Jimma University

Jimma Institute of Technology

School of Civil and Environmental Engineering

Hydraulic and Water Resource Engineering Department

Hydraulic Engineering Chair

Evaluation of irrigation potential and irrigation water supply systems efficiency: A case study in Wonchi district, south west Shoa zone, Oromia region, Ethiopia.

A thesis submitted to the school of graduate studies of Jimma University, Jimma Institute of Technology in partial fulfillment of the requirements for the degree of Masters of Science in Hydraulic Engineering.

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Jimma, Ethiopia

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October, 2016

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Declaration

I, the undersigned, person declare that this thesis is my original work, and has not been presented for a degree in this or any other University and that all sources of materials used for the thesis have been fully acknowledged.

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This thesis has been submitted for examination with my approval as university.

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Co-advisor	Signature	date

Abstract

Evaluation of irrigation potential and irrigation water supply systems efficiency is crucial especially for areas like wonchi district; where the issue of irrigation potential assessment was not addressed; and high irrigation water loss was observed; but not quantified yet. To address these issues irrigation potential was evaluated in terms of surface water and land resources potential. While irrigation water supply systems efficiency was evaluated in terms of unlined and lined canals conveyance efficiency and water losses. Surface water potential was determined based on rivers discharge measurement using area velocity method and irrigation water supply potential was determined from surface water resource potential, based on irrigation and major crop growth stage period.Suitable land of the study area was determined from land resource irrigation suitability analysis using GIS spatial analysis tools. Conveyance efficiency and water losses of unlined and lined canals were determined using inflow and out flow method, based on canal discharge measurements. Accordingly, the total surface water potential of wonchi district was determined to be about 406.22 Mm^3 *per year. The total irrigation water supply potential, used for irrigation during dry season was determined to be only about 7.964 Mm.*^{3} *(2%) of the district surface water potential. This supply potential can satisfy irrigation water demand of only about 3360 ha land area. However, 14763 ha, land area was determined to be suitable for irrigation. To satisfy this land area, irrigation water demand, about 34.996 Mm*^{3} *irrigation water was required. These supply and demand result comparison showed that the ratio was 19 % to 81% respectively. Similarly, irrigation water supply systems efficiency evaluated result revealed that conveyance efficiency of unlined canal was determined to be 55.88% and that of lined canal was 91.96%.From these results it was concluded that lining reduced water losses by 36.08% .Irrigation water supply potential is the limiting factor as compared to determined suitable land for irrigation in won chi district. So, there is need to increase irrigation water supply potential during dry season by collecting the rivers run off during the wet season. Lining distributary canals also need major focus to increase irrigation water supply potential and utilize suitable land resource for irrigation.*

Key words: *Irrigation, surface water, potential, water use efficiency, wonchi district.*

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I would also like to express my gratitude to Ethiopian Ministry of Irrigation, Water and Electricity, Ethiopian Metrological Service Agency, Wonchi Agricultural Development Office, Wonchi district Irrigation Development Authority, Ethiopian Agricultural Transformation Agency (ATA) and World vision, Ethiopia, Wonchi , ADP for their support on valuable data.

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Abbreviations

ADP	Area development program
ATA	Agricultural transformation agency
CWR	Crop water requirement
DEM	Digital elevation models
EATA	Ethiopian agricultural transformation agency
EMoIWE	Ethiopia ministry of irrigation, water and electricity
ESRI	Environmental systems research institute
FAO	Food and agricultural organization
GDP	Growth domestic product
GIR	Gross irrigation requirement
GIS	Geographical information system
HH	House holds
Mm^3	Million meter cube
NIR	Net irrigation requirement
NGOs	Non-governmental organization
ppm	Part per million
UK	united Kingdom
USA	united States of America
USDA	United state development agency

1. Introduction

1.1 Background

Irrigation potential evaluation refers to the process of identifying and mapping potential surface water resources and suitable land for irrigation, while irrigation water supply systems efficiency evaluation refers to assessment of conveyance performance of media used to convey the irrigation water from the source to the command area.

Irrigation potential evaluation is significant to identify whether the available potential resource can satisfy the irrigation demand of the area or not. While irrigation water supply systems efficiency evaluation is significant to quantify irrigation water loss and to identify select and adopt the best efficiently, irrigation water utilizing media that convey irrigation water from the source to the command area with minimum loss. It is believed that Ethiopia has total volume of 123 billion cubic meters (97.9%) of surface water potential**.** The total irrigable land in Ethiopia is estimated to be around 3.5 million hectare(FAO,1996).However, only about 10% of the 3.5 million hectares of land potentially available in terms of water resource and land has been developed. Besides, the available Water potential developed is inefficiently utilized due to water loss because of more of traditional use of irrigation water supply systems than modern, which accounts 66% and 34% respectively as shown in figure1.1.bellow.

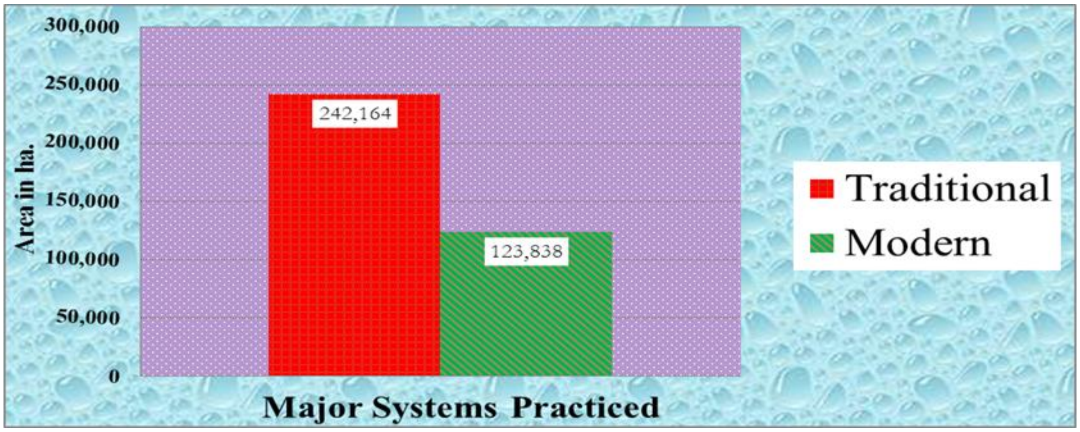


Figure 1.1: Current status of irrigation development in Ethiopia

Ministry of water resources emphasizes that in Ethiopia, irrigation has been playing a significant role in ensuring food security at household level and in improving the livelihood of the rural poor (Dejen *et al*,2012).According to world bank,(2006),agriculture contributes 47.7 % of the total GDP, as compared to 13.3% from industry and 39 % from services in Ethiopia. But agricultural production system is largely characterized by subsistence orientation, low levels of external inputs, and dependency on rainfall. This leads the country's agricultural production system vulnerable to draught due to rainfall instability and cause 10% of the population suffer food security problem annually (Makombe *et al*,2007).To solve such problem, irrigation promotion and efficiently utilizing the available water resource potential for irrigation by avoiding or minimizing losses is Mandatory.

The irrigation water losses due to irrigation water supply system while travelling from the potential source through the canal to crop field is called water conveyance loss(Peri,1993).Water conveyance loss consists mainly of operation losses, Seepage losses and Evaporation loss. According to Ghujal, and Randhe, (1981),the most important of these is seepage loss and evaporation loss in irrigation network system is not taken into consideration.

The issue of Water loss through irrigation network system has major impact on Water supply and management. Different studies carried out around the world to assess the potential, supply system efficiency, and irrigation water demand of different places of different countries to recommend appropriate irrigation potential utilization measures. The researchers have attempted to assess the potential in terms of water discharge measurement and land Suitability using GIS based techniques; supply system efficiency in terms of the degree of seepage loss and conveyance efficiency of unlined and lined canals in irrigation system; and irrigation demand based on crop water requirement of the area.

1.2. Statement of the problem

Wonchi district is one of the Ethiopian districts who planned in order to achieve the millennium goals of which water for all by the year 2015 and efficiently utilize the available water resources for irrigation to alleviate poverty.The district created awareness on water utilization for irrigation to the community and community motivation and demand for irrigation increased.

In contrast, the irrigation potential of the area was not assessed; and the irrigation water supply system that the districts practices is more of traditional (use of 88% unlined canal) and less modern (use of 12% lined canal) for utilization of the available water resource. But due to such practices inefficient utilization and high loss of irrigation water was observed in the district. However, the issue of how much water was lost and the efficiency of these two irrigation water supply systems was not addressed again besides to the surface irrigation potential in the study area. So, the study is to achieve the following objectives.

1.3. Objectives of the study

1.3.1. General objective

- The main aim of the study is to evaluate irrigation potential and irrigation water supply systems efficiency of the study area.

1.3.2. Specific objectives

- To determine surface water potential and suitable land of the study area.
- To determine and compare irrigation water supply potential with suitable land irrigation water demand
- To determine and compare conveyance efficiency of unlined and lined canals.

1.4. Research questions

The study answers the following questions.

- What is the amount of (surface water and suitable land) potential of the study area?
- Where the potential resources (water and suitable land) are located in the study area?
- How much of water will be lost as seepage, by using unlined and lined canals as irrigation water supply systems?
- How much canal lining reduce irrigation water loss?

1.5. Significances of the study

Irrigation potential evaluation is significant to: quantify suitable land, surface water and irrigation water potentials, and identify whether the available water potential resource can satisfy the suitable land irrigation water demand of the study area or not.

While irrigation water supply systems efficiency evaluation is significant to quantify irrigation water losses to identify, and select the best efficiently irrigation water utilizing media. By doing this scientific information on irrigation potential and utilization conditions were generated.

In general addressing the issue of irrigation potential and irrigation water supply systems efficiency is significant to generate information and divert the attention and increase motivation of irrigation developing sectors and communities towards more of modern irrigation practice adoption than traditional practice based on the information.

2. Literature review

2.1. Irrigation

Irrigation is a science of planning and designing a water supply system for the agricultural land to protect the crops from bad effects of drought or low rainfall (Basak,1999).The physical availability of resources(water and land) is fixed; yet their demand is growing due to this, the problem is how to balance demand and supply with this limited resource in an efficient and sustainable manner (FAO,1996).

2.2. Significance of irrigation in agriculture

The first use of irrigation as an aid to agriculture was made about the same time as man adapted himself to a social way of life (FAO, 1973). Under the climatic conditions prevalent in some parts of the world, it is clear that irrigation must have been a pre- requisite to organized society(Stan hill, 2002).Irrigation can help to ensure stable agricultural production as compared to traditional rain fed farming which is a high-risk enterprise. The aim of irrigation is to achieve a high standard of year-round agriculture, irrespective of rainfall availability (Rydzewski, 1987).

2.3. Over view of GIS and Previous GIS based irrigation potential assessment studies

GIS have become an increasingly important means for understanding and dealing with the Pressing problems of water and related resources management in world. GIS concepts and Technologies help us collect and organize the data and understand their spatial relationships. GIS analysis capabilities provide ways for modeling and synthesizing information that contribute to supporting decisions for resource management across a wide range of scales, from local to global. A GIS also provides a means for visualizing resource characteristics, thereby enhancing understanding in support of decision making (Johnson, 2009).

GIS is applicable for capturing, storing, querying, analyzing, and displaying geographically referenced data (Goodsmith, 2000). The increased availability of large, geographically referenced datasets and improved capabilities for visualization, rapid retrieval, and manipulation inside and outside of GIS demand new methods of exploratory spatial data analysis that are specifically tailored to this data-rich environment. Using GIS databases, More up-to-date information can be obtained or information that was unavailable before can be estimated and complex analyses can be performed.The main application in GIS is mapping (Campbell, 1984), where map represents geographic information as: collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend. GIS mapping can be an effective tool to organize, retrieve, and present spatial data for irrigation districts.

In the past, several studies have been made to assess the irrigation potential and water resources by using GIS tool. FAO,(1987) conducted a study to assess the land and water resources potential for irrigation for Africa on the basis of river basins and countries. It was one of the first GIS-based studies of its kind at continental level and proposed natural resources based approach to assessing irrigation potential. Its main limitation was in the sensitivity of the criteria for defining land suitability for irrigation and in the water allocation scenarios needed for the computation of the potential.

.Michel,(2001) has conducted study to determine irrigation suitability of Melka Sadi area using GIS. The location of the spots for profiles and auger holes were selected based on free and grid survey techniques and their locations were taken on the field using GPS. Soil samples were analyzed in the laboratory for topsoil texture, topsoil stoniness, subsoil stoniness, soil salinity, soil alkalinity and soil pH. Proximity analysis of ARC views extension spatial analysis resulted in six mapping units based on the location of three auger holes and three profiles. The result of laboratory and field analysis as attributes of point locations were also filed in to ARC INFO and ARCEVIEW GIS software’s and resulted six mapping units with different land qualities. The final irrigation suitability map of the project area was derived after overlay analysis. Most of the project area was found to be suitable for irrigation. Melaku ,(2003) carried out study on assessment of irrigation potential at Raxo dam area(Portugal) for the strategic planning by using RS and GIS. This study considered only theamount of available water in dam and topographic factor (slope) in identifying potential irrigable sites in downstream side of the dam.

Negash and Seleshi,(2004) conducted a case study of Abaye, Chamo basin GIS based irrigation suitability analysis. The study was concentrated on qualitatively as well as quantitative assessment of the existing physical resources. Land and water with respect to its

Suitability for irrigation, and developed a suitability database that would help for further investigation on the area. Map Scale of 1:1,000,000 were collected from Ministry of Agriculture (MoA) for soil and land use cover condition maps and topographical map scale 1:250,000 defining the basin were collected from Ethiopian Mapping Authority. Climatic data on humidity, wind velocity and sunshine hour; hydrological data and topographic data were used. In addition to these, other relevant data on investment cost of small-scale irrigation projects, socio economic aspect, and infrastructure were taken as input data.

Saymen, (2005) has conducted study performance evaluation and GIS based gravity irrigation suitable area map development at Godinomariam, Soil data and topography data were used for gravity irrigation suitability based on free and grid survey techniques soil samples were taken and the locations of the samples were determined using GPS. Soil samples were analyzed in laboratory for texture, stoniness, soil salinity, soil alkalinity and pH. Soil depth and subsoil permeability were determined in the field. From topographic map, contours were digitized and transformed to ARC view and then DEM was developed and finally a slope category was developed. Based on FAO evaluation methods for gravity irrigation, all laboratory results and field data were arranged. Overlay analysis was done and one surface irrigation suitable map was developed. Hailegebriel,, (2007) conducted a study on irrigation potential evaluation and crop suitability analysis using GIS and RS techniques in Beles sub basin, BeneshangulGumuz Region. The study considered slope, soil, land cover, water resources and climate factors in evaluating surface irrigation suitability.

Meron,(2007) carried out similar work on surface irrigation suitability analysis of southern Abay basin by implementing GIS techniques. This study, considered soil, slope and land cover factors to find suitable land for irrigation with respect to location of available water resource and to determine the combined influence of these factors for irrigation suitability analysis, overlay analysis was used in ArcGIS.

Kebede ,(2010) conducted a study was initiated with the objective of assessing the water and land resources potential of watershed in Dale *Woreda* of Sidama Zone for irrigation development and generating geo-referenced map of these resources by using GIS. Watershed delineation, identification of potential irrigable land, and estimation of irrigation water requirement and surface water resources of watershed were the steps followed to assess this irrigation potential.

2.4. Surface water resources and potentials in Ethiopia

Ethiopia has high water resource potential and an important opportunity in water-led development, but needs to address critical challenges of water development and management, in the planning, design, delivery, and maintenance of its irrigation systems if it is to capture its full potential (Awulachew,2011). Ethiopia has 12 river basins of which 9 wet & 3 dry (Denakil, Ogaden and Aysha).Annual runoff from the 9 river basins 122BM^3.Abbay and Baro-akobo contribute 77%. i.e(Abbay 53%, Baro-Akobo 24%), Omo-Ghibe 18% and the remaining others river basins contributes <10% (Abiti,2011).

Table 2.1**:** surface water resources and potentials in Ethiopia

S/N	***Basin Name***	***Source***	***Area(km^2)***	***Annual Run off (BM^3)***
1	Wabe Shebelle	Bale Highland	202,220	4.6
2	Abbay	West, South west Highland	199,912	52.6
3	GenaleDawa	Bale Highland	172,259	5.8
4	Awash	Central Highland	110,000	4.6
5	Tekeze	North WolloHighland	82,350	7.6
6	Denakil	North Wollo Highland	64,380	0.86
7	Ogaden	Northern Afar	77,120	-
8	Omo-Ghibe	Central, Western High Land	79,000	17.90
9	Baro-Akobo	Western Highland	75,912	23.6
10	Rift ValleyLakes	Arsi and Central High Land	52,000	-
11	Mereb	Adigirat High Land	5,900	0.26
12	Aysha	Northern Afar	2,223	-

Sourc**e:** EMoIWE

2.5. Surface water potential assessment and irrigation suitability evaluation criteria.

2.5.1. Irrigation suitability

Irrigation suitability is the suitability of land for irrigation. The basic physical factors in determining the suitability of land for irrigation are topography (slope), Soil, Land use cover, water quality and quantity, and climate (FAO, 1997).Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated and in most cases topography such as slope, soil**,** and Land use cover are considered to map the suitable area for irrigation using GIS techniques (FAO, 2006). Similarly, according to Jeffrey and John, (1990).Surface water potential for irrigation is assessed based on surface water availability and land suitability criteria as follows.

2.5.1.1. Water resource availability

Water resource availability is the most important parameter in determining irrigation potential and suitability of an area. It is evaluated in terms of the river discharge and Crop water requirement knowledge of an area (FAO, 1997).

2.5.1.2. Land suitability

Suitability is measure of how well the qualities of a land unit match the Requirements of a particular form of land use (FAO.2006).Land suitability is the fitness of a given type of land for a defined use. The land may be considered in its present condition or after improvements. The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO,1976).

2.5.1.3. Land suitability classification

In FAO frame work for land evaluation, the structure of the suitability classification is described recognizing qualitative, quantitative and of current or potential suitability in three main categories of decreasing generalization. Each category retains its basic meaning within the context of the different classifications and as applied it different kinds of land use.

2.5.1.4. Land suitability orders

Land Suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders Suitable and not suitable represented in maps, tables, etc. by the symbols S and N respectively (FAO, 2006).

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.

Order N (not suitable): Land which has qualities that appear to preclude sustained use of the kind under consideration.

2.5.1.5. Land suitability classes

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic number, in sequence of decreasing degrees of suitability within the Order.

Class S1(highly suitable): Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

Class S2 (Moderately Suitable): Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.

Class N (Not suitable): Land having limitations which appears as severe as to preclude any possibilities of successful sustained use of the land in the given manner. In general the land suitability for irrigation is identified based on Slope, land use/land cover, and Soil evaluation criteria as described in tables bellow.

Table 2.2: Slope evaluation criteria description

S/N	**Slope (%)**	**Category**
1	**0-5**	Highly Suitable (S1)
2	**5-8**	Moderately Suitable (S2)
3	**>8**	Not Suitable (N)

Table 2.3: Land covers evaluation criteria description

Category	Name	Description of land cover types
S1	Highly suitable	Cultivated: Dominantly, Moderately
S2	Moderately suitable	Grassland: Open, Bushed, Shrub
		Wood land: open, Riparian
N	Not suitable	Bush land: Dense
		Water bodies (Lake)
		Forest : closed
		Urban area

Table 2.4: soil suitability evaluation criteria description

	Criteria	**Category**	**Condition**
1	Drainage	**S1**	Well drained
		S2	Moderately well drained
		N	Poorly drained
2	Soil depth (cm)	**S1**	> 150
		S2	150 - 50
		N	< 50
3	Organic Carbon(OC)%	**S1**	> 10%
		S2	2 - 10%
		N	<2%
4	Available Phosphorus(P)ppm	**S1**	>15%
		S2	15 - 5%
		N	< 5%
5	Acidity and Alkalinity(PH)	**S1**	5.5- 7.0
		S2	5.5- 4.5 OR 7.0- 8.5
		N	< 4.5 OR >8.5
6	Cat ion Exchange Capacity (CEC) meq/100g soil	**S1**	35 - 70
		S2	35 - 16
		N	< 16

SOURCE: FAO, 2006.

On farm application efficiency may be worked out by the ratio of the crop water requirement as per Modified Penman Method for various crops for which irrigation is being provided by the project in each crop season i.e. Kharif, rabi and hot weather to the quantum of water which is made available to crops from the field outlets of canal system.

2.6. Irrigation water supply systems efficiency assessment

2.6.1. Water loss and canals water conveyance efficiency

Water conveyance efficiency may be defined as the percentage ratio of the amount of water delivered to fields or farms to the amount of water diverted from sources (Jadhav*et al*,2014).The water conveyance efficiency is a reflector of the losses in the conveyance systems. Conveyance efficiency is used to evaluate the efficiency of the system conveying water. Different Studies done on conveyance efficiency of Different conveyance system on different study sites. Accordingly, Jadhav*et al*,(2014),.has seen that conveyance efficiency was increased from 52% from 75% by lining of the canal.

Again according to Arshad*et al*,(2009),in Indus basin of Pakistan has been seen that lining reduced the water loss from 66% to 43.5% i.e. 22.5%reduction occurs. Thomas,(1980)adopted inflow-outflow method to estimate the water losses and data were used to determine total operational conveyance losses by calculating the volume of water entering the irrigation fields during a complete rotation. It was reported that total operational losses were 45 % of the inflow. In another study, the delivery losses ranged from 38% to 62 % in the watercourses of Khushab district (Sarkie*t al*,2013).Similarly,(Ghujal and Randhe,1981),showed the conveyance efficiency in the unlined irrigation system, which is about 56 %, can be increased to 88 %when the whole system is lined. Therefore there is considerable scope of improving the efficiency of water use by lining the system and additional area can be irrigated with in saved water. Besides, Lining of water canals is also expected to increase productivity by efficient utilization of resources, improved irrigation facilities, strengthened farmer's participation in the management of water, and generally promoted condition for progress of the rural areas (Zafar,2004).

3. Methods and materials

3.1. General description of the study area.

3.1.1. Location.

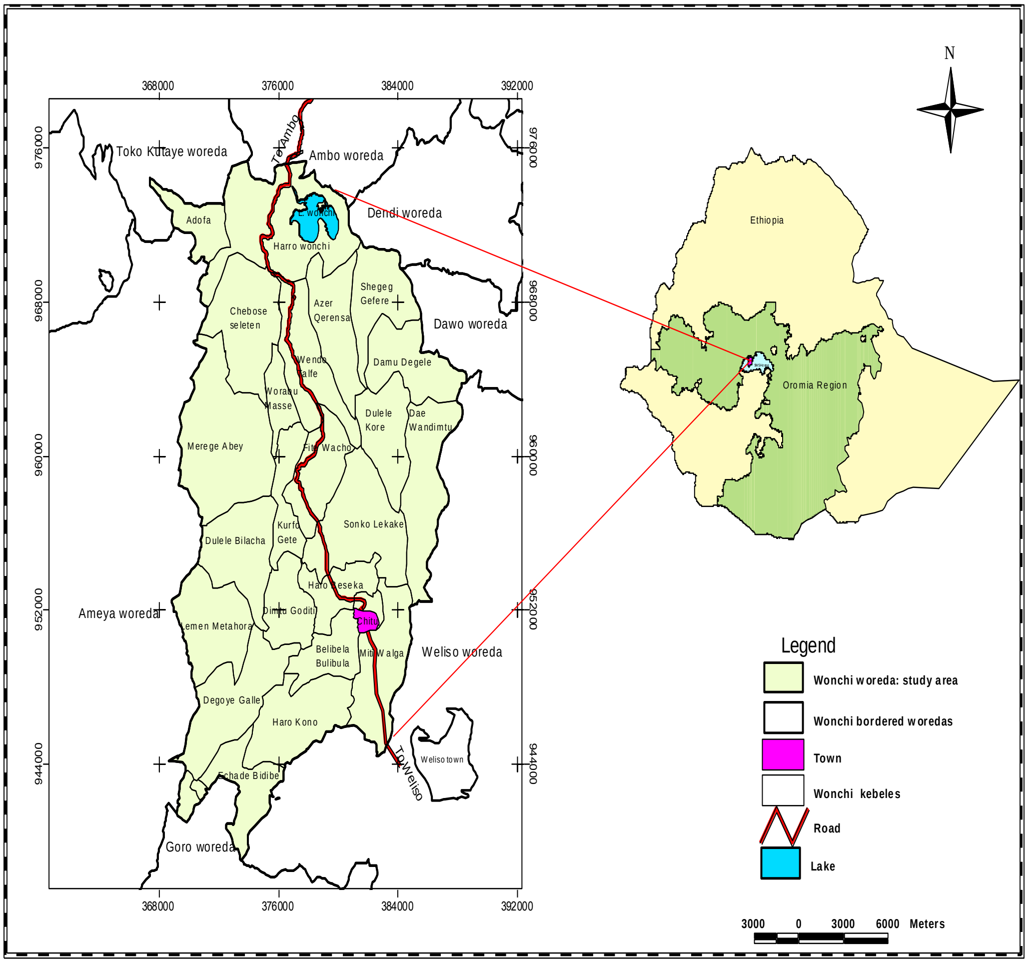


Figure 3.1: Location map of Won chi district

Won chi district is found in South West Shoa zone of Oromia region. It is located in the south west direction of the Ethiopian capital city, Addis Ababa at 123km.The latitudinal and longitudinal location of the district is from 37^{0}84’’E_38^{0}02’’E(8^{0}51’’N_8^{0}81’’N).The district generally lies with an elevation range of 1800-3387 m.a.s.l. and has total area of 459km^{2}and 24 Keble administrations.

3.1.2 .House hold and population

The total population of the district is 109,896 of which 50.2% male and 49.8% female With average family size of 5/HH and the average population density of 2332persons/km^2.The majority of the population that is about 96.8%,lives in the rural areas predominantly dependent on subsistent agriculture, while the remaining 3.2 lives in the towns.

Table3.1: description of wonchi district population

S/N	Description	Amount(number)
1	Adult male	29562
2	Adult female	29232
3	Boys	25606
4	Girls	25496
Total		**109,896**

Source: Won chi district administration

3.1.3. Land use and land cover

Out of the total area of the district 72.5% is cultivated land,13.7% grazing land,9.74% covered by natural forest,0.03% communal forest,1.03%is water body (lake) while others is 3%.

Table 3.2: Description of wonchi district land use pattern.

S/N	Land use system	Area in ha.
1	Cultivated Land	33,559
2	Grass Land	5335
3	Forest Land	641
4	Bush land	4961
5	Water body (Lake)	437
6	Others	937
Total		**45870**

3.1.4. Agro climate

Agro-ecologically the area is characterized by semiarid (midland) and humid (highland).The mid land part consists of 56% of the total land area, while the high land is 44%.The main rainy season is from June to September. The area receives an average rainfall of about 1162 mm, while that of temperature is estimated to be 10.5^{0}C-28.1^{0}C.

3.1.5. Water potential and irrigation development situation in wonchi district

The study conducted by ATA,(2015) report showed that there is no potential for underground water. However, the result of this thesis study found that, surface water potential of won chi district was found to be about 406.22 Mm^3 annually. For utilization of this potential, the districts practices more of traditional (unlined) and less modern (lined) of the irrigation water supply systems of the total practices in irrigated area as shown in fig-4.2,bellow.

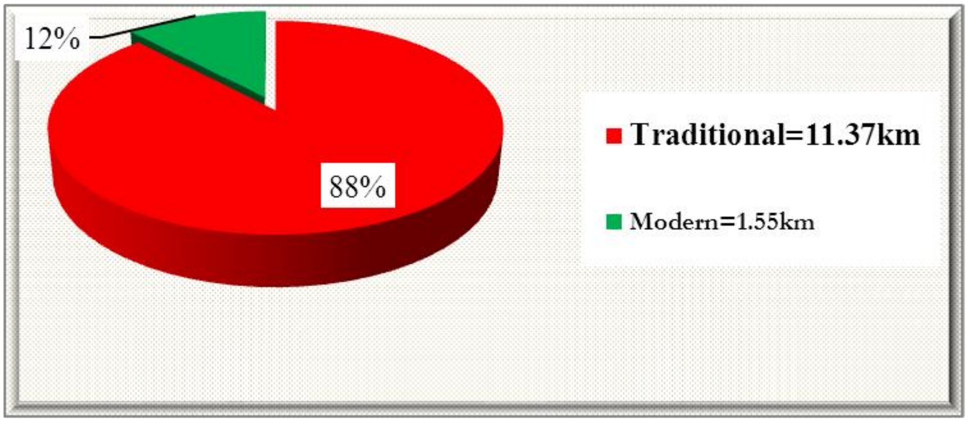


Figure 3.2: Irrigation development situation of wonchi district.

From the fig it was observed that tradition practice was 11.37km (88%) and modern practice was 1.55km (12%) considering types of canals length used to convey the irrigation water. In terms of area, actual irrigation developed in the area was 5518 ha and 650ha in traditional and modern practices respectively. In line with the Government plan, the society awareness, motivation and demand for irrigation was increased. However, un efficient utilization of irrigation water and high water loss was observed, due to use more of traditional (unlined canal) than modern (lined canal) for irrigation water supply system practices in the study area.

3.2. Data collection.

The study was conducted by using primary and secondary data collection methods. Primary data collected were, hydrological data, obtained by direct measurement of discharge using area velocity method. Secondary data collected were, spatial data, Metrological data, and crop data. Spatial data were collected from Ethiopian Ministry of Irrigation, Water and Electricity, metrological data were collected from Ethiopian Metrological Service Agency, and Crop data were collected from Wonchi district Agricultural Development Office

3.3. Study variables

The study was conducted to assess irrigation potential ,irrigation water demand and to evaluate irrigation water supply systems efficiency of the study area .To address these issues ,major variables determined/measured were: suitable land area , surface water and irrigation water potentials ,irrigation water demand ,and unlined and lined canals conveyance efficiency, canal water losses (evaporation loss and seepage loss).For irrigation potential evaluation, suitable land was determined from ,land resources and irrigation suitability assessed by GIS spatial analysis tools; surface water and irrigation water supply potentials were determined from surface water resources obtained by rivers discharge measurements. Irrigation water demand was determined based on crop water requirement and effective rainfall of the study area. For irrigation water supply systems evaluation, unlined and lined canals conveyance efficiency, canal water losses were determined from canals discharge and determined ETo for the area. The detail assessment and determination methods of each variable were explained as follows.

3.4. Variables assessment and determination methods

3.4.1. Surface water resource

3.4.1.1. Rivers discharge and measurement

The river discharge data was collected by using area velocity method of measurement, by measuring velocity using current meter and determining area of the river cross section at each point of measurement as follows.

$$\mathbf{A_I} = \frac{\mathbf{(TWI+BWI)}}{\mathbf{2}} * \mathbf{HI} \ldots\ldots [\mathbf{1}]$$

$$\mathbf{Q_I} = \boldsymbol{AI * VI} \ldots\ldots [\mathbf{2}]$$

Where: A_I=Cross sectional area (m^2) of the river, at point I (if trapezoidal shape).

TW_I and BW_I=Top width and Bottom width (m) of river cross section, at point I.

H_I=Water surface height (m) at point I.

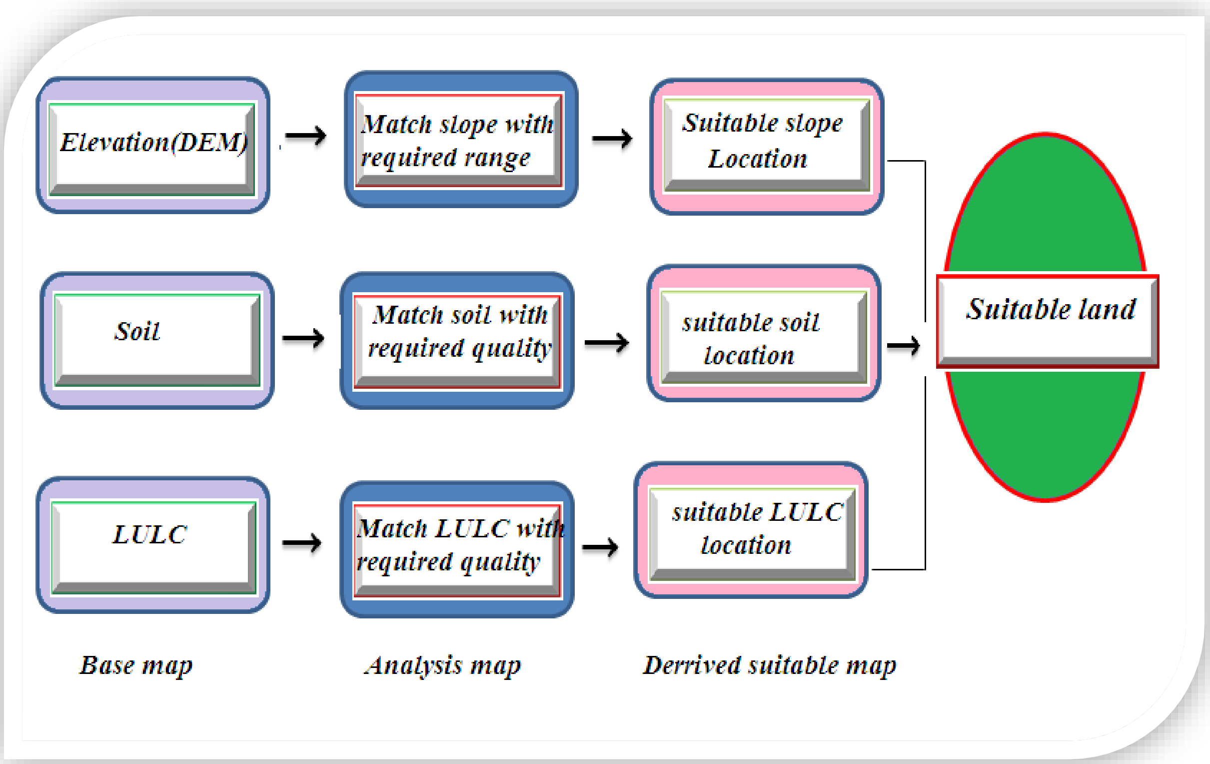
V_I=Velocity (m/s) at point I. and

Q_I=Discharge (m^3/s) at point I.

3.4.2. Land resource suitability and suitable land

Land resource suitability *was* assessed and determined based on land suitability evaluation criteria and suitability classis: highly suitable (S1), moderately suitable (S2) unsuitable (N), in terms of Land use land cover, slope and soil parameters. The soil data obtained from ATA ,soil analyzed result and Omo-gibe basin spatial data was used to assess land resource suitability and determine suitable land for irrigation using GIS spatial analysis tool.Acordingly,land suitability was evaluated and suitable land was determined based on: land suitability evaluation criteria described in table 2.2, table 2.3 and table 2.4 of section 2.

Accordingly, the GIS model used was expressed as a flowchart of processing steps as follows



Each box in the flowchart represents a map while each line indicates a GIS operation.

3.4.3. Irrigation water demand (irrigation water requirement)

Irrigation water requirement is the water that must be supplied through the irrigation water supply systems to ensure that the crop receives its full crop water requirement .Irrigation water requirement was determined based on crop water requirement (CWR) knowledge. Crop water requirement (CWR) is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field Conditions at a place (Dejen*et al*,2013).Crop water requirements (CWR) was determined from crop coefficient and reference evapotranspiration (ET_o) as follows.

$$\mathbf{CWR_i} = \sum_{t=0}^{T}(KCi * ETo)\ ,unit\ mm \text{ .... } [3]$$

ET_o was calculated following the Penman Monteith approach (FAO, 1992), as:

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

Where: Kc_i=Crop coefficient of the given crop i,duringthe growth stage t,

T = the last growth stage

CWR_i=Crop water requirement (irrigation water demand)

ETo= reference evapotranspiration [mm day-1],

Rn =net radiation at the crop surface [MJ m-2 day-1],

G=soil heat flux density [MJ m-2 day-1],

T= mean daily air temperature at 2 m height [°C],

u2= wind speed at 2 m height [m s-1],

es=saturation vapour pressure [kPa],

ea=actual vapour pressure [kPa],

es - ea =saturation vapour pressure deficit [kPa],

Δ =slope vapour pressure curve [kPa °C^{-1}],and

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

Net irrigation water requirement was determined on the base of CWR, and effective rainfall of the study area as:

$$\boldsymbol{NIR(ti) = CWR(ti) - Peff(ti)} \text{ .... } [\mathbf{4}]$$

Where: $NIR(ti)$ =Net irrigation requirement (mm)

$CWR(ti)$ =Crop i, water requirement for its t, duration growth stages (mm).

$Peff(ti)$ = Effective dependable rainfall (mm)

Gross irrigation water requirement was determined from the net irrigation water requirement and canal conveyance efficiency of the study area as:

$$\boldsymbol{GIR(ti)} = \frac{\mathbf{NIR(ti)}}{\mathbf{Ec}} \text{ .... } [\mathbf{5}]$$

Where: $GIR(ti) =$ Gross irrigation water requirement (mm)

$NIR(ti)$ =Net irrigation requirement (mm)

Ec= Canal conveyance efficiency (%)

Average irrigation water requirement was determined by averaging both net and gross irrigation water requirements as:

$$\mathrm{IWR}(t_i)=\frac{\mathbf{NIR(t_i,)\ +GIR(t_i,)}}{\mathbf{2}} \text{ .... } [\mathbf{6}]$$

Where: $\mathrm{WR}(t_i)$=Average irrigation water requirement(mm)

$NIR(ti)$ =Net irrigation requirement (mm)

$GIR(ti) =$ Gross irrigation water requirement (mm)

3.4.4. Canals discharge

For irrigation water supply systems efficiency determination, unlined and lined canals were selected from two irrigation projects ,namely from walga and Gunjo irrigation projects.Then canals discharge was obtained, using area velocity method and applying inflow and outflow principle. Determined discharges were used to determine the following variables.

3.4.4.1. Canal conveyance efficiency

Canal conveyance efficiency (Ec) is the ratio in percent of the amount of water delivered by a channel or pipeline to the amount of water delivered to the conveyance system. Conveyance efficiency (Ec) was computed with the adoption of the following formula (James, 1988).

$$\mathbf{Ec} = \frac{Q_O}{Q_I} * 100 \quad \ldots\ldots\ldots\ldots \quad [7]$$

Where: Ec = Canals conveyance efficiency in percent

Q_O=Quantity of water delivered by conveyance system (Outlet).

Q_I= Quantity of water delivered to a conveyance system (Inflow)

The rate of flow passing a point in an open channel was measured by multiplying the cross-sectional area of the flow section at right angles to the direction of flow by the average velocity of water. The cross-sectional area was determined by direct measurements, the velocity was measured by float principle by selecting straight section of channel about 20 m long with fairly uniform cross-section and three times velocity measurements was taken within the trial section to arrive at the average velocity of each cross sectional area. Since the velocity of the float on the surface of the water will be greater than the average velocity of the stream, it was necessary to correct the measurement by multiplying by a constant factor (velocity correction factor) which is usually assumed to be 0.66 (James, 1988). To obtain the rate of flow, this average velocity (measured velocity * correction factor) was multiplied by the average cross-sectional area of the stream.

$$\mathbf{Q} = \mathbf{0.66}\boldsymbol{A} * \boldsymbol{V} \quad \ldots\ldots\ldots\ldots \quad [\mathbf{8}]$$

Where: Q = Discharge rate (l/s)

A = Area of cross-section of channel (m^2)

V=Average velocity of flow (m/sec)

3.4.4.2. Canal water loss per 100m

The canal conveyance loss was measured using the inflow-outflow method, which involves measurement of the rate at which water flows in to a water course test section and the rate at which water flows out of it. By measuring the section length under test the loss of water per 100 m was calculated by the following formula (Michael, 1986)

. $\mathbf{Q} = \frac{(QI-QO)}{L} * 100\mathbf{m}$ .... [9]

Where: Q = Water loss rate in (l/s/100 m)

Q_O = Quantity of water delivered by a conveyance system (outlet) (l/s)

Q_I = Quantity of water delivered to a conveyance system (inflow) (l/s)

L = Length of Canal under test (m).

3.4.4.3. Total water losses from canals.

The total water losses from total length of canals under test were calculated by using:

QL=100-Ec, ... [10]

Where: Q_L= the percentage total loss (%)

Ec = the conveyance efficiency of the canal under test.

3.5. Data analysis

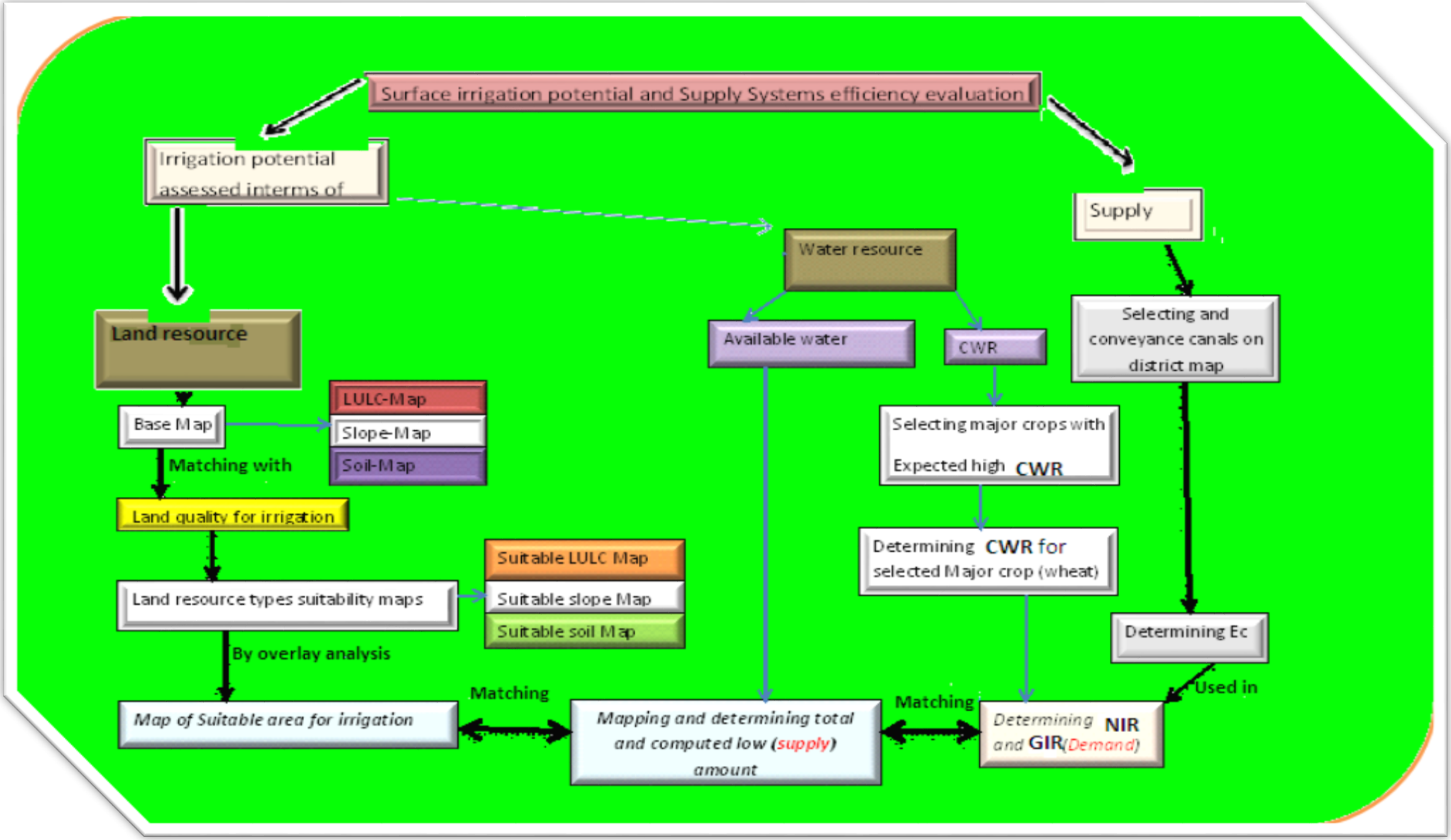
GIS spatial analysis tools and Microsoft excel were used for data analyses Spatial data were analyzed using GIS spatial analysis tools to identify land resource irrigation suitability and determine suitable land for irrigation. While Microsoft excel was used to analyze, metrological, hydrological, crop and canals discharge data

3.6. Materials

Materials used for the study were:

- ☞ GPS
- ☞ Current meter
- ☞ Tape meter
- ☞ Digital Camera
- ☞Compute

Table 3.3: Flowchart of the study, showing summary of the processes involved and output produced.



4. Result and discussion

4.1. Surface irrigation potential

Surface irrigation potential of wonchi district was evaluated, identified and analyzed in terms of available surface water resources (rivers discharge) and potential irrigable land of the area based on suitability evaluation criteria. The analysis results of surface irrigation potential and suitability evaluation was presented in the following sections.

4.1.1. Surface water resource

The surface water resource of wonchi district was assessed through direct measurement of flow discharge of the major rivers in the district. Where the location and potential of major rivers of the study area was shown in figure 4.1 and table 4.1 bellows respectively.

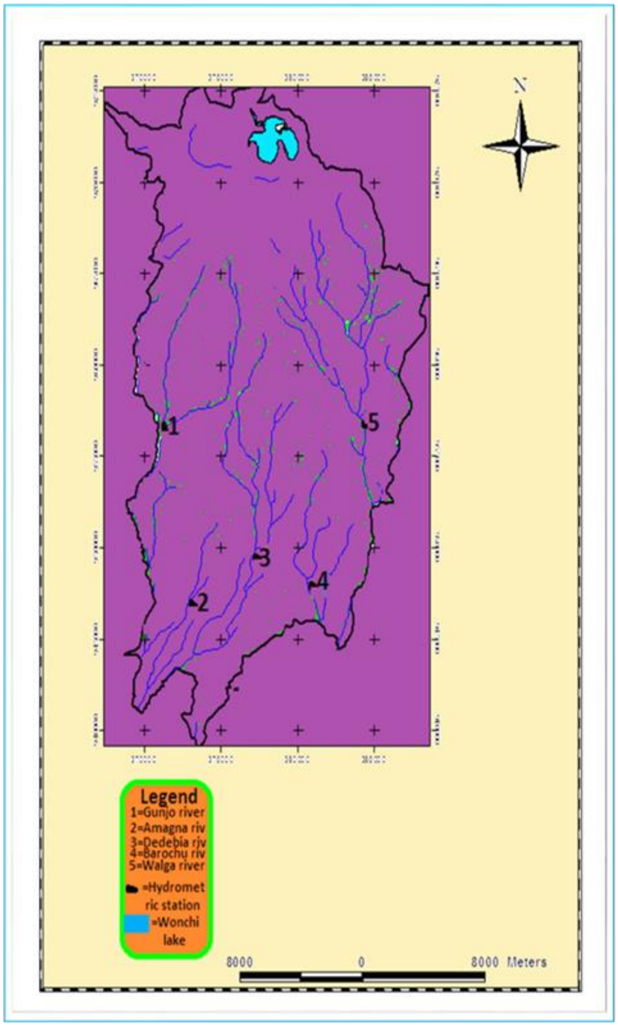


Figure 4.1: Location of major rivers of wonchi district

Table 4.1: Potential of major rivers of wonchi district

Name of rivers	Average annual flow		Coverage (%)
	m^3/s	Mm^3	
Gunjo	**2.18**	**67.81**	**16.69**
Amagna	**3.13**	**97.36**	**23.97**
Dedebia	**2.51**	**78.07**	**19.22**
Barochu	**1.85**	**57.54**	**14.16**
Walga	**3.39**	**105.44**	**25.96**
Total	**13.06**	**406.22**	**100**

The result in table 4.1, showed that the total annual surface water potential in the district was about 406.22 Mm^3.For this potential walga river contributed the major percentage (25.96 %), Amagna river contributed 23.97%, Dedebia river contributed 19.22%,Gunjo river contributed 16.69% and Barochu river contributed the list (14.16%) for the total potential of the district.

The total irrigation water supply amount computed for dry season, for full growth stages of wheat, considering its irrigation period was estimated to be about 7.964 Mm^3 (appendix-E, table E(2).

Comparing computed supply amount (7.964 Mm^3) with the total district water potential (406.22 Mm^3), the irrigation water supply amount during irrigation period was about 2% of the total district water potential. This means the water potential was very low /decreased during dry season or when irrigation is practiced and about 98% (398.1 Mm^3) of the district water potential was available in the time when irrigation was not practiced (during wet season).

So, this revealed that 98% (398.1 Mm^3) of the district water potential could be additionally collected during wet season and used for irrigation supplement during dry season.

4.1.2. Potential irrigable site and suitable areas determined

The potential irrigable land was determined and mapped by irrigation suitability analysis using GIS techniques; where the data set involved were: slope, land use /land cover, and soil factors, based on the standards, and widely used land suitability methods. Whereas the classification used were very suitable (S1), moderately suitable (S2), for the order of suitable (S) and not suitable (N).The detail description of each classification level was shown in appendix-B, table B(1).

Accordingly, potential irrigable site and suitable area was determined based on the following suitability classification and parameters analysis; where these classification and parameters of each suitability classification were selected based on FAO standard guideline, objective of the study and importance of each parameter in affecting irrigation suitability.

4.1.2.1. Land use / land cover suitability

LULC type is one of the parameters among those which determine whether the land is suitable for irrigation or not .One is its impact on the cost of irrigation practice to prepare the land for agriculture. For the purpose of irrigation suitability study, four LULC types were identified for won chi district from spatial data analysis.

These LULC types include: cultivated land, grass land, forest, and some settlements (town), as shown in figure 4.2 bellows.

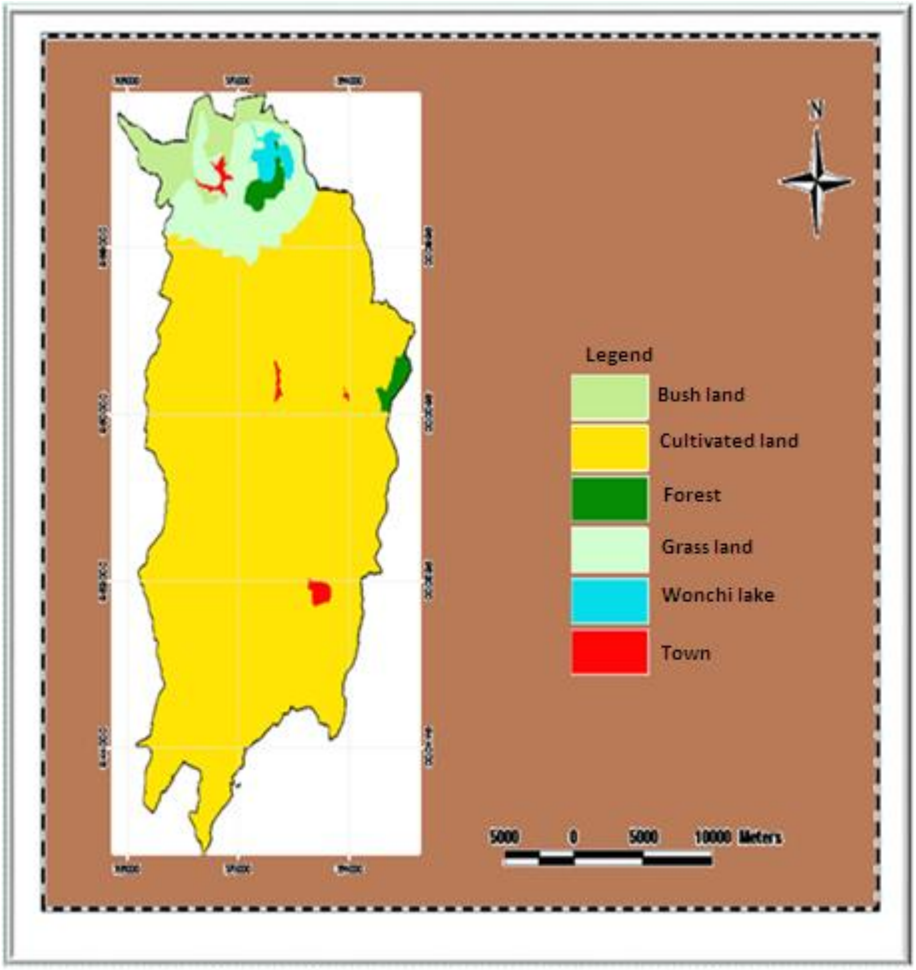


Figure 4.2:Land use/land cover map of won chi district.

LULC Suitability map was derived from LULC map based according to suitability classis: S1, S2 and N for highly suitable, moderately suitable and not suitable respectively as shown in figure 4.3 and table 4.2 .

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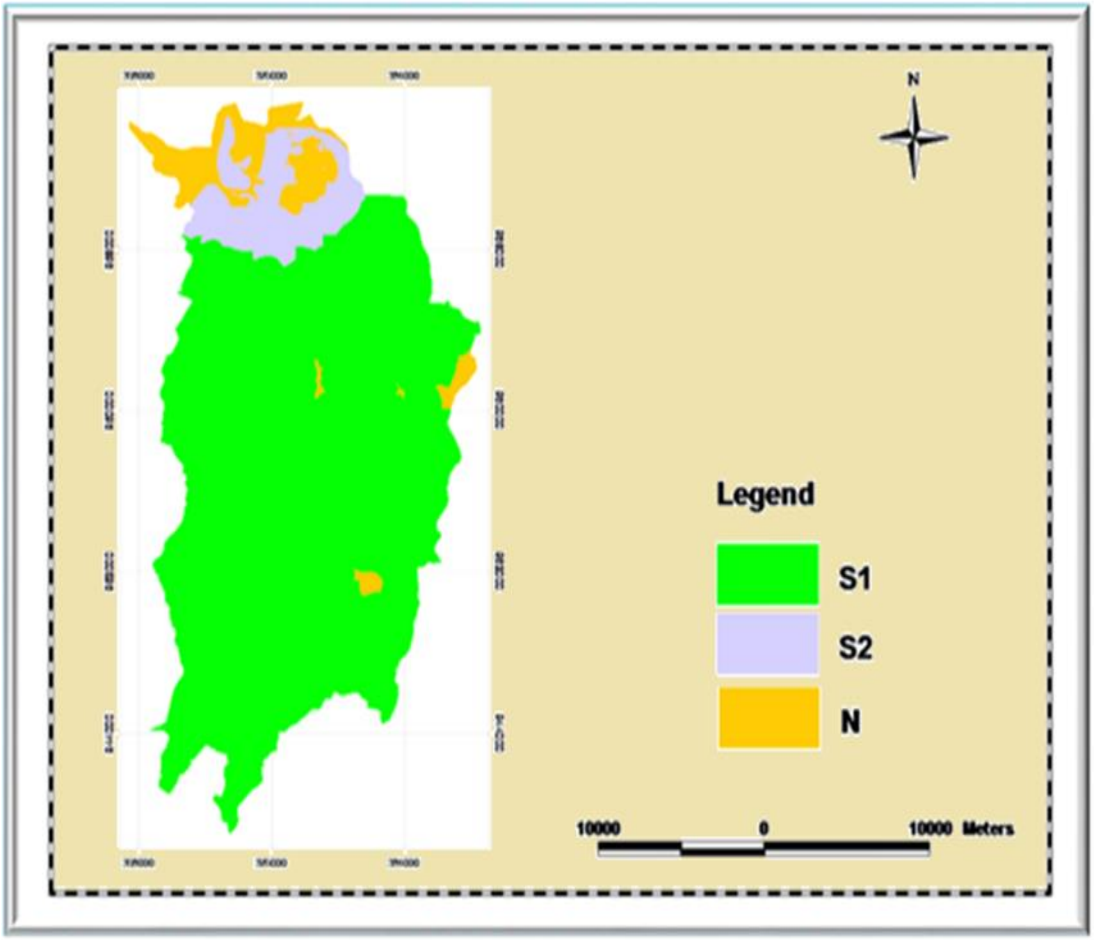

Figure 4.3:Wonchi district major irrigation suitability category from land use analysis

Table 4.2:Wonchi district irrigation suitability result from land use analysis

S/N	LULC type/ Suitability Parameters	Name	Suitability category/ Classes	Area coverage (ha)	% of total area of Suitability classes
1	Forest	Not suitable	N	641	1.4
2	Towns	Not suitable	N	937	2.0
3	Bush land	Not suitable	N	4,961	10.8
4	Water body (lake)	Not suitable	N	437	1.0
5	Cultivated Land	Highly Suitable	S1	33,559	73.2
6	Grass land	Moderately Suitable	S2	5,335	11.6
Total				**45,870**	**100**

The results revealed that 73.2 % of the total area of the district covering an area of 33,559ha had been classified as highly suitable for surface irrigation, 11.6%, covering an area of 5,335 ha. as moderately suitable , whereas the remaining 15.2 % of the area covering an area of 6976 ha could not be suitable for surface irrigation from LULC suitability analysis result.

4.1.2.2. Slope suitability

Slope has been considered as one of the evaluation parameters in irrigation suitability analysis. The digital elevation model (DEM) was used to derive the slope. Hence, to derive slope suitability map of Wonchi distric, DEM of the district area was clipped from Shuffle Radar Topographic Mission (SRTM) down-loaded from international water management institute (IWMI) site of national aeronautics and space administration (NASA) satellite with 30 meters resolution by rectangular masking layer of *the district* boundary using Global mapper11 software by assigning appropriate co-ordinate $8^0$51’’N_$8^0$81’’N latitude and $37^0$84’’E_$38^0$02’’E longitudes) and datum the project area was extracted. Then slope maps of the district was derived using the “Spatial Analysis Slope” tool in Arc GIS. The Slope derived from the DEM was classified as slope (0-5%), slope (5-8%) and slope (>8%), based on the classification system of FAO (1996), and the resulted slope map was shown in figure5.4 bellow.

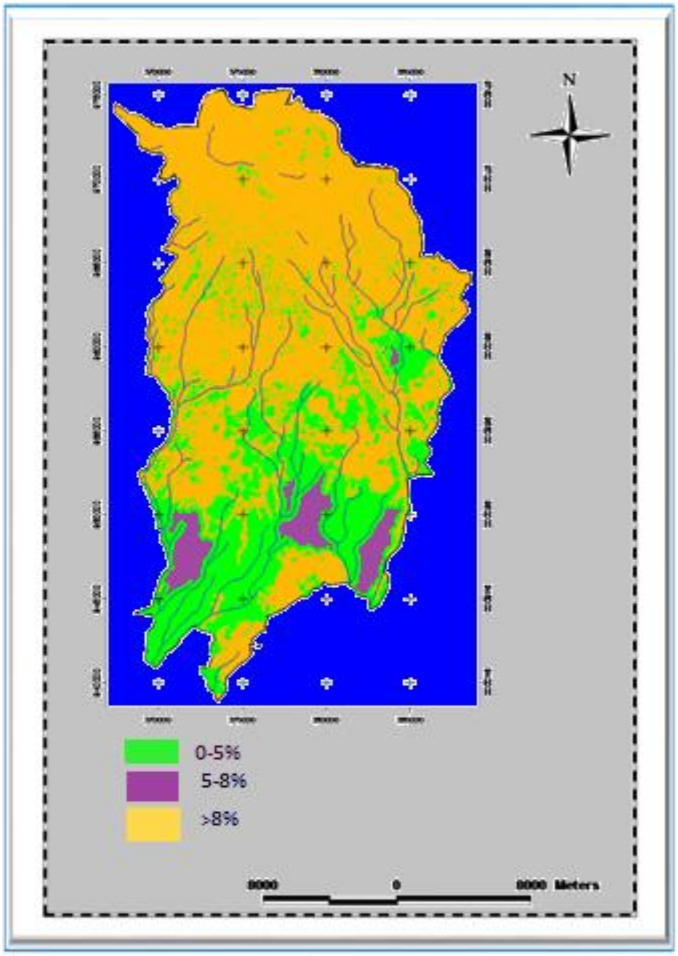

Figure 4.4: Slope map of Wonchi district

The slope suitability map was derived from the slope map based on the study objective ;where the slope suitability classes highly suitable (S1=0-5% slope), moderately suitable (S2=5-8% Slope) and not suitable (N= >8% slope) .

The suitability result from slope analysis was shown in figure 4.5, and table 4.3 bellow.

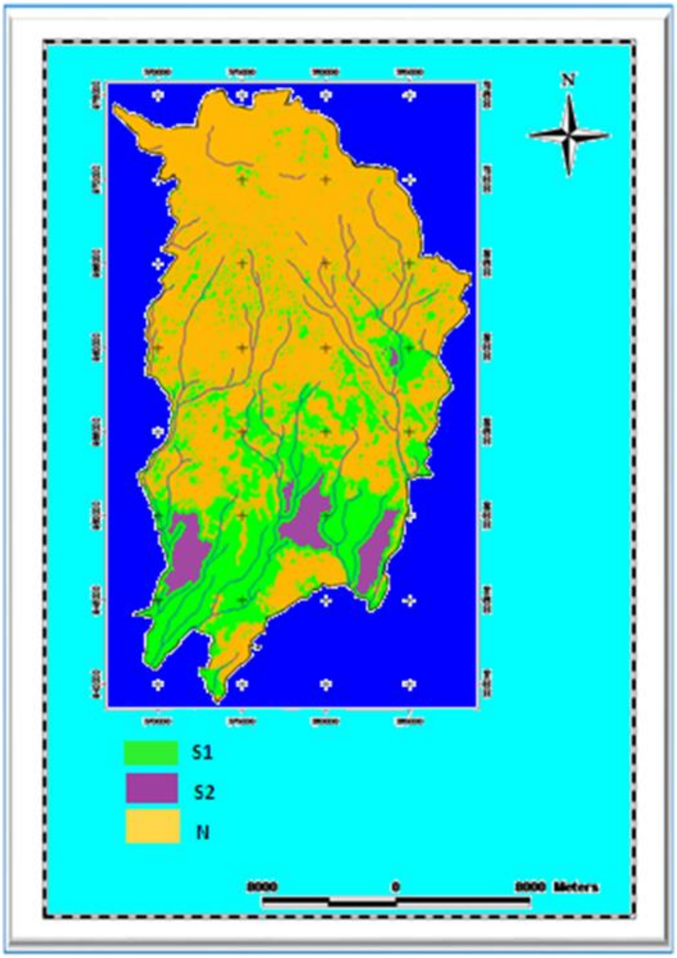

Figure 4.5:Wonchi district irrigation suitability from slope analysis

Table 4.3: Wonchi district irrigation suitability result from slope analysis

S/N	Slope range (%)	Suitability category	Name	Area coverage (ha)	% of total area of Suitability classes
1	0-5	S1	Highly Suitable	8635	18.83
2	5-8	S2	Moderately Suitable	7065	15.40
3	>8	N	Not Suitable	30,170	65.77
Total				45,870	100

The results in table 4.3, revealed that 8635 ha (18.83% of the total area of wonchi district) was identified to be highly suitable and 7065 ha. (15.40%) was identified to be moderately suitable for surface irrigation. i.e total of 15700 ha (34.23%) lies in the range of suitable; whereas the remaining 65.8% of the area (covering an area of 30,170) could not be suitable for surface irrigation in terms of slope analysis.

4.1.2.3. Soil suitability

For soil suitability evaluation the necessary soil data was collected from ,Ethiopian Ministry of water, irrigation and electricity as well as Ethiopian Agricultural Transformation agency (ATA).According to ATA, soil physical and chemical analysis result the dominant soil groups identified in the study area was eutric vertisols and moderately to well drained, in which its soil depth ranges from 3cm to210 cm, organic carbon contents ranges from 3.8 % to 5% , available phosphorus ranges from 8.5ppm to 13.5 ppm ,acidity and alkalinity (PH) ranges from 6 to 7 and CEC (meq/100g soil) ranges from 22.4 to 54.4.

The soil analysis result and its suitability condition of the study area was shown in table-5.4 bellow.

Table 4.4: Wonchi district soil analysis result and its suitability condition**.**

S/N	Criteria	Condition	Category	Suitability Order
1	Drainage	Moderately to well drained	S2 to S1	S
2	Soil depth (cm)	3-210cm	N to S1	N and S
3	Organic Carbon(OC)%	3.8-5	S2	S
4	Available Phosphorus(P)ppm	13.5-8.5	S2	S
5	Acidity and Alkalinity(PH)	6-7	S1	S
6	CEC (meq/100g soil)	22.4 -54.4	S2 to S1	S

Source: ATA soil analysis result

The soil analysis result and its suitability condition. in table 4.4 showed that, all the necessary soil parameters, falls only in one suitability order, suitable (S) except soil depth which falls in both suitability ranges (Suitable and unsuitable).

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Similarly, the spatial data collected from Ethiopian ministry of water, irrigation and electricity identified that soil depth falls in both suitable and unsuitable ranges in terms of soil analysis. So based on this result, soil depth was selected as the limiting parameter for soil suitability analysis and the soil map was produced for soil depth and the map was shown in figure 4.6 bellow.

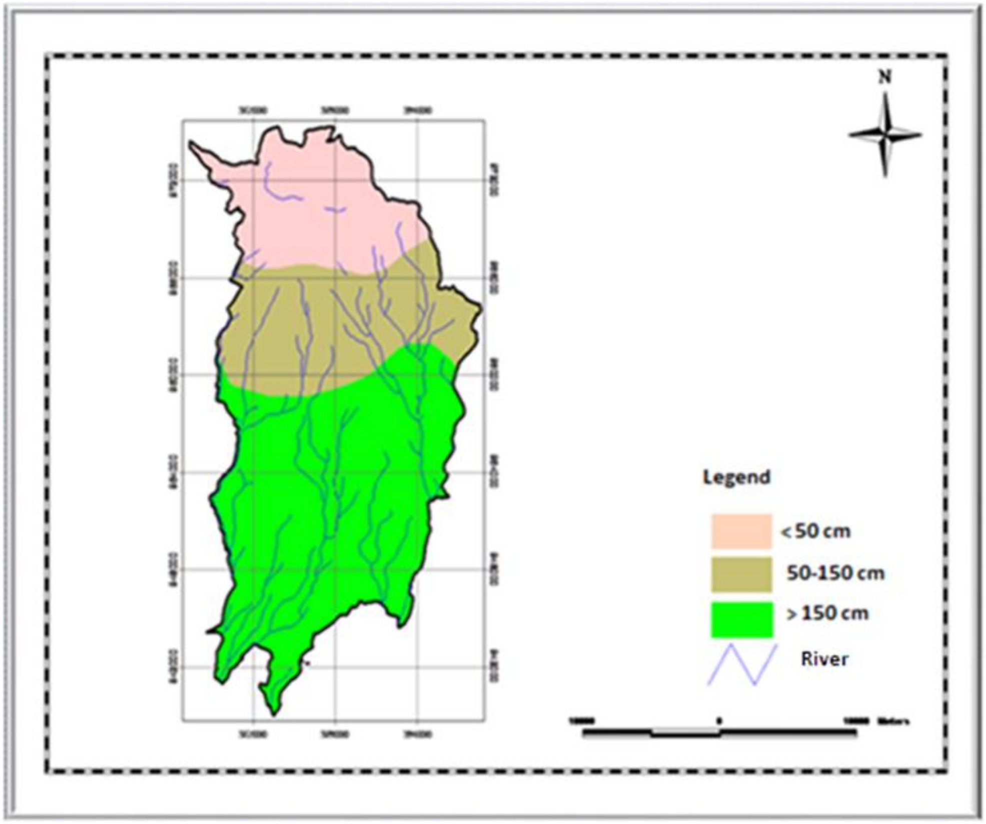

Figure 4.6: soil depth map of wonchi district.

The soil depth suitability map was derived from the soil depth map based on the study objective; where the soil depth suitability classes Highly Suitable (S1=>150cm depth), moderately Suitable (S2=50cm-150cm depth) and un suitable (N= <50cm depth) and the suitability result from soil analysis was shown in figure 4.7, and table 4.5 bellow.

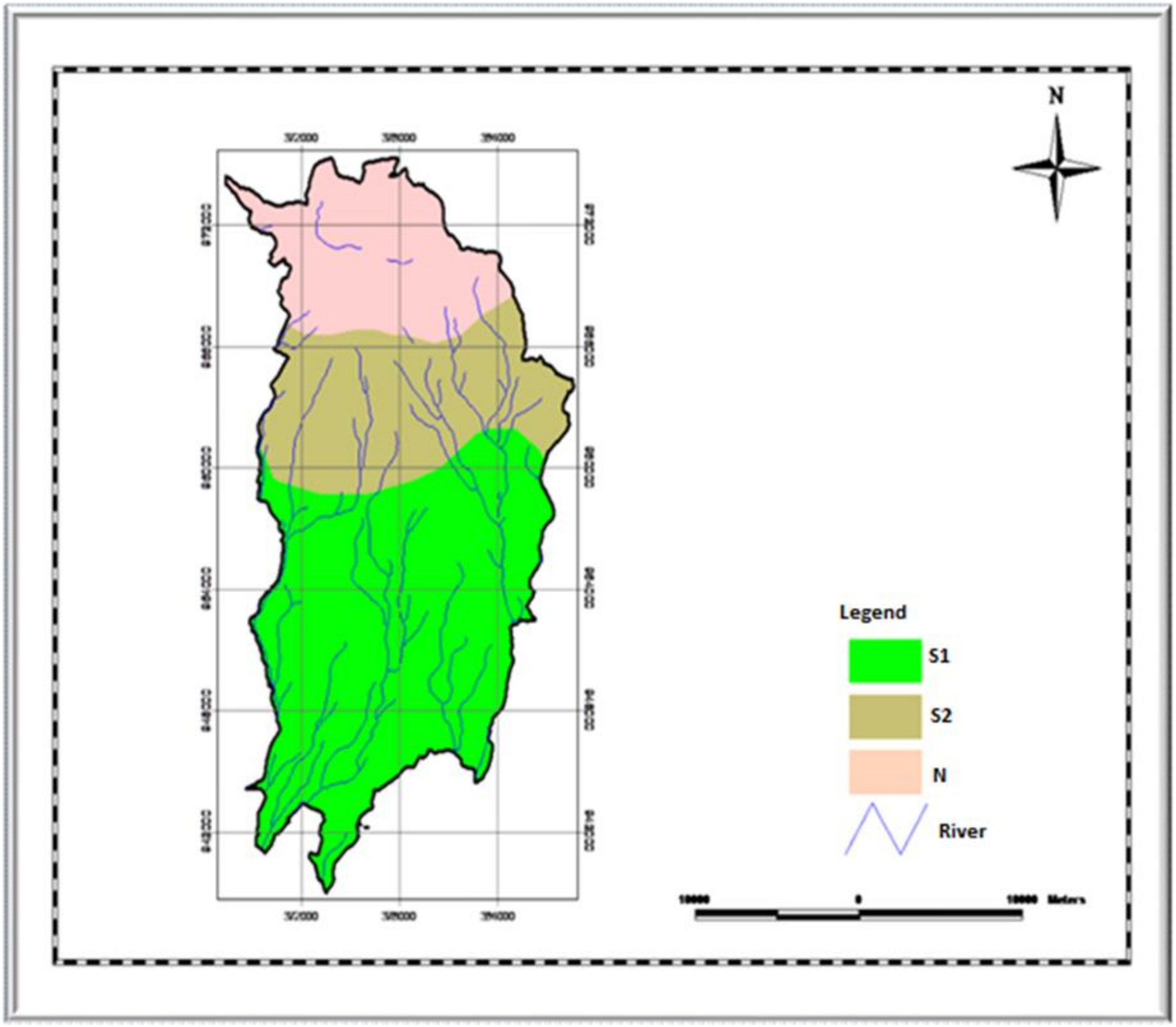

Figure 4.7:Wonchi district irrigation suitability from soil depth analysis.

Table 4.5: Wonchi district irrigation suitability result from soil depth analysis

S/N	Soil depth range (cm)	Name	Suitability category	Area coverage (ha)	% of total area of Suitability classes
1	<50	Not suitable	N	11,004	24.0
2	50-150	moderately Suitable	S2	13,926	30.4
3	>150	Highly Suitable	S1	20,940	45.6
Total				**45870**	**100**

4.1.2.4. Suitable land for irrigation

Potential irrigable land or suitable land for irrigation was obtained by creating overlay analysis in which data set involved were LULC, Slope and soil depth. Accordingly, the identified suitable land was shown in figure 4.8 and table 4.6, bellows.

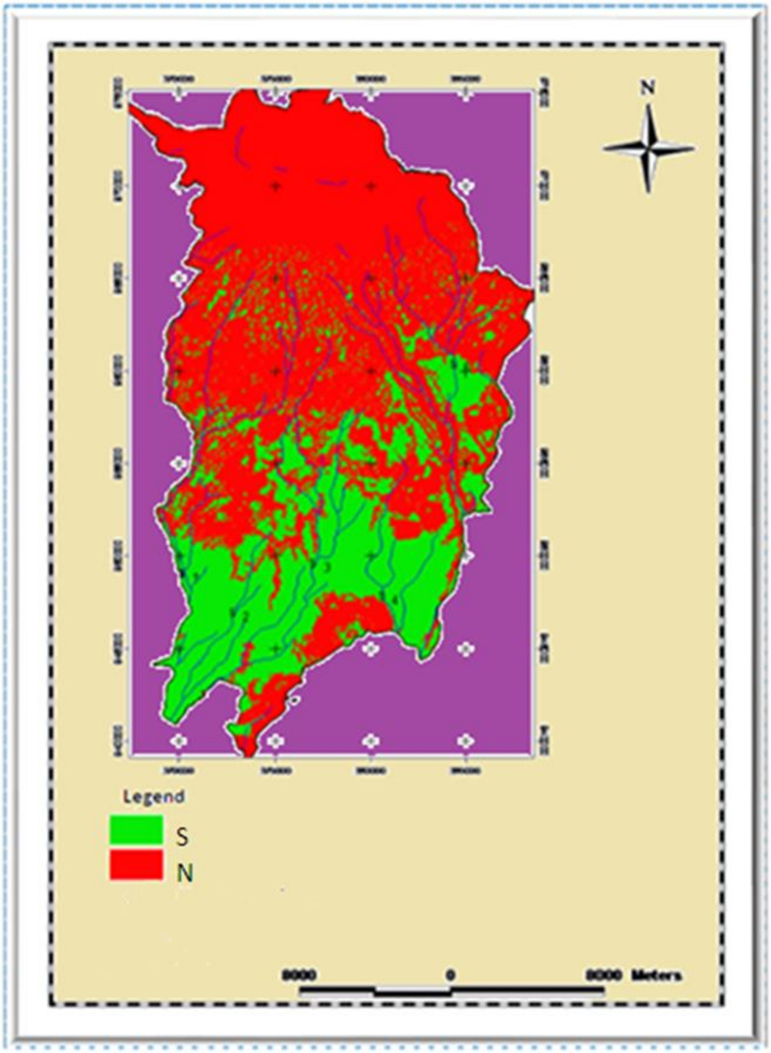

Figure 4.8: Map of Won chi district suitable area for irrigation

Table 4.6: Wonchi district suitable area for irrigation

S/N	Suitability category	Name	Area coverage (ha)	% of total area of Suitability classes
1	S	Suitable	14763	32.2
2	N	Not Suitable	31,107	67.8
Total			**45870**	**100**

4.1.3. Irrigation water supply comparison with suitable land demand

The total flow (supply amount) was computed for dry season from the annual monthly flow amount, based on selected major crops (wheat) full growth stages and considering wheat irrigation period from December 15 to June 14. The result obtained was about 7.964 Mm^3 as shown in appendix-E, table E (2).

By taking both NIR and GIR (appendix-E, table E (1), the supply amount can satisfy only about 3360 ha. in average. Where NIR is net irrigation requirement without any losses of irrigation water (assuming 100%) conveyance efficiency, while, GIR is gross irrigation requirement, assuming irrigation water losses due to conveyance efficiency, where the conveyance efficiency in the study area was determined to be about 55% (Section 4.2, table-4.10).

According to irrigation water requirement / irrigation water demand and supply assessment result shown in appendix-E ,table E(1) and table-E(2), to satisfy the irrigation water demand of these identified suitable area (14763 ha) about 34.996 Mm^3. However, the total irrigation water supply computed from hydrological data was about 7.964 Mm^3 as computed for full growth stages of selected major crop of wonchi district (wheat) during its assumed irrigation period as shown in appendix-E, table E(2).

This result showed that the irrigation water supply amount was 19 % as compared to the irrigation water demand which comprises 81% as shown in figure 4.9 bellow.

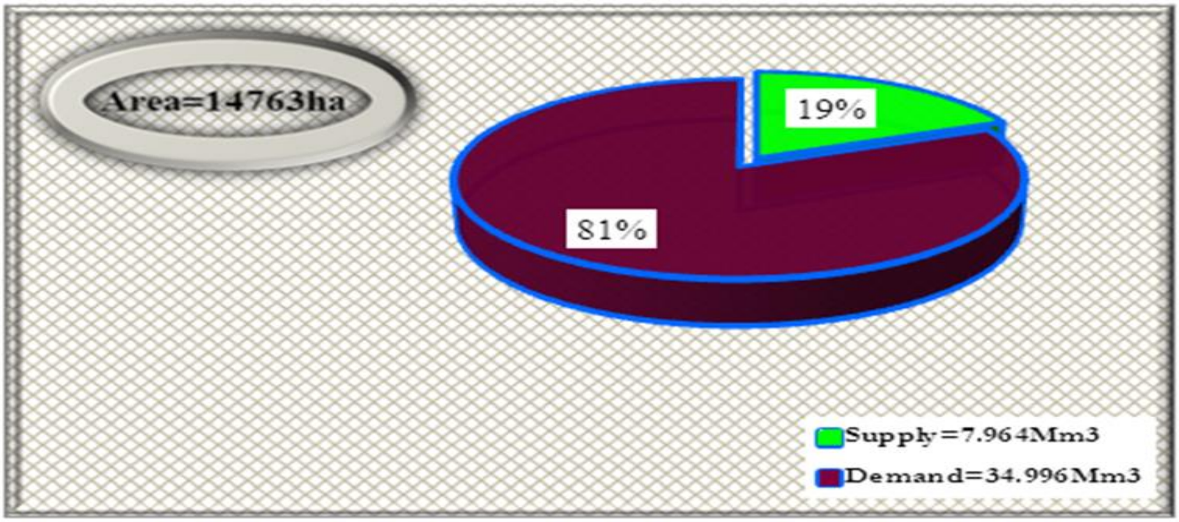

Figure 4.9: Irrigation water supply comparison with suitable land demand

These result revealed that water resource is the limiting factor as compared to identified land resource suitable for irrigation in wonchi district.

4.2. Irrigation water supply systems efficiency determined

For determination of canal conveyance efficiency four distributary canals were selected from Gunjo and Walga irrigation project command areas. Both lined and unlined canals were selected from each of Walga and Gunjo irrigation project sites. Lined distributary canal selected from walga irrigation project was coded by WLC-01.and unlined canal was coded by WUC-02,while both lined and unlined distributary canals selected from Gunjo irrigation Project were coded by GLC-01 and GUC-02 respectively. The location of selected distributary canals was shown in fig-9.10, and their design specification was shown in table 4.7bellows.

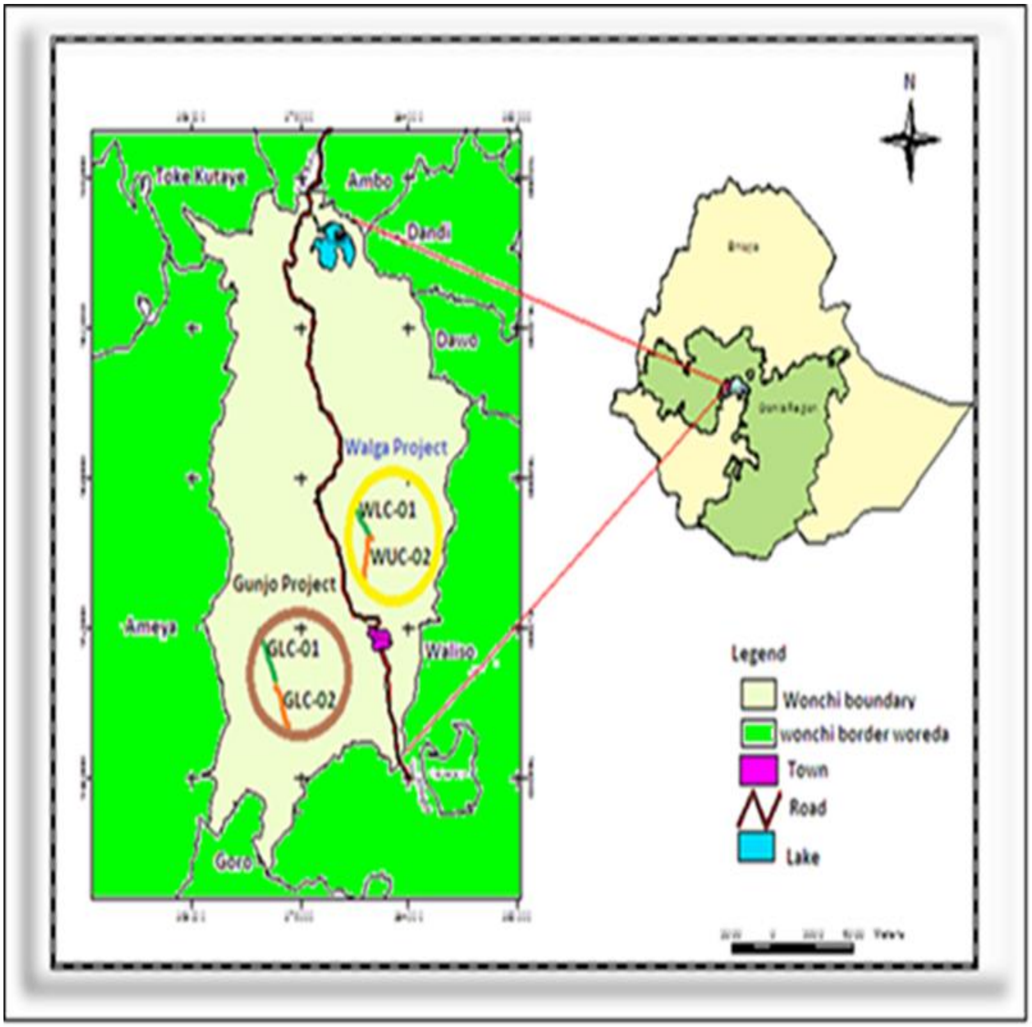

Figure 4.10: Location of selected distributary canals.

Table 4.7: Design specification of selected distributary canals

Distributary canal	Designed discharge (l s^{-1})	Total length (m)	Average water depth (m)	Average bottom width (m)
WLC-01	39	850	0.30	0.55
WUC-02	39	1200	0.20	0.60
GLC-01	31	700	0.25	0.50
GUC-02	31	900	0.15	0.60

4.2.1. Measured discharge

The result of measured discharges from selected four distributary canals were shown in table 4.8 bellow.

Table 4.8: Discharge measured in the distributary canals.

Distributary canals	**Inflow rate (L S^{-1})**	**Out flow rates (L S^{-1})**	**Section length (m)**
WLC-01	31.56	28.32	250
WUC-02	27.21	16.03	290
GLC-01	26.67	25.12	300
GUC-02	24.07	12.72	305

4.2.2. Determined canals conveyance efficiency and water losses

Both measured water losses and conveyance efficiency of unlined and lined distributary canals selected from Walga and Gunjo irrigation project sites were shown in table 4.9.

Table 4.9: Water losses and conveyance efficiency in the distributary canals

Distributary canals	Loss (L S^{-1})		Percentage loss		Conveyance efficiency (%)
	per selected canal length	per 100m	(Per 100m)	Total loss	
WLC-01 (Lined)	3.24	1.30	4.10	10.27	89.73
WUC-02 (Unlined)	11.18	3.86	14.19	41.09	58.91
GLC-01 (Lined)	1.55	0.52	1.95	5.81	94.19
GUC-02 (Unlined)	14.35	4.71	19.57	47.15	52.85

.

The average water losses at lined distributary canal coded,WLC-01,was assessed as 1.3 L/s per 100 meter length of the canal (4.1% of flow per 100 meter length).The average losses of the water at the other lined distributary canal coded GLC-01 was 0.52 L/s per 100meter length of the canal (1.95%) of flow per 100meter length. The total losses of water over the total

Length of the two lined distributary canals were 10.27% and 5.8% for walga lined canal (WLC-01) and for Gunjo lined canal (GLC-01) respectively.

However, the average water losses at un lined distributary canal coded,WLC-02,was assessed as 3.86 L/s per 100 meter length of the canal (14.19% of flow per 100 meter length).The average losses of the water at the other un lined distributary canal coded GLC-02 was 4.71L/s per 100meter length of the canal (19.57%) of flow per 100meter length. The total losses of water over the total length of the two un lined distributary canals were 41.09% and 47.15% for walga unlined canal (WLC-02) and for Gunjo unlined canal (GLC-02) respectively. Similarly the conveyance efficiency of lined distributary canals was assessed as 89.73 % and 94.19 % for WLC-01 and GLC-01; while 58.91% and 52.85% for WUC-02 and GUC-02 respectively. Different losses contributed to the total losses from both unlined and lined canals were determined as appendix Table F (4) and the result obtained was compared shown in table 4.10 below.

4.2.3. Comparison of irrigation water supply systems efficiency

Comparison of water losses and Conveyance efficiency of lined and unlined distributary canals were shown in table 4.10 bellow.

Table 4.10: Comparison of lined and unlined canals conveyance efficiency and water losses.

Distributary canals	Conveyance Efficiency (%)		Canals water losses (%)					
			Total losses		Et ,loss		Seepage loss	
	Lined	Unlined	Lined	unlined	Lined	unlined	lined	Unlined
WLC-01 (Lined)	89.73	-	10.27	-	0.00	-	10.27	-
WUC-02 (Unlined)	-	58.91	-	41.09	-	0.00	-	41.09
GLC-01 (Lined)	94.19	-	5.81	-	0.00	-	5.81	-
GUC-02 (Unlined)	-	52.85	-	47.15	-	0.00	-	47.15
Average	**91.96**	**55.88**	**8.04**	**44.12**	**0.00**	**0.00**	**8.04**	**44.12**

Comparison of total losses and conveyance efficiency between lined and unlined distributary canals, it was determined that 8.04 % of water was lost when distributary canals were lined and 44.12% was lost when distributary canals were unlined .The evaporation loss from both unlined and lined canals were determined to be zero (nill),from both unlined and lined canals; while seepage loss was determined to be about 44.12% from unlined canals and 8.04%% seepage loss was determined from lined canals.

This indicated that irrigation water loss in the area is due to seepage loss and the difference total losses and conveyance efficiency between lined and un lined canals was determined to be 36.068%.This revealed that lining reduced water losses by 36.08% and increased canal conveyance efficiency by 36.08%.

5. Conclusions and recommendations

5.1. Conclusions

The study was conducted to assess irrigation potential and irrigation water supply systems efficiency of wonchi district. Irrigation potential was evaluated in terms of surface water and land resources potential. While irrigation water supply systems efficiency was evaluated in terms of unlined and lined canals conveyance efficiency and water losses. Surface water potential were determined based on rivers discharge measurement using area velocity method and irrigation water supply potential was determined from surface water resource potential, based on irrigation and major crop growth stage period.. Suitable land of the study area was determined from land resource irrigation suitability analysis using GIS spatial analysis tools. Conveyance efficiency and water losses of unlined and lined canals were determined using inflow and out flow method, based on canal discharge measurements.

Accordingly, from water resource analysis, the total surface water potential of wonchi district was determined to be about 406.22 Mm^3 per year. The total irrigation water supply potential, used for irrigation during dry season was determined to be only about 7.964 Mm^3 (2%) of the district total surface water potential. This result revealed that water potential decreased during dry season (during irrigation period) and about 98% of the district water potential was available when irrigation was not practiced (during wet season).Irrigation water supply potential determined can satisfy irrigation water demand of only about 3360 ha of suitable land area.

From land resource irrigation suitability assessment, 14763 ha, land area was determined to be suitable for irrigation. To satisfy this suitable land area irrigation water demand, about 34.996 Mm^3 irrigation water was required. These supply and demand result comparison showed that the ratio was 19 % to 81% respectively. This showed irrigation water supply potential is the limiting factor as compared to determined land suitable land for irrigation. in won chi district. Similarly, irrigation water supply systems efficiency evaluated result revealed that conveyance efficiency of unlined canal was determined to be 55.88% and that of lined canal was 91.96%.From these results it was concluded that lining reduced water losses by 36.08% in won chi district.

In general, from the analysis result of the study, the following conclusions were drawn.

☞GIS model analysis approach is the most power full and economical tool to determine irrigation potential and to provide information for planners and irrigation developing stockholders..

☞From total area of wonchi district, 32.2 % was determined to be suitable, while 67.8% was unsuitable for irrigation.

☞Irrigation water supply potential of wonchi district during irrigation period was determined to be 2% of the total district yearly surface water potential.

☞Water potential decreased during irrigation period and irrigation water supply potential was determined as the limiting factor as compared to identified suitable land for irrigation in wonchi district.

☞About 98% of the district water potential can be collected during wet season and used for irrigation supplement during dry season (during irrigation period).

☞Comparing the average 44.12% of water loss from unlined to the average water loss of 8.04% from lined canal, it was estimated that lining reduced water loss by 36.08%.

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5.2. Recommendations

Based on the results of this study the following points were recommended for further consideration:.

♦The reliability of the analysis results depends on the GIS data set used for the analysis. For land resource irrigation suitability assessment, data sets used for the analysis was spatial data sets with high resolution due to absence of recent spatial data sets with smaller resolution . So, for further study, it is recommended to use recent spatial data with smaller resolution if available for better reliability.

♦Surface water resource and irrigation water potential was assessed using one year's hydrological data, due to lack of more years gauged hydrological data. This might underestimate or overestimate the analysis result. But more years' gauged hydrological data is recommended further, for better reliability.

♦From the analysis, 14,763ha (32.2%) of the total district area was determined to be suitable for irrigation. However, irrigation water potential estimated during dry season was too low to satisfy determined suitable land area .So it, is recommended to utilize suitable land resource in won chi district by increasing irrigation water supply potential.

♦Irrigation water supply potential in won chi district, during dry season was determined to be about 2% of the district total surface water potential .This shows 98% of the district total surface water potential was available during wet season. So, it is recommended to increase, irrigation water supply potential of wonchi district during dry season (during irrigation period) by collecting the district surface water run off during the wet season.

♦Besides to surface water run off collection during wet season, lining irrigation water conveying canals is recommended to increase irrigation water supply potential

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Appendices

Appendix-A: Hydrological data

Table A(1): Summary of Major rivers flow condition of wonchi district**.**

Name of rivers	Monthly flow (m^3/s)												Average annual flow (m^3/s)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Gunjo	0.84	1.08	1.32	1.32	2.52	5.41	4.7	3.72	2.52	1.2	1.44	0.12	**2.18**
Dedebia	1.32	1.44	1.56	1.92	4.28	6.16	3.9	2.08	2.16	2.4	1.56	1.44	**2.51**
Walga	2.04	2.04	2.28	2.52	1.56	9.27	7.19	4.8	2.2	2.92	2.28	1.56	**3.39**
Barochu	0.48	0.72	1.08	1.44	1.68	4.18	3.1	3.4	2.04	1.94	1.56	0.6	**1.85**
Amagna	0.72	1.08	5.08	1.2	6.84	7.2	6.9	2.64	1.96	1.2	2.52	0.24	**3.13**
Total	**5.4**	**6.36**	**16.32**	**8.4**	**11.88**	**32.22**	**25.79**	**16.64**	**10..88**	**9.66**	**9.36**	**3.96**	**13.06**

Appendix-B: Land suitability description.

Table B(1): Land Suitability Classification Levels description

Order	**Class**	**Name**	**Definition**
S		Suitable	The land can support the land use. Benefits justify inputs without unacceptable risk of damage to land resources.
	S1	Highly Suitable	Land without significant limitations. The potential yield level expected is 85% or more of optimum yield.
	S2	Moderately Suitable	Land having limitations that either reduce productivity or increase the inputs needed to sustain productivity levels compared with those needed on S1 land. The potential yield level expected is 60-85% of the optimum yield.
N		Unsuitable	Land that cannot support the land use sustainable, or land on which benefits do not justify inputs

Source: FAO, (1983)

Appendix-C: Crop data

Table C(1): Major Crops of wonchi district.

Major Crops	Area coverage of the total Production		Rank
	In hectare (ha.)	**In (%)**	
Wheat	6731	23.4	1
Enset	6154	21.4	2
Barley	5515	19	3
Teff	5458	19	4
Maize	2510	8.7	5
Bean	1831	6.4	6
Vetch	197	0.7	7
Pea	170	0.6	8
Haricot pea	146	0.5	9
Sorghum	35	0.2	10
Potato	27	0.1	11
Total	**28774**	**100**	

Source:Wonchi district agricultural development office.

Table C(2): Different crops coefficients **(kc)** at their different growth stages.

Crops	Initial	Crop development	Mid-season	Late & harvest
Barley	0.35	0.75	1.15	0.45
Bean	0.35	0.7	1	0.9
Cabbage	0.45	0.75	1.05	0.9
Carrot	0.45	0.75	1.05	0.9
Cotton	0.45	0.75	1.15	0.75
Cucumber	0.45	0.7	0.9	0.75
Lettuce	0.45	0.6	1	0.9
Maize	0.4	0.75	1.15	0.75
Onion	0.5	0.75	1.05	0.85
Pea	0.45	0.8	1.15	1.05
Pepper	0.35	0.75	1.05	0.9
Potato	0.45	0.75	1.15	0.75
Sorghum	0.35	0.75	1.11	0.65
Sugar beet	0.45	0.8	1.15	0.8
Tomato	0.45	0.75	1.15	0.8
Wheat	0.35	0.75	1.15	0.7

Source : FAO ‘56’ (Richard 1998)

Table C(3): description of duration (days) required for each crops growth stages

Crops	**Crops growth stages**				**Total days**
	Initial	**Crop development**	**Mid-season**	**Late and harvest**	
Barley	15	30	65	40	150
Bean	20	30	40	20	110
Maize	20	35	40	30	125
Teff	15	30	65	40	150
Pea	20	25	35	15	95
Potato	25	30	30	20	105
Sorghum	20	30	40	30	120
Tomato	25	40	40	25	130
Wheat	15	30	65	40	150

Table C(4): Description of crops growth stages

Crop development stages	Distinguishable characteristics
Initial stage	This is a period from sowing or transplanting through germination and plant emergence until about 10 % ground cover is achieved. Water loss is practically all evaporation at this time
Crop development	This period starts from the end of initial stage to attainment of effective full ground cover (ground cover ≅ 80 %
Mid- season stage	This period starts at the end of crop development stage to the time of start of maturing /ripening/ of a crop as indicated by discoloring of leaves or leaves falling off. The crop is physiologically capable of the highest water use during this time. The crop coefficient is highest.
Late- season stage	This period starts at the end of mid- season stage until full maturity or harvest of a crop.

Appendix-D: Metrological data

Table D(1): Rain fall data of wonchi district

Year	Rain fall (mm) in Months of the Year												Annual
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	
2005	130	0	118	140	96	134	235	168	140	173	75	0	1409
2006	0	113	157	70	163	180	167	272	110	48	81	0	1361
2007	45	150	81	57	188	191	230	160	138	38	0	0	1278
2008	0	0	16	121	203	163	121	322	221	84	248	0	1499
2009	39	8	133	63	88	104	130	185	83	100	0	40	973
2010	23	47	54	74	165	130	165	230	134	0	0	25	1047
2011	25	0	45	150	115	133	155	174	135	0	85	0	1017
2012	0	0	115	101	135	95	123	146	165	5	0	11	896
2013	0	0	150	135	130	235	135	122	133	94	0	0	1134
2014	36	15	40	143	115	305	141	90	191	32	25	0	1133
2015	0	0	74	149	110	283	165	115	122	1	15	0	1034
Mean	**27**	**30**	**89**	**109**	**137**	**178**	**161**	**180**	**143**	**52**	**48**	**7**	**1162**

Table D(2): Climate data of won chi district

Months	Temperature (°C)		Humidity (%)	Wind speed (m/s)	Sun shine hours(hr.)
	Min	Max			
January	10.8	29.4	62.1	2.9	2.7
February	12.3	30.7	65.2	3.8	6.7
March	11.9	29.6	62.6	2.3	7.2
April	11.9	30.1	79.6	2.4	7.5
May	11.4	29.3	88.9	1.5	6
June	11.1	26.5	92	0.9	6
July	11.3	24.9	94.5	0.8	2.6
August	10.8	23.9	93.5	0.7	4.1
September	9.8	26.5	94.2	1.1	5.3
October	9.2	27.8	75.5	2	7.7
November	10.7	28.4	63.9	3.5	8.7
December	10.5	28.1	61.7	4.4	9.4

Appendix-E: Irrigation water demand and supply potential of wonchi district

Table E(1): Crop water requirement and irrigation water requirement of wonchi district

Months	Decade	Stage	Eto/Dec (mm)	Crop Cofficient (Kc)	Etc/Dec (mm)	Peff/Dec (mm)	NIR/Dec (mm)	GIR/Dec (mm)
Dec	1	int	43.5	0.35	15.225	-3	18.2	33.1
Dec	1	Dev	2.3	0.75	1.725	0.2	1.5	2.8
Jan	2	Dev	92.8	0.75	69.6	7.7	61.9	112.5
Jan	1	Mid	3.2	1.15	3.68	0.3	3.4	6.1
Feb	2	Mid	81	1.15	93.15	47	46.2	83.9
Feb	3	Mid	87	1.15	100.05	63	37.1	67.4
Mar	4	Mid	9.2	1.15	10.58	11.5	0.0	0.0
Apr	1	lat	80.6	0.7	56.42	74.5	0.0	0.0
May	2	lat	40.6	0.7	28.42	55.1	0.0	0.0
Total					**378.85**	**256.3**	**168.3**	**305.8**

Table E(2): Irrigation water supply potential of wonchi district

Months	Decade	Stage	Flow discharge computed (Supply amount) in Mm^3/Dec
Dec	1	int	0.171
Dec	1	Dev	0.016
Jan	2	Dev	0.531
Jan	1	Mid	0.018
Feb	2	Mid	1.41
Apr	3	Mid	0.726
Mar	4	Mid	0.252
Apr	1	lat	1.638
May	2	lat	3.202
Total			7.964

Table E(3): Irrigation water demand for Suitable land area determined (14,763ha.)

Months of growth stages	Irrigation demand for the area identified (irrigation requirement) in Mm^3	
	NIR	GIR
Dec	2.687	4.887
Jan	0.221	0.413
Feb	9.64	17.509
Mar	6.821	12.386
Apri	5.477	9.95
May	0	0
Total	**24.846**	**45.145**

Appendix F: Canals water potential, and water losses calculated

Table F (1): Canals total water potential during irrigation period and wheat growth stages

Distributary Canals	Canals flow discharge(L/s)		Average canals flow (potential)		
	Inflow	Outflow	In (L/s)	In (m3/s)	Mm3/150days
(A)	(B)	(C)	(D)	(E)	(F)
WLC-01	31.56	28.32	29.94	0.03	0.4
WUC-02	27.21	16.03	21.62	0.02	0.3
GLC-01	26.67	25.12	25.9	0.03	0.3
GUC-02	24.07	12.72	18.4	0.02	0.2
Total					1.2

Table F (2): ET calculated for months of wheat growth stages and irrigation period

Months	Days of growth stage per months	Eto (mm/day)	Et(mm)
(G)	(H)	(I)	(J=H*I)
Dec	16	2.9	46.4
Jan	30	2.3	69
Feb	30	3.2	96
Mar	30	2.6	78
Aril	30	2.9	87
May	14	2.3	32.2
Total			**409**

Table F (3): Evaporation losses from distributary canals

Distributary canals	Average canals water depth(m)	Average canals water width(m)	Et(m)	ET(m3)
(K)	(L)	(M)	(N)	(O=L*M*N)
WLC-01	0.3	0.55	0.409	0.07
WUC-02	0.2	0.6	0.409	0.05
GLC-01	0.25	0.5	0.409	0.05
GUC-02	0.15	0.6	0.409	0.04
Total				**0.20**

Table F (4): Canals water losses

Distributary canals	Potential(Mm3)	Conveyance efficiency (%)	Losses		
			Total loss (%)	ET losses (%)	Seepage losses
(P)	(Q)	((R=(C/B)* 100))	(S=100-R)	((T=(O/Q)*100))	(U=S-T)
WLC-01	0.4	89.73	10.27	0.0000	10.27
WUC-02	0.3	58.91	41.09	0.0001	41.09
GLC-01	0.3	94.19	5.81	0.0000	5.81
GUC-02	0.2	55.85	47.15	0.0002	47.15