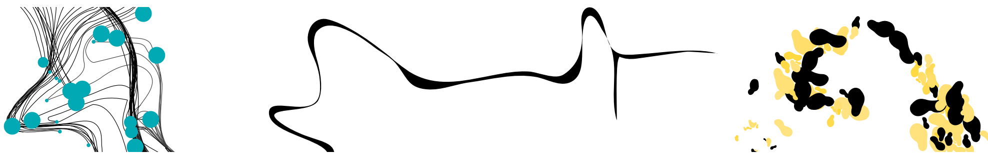

Spatial Information System for Management of Small-scale Irrigation Schemes in Northern Ethiopia

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Ph.D. research proposal

Abstract

Irrigation development is an important means for achieving food security in many arid and semi-arid countries, including Ethiopia. Rainfed-agriculture is the main production system at the study area. However, due to moisture stress, production is limited to rainy season and the production and productivity through this system is very low. In order to tackle this challenge, the regional government has introduced several irrigation schemes. Moreover, as part of the growth and transformation plan (GTP) of Ethiopia, several small-scale irrigation projects have been implemented throughout the country, including Tigray regional state, where this research is proposed to be conducted. The irrigation schemes have improved to some extent the livelihood of the local communities and have thus contributed to economic development of the region. However, there is a challenge for sustainable use of water for irrigation. The challenge can be classified as inadequate knowledge on water use efficiency, water shortage and lack of integration and coordination. These challenges can be attributed to technical and institutional factors, which lead to lower social-economic benefits from irrigation schemes. This research is trying to address some of the shortcomings of irrigation planning and monitoring through development of Irrigation schemes Spatial Information System (IrSpIS). In this context irrigation advisory services intended to assist irrigation manager(s) with proper irrigation planning, execution and monitoring activities. In the study area, the challenge of water use efficiency is caused by the shortage of water, on the one hand, and over-irrigation on the other, which results in high soil salinity and low productivity. Therefore, a suitable system needs to be established to support farmers and managers in improving water use efficiency. The main questions for irrigation water requirements are when to irrigate and how much water to apply. Irrigation water requirements are an important component of the water management in irrigated agriculture. In this part of research main focus will be to characterize small-scale irrigation schemes based on socio-economic, technical, and institutional aspects. In addition, classify irrigation schemes using remote-sensing based indices in order to facilitate feature extraction for mapping. Furthermore, evaluating performances of irrigation scheme using Triple sensor approach. The Triple sensor are using in-situ measurement, remote sensing data and a model based approach. Finally, a spatial monitoring and information system will be developed for small-scale irrigation areas. Therefore, this system will be distributed in a web-based applications platform. Lastly, this IrSpIS is meant to assist irrigation manager(s) at different scale levels for better irrigation management. The three scales are focused on level I at 250m, level II 100m and level III 30m spatial resolution.

Keywords: Ethiopia, irrigation schemes, Triple sensor, water productivity.

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List of Abbreviations

AWP	Agricultural Water Productivity
BoWR	Bureau of Water Resources
BoARD	Bureau of Agriculture and Rural Development
CWP	Crop Water Productivity
CWU	Consumptive Water Use
DA	Development Agent
EENSAT	Ethiopian Education Network to Support Agricultural Transformation
ET	Evapotranspiration
ETa	Actual Evapotranspiration
ETc	Crop Evapotranspiration
ETo	Reference Evapotranspiration
ETp	Potential Evapotranspiration
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
FAO	Food Agriculture Organization
FC	Field Capacity
FCS	Food Consumption Score
FGD	Focus Group Discussion
GIS	Geographic Information System
GPS	Global Positioning System
GTP	Growth and Transformation Plan
HFIAS	Household Food Insecurity and Access Scale
IrSpIS	Irrigation schemes Spatial Information System
IrriSatSMS	Irrigation water management by satellite and SMS
IWR	Irrigation Water Requirement
Kc	Crop Coefficient
LSWI	Land Surface Water Index

MAD	Maximum Allowable Depletion
MAP	Mean Annual Precipitation
MODIS	MODerate-resolution Imaging Spectroradiometer
MoWIE	Ministry of Water, Irrigation and Electricity
NGO's	Non-Governmental Organization's
NDVI	Normalized Difference Vegetation Index
NDVI(TIN)	NDVI and time-integrated
REDSIM-IS	Information-Decision Support System-Information System
RMSE	Root-Mean-Square-Error
RS	Remote sensing
SA	Sensitivity Analysis
SEBS	Surface Energy Balance System
SMS	Short Message Service
SPSS	Statistical Package for Social Sciences
SWAT+	Soil and Water Assessment Tool
SVM	Support Vector Machine
TC	Triple Collocation
Tr	Transpiration
UA	Uncertainty Analysis
WaPOR	Water Productivity through Open access of Remotely sensed derived data
WDI	Water Deficit Index
WP	Water Productivity
WUA	Water Users Association

1 Introduction

1.1 Preface

This chapter provides background information and problem identification about irrigation especially in Ethiopian context. In addition, to achieve the research objectives, four specific objectives are introduced and each objectives have questions to be answered to achieve the proposed objective, and research outputs are discussed. Furthermore, justification for a system and scope of the study is described.

1.2 Background

Irrigation is vital for realizing the full potential of the agricultural sector in the world's societies and serves for local, national, and international markets [1]. According to [2], the food requirements of an ever-increasing world population necessitates higher agricultural production, a large share of which is expected to come from irrigated land. It is anticipated that 83% of produce by the year 2030 should come from irrigated croplands. In the coming years, the role of irrigation is expected to increase [3]. In Africa, a faster growth in agriculture is a precondition for sustainable economic growth and poverty reduction [4]. Irrigation development is an important means for achieving food security in many arid and semi-arid countries, including Ethiopia. Ethiopian agriculture is predominantly rainfed [5]. The rainfall is however characterized as erratic with extreme spatial and temporal variability that affects more than 80% of the population, which is dependent on agriculture [6]. As a result, scarcity of water is a major challenge for increasing agricultural productivity to feed the increasing population. According to [7], Ethiopia's estimated population is 99.8 million by 2020. To sustain livelihoods in these areas modern, irrigated agriculture development led industrialization has the country's development strategy. Moreover, the Ethiopian government has launched a five years growth and transformation plan (GTPII) to reach the level of middle-income country economy by 2025. One of the strategies is to increase the total area of irrigated land from the current 2.3 million hectares to about 5.9 million hectares and to rehabilitate the existing one so as to increase agricultural products to ensure food security [7]. For instance, agricultural development through irrigation has been a priority for the Ethiopian government since 1991 to increase food production and achieve food self-sufficiency [8, 9].

According to the Ministry of Water, Irrigation and Electricity (MoWIE), irrigation development is classified based on the size of the command area: small-scale (less than 200 hectares (ha)), medium-scale (200 ha to 3000 ha) and large-scale is greater than 3000 ha [8, 10]. As part of the Growth and Transformation Plan (GTP) of Ethiopia [6], several small-scale irrigation projects have been implemented throughout the country, including Tigray regional state, where this research is proposed to be conducted [8, 11, 12, 13]. The irrigation schemes have improved to some extent the livelihood of the local communities and thus contributed to economic development of the region. However, the management of these schemes are very poor and unsatisfactory [8, 14]. On top of this, there is no database or information on these schemes to support planning and monitoring. Hence, the expected contribution of these schemes are not to the expected level [10, 14]. Many agencies today still use outdated paper maps and print-out reports to manage their irrigation system [15, 9]. On the other hand, Ethiopian irrigation policy focused on the development of data system to provide reliable and usable data to decision makers at all levels [6]. According to [6], to improve resilience of rainfed systems and sustained irrigation schemes, it is important that entities such as the Ministry of Agriculture, regional governments and the Agricultural Transformation Agency collaborate. Spatial information technology can often facilitate such collaboration. In most developing countries, irrigation planning and development need to be strongly supported with spatial information system in order to properly link the spatiotemporal information required to achieve sustainable development [16].

The regional government has implemented several water harvesting technologies to improve the livelihood of the people [8, 14]. It is important to monitor the planning and performance of these technologies. Even though there were attempts to evaluate the performance of the technological structures, they were limited to scheme level and at few places in the region. According to [17], the performance indicators of small-scale irrigation factors focused on structural, social and institutional aspects. In their research, irrigation schemes in Ethiopia are not functioning at their optimal capacity. In addition, small-scale irrigation schemes are under performing due to construction failures, low technical and financial capacity for sustained operation and management of schemes. Whereas [18], compared technical efficiencies of irrigated and rain-fed plots in Tigray. In their research, when improve water allocation and distribution in irrigation scheme level, so agricultural production can be more than double.

Mapping of small-scale irrigated areas and information is essential to establish a spatial information system on irrigation for Tigray. Geographic Information System (GIS) and Remote sensing (RS) tools used to identify check dam using Landsat image, topographic map, google earth image and field survey for validation [19]. In their research, it is important approach to identify check dams and provide decision support for soil and water conservation [19]. Moreover [20], developed a method to identify irrigated and rainfed areas using Normalized Difference Vegetation Index (NDVI), to create a time series growth period of wheat. In their research, NDVI and time-integrated NDVI(TIN) show significant difference between irrigated and rainfed areas using a support vector machine (SVM) algorithm classification model. However, this method was required field observation data for mapping of irrigated and rainfed wheat areas.

Improving water use efficiency or enhancing agricultural water productivity (AWP) is a critical response for water scarce areas. Water productivity is estimated from the amount of water consumed by the agricultural system, and evapotranspiration [21]. In their research [21], for regional and basin level water productivity, they proposed that it is better to use consumptive water use (CWU) for the value of production per unit of crop. This consumptive water use in irrigated areas implies the potential evapotranspiration (ETp). Moreover, at field scale to estimate water consumed (Evapotranspiration (ET)) using water balance equation is useful. In their study used only in-situ measurement, not used more recent approach utilizing remote-sensing imagery. In the analysis of the temporal and spatial variability of irrigation water demand which was carried out by [22] in China, Penman–Monteith method and daily meteorological data combined socio-economic statistical and land use data were used to provide quantitative information for irrigation water demand of different crops. Due to the uncertainty from the spatial and temporal resolutions of remote sensing data, using satellite image to predict irrigation water demand is a challenge [22].

Vuoloa et al. [23] presented an operational irrigation advisory service based on the satellite observations and FAO approach for calculating crop water requirements at field levels in Southern Italy, Austria and Southern Australia. Arampatzis et al. [24] presented a methodology towards rationalization of water resources management in Greece, through proper irrigation of crops, using meteorological data to calculate daily net crop water requirements using modified FAO Penman-Monteith. As their proposed method relies on simple mass balance equations and meteorological data, it does not require detailed soil measurements. In this research integration of various data sources will be utilized and explore the potential of satellite supported technology, a model and statistical methods to improve planning and monitoring of water management in irrigation schemes. On this basis, the proposed research project is focused on three scale levels, level I 250 m , level II 100m and level III 30 m. This research project will be characterized small-scale irrigation schemes based on socio-economic, technical, and institutional aspects. Subsequently, extract irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping. Afterwards, evaluate irrigation scheme performances using Triple sensor approach. The Triple sensor are using in-situ measurement, remote sensing data and a model based approach. Finally, a spatial monitoring and information system will be developed for small-scale irrigation areas for better irrigation management.

1.3 Problem identification

The irrigation schemes have improved to some extent the livelihood of the local communities and thus contributed to economic development of the region. There are promises of an irrigation, though sustainable use of an irrigation is a challenge. The challenge can generally be classified as inadequate knowledge on water use efficiency, water shortage and lack of integration and coordination. Inefficient utilization of irrigation water is a severe problem in many irrigation schemes. This is due to mismatch between planned and actual amount of water. This includes different planting date and different type of irrigated crops of the farmers [13]. This will result in the withdrawal of more water than required per unit area, and thereby reduce the water use efficiency. Moreover, inadequate knowledge on irrigation scheduling is a problem in Ethiopia in general and particularly in Tigray [13]. According to [8], crop water requirements change with climatic conditions, crop type and growth stage. Also, lack of irrigation scheduling results crop failure and poor yield [13]. In addition, uncontrolled use of irrigation water by farmers, for example, results in inequitable use and over watering, which consequently leads to salinity build-up [8, 11]. These and lack of more information have made the irrigation practice difficult. Another challenge for poor performance of small-scale irrigation in the study area is water scarcity [13]. Tigray is one of the regions that faces a high risk for loosing access to water and suffering from climate change [6]. The climate of the region is characterized by huge spatiotemporal variation in rainfall, high temperature and frequent droughts [6]. Poor rainfall which result in low water storage in the reservoirs plus water losses by seepage and conveyance loss results in irrigation water shortage before the crop ripens [13]. This all results in poor scheme level water allocation and distribution, and huge water losses [8, 11, 14, 13].

Lack of integration and coordination among the various actors in irrigation is another challenge. At country level, several small-scale irrigation schemes are also under study, at design and construction level. However, there is no standardized system to monitor the existing irrigation schemes [10]. According to [8], poor performance at the scheme level is due to absence or minimum collaboration among different organizations in the region. Moreover, involved stakeholders seem to lack such outreach and information dissemination capability which is also a result of less skilled and knowledgeable experts, insufficient resources and research inputs [8]. Additionally, the knowledge gap of development agent (DA) and water users association (WUA) on crop-specific distribution also a challenge. Besides, lack of awareness among farmers also plays a significant role for such irrigation inefficiency and results in poor coordination [13]. Also, there exists no data on available water use efficiency in terms of the irrigation demand and supply from the reservoirs. Furthermore, irrigation water efficiencies are not well documented [9]. As a result, appropriate irrigation practice does not take place in time and space. This research is thus, an attempt to improve the planning and managements of water use efficiency and agricultural water productivity in small-scale irrigation schemes.

1.4 Research objectives

The objective of this research is to explore the potential of satellite supported technology, in-situ measurement, a model based and statistical methods to improve planning and monitoring of water management in irrigation schemes. On this basis, the proposed project is to develop an irrigation scheme spatial information system (IrSpIS) for irrigation planning and monitoring, which can be used to connect possible stakeholders for better irrigation management. This research will characterize small-scale irrigation schemes in Tigray based on socio-economic, technical, and institutional aspects. Moreover, extract irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping. Furthermore, the research will evaluate irrigation scheme performances using Triple sensor approach. On this basis, a system will be developed to assess the near real-time data processing at different scales.

This will improve the agricultural water productivity and water use efficiency in the study area. Therefore, the specific objectives of this research are:

- To characterize small-scale irrigation schemes in Tigray based on socio-economic, technical, and institutional aspects
- To classify irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping
- To evaluate irrigation scheme performances using the Triple sensor approach
- To develop a spatial monitoring and information system for small-scale irrigation areas

Research objectives and questions

The specific research objectives and corresponding research questions are:

Objective 1

To characterize small-scale irrigation schemes in Tigray based on socio-economic, technical, and institutional aspects. To achieve the aim of this objective, the following research questions need to be answered:

1. What are the socio-economic impacts of irrigation on livelihood of farmers?
2. What is the (technical) efficiency in use of water and water productivity in irrigation schemes in the study area?
3. What is the efficiency and effectiveness of local institutions in the planning and monitoring of an irrigation scheme?

Objective 2

To classify irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping. To achieve the aim of this objective, the following research questions need to be answered:

1. How to map different types of small-scale irrigation schemes using remote sensing and derived products?
2. How to map small-scale irrigated areas at different scale?

Objective 3

To evaluate irrigation scheme performances using Triple sensor approach. To achieve the objective, the following research questions need to be answered:

1. How can water use efficiency and crop productivity using the Triple sensor approach be monitored?

2. What is the agricultural water productivity of the irrigation scheme at Zamra catchment?
3. How to improve the assessment of irrigation productivity at Zamra catchment?

Objective 4

To develop a spatial monitoring and information system for small-scale irrigation areas. To achieve the aim of this objective, the following research questions need to be answered:

1. What type of information should be provided at field, irrigation scheme and Zamra catchment for different users?
2. What should be the characteristics of an operational irrigation spatial information system?
3. How to improve irrigation management system in uncertain environment?
4. How will the IrSpIS improve the irrigation system performances?

1.5 Research outputs

MSc topics

Two MSc research topics are also expected as outputs of this research effort, which will be conducted in parallel while complementing this work. These are draft ideas and can be re-defined as the research progresses.

1. To monitor irrigation scheme performances using AquaCrop model and SWAT+ model
2. To design a prototype of a spatial monitoring and information system for small-scale irrigation areas
3. To evaluate small-scale irrigation performances related to agricultural water productivity and water use efficiency

Each objective is expected to be an input for scientific publications. Finally, the outputs will be compiled into a PhD thesis.

1. Characterize irrigation system performance in the study area using socio-economic, technical and institutional aspects
2. Extract small-scale irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping
3. Evaluate irrigation scheme performances using the Triple sensor approach
4. Develop an irrigation planning and monitoring information system for small-scale irrigation areas

Relevance to policy questions and dissemination of results

The proposed PhD study complies with the country's growth and transformation plan (GTPII) to reach middle income country economy by 2025. One of the strategies of GTPII is to increase food production of irrigated lands by expansion of irrigation schemes and rehabilitating existing ones. Moreover, another goal of the study is to have a direct impact on Ethiopian GTPII, with special emphasis on food security, water use efficiency and sustaining the environment. This study will contribute significantly in irrigation planning and monitoring using spatiotemporal information and develop a system and to connect possible stakeholders for better irrigation management. This system means to assist irrigation manager(s) at different scale levels for better irrigation management. Moreover, through this project two MSc student theses projects will be included. Results will be disseminated through development of a spatial monitoring and information system, scientific publications, workshops, and through the Ethiopian Education Network to Support Agricultural Transformation (EENSAT) project website.

1.6 Justification for a system

In the study area, as in many other parts of the world, water allocation and distribution, and actual irrigation is mainly carried out based on tradition. In many cases despite scarcity of water, over-irrigation is taking place, resulting in low water productivities. Therefore, a suitable system needs to be established to support farmers and manager(s) toward improving water productivity. The main issues for irrigation water requirements are when to irrigate, and how much water to apply. Irrigation water requirement is an important and often complex component of the water management in irrigated agriculture. Irrigation water is commonly based on the amount of Evapotranspiration (ET). If actual ET (ETa) and potential ET (ETp) are estimated with a sufficient precision, then crop water requirement as well as irrigation water requirement can be defined accordingly. Actual Evapotranspiration together with potential evapotranspiration, soil moisture data will be used to assess the near real time irrigation water requirements. Volumetric water content system can be used for calibrations of model using soil moisture sensor. It is the controller of the Field Capacity (FC) of the soil and values for Maximum Allowable Depletion (MAD), which is the amount of water that plants are allowed to use from soil, before irrigation is initiated. For irrigation management, it is necessary to continuously monitor ETa at appropriate spatial and temporal resolutions related to an irrigated field. For water managers, knowledge of the spatial and temporal distribution of irrigation water requirement (IWR) is necessary to know how to distribute water in network and how much is needed (demand) and how much is available (supply) for agricultural use [25]. Actually, estimation of actual amounts of irrigation requirements based on near real time crop water requirement and forecasted weather data is one of the most important information for farmers. Weather forecast data can help farmers to make rational decisions about time and amount of water to use for irrigation. The operational forecasts weather data provided by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) will be used in this study. Weather forecasts data will be collected from EUMETCast reception and the data will process on a server (Figure 1). Subsequently, will integrate into a system (IrSpIS) and distribute to web based application in different formats like reports, graphs and GIS layers.

1.7 Scope of the study

The study area covers in Zamra catchment, Northern Ethiopia. Spatial information system for management of small-scale irrigation scheme is important for irrigation management. Therefore, this study will cover four components. Firstly, characterize small-scale irrigation schemes in Tigray based on socio-economic, technical, and institutional aspects. Secondly, classify irrigation schemes using remote-sensing based indices in order to facilitate feature extraction for mapping. Thirdly, evaluate irrigation scheme performances using Triple sensor approach. Finally, develop a spatial monitoring and information system for small-scale irrigation areas. Therefore, first and second objectives will be done in Northern Ethiopia, third and fourth objectives will focus on the Zamra catchment.

2 Research approach

2.1 Preface

This chapter provides the planned research approach to fulfill the proposed objectives. Moreover, describe the study area, sources of uncertainty, anticipated challenges and sources of data is presented.

Research workflow

The planned research will follow the workflow in Figure 1. The first part of the research is to characterize small-scale irrigation schemes in Tigray based on socio-economic, technical, and institutional aspects. This data includes primary data (field survey, remote sensing data) as well as secondary data (reports). The second part also classify irrigation schemes using remote-sensing-based indices to see the spatial distribution of the existing irrigation schemes. The third part of the research is evaluate irrigation scheme performances using the Triple sensor approach. The fourth part of the research is development of a spatial monitoring and information system for small-scale irrigation in Zamra catchment.

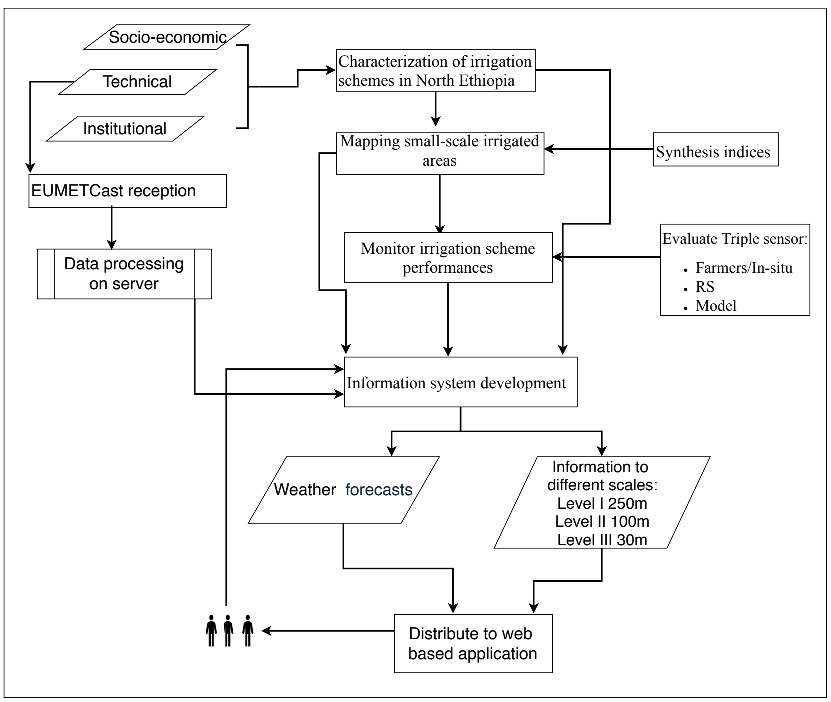

Figure 1: Proposed workflow

2.2 Characterize small-scale irrigation schemes in Tigray based-on socio-economic, technical and institutional aspects in Northern Ethiopia

2.2.1 Background

Agriculture is the main economic activity in the Region, in which 85 % of the population depends for sustenance. The annual population growth rate for Tigray is 3.3 %. In Tigray average land holding size is 0.25-1.0 ha per family [8]. The practice of water harvesting technologies in Tigray dates back so many centuries. Since 1995, through massive irrigation development, about 50 micro-dams (each with a capacity to hold about 50,000–2,000,000 m^3 of water), and 11 diversions have been constructed in drought prone areas resulting in increase of 2000 ha of irrigated land only [26]. Currently, there are many water harvesting structures implemented by the regional government and different Non-Governmental Organization's (NGO's). By the end of 2015, the area under full season and supplementary irrigation through the implementation of different water harvesting technologies is 327,587 and 128,316 ha respectively [27]. The Water Resources Bureau of the Tigray Regional State has identified irrigation structures/technologies of which are utilized to promote full season irrigation and used for supplementary irrigation purposes. These are managed either privately or by the community (Table 1).

According to [17], the performance indicators of small-scale irrigation factors focused on structural, social and institutional aspects. In their research, irrigation schemes in Ethiopia are not functioning at their optimal capacity. In addition, small-scale irrigation schemes are under performing due to construction failures, low technical and financial capacity for sustained operation and management of schemes. Whereas [18], compared technical efficiencies of irrigated and rain-fed plots in Tigray. In their research, when improve water allocation and distribution in irrigation scheme level, so agricultural production can be more than double. In addition, provide training for farmers to improve irrigation agronomy and access to market. Existing irrigation within the study area has many challenges [8, 14]. These challenges can be attributed to technical and institutional issues, which lead to lower social-economic benefits from irrigation schemes. In addition, the regional government has implemented several water harvesting technologies to improve the livelihood of the people. Many governmental and non-governmental organizations include the planning and the implementation of the technologies as part of their annual plans and implement them accordingly. It is important to monitor the planning and performance of these technologies. Even though there were attempts to evaluate the performance of the technological structures, they were limited to scheme level and at few places in the region. Furthermore, there exists limited research at regional level that assesses irrigation performance through integrating the socio-economic, technical and institutional aspects. Therefore, the specific objective of this study is to characterize small-scale irrigation schemes in Tigray based on socio-economic, technical, and institutional aspects. To achieve the

Table 1: Structures used for irrigation in Tigray

No	Type of irrigation Structure
1	Hand Dug Wells (private and Community types)
2	Check dam (Storage and diversion types)
3	River Diversion (modern and traditional)
4	Spring Development
5	Night Storage pond
6	Relay pumps
7	Lengthening canals
8	Subsurface/ sand storage dams
9	Crossings
10	Pump irrigation (Small, medium and big)
11	Dam (small, medium and big)
12	Ponds and mini dams
13	Boreholes (Shallow and Deep)

objective, the following research questions need to be answered.

1. What are the socio-economic impacts of irrigation on livelihood of farmers?
2. What is the (technical) efficiency in use of water and water productivity in irrigation schemes in the study area?
3. What is the efficiency and effectiveness of local institutions in the planning and monitoring of an irrigation scheme?

2.2.2 Methodological approach

To characterize small-scale irrigation schemes will be based on socio-economic, technical, and institutional aspects. For assessment different variables will be defined in the study area: like sources of water, water application methods, diversion structure materials, farm inputs supply, type of crop grown and gender issues in decision making. We will evaluate the socio-economic impacts of irrigation on livelihood of local people [17]. Assessment variables will be focused on agricultural productivity, annual household expenditure, household food insecurity and access scale (HFIAS) and food consumption score (FCS). In addition, the technical evaluation performance will be evaluated using actual command area assessment and performance indicators [18]. The actual command area assessment will use GIS and RS techniques, field work for ground truth validation and secondary data from Woreda and Agricultural Bureau. In addition, performance indicators used for instance are [28]:

1. Irrigation Efficiency (%) = Actual Irrigation (ha)/ potential Irrigation (ha)

2. Output per unit command (Birr/ha) = Production/Command area
3. Output per unit irrigation supply (Birr/m ^{3}) = Production/Diverted irrigation supply
4. Output per unit water consumed (Birr/m ^{3})= Production/Volume of water consumed
5. Cost Per Hectare (Birr/ha) = Investment Cost/ Command area

According to [28, 29], the advantages of these indicators include: firstly, these indicators are based on relative comparison of absolute values. Secondly, these indicators are reveal sufficient information about the output of the system. Furthermore, institutional assessment will be included to characterize irrigation performance [17]. Organizations human resource development, hard and soft infrastructure, policy frame work, finance and budget. Finally the assessment will identify different users for information dissemination and exchange and fusion of data. The potential organizations are the Bureau of Water Resources, Bureau of Agriculture and Rural Development, Environmental Protection and different NGO's.

Data

Socio-economic data and remote sensing data will be sourced as input to characterize irrigation schemes. The primary data will be collected using focus group discussions (FGD), interviews and structured household surveys one after the other. Structured questioners will be used for sections of Information for household ID number, housing and assets, source of water, water application practices, type of crop grown, food consumption, non-food consumption, Household Food Insecurity Anxiety Scale, self-assessed food security, access to Institutional Services. And Woreda level experts from the Water Resources Offices and specialized enumerators have administered a face to face interview will select. The Focus Group Discussion (FGD) will be conducted with users of the irrigation in the household. According to [30], FGD is one of the most widely applied data collection methods for qualitative research in a particular and mixed method approach in general. The study will also use secondary data. Secondary sources will be collected by re-viewing various research publications; government policy and strategy documents; and various organizations and institution working on the above-mentioned topics.

Materials and software

The research will be conducted using the following materials and software: Global Positioning System (GPS) will be used for ground truth data collections. GIS and remote sensing software will be used for geospatial data collection and analysis of irrigated lands. Statistical Package for Social Sciences (SPSS) or R will be used for statistical analysis of the Household survey. In addition, a camera will use to capture field observations.

Sampling design

A stratified sampling approach is used to select sample population in which random sampling will be used for actual sample points. Representative irrigation sites at Zamra catchment will be selected using stratified random sampling. Irrigation sites will be stratified using type of irrigation systems. For instance, major irrigation system types are reservoirs, river diversion traditional and modern and wells irrigation. Irrigated fields will be selected using random sampling. The respondent for this part of the survey will be member of the households who are principal users of the irrigation. In doing so, four data collection tools are used: questioner, interview, FGD and observing.

2.3 Classify irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping in Northern Ethiopia

2.3.1 Background

Mapping of small-scale irrigated areas and information is essential to establish a spatial information system on irrigation for Tigray. According to [31], it is important for food security and water resource management studies, to get accurate information about the location and extent of irrigation. Irrigation is important to agriculture in arid and semi-arid areas for food security. According to [20], presented a simple, robust method to map irrigated and rainfed wheat areas in a semi-arid region of China. In their research, they only evaluated for one major crop in the study area. GIS tools used to identify check dam using Landsat image, topographic map, google earth image and field survey for validation. In their research, it is important approach to identify check dams and provide decision support for soil and water conservation [19]. Xiang et al. [31], developed a method for identifying irrigation in cropland based on the relationship between mean annual precipitation (MAP) and land surface water index (LSWI) in Northeastern China. In their research, a significant LSWI difference was found between the irrigated and non-irrigated crop lands compared to the adjacent forests. Moreover, validation of the result using field survey, showed that well performed in indicating spatial variations of irrigated areas. Furthermore [20], developed a method to identify irrigated and rainfed areas using Normalized Difference Vegetation Index (NDVI), to create a time series growth period of wheat. In their research, NDVI and time-integrated NDVI(TIN) show significant difference between irrigated and rainfed areas using a support vector machine (SVM) algorithm classification model. However, this method was required field observation data for mapping of irrigated and rainfed wheat areas. The absence of extensive research and documentation regarding irrigation management schemes contributes to this [9]. In addition, no standardized system to monitor the existing irrigation schemes, in-existence of adequate baseline data, information and information system [10]. The limited skilled manpower, insufficient resources and research inputs have all contributed to this [8]. Studies demonstrated the feasibility of evaluation of irrigation schemes to facilitate feature extraction for mapping small-scale irrigated area, which were not attempted in the context of the study area. Therefore, the specific objective of this study is to extract irrigation schemes using remote-sensing-based indices in order to facilitate feature extraction for mapping in Northern Ethiopia.

To achieve the aim of this objective, the following research questions need to be answered.

1. How to map different types of small-scale irrigation schemes using remote sensing and derived products?

2. How to map small-scale irrigated areas at different scale?

2.3.2 Methodological approach

Irrigation schemes will be classified using remote sensing based indices in order to facilitate feature extraction for mapping. The overall activities used to realize this objective are given as follows. Using medium resolution multi spectral and multi temporal image irrigation schemes will be identified in the study area [19]. In addition, mapping irrigated and rainfed areas at different scales will use remote sensing and derived products [20, 31]. Remote sensing derived products for this purpose will be from FAO portal to monitor Water Productivity through Open access of Remotely sensed derived data (WaPOR) time series data, using Water Deficit Index (WDI) approach. WDI will be calculated as the ratio of the season precipitation over the seasonal IET: I, Interception, E, Evaporation, T, Transpiration and P is seasonal precipitation. Therefore the formula can be accessed from [32]:

$$WDI = P/IET$$

The WDI approach is validated with different indices from high resolution satellite data, free Planet Scope Ortho Tile 3m spatial resolution. The performance of the relationship will be evaluated using Root Mean Square Error (RMSE) and Coefficient of determination (R^2) between indices and the calculated WDI. WDI will be mapped with best indices high R^2 and low RMSE value. In this case we will evaluate different indices to select the significance ones at different scales [33, 20]. The spatial scales are an irrigated fields, irrigation scheme and Zamra catchment level irrigated areas. Therefore, the formula to calculate different indices: LSWI, NDVI, NDWI, and GI is found in (Table 2). The flowchart of the proposed approach is presented in Figure 2.

Data

Remote sensing data and derived products will be sourced as input to evaluate irrigation schemes. Landsat satellite images and Sentinel-2 satellite image to be used for classification will be sourced from Earth observation hub United States Geological Survey via http://earthexplorer.usgs.gov/. Furthermore, wapor time series data will use to calculate Water Deficit Index from FAO-WAPOR via https://wapor.apps.fao.org/home/1. For accuracy assessment Planet Scope Ortho Tile satellite data via https://www.planet.com will be used.

Table 2: The description and formula of different indices

Abbreviation indices	**Description**	**Formula**	**Spatial Res.**	**Source**
LSWI	land Surface Water Index	(RED-SWIR)/(RED+SWIR)	10km*10km	[31]
NDVI	Normalized Difference Vegetation Index	(NIR-RED)/(NIR+RED)	30m*30m	[20]
NDWI	Normalized Difference Water Index	(NIR-MIR)/(NIR+MIR)	30m*30m	[33]
NDVI–NDWI	Cluster analysis combining the NDVI and NDWI	(NDVI–NDWI)	30m*30m	[33]
GI	Green Index	NIR/RED	30m*30m	[33]
NDVI	Normalized Difference Vegetation Index	(NIR-RED)/(NIR+RED)	10m*10m	[34]
NDRE	Normalized Difference Red Edge Index	NIR-RED-e/NIR+RED-e	5m*5m	[35]

Note: NIR (Near infra-red band), RED (Red band), SWIR (Shortwave infrared), MIR (Mid-infrared)and RED-e (Red-edge)

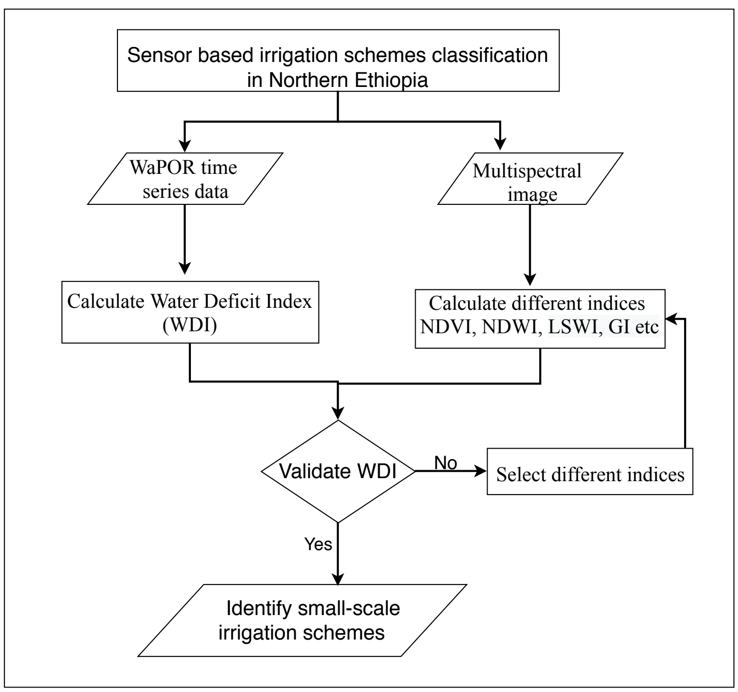

Figure 2: Flowchart identify small-scale irrigation schemes

2.4 Evaluating irrigation scheme performances using the Triple sensor approach in Zamra catchment

2.4.1 Background

Improving water use efficiency or enhancing agricultural water productivity is a critical issue for water scarce areas. Water productivity is the ratio of crop yield/ biomass to actual evapotranspiration (ETa) and an important indicator in performance assessment of irrigation network [36]. One of the reasons of the low water productivity is high (ETa) which is related to over irrigation in the fields and irrigation network. Agricultural biomass or production can be expressed as (Kg) or income (Birr) [28]. Water productivity is estimated from the amount of water consumed by the agricultural system and evapotranspiration [21]. In their research [21], for regional and basin level water productivity, proposed that it is better to use consumptive water use (CWU) for the value of production per unit of crop. This consumptive water use in irrigated areas implies the potential evapotranspiration (ETp). Moreover, at field scale to estimate water consumed (Evapotranspiration (ET)) using water balance equation is useful. In their study used only in-situ measurement, not used more recent approach utilizing remote-sensing imagery. The FAO-56 method is also used to estimate water consumed for irrigation. This method uses potential evapotranspiration (ETp) as parameter. The (ETp) is the amount of water needed by the crop to grow optimally. It is calculated based on FAO-56 methods and applying crop coefficient (Kc) for each crop and reference evapotranspiration (ETo) data. So, Kc and ETo maps need to be calculated at irrigated field level. The most common approach used to estimate ETo and Kc is FAO-56 Penman-Monteith which is based on crop specific parameters [37]. FAO-56 Penman-Monteith method needs meteorological data (air temperature, humidity, wind speed, and solar radiation) [38]. On this basis, ETo and Kc are adjusted and used for calculation of ETp of each crop.

However, some researches recommend remote sensing methods that are based on relationship between spectral response of crop and the corresponding values Kc and ETp [39, 40, 41]. According to [42], crop evapotranspiration (ETc) map was used to measure irrigation performance from individual field to irrigation scheme levels, by combining the FAO-56 approach and NDVI relationship. From their research [42], it was useful to identify the actually cropped area, formulate a common cropping pattern, cultivation, and schedule to farmers. In [41], a methodology is presented to estimate crop water demand at different scales using Landsat images-based vegetation index. Their study was carried out in four growing seasons. In their research, an ETc map was useful for farmers to supply appropriate amount of irrigation water corresponding to growth stage.

To derive water productivity, crop yield/ biomass needs to be estimated. Crop yield predictions by regression modelling is most commonly used method for yield estimation [43]. According to [44, 45, 46], water productivity is estimated using AquaCrop model. AquaCrop is a water productivity model that simulates above ground biomass production in exchange for water transpired by the crop [46]. According to [44], to improve Teff water productivity AquaCrop model is considered as a valid model. In their research, AquaCrop model was used to asses water management by evaluating water use efficiency. In the analysis of the temporal and spatial variability of irrigation water demand which was carried out by [22] in China, Penman–Monteith method and daily meteorological data combined socio-economic statistical and land use data were used to provide quantitative information for irrigation water demand of different crops. Due to the uncertainty from the spatial and temporal resolutions of remote sensing data, using satellite information to predict irrigation water demand is a challenge [22]. In this part of research focus will be on in-situ measurement, remote sensing data and using a model based approach.

Inefficient utilization of irrigation water is one of the major problems for most irrigation schemes in the study area. According to several authors [8, 14] existing irrigation schemes have less than 50% efficiency. This implies that more than 50% of the water is lost through evaporation, seepage, and poor irrigation application methods [14]. This challenge emanates from lack of proper technologies to communicate with the various water users in advance, among others. Thus, no comprehensive studies in the context of the study area carried out to assess water use efficiency and water productivity on the existing irrigation schemes. Therefore, the specific objective of this study is to evaluate irrigation scheme performances using the Triple sensor approach. To achieve the objective, the following research questions need to be answered.

1. How can water use efficiency and crop productivity using the Triple sensor approach be monitored?

2. What is the agricultural water productivity of the irrigation scheme at Zamra catchment?

3. How to improve the assessment of irrigation productivity at Zamra catchment?

2.4.2 Methodological approach

Monitoring of irrigation schemes water use efficiency and water productivity using in-situ, satellite and model based approach will be performed. To predict water productivity, crop yield/ biomass needs to be estimated. Water productivity is the ratio of crop yield/ biomass to ETa and an important indicator in performance assessment of irrigation network [36]. Irrigation performance indicators tell managers about current performance and help them to improve it [47]. To answer the research question, three activities are considered:

1. Estimate crop water productivity (CWP) using in-situ measurement

2. Derive crop water productivity using remote sensing data

3. Estimate CWP using AquaCrop model/Soil and Water Assessment Tool (SWAT+) model and find out the most appropriate water productivity

predictor. Best sensor analysis selection is represented in the flowchart (Figure 3).

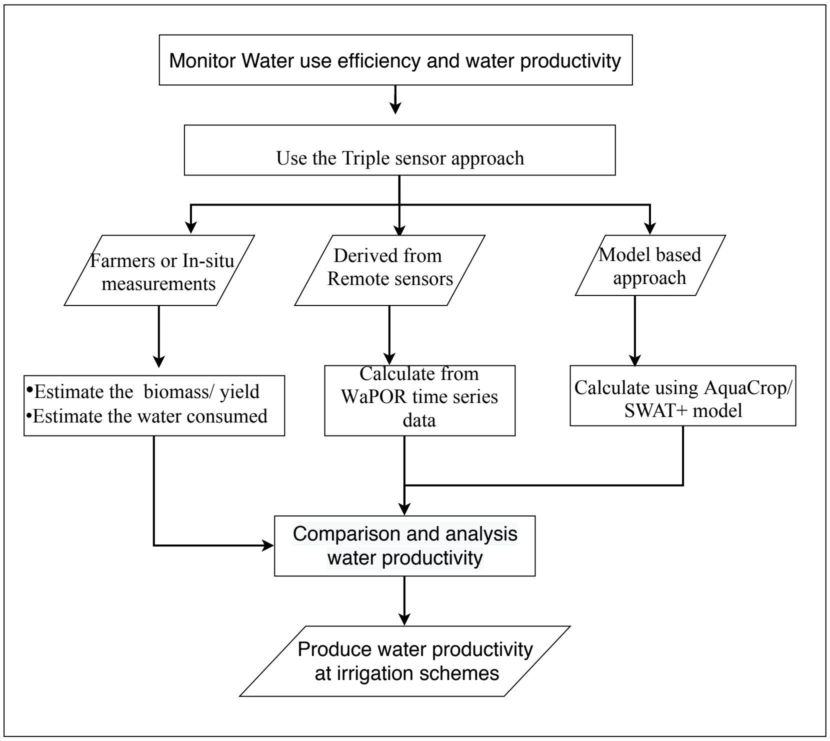

Figure 3: Best sensor analysis using the Triple sensor approach

1. Estimate crop water productivity using in-situ

Crop water productivity will be estimated using in-situ measurement at field level and will be up scaled to irrigation scheme and Zamra catchment level. Water productivity will be calculated as the ratio of total yield/ total weight of above ground biomass to total evaporation. Total evaporation is the sum of soil evaporation, plant transpiration and interception [48]. This will be performed at field level, therefore the formula is :

$$WP_{PET} = Y/\sum(E+T+I)$$

$$WP_{PET} = Y/\sum(P-Q_s-R)$$

Where Y is total yield/ total weight of above ground biomass in gm^2 and evaporation (E), transpiration (T), interception (I), precipitation(P), surface runoff (Q_s) and deep percolation (R). However, runoff and capillary rise is removed as it is not significant in arid and semiarid areas as learned from previous studies [49, 50]. Crop yield will be measured at physiological maturity growth stage [49]. In their research, dry biomass was determined after oven-drying at 70.8^{0}C. Irrigation and rainfall will be measured, and summed for the period of land preparation and crop growth [49]. The amount of irrigation will be monitored at each irrigation by measuring the volumetric water content. In this part of research, a 5TE soil moisture sensor and Em50 digital data logger will use for measuring volumetric water content at a field level. 5TE soil moisture sensors are robust, and measuring volumetric water content, Electrical Conductivity (EC) and temperature [51]. Irrigation outflow will be measured using current meter for primary canal. In addition, in an irrigated field, water flows will be measured using Parshall flume instrument. The measurement will be performed once at each farm and the flumes are not permanently installed in the field. According to [52], rainfall data is high variable nature might not be adequately represent the condition when measured from the automatic weather stations. In this research, rainfall data will be collected from rain gauge at a field station. Therefore, to calculate water productivity for an irrigation scheme is summation of water productivity of an irrigated fields. Moreover, Zamra catchment water productivity will be aggregated from irrigation schemes. This in-situ measurement will be validated using socio-economic data from farmers and irrigation experts. This data will be collected by observation, questioners, interviews and existing sources from the potential organizations. This data collection will be included biomass, yield, area irrigated and amount of water consumed.

Sampling design

Irrigated fields will be selected using random sampling also considering soil types. Representative fields will be placed at different streams upper, middle and lower. The instruments need for one irrigation scheme is one rainfall gauge, one current meter and two parshall flume. Besides, required a 5TE soil moisture sensor and Em50 digital data logger. For instance, a piece of land (50m*50 m) install 5 sensors at each 20 m interval between each sensors. Consequently, for one irrigation scheme, it will be included 9 farmers and 45 5TE soil moisture sensor and 9 Em50 digital data logger.

2. Derive crop water productivity using remote sensors WaPOR use

Deriving crop water productivity using remote sensing data will be performed at irrigated field, irrigation scheme and Zamra catchment. Water productivity will be calculated based on the ratio of crop yield/biomass to Actual evapotranspiration [36]. Time series provided by remote sensing data can be used to model phenology factors such as the start and the end of the growth season. Yield variation can be monitored by determination of anomaly in the timing of these factors [53]. The potential of linear regression models to predict yield based on NDVI, two-band variant of the enhanced vegetation index, normalized difference water index from MODerate-resolution Imaging Spectroradiometer

(MODIS) data during crop growth season was investigated by [54]. This part will focus on deriving water productivity using remote sensors WaPOR use. WaPOR remote sensed derived data will be used to monitor water productivity. Water Productivity (WP) expresses total biomass production (kg per hectare) in relation to the total volume of water consumed(mm or m^3). Therefore, the formula can be accessed from [32]:

$$WP = Totalbiomassproduction/Actualevapotranspiration$$

Actual evapotranspiration ($ETIa$) = (sum of soil evaporation E, canopy transpiration, T, and interception, I).

3. Estimate crop water productivity using a model

Estimation of water productivity will be calculated using AquaCrop model [45, 55]. The water productivity model approach will be performed at irrigated field, irrigation scheme and Zamra catchment. According to [44], to improve Teff water productivity AquaCrop model is considered as a valid model. In their research, AquaCrop model will be used to asses water management by evaluating water use efficiency. AquaCrop is a water productivity model that simulates above ground biomass production in exchange for water transpired by the crop [46]. For this study, crop and soil parameters of model version 6.0-6.1 will be used, the procedure is defined in [55]. Figure 4 shows the combined effect of soil salinity and soil water stress on canopy development, stomata closure, crop transpiration and biomass production [55]. Input requirements (irrigation, rainfall and ETo). AquaCrop separate ET into soil evaporation and crop transpiration to calculate biomass [55].

The formula to calculate biomass water productivity (WP*):

$$B = WP * \sum(Tr/ETo)$$

The cumulative (B) dry above-ground biomass production is obtained from the normalized biomass water productivity($WP*$), and the ratio of the daily crop transpiration (Tr) over the reference evapotranspiration for that day (ETo). According to [55], the biomass water productivity expresses the above-ground dry matter (g or kg) produced per unit land area (m^2 or ha) per unit of water transpired (mm or m^3). The model requires local weather data (precipitation, minimum and maximum temperature, reference evapotranspiration) to simulate daily crop growth and development [44, 46]. According to [55], the reference evapotranspiration (ETo) is obtained from meteorological data with the help of the FAO Penman-Monteith equation described by [38]. The daily crop transpiration (Tr) will be calculated by the formula given below [55].

$$Tr = Ks_{Tr} Kc_{Tr} ETo$$

Daily crop transpiration (Tr) is calculated by multiplying ETo with the crop transpiration coefficient (Kc_{Tr}) and by considering the effect of water stress

(Ks) and cold stress (Ks_{Tr}) on that day. Therefore, yield is calculated by the product of the final biomass multiplied by the harvest index [55]. The major crops in the study area is tomato, potato, cabbage, onion and lentil as irrigated crop and rainfed crops are wheat, barley, maize, sorghum, and teff from the Woreda Office of Agriculture and Rural Development. According to [38], length of crop development stages from Food Agriculture Organization (FAO) is found in Table 3.

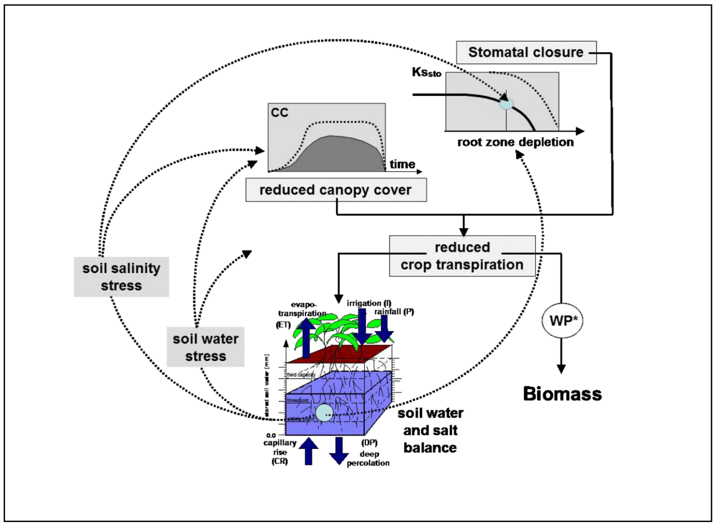

Figure 4: Steps for AquaCrop Model source [55]

To determine the most appropriate sensor predictor for water productivity. First the Triple sensor will be merged and then select which one is the best estimator at different scales. According to [56], Triple collocation (TC) is used to estimate the root-mean-square-error. This method is based on the statistical covariance analysis on three independent data sources. The performance of the Triple sensor approach will be validated using RMSE.

Table 3: Lengths of crop development stages and Kc values

No	Crop name	Initial-Dev	Crop-Dev	Mid-Dev	Late	Total	Kc-inital	Kc-mid	Kc-end
1	Onion	20	45	10	20	95	0.7	1.0	1.0
2	Potato	25	30	30/45	30	115/130	0.5	1.15	0.75
3	Tomato	35	45	70	30	180	0.6	1.5	0.70-0.90
4	Cabbage	40	60	50	15	165	0.7	1.05	0.95
5	Lentil	25	35	70	40	170	0.4	1.10	0.3
6	Maize	30	50	60	40	180	0.7	1.20	0.60
7	Wheat	15	30	65	40	150	0.3	1.15	0.25-0.4
8	Barley	15	25	50	30	120	0.3	1.15	0.25

Table 4: Some of performance indicators

Indicator	**In time direction**	**In space direction**
Depleted fraction	Changes in actual water use	Differences in water balances
Delivery performance ratio	Changes in quality of services to users	Uniformity of water delivery
Sustainability of irrigation area	Intensity of cropped land	Crop occupancy rate of area
Water productivity (WP)	Changes in crop yield	Spatial variation of WP
Crop water deficit	Reduction in evapotranspiration	Detect water short area

Calculation and analysis of irrigation performance indicators

Performance indicators assist managers to know the (current) performance and find a solution to improve it [47]. Proper performance indicators will be selected and calculated over space and time to support better management of water resources. Some of performance indicators are listed in Table 4 [47].

Data

Rainfall data will be collected from the agroclimatic station closest to each field and meteorological station. In addition, irrigation flow will be measured using current meter from the primary canal and parshall flume instrument will be measured irrigation flow to fields. Besides, soil moisture content measure using 5TE soil moisture sensor and Em50 digital data logger. Furthermore, wapor time series data will use to derive crop water productivity from FAO-WAPOR via https://wapor.apps.fao.org/home/1.

2.5 Development of a spatial monitoring and information system for small-scale irrigation in Zamra catchment

2.5.1 Background

The basic objective of Irrigation Spatial Information System (IrSpIS) is to support farmers, water user association, development agents water authorities and local agricultural authorities for better management of water resources, in particular in irrigation management. This will include assessment of the near real time irrigation water requirements so that timely, effective and efficient distribution and application of water can take place. IrSpIS provides the users with irrigation management information, using integration of different sources of data. Irrigation systems have been developed and applied in many areas to support farmers in efficient application of water. The Irrigation water management by satellite and SMS (IrriSatSMS) was developed to provide daily irrigation water management services shown in Figure 5 [52]. Based on Landsat 5 derived NDVI data was used to determine crop coefficients for individual crops. The satellite images were collected across Australia every 14–20 days. This information was used in combination with ground weather station data to derive crop water use. As a result, daily irrigation water management information was sent out to irrigators by SMS messaging. In [24], a methodology is presented towards rationalization of water resource management in Greece, through proper irrigation of crops, using meteorological data to calculate daily net crop water requirements using a modified FAO PenmanMonteith model. FAO-56 Penman-Monteith method needs meteorological data (air temperature, humidity, wind speed and radiation) [38]. As their proposed method relies on simple mass balance equations and meteorological data, it does not require detailed soil measurements. Effective rainfall and crop coefficients were obtained using the FAO method and were modified locally [23]. They presented an operational irrigation advisory service based on the satellite observations and FAO's approach for calculating crop water requirements at field levels in Southern Italy, Austria and Southern Australia.

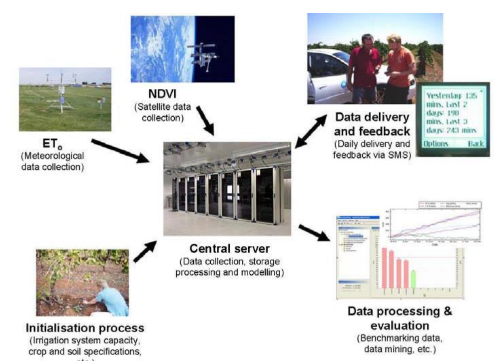

Figure 5: Components of the IrriSatSMS approach source [52]

Baille and Hunink [57] developed an Information-Decision Support System (REDSIM-IS) based on low cost remote sensing data and simplified water balance and crop models in south-eastern Spain to address problems in water management with emphasis on the implementation of the Water Framework Directive and the European Water Scarcity and Drought Policy. They used to assist growers in implementing and managing efficiently deficit irrigation techniques. Lorite et al. [58], developed Local Irrigation Advisory Service to provide general irrigation schedules, irrigation performance assessment, irrigation training for technicians and farmers, dissemination of relevant information and monitoring water quality in southern Spain. In their research, irrigation schedules were obtained using a simplified model which considers the effective rainfall and the crop evapotranspiration, with average values for soil water properties and considering a single sowing date for each crop and an advanced water balance simulation model to obtain the optimal irrigation schedules. According to [59], database is defined as a data storage for storing irrigation management decision and model operation. Database design includes basic database, real-time database and spatial database. Therefore, a database will provide different information for different users shows in (Table 5). According to [60], a database can integrate data from different sources. In this part of research project, we will optimize and integrate different scales in a database. As a result, no redundant data and inconsistent data are embedded.

At country level, several small-scale irrigation schemes are also under study, at design and construction level. However, there is no standardized information system to monitor the existing irrigation schemes [10]. According to [8], poor performance at the scheme level is due to absence or minimum collaboration among different organizations in the region. Moreover, involved stakeholders seem to lack such outreach and information dissemination capability which is also a result of less skilled and knowledgeable experts, insufficient resources and research inputs [8]. Studies demonstrated the feasibility development of a spatial monitoring and information system for small-scale irrigation systems, which were not attempted in the context of the study area. Therefore, the specific objective of this study is to develop a spatial monitoring and information system for small-scale irrigation areas. To achieve the objective, the following research questions need to be answered.

1. What type of information should be provided at field, irrigation scheme and Zamra catchment for different users?
2. What should be the characteristics of an operational irrigation spatial information system?
3. How to improve irrigation management system in uncertain environment?
4. How will the IrSpIS improve the irrigation system performances?

2.5.2 Methodological approach

A spatial monitoring and information system will be developed for small-scale irrigation system. For a system to be developed we need three steps: the near-real time data processing, organizing the data in the IT system, and delivering the output to the users. The challenge is to translate the IrSpIS information, maps, images and numerical data to the users in an adequate way, user friendly and timely enough. To answer the research question, four activities are considered:

- What type of information is required from different users at different scale levels (system analysis)
- How to provide information and the characteristics of an operational irrigation schemes (system analysis)
- How to present information to different users (system design)
- How all of the previous actions will be organized in a system (system development)

First, different type of information which are required by different users at field, irrigation scheme and Zamra cathement levels will be determined. According to [47], it will be necessary to identify who will collect a data, how, where and when they will be collected. In addition, understanding the characteristics of an operational irrigation advisory system, and how to provide information are important. This part addresses the integration of the information and provides the basis for individual advisory services to different users (Table 5). Next, how to present information to different users (system design) is shown in Figure 6. This will focus on development of tools for visualization and communication of the information to the users, for example, as GIS layers, statistics and time series. Subsequently, how all of the previous actions will be organized in an IrSpIS (system development). This part addresses the distribution and dissemination of the information to the users. The irrigation monitoring and information system development framework is illustrated in Figure 6. This is based on the framework proposed by [47].

The aim of this study is to focus on the technical view of irrigation monitoring and information system at different scales. In Figure 7 processing elements (inputs, process and outputs) are illustrated. In this part of the research project we will design a system that is flexible, easy to use, and easily transferable [52]. Finally, to implement a system, both software and hardware needs to be set up to deliver irrigation management data. According to [47], implantation phase contain actual collection, processing, analysis and reporting of the data (Figure 6). According to [23], providing irrigation information to farmers is useful, because it shows an increase in irrigation efficiency by reducing irrigation volumes. This system will be distributed in a web-based application platform. In addition, the users of the system will be irrigation manager(s) at different scale levels (low, medium and high) shows in (Table 5).

Table 5: Spatial and temporal scales information to different users

No	Scale	Spatial scale	Temporal scale	Information	Users
1	Low	250m (Zamra catchment)	Seasonal	Total irrigated area Yield obtained Crop water productivity Weather forecast	Woreda irrigation experts Landuse planners Regional irrigation experts
2	Medium	100m (Irrigation scheme)	Monthly and seasonal	Irrigation water requirements Crop water productivity Amount of water in the reservoir Weather forecast Irrigated area	Development agent
3	High	30m (Irrigated field)	3-10 days	Irrigation water requirements Crop water productivity What to produce	Farmers Water use association

2.6 IrSpIS model

An irrigation schemes spatial information system (IrSpIS) includes information, theoretical and empirical relationships, analytical tools, proper organization of data, hardware, software and user interface which allows easy interaction of users with the system in the system environment. This system will be designed based on the needs and requirements of users and it is considered as one of the government policy measures to improve water management, therefore it is supposed to be technically and financially supported by related government and non-government institutions. Different parts of the IrSpIS are illustrated as following:

Users

Farmers to support planning on when and how much to irrigate. Water Use Association (WUA) is responsible for water distribution, including Abo-mai Tigrinyan term that literally means 'father of water'. He is the manager of the irrigation system. Bureau of Agriculture and Rural Development (BoARD) is responsible for follow up and evaluation of the performance of irrigation system by Development Agent. Bureau of Water Resources (BoWR) of the Woreda is responsible of studying water supply sources, including localization and construction of infrastructure to make this water available.

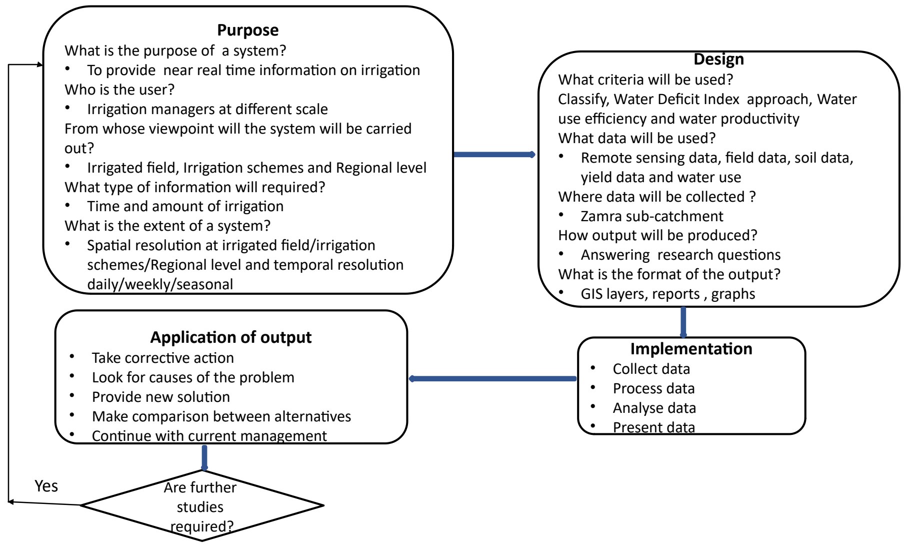

Figure 6: Framework Irrigation advisory system source [47]

Inputs

Remote sensing and derived products data, weather forecasting data, soil moisture, crop data and irrigation management information infrastructure.

Models

Water deficit index, crop water productivity and water balance.

Tools

Statistics, hydrology, GIS, Python programming language and PostgresSQL database system for its flexibility and strong support of spatial data and queries.

Environment

Irrigation network, existing soft and hard infrastructures in the study area.

Outputs

Irrigation water requirements, crop water productivity, time of irrigation and performance indicators.

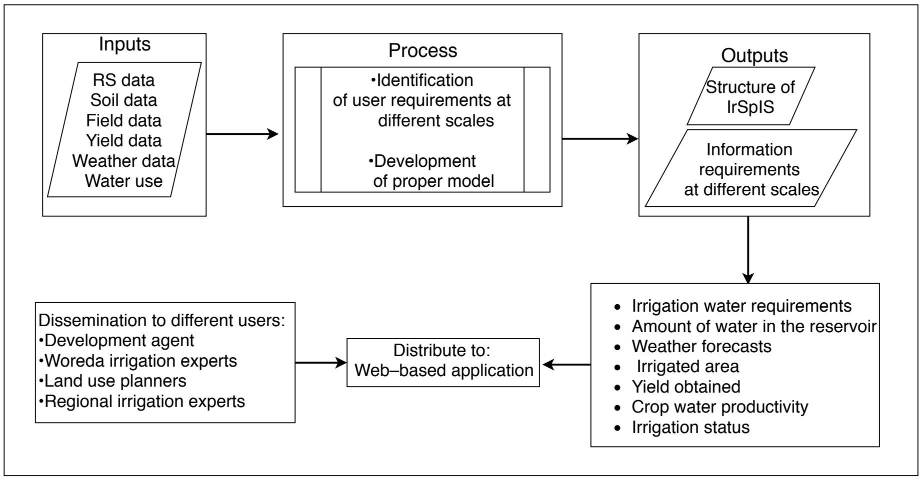

Figure 7: Irrigation advisory system inputs, process and outputs

2.7 Description of the study area

The study will be conducted in Zamra sub-catchment, which is a tributary of Tekeze sub-basin. The Tekeze sub-basin has a total area of 82,350 km^2 and the study area, Zamra catchment has an area of 3492km^2 (Figure 8). There are seven Woredas/Districts with in the catchment. The maximum and minimum Districts area covered from the catchment is 799 km ^{2} and 35km ^{2} respectively. The traditional plough locally called 'Mahiresha' is used as main implement for making tillage. Ploughing begins after the first shower of rain is received. Frequency of ploughing depends on crop type, availability of oxen, soil type, agro-ecology and topography. Altitude varies from 1234 to 3935 meter above sea level (masl). The area is classified into three main agro-ecology zones lowland, midland and highland; 8%, 58% and 34% respectively. The dominant soil type in the study area is sandy loam 80%, clay 17% and loamy sand 3%.

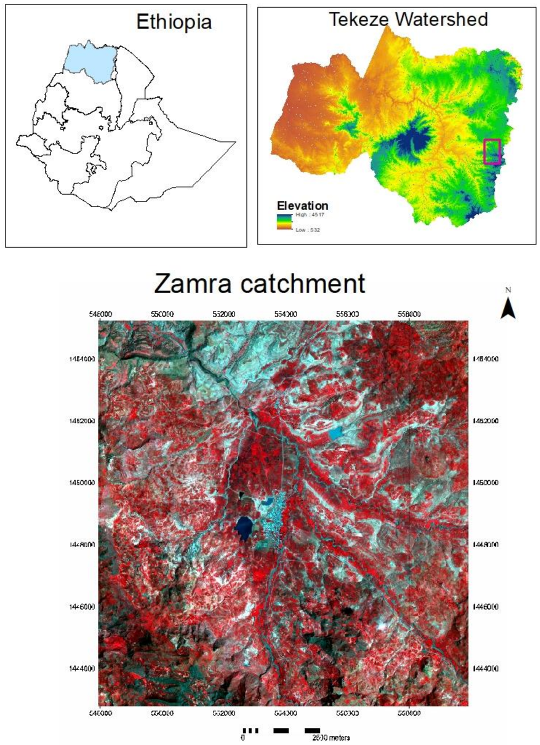

Figure 8: Study area map

2.8 Source of uncertainty

To assess overall uncertainty, the contributing sources of uncertainty must be understood. Several processes in the irrigation schemes spatial information system including data collection, modelling, estimation and predictions, results analysis and interpretation contribute to uncertainty. The major sources of uncertainty can be grouped as the following:

Uncertainty in the input data

Remote sensing images: Satellite data acquisition includes quantization of information from the earth surface, as we all know reality is continuous, therefore quantization will lead to loss of information as the earth's surface is divided into a set of pixels. In most cases, spatial resolutions of the input images are incompatible with each other. This problem is dominant for example in integrating of different images from multiple sensors. Mixed pixels are another source of uncertainty regarding the low spatial resolution of MODIS data. The quality of satellite visible channel input and corresponding NDVI values are important in agriculture applications. Temporal resolution and the availability of images limit using the remote sensing data in intended time. For example, crop monitoring during growth season is limited by satellite coverage frequency and clouds cover [61]. Cloud cover is important especially for using low resolution images. In irrigation advisory system process, cloud cover results error in estimation of ETa using land surface temperature through Surface Energy Balance System (SEBS) [62].

Weather data: The sparseness, point data feature and maintenance of the weather stations instruments are main sources of uncertainty.

Field measurements: Significant sources of uncertainty for field measurement is observer error as well as the gap between the scale of the field sampling and the spatial resolution of the remote sensing images [63].

Uncertainty in the outputs

ETa: Spatial resolution mismatch between vegetation data and meteorological data can result in uncertainties in ET [64].

ETo: is most sensitive to the temperature [65].

Irrigation water requirement (IWR): Prediction of IWR are constrained by uncertainty in spatial and temporal variability of factors that influence the demand for irrigation water: soil parameters, cropped areas, weather, growth season, water availability, precipitation, cropping patterns and other different input parameters which are used to calculate IWR [66].

Weather parameter maps: The uncertainties are mainly related to the different data sources (remote sensing and weather station data), spatial resolution mismatch between finer weather station data and coarser remote sensing data, dependency and variability of weather parameters.

Advices: Generally, uncertainties in IrSpIS are contributed to five aspects [67, 68]. Scientific aspect: estimation of model parameters, spatial and temporal resolutions of satellite imagery; Technical aspect: in situ data which are required for models, the adequate and applicable advices; Institutional aspect: information dissemination, exchange and fusion of data from different users; Sociological aspect: irrigation tradition, knowledge of the farmer, economic incentive; Budgetary aspect: local experimentation and staff allocations for implementation. Uncertainty Analysis (UA) will be conducted using statistics from sensitivity analysis outputs. For a complete assessment of model performance, uncertainty will include calculation of relative and absolute error measures and correlation coefficients.

Uncertainty analysis

One of the essential elements in the description of environmental parameters prediction is uncertainty quantification. Uncertainty analysis (UA) will be carried out to assess how uncertainty in the outputs is appertained to the different sources of uncertainties in the inputs. Changes in weather parameters have an effect on evapotranspiration, changes in precipitation patterns affect water availability, changes in water availability have an effect on production, and all can affect farmer benefit. Errors in input and model parameters can be quantified via sensitivity analysis (SA). According to [69], SA is the study of how different sources of uncertainty in model inputs can affect the uncertainty in the model outputs. When the effects of several input parameters on the model output is evaluated (one factor at a time while holding other factors fixed).

2.9 Anticipated challenges and plan to overcome

Challenges are instruments installation, nosy objects shall be avoided and lack of farmer awareness. Since the instruments are installed inside farmlands, establishing trust with farmers is a concern. Discussion with farmers and information exchange to reach agreement is needed. Moreover, working closely with irrigation manager(s) at Kebele and Woreda level. In addition, sustainability of water resource management will be considered. Water resource management practices are sustainable if they are environmentally, socially and economically viable. Considering the sustainability of IrSpIS, a sustainable system involves validity of the provided information, its availability, accessibility and affordability of provided services to its users. IrSpIS as conceptualized in this research is complex and dynamic, in which different sources of data and information need to be collected and organized. For instance, remote sensing, soil data, crop data and weather data and various statistical methods to provide information which are operationally useful to its users. For information to be used properly, it needs to be made easily and timely accessible. Therefore, to develop an IrSpIS for small-scale irrigation areas to all its users in an affordable manner. It should be considering costs, and existing hard and soft infrastructures. To make an IrSpIS sustainable all, the above issues will be considered in the prototyping of a system.

Table 6: Type and source of data to be collected and equipment needed

Required data	**Data type**	**Sources and equipment needed**
Meteorological data	Primary/secondary	Meteorological Office and EENSAT stations provided
Discharge of water	Primary	Current meter and Parshall flume (EENSAT provided)
Reservoirs level monitoring	Primary	Diver (EENSAT provided)
Soil moisture content	Primary	Soil moisture sensor (EENSAT provided)
Irrigation schemes and irrigated area	Primary	WaPOR time series data
Irrigated area and irrigation schemes	Primary	Sentinel-2, Landsat and Planet satellite image
Socio-economic data	Primary	Socio economic survey
Technical	Primary/secondary	RS data and Report
Institutional data	Primary/secondary	Interview and Report

2.10 Data sources

For this research primary and secondary data will be used. The secondary data will be obtained from different sources (Table 6).

3 Research schedule

Effort will be made to prepare at least one paper in each research objective.

Time table

Q: Quarter

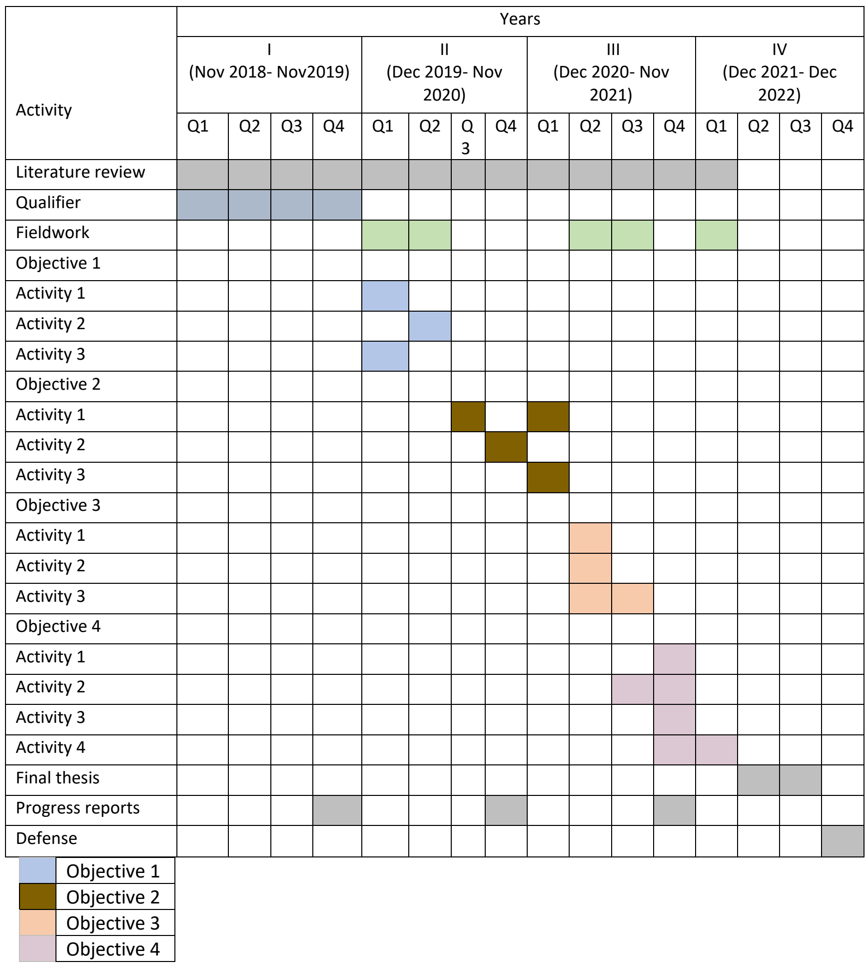

Figure 9: Proposed time line

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