431891.8	897531	ID#144	432834.2	897819	14	Built up
133	431986.7	897401.6	ID#145	432848.1	897444	14	Built up
134	431925.8	897836.4	ID#146	432950.2	897312	14	Built up
135	431959.9	897936.7	ID#147	432847.4	897174	14	Built up
136	431835.3	898011.5	ID#148	448451.1	885942	14	Built up
137	432000.5	898050.7	ID#149	448458	885993	14	Built up
138	431863	897799.3	ID#150	448437.1	886054	14	Built up
139	432173.6	897643.2	ID#154	480545.8	901471	14	Built up
140	432707.9	897716.7	ID#155	480510.6	901458	14	Built up
141	432490.8	897724.1	ID#156	480494.8	901537	14	Built up
142	432623.1	897648.9	ID#157	480573.9	901525	14	Built up
143	432834.2	897819	ID#158	480617.4	901474	14	Built up
144	432848.1	897444.1	ID#159	480552.9	901359	14	Built up
145	432950.2	897311.6	ID#160	480526.5	901426	14	Built up
146	432847.4	897173.6	ID#161	480426.9	901400	14	Built up
147	448451.1	885942.5	ID#82	450234	901057	25	cultivated
148	448458	885993.2	ID#83	450126.7	901018	25	cultivated
149	448437.1	886053.6	ID#84	450186.4	901225	25	cultivated
150	449073	886150.9	ID#85	460863.6	908005	25	cultivated

151	449178.8	886222.5	ID#86	460837.1	908015	25	cultivated
152	449138.4	885500.5	ID#87	466673.4	902086	25	cultivated
153	480545.8	901471.3	ID#88	466557.4	901984	25	cultivated
154	480510.6	901458	ID#89	467151.1	901427	25	cultivated
155	480494.8	901537.1	ID#90	467786.7	901028	25	cultivated
156	480573.9	901524.9	ID#91	468436.6	901061	25	cultivated
157	480617.4	901473.8	ID#92	468468.3	900942	25	cultivated
158	480552.9	901358.8	ID#93	468970.8	900931	25	cultivated
159	480526.5	901426.5	ID#94	469779.8	900933	25	cultivated
160	480426.9	901400.4	ID#95	471002.2	900774	25	cultivated
161	479207.6	902890.8	ID#96	471051.1	900656	25	cultivated
162	478988.9	902999.7	ID#97	471679.6	900717	25	cultivated
163	477698.8	902982.3	ID#98	471734.7	900730	25	cultivated
164	477714.5	902976.8	ID#99	472392.2	900299	25	cultivated
165	477444.4	903288.9	ID#100	472429.1	900214	25	cultivated
166	476987.6	903321	ID#101	473299.1	899820	25	cultivated
167	477035.4	903223.4	ID#102	473803.7	899638	25	cultivated
168	476944.7	903191	ID#103	475424.6	900221	25	cultivated
169	476913.1	903367.8	ID#104	475603.5	900407	25	cultivated
170	476976.3	903472.4	ID#105	475544.1	900354	25	cultivated
171	476931.1	903375.1	ID#106	475483	900273	25	cultivated
172	476843.3	903589.1	ID#107	475428.7	900168	25	cultivated
173	476846.2	903609.7	ID#108	475492.7	899642	25	cultivated
174	476789.9	903601.2	ID#109	471598	899899	25	cultivated
175	476835.3	904404.7	ID#110	467095.3	904967	25	cultivated
176	476752.1	904485.6	ID#111	466862.6	904708	25	cultivated
177	476760.7	904425.6	ID#112	465617.8	905566	25	cultivated
178	476911.9	904469.1	ID#113	461983.6	904781	25	cultivated
179	476912.7	904288.7	ID#114	459592.6	904763	25	cultivated
180	476834.8	904248.1	ID#115	458106.8	904818	25	cultivated
181	476625.7	904870.9	ID#116	456723.7	904854	25	cultivated
182	476574.7	904792.3	ID#117	456661.7	904696	25	cultivated
183	476651.9	904776.3	ID#118	455213.7	904691	25	cultivated
184	476572.8	904858.5	ID#119	455005.4	904634	25	cultivated
185	476449	904741.7	ID#120	448537.7	906342	25	cultivated
186	476666.3	904939.1	ID#121	446816.2	906299	25	cultivated
187	472266.8	905262.1	ID#140	432173.6	897643	25	cultivated
188	472325.3	905156.5	ID#151	449073	886151	25	cultivated
189	472394	905223.6	ID#152	449178.8	886223	25	cultivated
190	472943.9	905634.4	ID#153	449138.4	885500	25	cultivated
191	472695.4	905730.6	ID#162	479207.6	902891	25	cultivated
192	472848.8	905504.7	ID#163	478988.9	903000	25	cultivated

193	471862.6	906154.2	ID#164	477698.8	902982	25	cultivated
194	472079.6	905132.2	ID#165	477714.5	902977	25	cultivated
195	472085.7	904978.1	ID#166	477444.4	903289	25	cultivated
196	472157.7	905028.9	ID#168	477035.4	903223	25	cultivated
197	472382.2	905009.1	ID#169	476944.7	903191	25	cultivated
198	472395.2	904873.2	ID#173	476843.3	903589	25	cultivated
199	472478.4	904788.2	ID#174	476846.2	903610	25	cultivated
200	470847.8	905695	ID#175	476789.9	903601	25	cultivated