Evaluation of Groundwater Level Variations Under Surface Irrigated Scheme: A Case Study of Wonji shoa Sugar Estate.

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A Thesis Submitted to Water Resources Engineering department,

School of Civil Engineering and Architecture

Adama Science and Technology University

Adama, Ethiopia

September 2018

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A Thesis Submitted to Water Resources Engineering Department,

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Presented in Partial Fulfillment of the Requirement for the Degree of Masters in Irrigation Engineering

Office of Graduate Studies

Adama Science and Technology University

Adama, Ethiopia

September 2018

APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Amenu Tadessa Abdisa have read and evaluated his thesis entitled "Evaluation of Groundwater Level Variations Under Surface Irrigated Scheme: A Case Study of Wonji shoa Sugar Estate" and examined the candidate. Therefore, this is to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Master in Irrigation Engineering.

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DECLARATION

I hereby declare that this MSc Thesis is my own original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

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To**:** Water Resources Engineering Program

Subject: Thesis Submission

This is to certify that the thesis entitled *"*Evaluation of Groundwater Level Variations Under Surface Irrigated Scheme: A Case Study of Wonji shoa Sugar Estate*"* submitted in partial fulfillment of the requirements for the Degree of Master's in Irrigation Engineering, the Graduate Program of the Program Water Resources Engineering, and has been carried out by Amenu Tadessa Abdisa Id. No GSR/0008/09, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby he can submit the thesis to the program for further evaluations.

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DEDICATION

This thesis is dedicated to my mother, Maritu Abdisa and my fatherTadessa Abdisa, those who had impatient desire to see my Success.

BIOGRAPHICAL SKETCH

The author, Amenu Tadessa Abdisa was born on July 1991, in Nedjo Woreda West Wollega Zone of Oromia National Regional State. He attended his primary education at Yembal Gara Oli Primary School and Senior Secondary School at Nedjo Senior Secondary School. Following the completion of his high school education, he joined Adama Science and Technology University, in 2011 to pursue tertiary education and graduated with the degree of Water Resources and Irrigation Engineering in July, 2016. In campaign 2017 he joined the School of Graduate Studies at Adama Science and Technology University to study for the degree of Master of Science in Irrigation Engineering.

ACKNOWLEDGMENTS

Above all, I would like to praise, honor and glorify the Almighty God. God have given me the opportunity, strength, peace, and health to successfully complete this piece of work and for the inexorable support in my overall life.

I would like to express my deep hearted gratitude to my Major Advisor, Dr. Abel Tadesse and my Co-Advisor Mr. Nafyad Serre Kawo for providing me with their genuine guidance, constructive comments and encouragements to finalize the time-taking research work.

I would like to give my unreservedly acknowledge to Wonji Shoa Sugar factory management members: (Mr. Demissew Tsega, Ato Mengistu Mosie, Ato Tulu Lema, Ato Gezahgn Felek for providing and facilitating me with the material support for my study on behalf of the Wonji Sugar Factory).

I would like to give my unreservedly acknowledge to Ato Abinet Shumi those who gave a lot of their contribution for my research works especially by giving transport service like motor cycle and car. I would like to thank Ato Gemechis Dereje, Ato Miresa Zewude, Ato Emiru Diriba and Ato Benti Dejene those who helped me during the collection of data and measurement.

The last but not the least, heartfelt thanks to Emanuel Dereje for his financial support and for his initiation for the completion of this research work.

LIST OF ACRONYMS AND ABBREVIATIONS

%	Percentage
f_c	Constant Infiltration
f_o	Initial Infiltration
A	Area
EPDF	Ethiopian People's Revolutionary Democratic Front
ESC	Ethiopian Sugar Corporation
ESCRT	Ethiopian Sugar Corporation Research and Training
F	Field
FAO	Food and Agriculture Organization
g	Gram
GPS	Geographic Positioning System
GRDC	Grain Research and Development Corporation
GW	Groundwater
GWT	Groundwater Table
GWTD	Groundwater Table Depth.
Ha	Hectare
HDC	Horticulture Development Corporation
Hr.	Hour
IR	Infiltration Rate
km	Kilometer
Km^2	Square Kilometer
l	Liter
l/s	Liter per Second
LULC	Land Use Land Cover
m	Meter
MER	Main Ethiopian Rift
ml	Milliliter
mm	Millimeter
mm/hr.	Millimeter per Hour
Na_2CO_3	Sodium Carbonate

$NaPO_3$	Sodium Hexametaphosphate
NSR	Night Storage Reservoir
^oC	Degree Celsius
PVC	Polyvinyl Chloride
T	Time
UNESCO-EOLSS	United Nations Educational, Scientific and Cultural Organization-Encyclopedia of Life Support Systems
USDA	U.S. Department of Agriculture
UTM	Universal Transverse Mercator
V	Volume
WSSE	Wonji-shoa Sugar Estate
WSSF	Wonji-shoa Sugar Factory
WTF	Water Table Fluctuation

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ABSTRACT

The present study attempted to evaluate groundwater level variations under surface irrigated scheme *of Wonji-Shoa Sugar Estate (WSSE), Upper Awash Valley of Ethiopia. The recent level of GWTD was measured at the field from May to July. Groundwater table depth measuring in 2018, using previous installed piezometer tubes and the infiltration rates of the soil in the study area is estimated using double ring infiltrometer and also the soil texture of the field was analyzed using hydrometer method. This study clearly showed that the GWTD at WSSE was extremely shallow. From the current studies the mean average GWTD of the study area ranged between 0.54 m and 0.62 m; thus, all plantation fields were classified to be shallow (waterlogged). From current soils result analyzed, shallow ground water table can be observed mostly in the field having clay soil which is southern part of the study area especially F-163 (Figure 3.1).Compared to local precipitation, irrigation water has a major impacts in groundwater recharging in the irrigated area. The monthly ground water table depth responses of the 8 piezometers, observed at different parts of the plantation field were recorded during the observation period and the GWTD varies from 0.1 m (F-133) and 1.85m depth (F-135). The irrigated fields F-50 and F-135 have relatively deep GWT depths; whereas the irrigated fields F-24, F-63, F- 207, F-66, F-101 and F-163 have relatively shallow GWT (Appendix table 8). GWTD during rainy season was increased by 5% from May to June and 8% from June to July. As a result, the major causes of groundwater levels came from the excess irrigation water especially absence of proper central drainage structures, an old earthen canals and over irrigation water without considering the infiltration capacity of the soil and soil texture. The measuring of GWTD with estimated soil infiltration rates area, indicated in the current study, is believed to provide a tool for water management and, hence, crucial for the decision making and actions taking processes. In most field, unfunctional piezometers have been abandoned, but, these piezometers would have substantial importance for groundwater levels study. Thus, protection and management of piezometers is highly recommended.*

Keywords***:*** Groundwater levels, Piezometers, Infiltration, waterlogging impact

1. INTRODUCTION

1.1. Background

Irrigation is the artificial application of water to the soil usually for increasing productivity of the crops. In crop production, irrigation is mainly used to replace missing rainfall in periods of drought, but also to protect plants against frost. At the global scale, approximately 2 788 000km^2 of agricultural land is equipped for irrigation. 68% of this area is located in Asia, 17% in America, 9% in Europe, 5% in Africa and 1% in Ocean. Most of this vast area is gridded by irrigation canals (Carlos, 2009). FAO (1995) in Haile Gabriel (2007) stated that river basin development planning has been widely adopted in Africa, and often enough water resource development has come to be synonymous with river basin development.

Ethiopia has twelve major river basins and one of the major 12 river basins is Awash River. It is part of the Central Rift Valley in Ethiopia ranging from 8.5°N to 12°N and covering an area of about 112,696 km^2. The basin covers the central and northern part of the rift valley and is bounded to the west by Blue Nile Basin, to the southeast by Rift valley Lakes Basin and to the south by Wabi Shebelle Basin. It originates from Central West part of Ethiopia, flowing 1200 Km long, and provides a number of development opportunities to the country. It is the most intensively utilized river basins in the country. Awash River originates and remains entirely in the country. The river basin has a lowest elevation of 210 m and a highest elevation of 4195 m. The total mean annual flow of the river is estimated to be 4900 million cubic meters per year (Ayana et al., 2015).

The Awash basin is the most developed area with more than 60% of the potential irrigable area has been developed. In the Upper Awash valley the Ethiopian sugar corporation (ESC) intensively utilizes most its developed land. The horticulture development corporation (HDC) farms in the upper valley suffer some shortfalls in developed land use and efficient water utilization, apparently constrained by shortage of labor, machinery and sometimes water. The ESC at Wonji-shoa and Matahara are the dominant state farms pre-existed and holds the major portion of irrigable land (Berhanu, 2008).

In irrigation sites where furrow irrigation method is used, knowledge of hydrological systems of the area including the mode of interaction between surface waters and the aquifer system is important to avoid possible environmental risk. This requires awareness of the hydrogeological setting including the configuration and characteristics of aquifer geometry and hydraulic properties of formation underlying the irrigation site. One important issue traditionally overlooked in furrow irrigation method is the interaction between irrigation water and groundwater (Wakgari et al., 2010).

For the last 60 years, WSSE has been producing sugar (white and brown) at the expense of sustainable use of available land and water resources; currently faced with negative externalities. The main factor challenging the sustainability of the sugar estate is the rise of ground water table depth (GWTD) to the crop root zone. GWTD is a dynamic variable both in space and time. Shallow GW levels tend to fluctuate at greater frequency and extent compared to deep ones. GWTD can fluctuate daily, seasonally, annually, and over long periods of time in response to a variety of conditions (variation of precipitation, climate change, rate of irrigation, and pumping). The dynamics of GWTD are mostly a reflection of the GW system to external factors (climate and human activities) and often a hydrological indicator of the state of ecology of the region (Dinka et al., 2013).

GWTD rises due to increasing GW storage from different sources, such as infiltration from rainfall, recharge due to stream seepage, canal infiltration and seepage surface flow. In irrigated areas, observing, diagnosis, and mapping of waterlogged areas are mandatory for proper management of the valuable water and land resources. Especially information related to the spatial and temporal variability of GWTD can be of great economic and environmental importance. Water managers, therefore, should be informed about the variation of GWTDs in both space and time. Observing and evaluating GWTD in irrigation areas is important in order to observe changes of the GWTD due to excess rainfall and irrigation, determine the vulnerable areas and make proper irrigation planning. The rate of annual increment of GW rise, coupled with seasonal fluctuation, has obvious repercussions and grave consequences for the sustainability of WSSE in particular and to the region in general.

As Smith (2008) sated in Wakgari (2011), if groundwater level grows exceedingly beyond its natural flow, groundwater flooding will be inevitable.

This can cause difficult and unhealthy environment that enhance ecological and environmental damage. Likewise, if the shallow groundwater at Wonji wetland continues growing, land flooding by groundwater will take place that result in loss of the productive lands. The major cause for the rise of GWTD in the area is an intensive use of furrow irrigation system for long periods of time, coupled with poor drainage systems. Groundwater rising to the crop root zone is one of the most unfavorable effects of irrigation projects, which occur slowly, and its problem tends to emerge over years (Getahun et al., 2013).

The adverse impacts of shallow GWTD to human health, environment, and crop production are well documented by different (local and international) literatures (Dinka et al., 2013). Depending on the previous conducted research and the current visible problems at Wonji Shoa sugar estate, this study may find out current level of groundwater in WSSF and also it may analysis the impacts of surface irrigation on groundwater levels.

1.2. Statements of the Problems

Most irrigation projects of more recent times nearly always received their water by diversion from rivers or from reservoirs and the main mechanism for the conveyance of water to farms is through earthen channels. The water losses which occurred in conveying water to the tertiary off takes via main, lateral, and sub lateral canals goes deep and causes ground water levels. Critical waterlogging and salinization problems occur which might have been the result of conveyance losses, over-irrigation and rising of groundwater table. The waterlogging in some sugar plantation irrigation fields of Wonji sugar estate have an effects on yield of sugar cane and the productivity of the estate. A better understanding of groundwater levels and recharge patterns in WSSE is critical for development in the estate and, as an analogue, for the country.
The effects of irrigation water on groundwater levels that may cause losses of valuable resource, halt environment and reduce yield. In irrigated areas, observing, diagnosis, and mapping of waterlogged areas are mandatory for proper management of the valuable water and land resource. Unless the potential causes for the rise of GWTD are identified and feasible corrective measures for mitigating GW rise are introduced, severe crises in the region are inevitable. The situation of GWTD at the WSSE calls for an urgent need to identify and understand the potential causes of waterlogging (Dinka et al., 2014).

Despite years of research and management efforts on the GWTD of the area by many researchers by installing piezometers, the increase in GWTD could not be recovered.

Therefore the present study is attempts to identify the groundwater level condition within the selected irrigated fields of Wonji sugar estate and analysis the effects of surface irrigation (furrow irrigation) on groundwater levels.

1.3. Significance of the Study

The information generated via this study will help in narrowing the information gaps regarding the impacts of surface irrigation on groundwater levels. It will also shed some light on the cause of waterlogging problem of the estate. Furthermore, it will provide useful for monitoring and evaluation of the GWTD with current condition of the field and it may shows the infiltration capacity of the soil that used as input to properly manage the irrigation water.

1.4. Objectives

1.4.1. Major objective

The general objective of this study is to analyze the effects of surface irrigation practices on groundwater levels in Wonji irrigated farm.

1.4.2. Specific objectives

The specific objectives of this study were:-

- To analyze infiltration rate and characteristics of the irrigated soil.
- To identify the groundwater level conditions and extent of fluctuations.
- To analyze surface irrigation water impacts on groundwater levels and recommend remedial measures.

1.5. Research Question

The research questions that were attempted to be answered from this study are:

- What is the infiltration rate of the soil in the study area?
- What are causes for rises of GWTD in study area?
- What is the expected major factor that cause waterlogging?

1.6. Scope of the Study

In the sugar estate surface irrigation schemes, this study focuses on impacts of surface irrigation water on groundwater levels, with special attention to identify the water table condition of the irrigation farm by using existing piezometer in the field. In this study full seasonal and yearly groundwater level information will not expected because of time and cost limitation. Also, this study will not take into account the estimation amount of conveyed water, crop water requirement, runoff, and groundwater levels that cause waterlogging due to absence of the designed irrigation data at Wonji shoa sugar estate.

2. LITERATURE REVIEW

2.1. Irrigation

Irrigation is fundamental for economic development and plays a vital role in improving the welfare of a society. However, irrigation is not always a blessing as it can create problems due to mismanagement of land and water, which results in salinization of land and water resources, as well as adverse environmental damage. Unpredicted environmental problems could arise when the consumptive water demand of crop and water supplies mismatch. This could cause abnormal hydrological flow situation such as rising of shallow groundwater table induced by excess recharge from irrigation, a condition which violates the natural recharge–discharge system of the watershed environment. According to Mohammad et al. (2004) and Kos (2008) in Wakgari et al. (2011) salinization, soil alkalinity, waterlogging, soil acidification, ecological degradation and change in groundwater level are the most common problems and threats attached to irrigation projects.

2.1. 1. Surface irrigation water loss

Surface irrigation is the oldest and most common method of applying water to crops. It involves moving water over the soil in order to wet it completely or partially. The water flows over or ponds on the soil surface and gradually infiltrates to the desired depth. Surface irrigation methods are best suited to soils with low to moderate infiltration capacities and to lands with relatively uniform terrain with slopes less than 2-3% (FAO, 1974). Surface irrigation is the most common method of irrigation and can be the most inefficient. This is not because it is poor technology; it is because of difficult to manage properly (Abdelmonem and Kamal, 2010**).**

Surface water irrigation has natural limitations imposed by a huge variability of yearly precipitation in arid and tropical zones. Groundwater based irrigation is mostly performed by wells penetrating unsystematically to different depth, thus touching unsystematically the active and passive groundwater recharge zone; on the long run this produces a disturbance of the natural flow regimes facilitating the access of contaminants into the depth, that would not occur by natural mixing processes.

Over irrigation aims at increasing agricultural production by providing dependable watering of crops during gaps in monsoon and during non-monsoon period. Whenever adequate drainage is assured and additional water source available it is mostly useful to give dual benefit of augmenting ground water resource.

But, Irrigation salinity occurs due to increased rates of leakage and groundwater recharge causing the water table to rise. Water requirements of crops are met, in parts, by rainfall, contribution of moisture from the soil profile, and applied irrigation water. A part of the water applied to irrigated field crops is lost in consumptive use and the balance infiltrates to recharge the groundwater. The process of re-entry of a part of the water used for irrigation is called return flow. Percolation from applied irrigation water, derived both from surface water and groundwater sources, constitutes one of the major components of groundwater recharge (Bhagyashri and Bhavana, 2011). Rising water tables can bring salts into the plant root zone which affects both plant growth and soil structure. The salt remains behind in the soil when water is taken up by plants or lost to evaporation. Recharge rates in irrigation areas can be much higher than dry land areas due to leakage from both rainfall and irrigation. This causes potentially very high salinization rates. Water tables within two meters of the soil surface indicate the potential for salts to accumulate at the soil surface. Inefficient irrigation and drainage systems are a major cause of excess leakage and increase the risk of salinity and waterlogging in irrigation areas (Dordevic, 2011).

2.1.2. Irrigation canals

Canals are man-made channels to divert or to distribute the available quantity of water to the farmlands. It is designed either lined canal or unlined canal. Lined canals and unlined canals both are manmade. The difference is that lined canal is lined with concrete, bricks or stone. Purpose is to avoid seepage of water through soil, where soil is made of sand. The canal lining becomes essential for stability of the canal banks in expansive soils. Continuous seepage from canals may cause serious waterlogging accompanied with salt accumulation, converting a once fertile land into a huge waste and spoil (Swamee et al., 2000).

On the other hand unlined canal is used to recharge the ground water through the seepage. Groundwater is recharged from, and eventually flows to the surface naturally; natural discharge often occurs at springs, seeps and can form oases or wetlands. Hence the canal has an impact on the groundwater recharge (Saha et al., 2014).

Canal are very effective to reduce the agricultural water demand in an area. Canals can carry water easily from source to the destination. However canals can lose its water between 10-40% due to losses (Kumar, 2017).

A system of irrigation canals which is also known as canal network transports water from its source to fields. The canal network comprising of main canal, branch canal, major & minor distributaries, field channels and water courses. In canals mainly two kind of losses take place, one is evaporation loss and another is seepage loss. As the canal water is exposed to atmosphere, evaporation losses also take place. In most of cases evaporation losses are not significant. The rate of loss of water mainly depends upon the temperature of a region, prevailing wind velocity of the region, humidity and area exposed to the atmosphere. Seepage loss is the most significant irrigation water loss from a canal (Khyati et al., 2016).

2.1.3. Waterlogging

Waterlogging soil means a soil saturated with water in the root zone. Also a soil is said to be waterlogging when the ground water table gets connected to soil water in the crop root zone and remains like this for the remaining period in a year. Groundwater rises lead to waterlogging and the related salinity problems in many irrigated lands around the world, which has happened where the pace of drainage development is not in balance with irrigation development, or where maintenance of drainage has largely been neglected (Getahun, 2015). It may be temporary, seasonal or permanent. Soil having permanent ground water near the surface is considered to be waterlogging. Waterlogging may or may not be associated with Salinity. Waterlogging may also occur as a form of standing water in the farm, which does not lower with time (Jose et al., 2009).

Waterlogging may also occur as a form of standing water in the farm, which does not lower with time (Saha, 2015). Waterlogging is often compounded by soil compaction. However, reduced tillage and permanent bed systems may alleviate soil compaction and the severity of waterlogging. Cloudy weather associated with wet seasons may enhance the waterlogging effect as well as the incidence of some cotton diseases.

Low rates of evaporation and reduced radiation (sunshine) may encourage waterlogging and reduction in yield. Monitoring, diagnosis and mapping of waterlogged area in irrigated agriculture is a perquisite for management of valuable land resources.

Groundwater table monitoring can indicate whether the groundwater table depth is rising, falling or remaining static and hence, used to identify the areas at risk of soil salinization. A rising trend of GWT under irrigated agriculture can provide an early indicator of an increased risk of soil salinity and vice versa.

A rise in groundwater results when irrigation induced recharge is greater than the natural discharge (Musa, 2009).

There are three basic requirements for waterlogging to occur in the root zone of plants; supply of water sufficient to produce saturation of the soil within the root zone, mechanisms and physical characteristics by which water is supplied and retained within the root zone, adequate time for saturation of the plant roots to produce anaerobic conditions and associated changes in biological and chemical activity which is detrimental to plant health (El-Nashar, 2013).

2.2. Surface irrigation water losses

As Erhan et al. (2007) stated in Yosuf (2015) conveyance losses were reported as the difference between the volume of water supplied to irrigation customers and water delivered to the system; and it takes the following forms; outfall or water flowing out of the downstream end of delivery systems, unrecorded usage, seepage, leakage, evaporation and others. The most important of these are seepage and leakage. Seepage is the movement of water through the beds of irrigation channels while leakage is the loss of water from channels through channel banks and structures. Bothe together called canal conveyance losses. Balaban (1970) in Akuzzuu (2008) stated that the problems resulting from water conveyance loss due to seepage in canals are divided into two groups. The first is prodigality of water, which is obtained at a high cost and with difficulty from various sources. The second is the problem of drainage, salinity, and alkalinity, which result from a rising water table.

Tariq (2014) defined that Seepage is the process of movement of water from the bed and sides of the canal into the soil. And also seepage in irrigated agriculture has been defined as the movement of water in or out of earthen irrigation canals through pores in the bed and bank material.

There are many factors that affect seepage from canals: texture of the soil in the canal bed and banks, water temperature changes, siltation conditions, bank storage changes, soil chemicals, water velocity, microbiological activity, irrigation of adjacent fields, and water table fluctuations. Current meter was used to collect discharge measurements from several locations and inflow-out flow technique was applied to estimate seepage and leakage losses.

Seepages from fine textured or clay soils of selected primary, secondary, and tertiary canals while leakages from division structures, gates, broken canals and over flow on top of canals were determined (Yosuf, 2017).

The losses from canals need to be minimized to ensure the efficient performance and effective utilization of water. Seepage loss is one of the major components of water loss from canals. Seepage rates are obtainable either by direct measurement or by estimation. Measurement of seepage from large canals by ponding method is practically impossible due to continuous running and large widths of canals (Uchdadiya & Patel, 2014).According to Akbar (2003) expressed in Yosuf (2015), factors determining the amount of seepage in an unlined canal can be classified as the following four groups: soil and lining characteristics; geometry and hydraulics of the canal; sediment characteristics and Service year of the canal.

The only means of preventing seepage from canals is to install a suitable lining. It must be said, however, that linings are not always in-stalled to prevent seepage, since a lining may be necessary to minimize maintenance for a canal that is subjected to the tramping of cattle or the destructive action of gophers, but, except for these special cases, linings are installed to minimize seepage. However, the goal may not be to conserve water but to prevent waterlogging of adjacent productive land. For instance, on the Riverton project, a section of the canal was lined with an impervious material, although the quantity of water seeping from this channel was an insignificant factor. But, the adjacent area did not have drainage; hence, any quantity of seepage water, no matter how small, would eventually waterlog the land (Wei, 2011).

Leakage losses were occurred due to malfunctioning or failure of off take structures, division structures and gates; overflow of irrigation water on top of damaged canals; and abstraction of water by unauthorized users for household consumptions. Most of irrigation structures are either not present or not functioning properly.

It is common to see canal breaches; muds and woods are serving as water controlling structures and; considerable amount of water flowing into drains. Flow of large amount of unmanaged water into drains were significant when visually compared to seepage losses (Yosuf, 2015).

2.3. Storage Reservoirs

Reservoir is a natural or artificial place where water is collected in great amount and stored for use, especially for supplying a community, irrigating land and furnishing power. Storage of water is released from the reservoir through canals for cultivation (Tomac, 2014). Dordevic (2011) analyzed that the main positive and negative impacts of reservoirs on the environment. The most important are: the improvement of hydrological regimes (decreasing maximal and increasing minimal flows), the creation of optimal water management, utilization and protection of water, and the creation of better conditions for river and coastal ecosystems. Negative impacts and measures for its mitigation or elimination are also on the riparian area as a result of changed groundwater regimes. This impact is especially visible at reservoirs on alluvial rivers, with low riparian area.

2.4. Groundwater

Groundwater refers to all the water occupying the voids, pores and fissures within geological formations, which originated from atmospheric precipitation either directly by rainfall infiltration or indirectly from rivers, lakes or canals (Ojo et al., 2012). Also according to Chilton (1992) stated in Ojo et al. (2012) Groundwater is a valued fresh water resource and constitutes about two-third of the fresh water reserves of the world.

Groundwater resources in the aquifer gets seasonally recharged and discharged through rainfall and other sources which is reflected in the water level fluctuations. Water-level changes can be divided into several categories. There are short term changes that can only be seen when water-level measurements are made many times a day. A groundwater system comprises the subsurface water, the geologic media containing the water, flow boundaries, and sources (such as recharge) and sinks (such as springs, inter aquifer flow, or wells). Water flows through and is stored within the system. Under natural conditions, the travel time of water from areas of recharge to areas of discharge can range from less than a day to more than a million years. Water stored within the system can range in age from recent precipitation to water trapped in the sediments as they were deposited in geologic time.

The variability of aquifer response times is illustrated by the time required for the hydraulic head (water levels) in a groundwater system to approach equilibrium after some hydraulic perturbation, such as well pumping or a change in recharge rate. This can be estimated for confined groundwater systems (William et al., 2002).

There are long term changes that can only be seen after data are collected for many years. There are minor changes of only a few hundredths of a foot, and changes that are hundreds of feet. Fluctuations are generally due to one of three major factors: change in the volume of water stored in the aquifer, changes in atmospheric pressure, and changes caused by aquifer deformation.

Many of the causes of water-level changes can be easily recognized simply by the shape of the groundwater-level hydrograph. Other changes are more subtle, and their causes are not immediately recognizable. Below this zone of water level fluctuations, the aquifers remain perennially saturated (Wei, 2014).

2.5. Groundwater Levels

Groundwater recharge may be defined as ‘the downward flow of water reaching the water table, forming an addition to the groundwater reservoir. For efficient and sustainable management of the groundwater resource, understanding and quantification of groundwater recharge have paramount importance (Mohammed et al., 2012). Water flows from higher water content to lower water content due to gravity, soil water tension and hydraulic gradient. This is observed in groundwater recharge as it moves and enters in to aquifers, saturated soil and unsaturated soil zones (Magnus & Adindu, 2011).

The ground water level fluctuation graph of observation well 169 (Figure 2.1) clearly indicates that the water table remains above the reference level throughout the recorded periods (January to August, 2009). The fluctuation increases during peak irrigation season (January, February) and then decreases with slight fluctuation from March to June. During rainy season (June to August), the water table once again raised to its maximum level almost intercepting the ground surface (Zelalem, 2010).

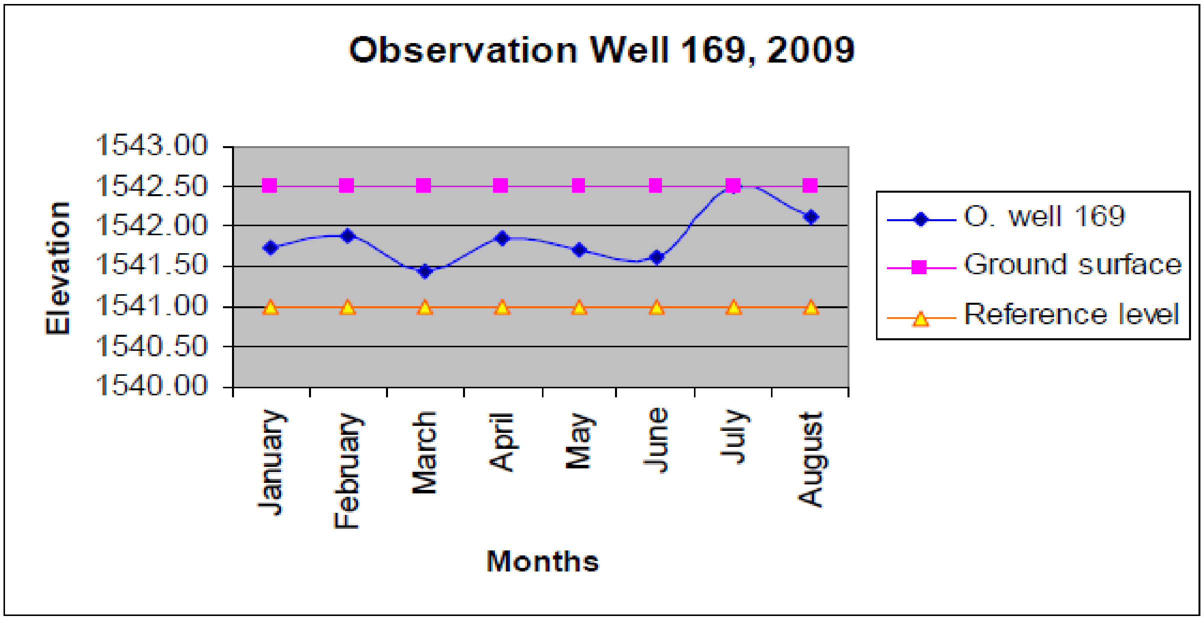

Figure 2.1: Groundwater fluctuation at observation well 169 (Zelalem, 2010)

The point about recharge being water that reaches the water table is important: some methods of recharge estimation, such as soil moisture fluxes, assume that all water moving below the soil zone eventually contributes to recharge. However, this may not be the case where there are lateral flows in permeable subsoil's. The factors that influence the amount and type of recharge include: precipitation (volume, intensity, duration), topography, vegetation (cropping pattern, rooting depth) and evapotranspiration, soil and subsoil types flow mechanisms in the unsaturated zone, bedrock geology, available groundwater storage, presence of influent rivers & presence of karst features (Bruce, 2000).

Recharge to unconfined aquifers is derived from the downward infiltration from the land surface of precipitation, irrigation water, and/or seepage from surface water bodies.

In a natural system, recharge to the shallow aquifer is largely dominated by precipitation characteristics; primarily duration, magnitude, and intensity of precipitation. Whereas, in an agriculturally stressed aquifer, the irrigation return flow can contribute a large portion of total recharge. This part of the recharge is governed by the pumping and irrigating related to agricultural practices (Yang, 2018).

2.6. Infiltration Capacity of the Soil

Infiltration is the process by which water on the ground surface enters the soil surface. Precipitation falling on the soil wets down and it starts penetrating into the soil. Water restores to the formal level the soil moisture deficiency excess moving down by the gravity force through percolation or seepage to build up the water table. The water is driven into the porous soil by force of gravity. First the water wets soil grains and then the extra water moves down due to gravitational force. The rate at which a soil absorbing the water in a given time is called infiltration rate and it depends on soil characteristics such as hydraulic conductivity, soil structure, vegetation cover (Balmuri, 2014). The amount of water entering the soil per unit time is called Infiltration Rate and the rate at which infiltration becomes constant is called as basic infiltration rate and it is also called as constant infiltration rate.

The amount of water per unit time which a given soil profile takes in through its surface when it is continued in contact with water at the atmospheric pressure is called infiltration capacity and the cumulative infiltration divided by the total time of infiltration measured from the beginning of infiltration termed as Average infiltration rate (Ayu et al., 2013).

2.6.1. Soil texture

Soil is comprised of a variety of minerals and organic matter. Soil texture is simply defined as the relative proportion of sand, silt, and clay particles found in soil. These particles differ amongst each other in terms of their size. Particles that range in size from 0.05-2.0 mm are sand. Particles that fall between 0.002-0.05 mm are considered silt. The smallest particles are clay, which is less than 0.002 mm in size. The relative fraction of these soil particles is important because it can determine factors such as the soil’s water holding capacity, aeration, drainage, and plant rooting depth (Adeniji et al., 2013).

Soil texture is an important soil characteristic that drives crop production and field management. The textural class of a soil is determined by the percentage of sand, silt, and clay (Figure 2.2). Soils can be classified as one of four major textural classes: sands, silts, loams and clays (Beverwijk, 1867).

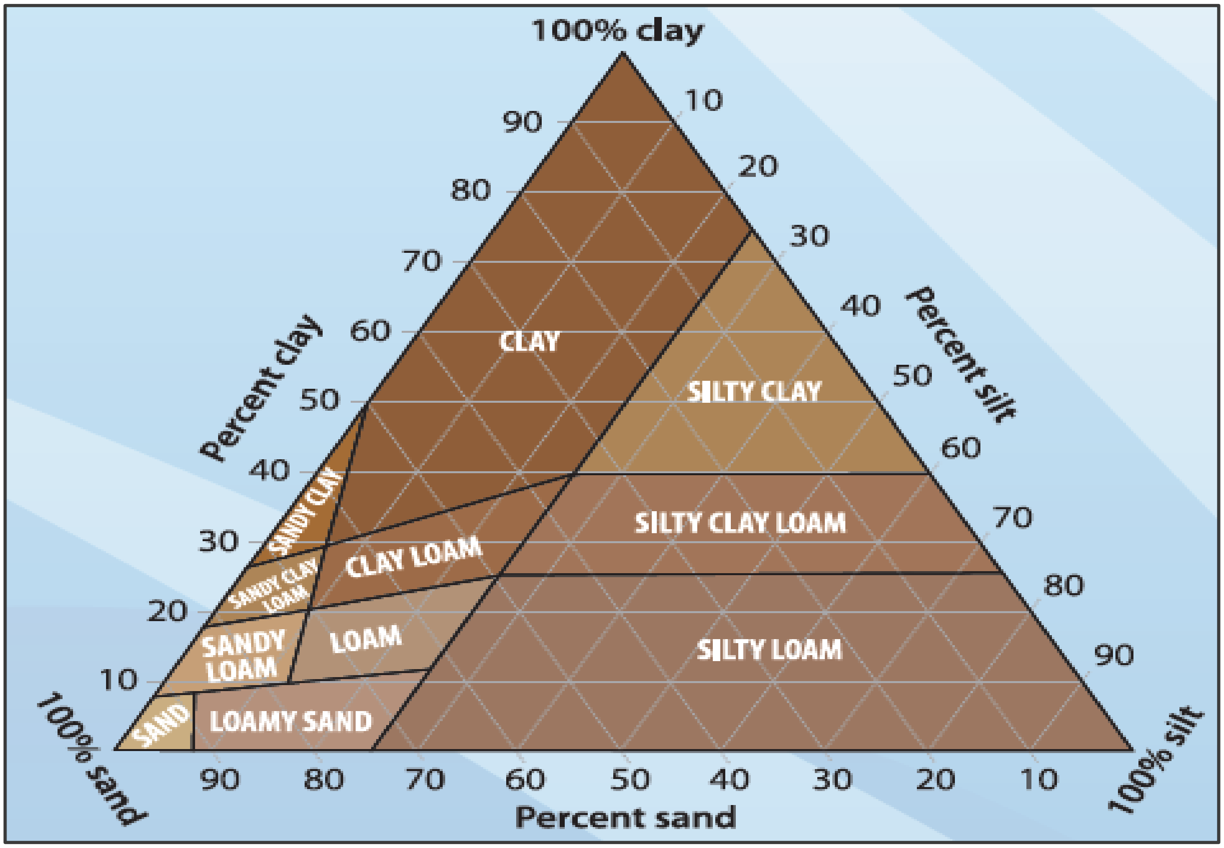

Figure 1.2: A soil textural triangle is used to determine soil texture (GRDC, 2018)

Sand 50% + Silt 30% + Clay 20% = SILTY LOAM.

Sand 80% + Silt 5% + Clay 15% = SANDY LOAM (GRDC, 2018).

2.6.2. Double-ring infiltrometer

Double-ring Infiltrometers was well known technique for measuring or estimating the infiltration rate of soils. The double ring infiltrometer is suitable for almost any type of soil with the exception of clogging soil, stony soil or the soil of steep slope. Explained the factors that are affecting the infiltration capacity at the soil surface are soil compaction which is caused by ruts & treading, washing of fine particles into surface pores, cracks & fissures (Gayatri, 2016). Results of field measurements are used to estimate parameter of infiltration rate.

Horton Infiltration Model has three parameter determining the process of infiltration that are K, initial infiltration (f_o) and constant infiltration (f_c). The maximum rate of infiltration (Infiltration Capacity) at the constant infiltration rate (f_c) indicates amount of water that can be infiltrated into the soil per unit time. The time it takes to achieve (Ayu, 2013).

Double ring infiltrometers are developed in reaction to fact that single-ring infiltrometers tends to estimate the over infiltration rates. This has been ascribed the fact that liquid in the cylinder is not purely vertical but it also diverges laterally. Double ring infiltrometers understate the standard errors affiliated with the single-ring infiltrometers because the water in the outer ring forces vertical infiltration of water inside the inner ring. Whereas there are two techniques used in double-ring one is constant head method and the other is falling head method. In constant head method water is systematically added to both the inner and outer rings. The volume of water wanted to maintain the constant level of inner-ring is measured (Balmuri, 2014).

2.6.3. Soil infiltration measurements

Soil infiltration rate was measured using standard double ring Infiltrometer technique and infiltration rate measurement was taken from three sampling sites in the study field. A standardized approach was applied at each of the sampling sites according to the method described in (USDA, 1999). Ayu (2013) stated that the rate of infiltration is the amount of water that goes into the soil per unit of time and determine the soil moisture availability for plants. According to Antigha and Essien (2007) stated in Akintoye (2012) there are variations in the infiltration rates of tropical soils including soils of the study area. These variations are due to high rainfall, land use type, and the influence of vegetation. Observably, the dynamics of soil characteristics in relation to this changing infiltration rate may act in different proportion as either assets or constraints to the quality of land resources.

The amount of time it takes for the water in the inner ring to infiltrate into the soil was noted and the infiltration rate was then computed as (Franzluebbers, 2002).

$$Infiltrationrate(\frac{cm}{hr}) = \frac{V}{A*T}$$

Where, V = Volume of water (cm^3)

A= the area of the inner infiltration ring (cm^2)

T = the time recorded (hour).

For measuring the depth of water in ring we need hook gage, steel tape or scale (National Institute of Technology Rourkela, 2014).

2.7. Soil Wetness and Depth of Water Table

There is no doubt that much of the plantation is wet (defined as surplus water within 2.0 m of the surface). Of 474 soil profile and auger sites with data some 296 - or 62% - encountered water. On analysis, however, some interesting statistics emerge. The percentage of sites having water within various depth intervals to 2.0 m, the limit of our auguring. Depth 0.0 - 0.6 m selected as the first interval because 0.6 m is the main root zone for sugarcane (Table 2.1). Data was separated according to the estate and the out grower areas.

Table 2.1: Percentage occurrence of water within various depth intervals (WSSF, 2013*).*

Depth interval, m	WSSF 2013		WSSF 2008
	Plantation %	out growers %	
Within 0.6	7	3	18
Within 1	21	4	54
Within 1.5	53	12	74
Within 2	69	28	-
+/- Water greater than 2	21	72	+/- water >1.5 26

The plantation is drier in 2012 compared to 2008; 53% as against 74% of sites having water within 1.5 m. It is probable that this 74% would be even higher had the estate bored to 2.0 m depth. Within the 0.6 and 1.0 m the depth was also less wet sites today than in 2008. This improvement may be due to increased drainage works since 2008. The out grower areas are more than four times drier than the plantation in the top 1.5 m; 12% of sites encountering water compared with 53% of sites. Overall within 2.0 m, water was found at 28% and 69% of sites respectively (Table 2.1). Coupled with the soil drainage classification, this implies less water and/or better water management on the out growers land (Ethiopian Sugar Corporation, 2013).

3. MATERIALS AND METHODS

3.1. Descriptions of the Study Area

Wonji Shoa Sugar Estate is located in the central rift valley of Awash River basin around 107 km south east direction of Addis Ababa, exactly in 8^0 30' to 8^0 35' N and 39^0 10' to 39^0 20' E at an altitude of 1540 mean sea level. Wonji plain experiences bimodal and erratic rainfall distribution pattern. In addition, the piezometric location, open pit location and infiltrometer location was shown the Wonji shoa sugar estate map by using GIS software (figure 3.1).

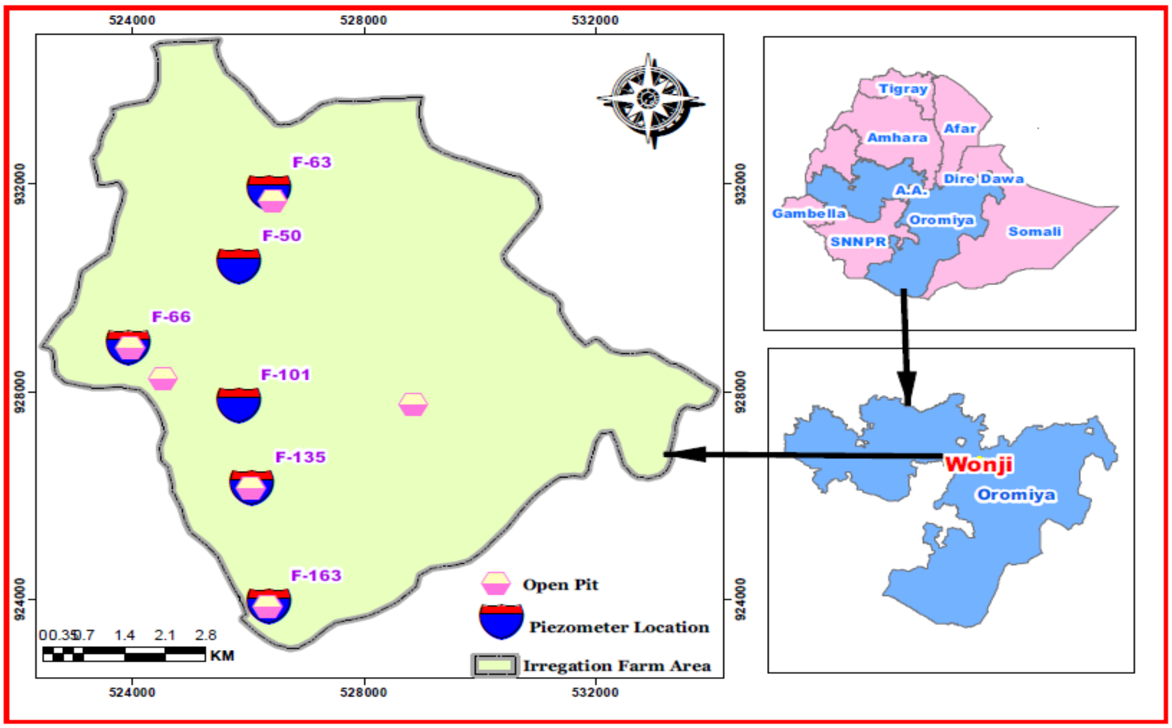

Figure 2.1: Location of the study area

The long-term average annual rainfall is about 830 mm, mostly (≈76%) falling during the main rainy season (Jun-Sept) (Dinka et al., 2014). Temperature of the area (15.2–27.6 °C) is specifically suitable for sugarcane. The climate of the area is between the transition of the two zones: semi-arid to dry sub-humid.

3.1.1. Land use of the study area

The area was mostly known as grazing land for semi-pasturalists. Over the past five to six decades, the Wonji area has undergone a significant change in its LUC conditions. Most of the grazing lands were changed to agriculture; forests were destroyed by the in-migrants from other parts of Ethiopia (mostly from the south) because of the job opportunities created (Dinka et al., 2013). At the country level, root causes of LULC change could be demographic, institutional, political, socio-cultural, developmental and/or environmental. Expansion of mixed crop-livestock systems into former grazing land and other natural areas and intensification of agriculture are the two largest changes that have been detected (Olson & Maitima, 2006).

However, their impact on resources remains almost always the same. At regional level, the gains or losses of different land use types in and around protected areas are mainly impacted by interactions between institutional and environmental factors. The consequence of those LULC can only be observed in a longer time frame (Lambin, 2003).

3.1.2. Existing irrigation system in the study area

Wonji irrigation farm is one of the largest commercial farms in Ethiopia which irrigates about 8000 ha of land by diverting Awash River to the irrigation field. Water from the river is pumped using six pumps with a design capacity of 730 l/s, two pumps with a design capacity of 330 l/s and one pump with a design capacity of 138 l/s. It uses furrow irrigation method where large quantity of water is artificially constrained to flow in trenches and canals through sugar cane plants (Wakgari et al., 2011).

The distribution of irrigation water is facilitated by the presence of five on-channel reservoirs which have a total design storage capacity of 376,875 $m^3$and twelve small reservoirs scattered all over the plantation (Paulos et al., 2006).

Out of the total 275,208 m long earthen canal distributing water throughout the scheme, currently few canal networks are covered with Geomembrane plastic. Soils of the whole canals system is categorized as clay or fine textured constructed on very flat plain having longitudinal slope of 0.05 to 0.06% (Yosuf, 2015). At Wonji Shoa Sugar Estate, an open canal surface irrigation system was developed and furrow irrigation was carried out.

According to Girma and Awulachew (2007), most of the irrigation canals of the scheme have lost their original dimensions and main canals are silted up and most of them are flowing up.

3.1.3. Soils of the study area

The soils of WSSE are of alluvial origin developed under hot, tropical conditions. Texturally, the soil can be categorized into light (course textured) and heavy (clayey black) soils (Figure 3.2). Consequently, these soils are regarded as problematic by plantation's agricultural managers (Dinka et al., 2014).

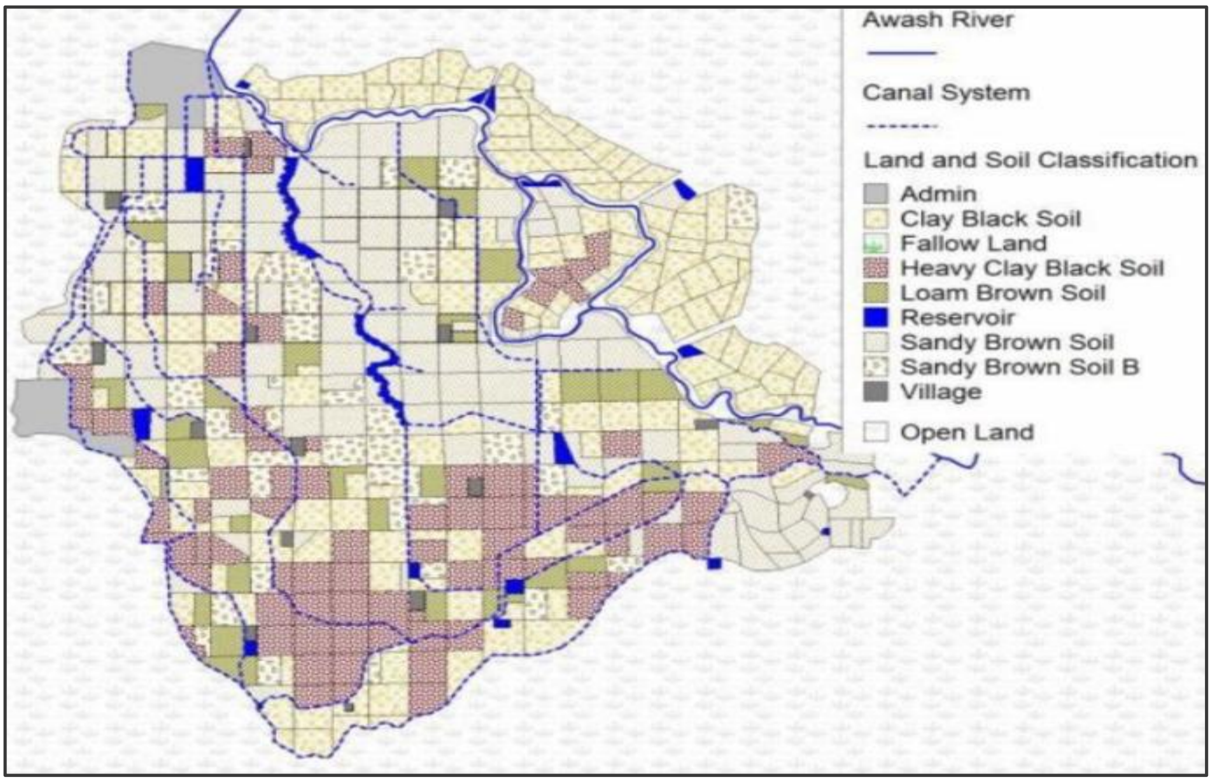

Figure 3.2: Soil type distribution of Wonji plantation (Teshite, 2018)

Dechasa (1999) in Dinka et al. (2014) stated that the geology of Wonji plain is characterized by volcanic activities and rift tectonics, which is characteristics of the Main Ethiopian Rift (MER). In the estate, generally, the topography of the farm has gentle slopes with flood prone plains of Awash River. Also the soils of Wonji-Shoa have been described predominantly as a complex of gray, cracking clays in the topographic depressions and semiarid, brown soils.

The main crops cultivated are sugarcane, haricot bean and crotalaria. Sugarcane is planted at a rate of 16-18 t/ha in the estate and it is cultivated as perennial mono crop (Mulugeta et al., 2017).

The plantation soils are classified into five major soil management groups (A_1, A_2, BA_2, $B_{1.4}$, and C_1) (also called 'soil cycles' in the study area), mostly categorized based on the water-holding capacity and moisture content (PF_2) of the soil to suit irrigation management practices (Hassen, 1993). The first three soil cycles (A_1, A_2 and BA_2) are fine-textured clay soils with high moisture-holding capacity and high critical moisture content characterized by serious waterlogging and drainage problems. $B_{1.4}$ and C_1 soil cycles are coarse-textured soils with no drainage problem.

Thus cane production is continuous on these soil cycles, without the practice of a fallow period. On the other hand, a leguminous plant called *Crotalaria* is grown on the first three soil cycles after the cane completes one crop cycle. The *Crotolaria* is chopped at the green stage and mixed with soil for green maturing (Dinka et al., 2013).

3.1.4. Geology and hydrology of the study area

The vertical and horizontal contacts between the different geological series of the Wonji area are resolved using two dimensional high-resolution geophysical imaging method which is a very effective means of characterizing shallow fractured aquifers. Results from this geophysical surveys show that the Wonji aquifers locally consist of alluvial sediments and fractured ignimbrites, generally within low electrical resistivity. The low electrical resistivity corresponds to high permeable and saturated formations (Wakgari et al., 2011). In irrigation sites where furrow irrigation method is used, knowledge of hydrological systems of the area including the mode of interaction between surface waters and the aquifer system is important to avoid possible environmental risk.

This requires awareness of the hydrogeological setting including the configuration and characteristics of aquifer geometry and hydraulic properties of formation underlying the irrigation site. One important issue traditionally overlooked in furrow irrigation method is the interaction between irrigation water and groundwater.

In large part, this is due to the persistent gaps in awareness about the interactions between irrigation water and groundwater including understanding the underlying lithology and geological structures (Dinka et al., 2014).

3.1.5. Groundwater abstraction and monitoring system

The groundwater table of the area was characterized as shallow and spatially and temporally varying (Dinka & Ndambuki, 2014). However, there is no clear-cut information about the depth of groundwater table below the soil surface.

Though, Teshite (2018) groundwater table depth may differ from the finding of Dinka & Ndambuki (2014) due to lack information on current status of groundwater approximate depth of 1.5m was assumed. In this study most of the plantation is affected by waterlogging problem due to shallow ground water table and they revealed that the depth of groundwater table in the plantation is approximately 1.5m on average based on ground water monitoring conducted over the period of 2007-2009.

3.2. Framework of the Study

Framework of the study is the structure of the thesis through which it done (Figure 3.3).

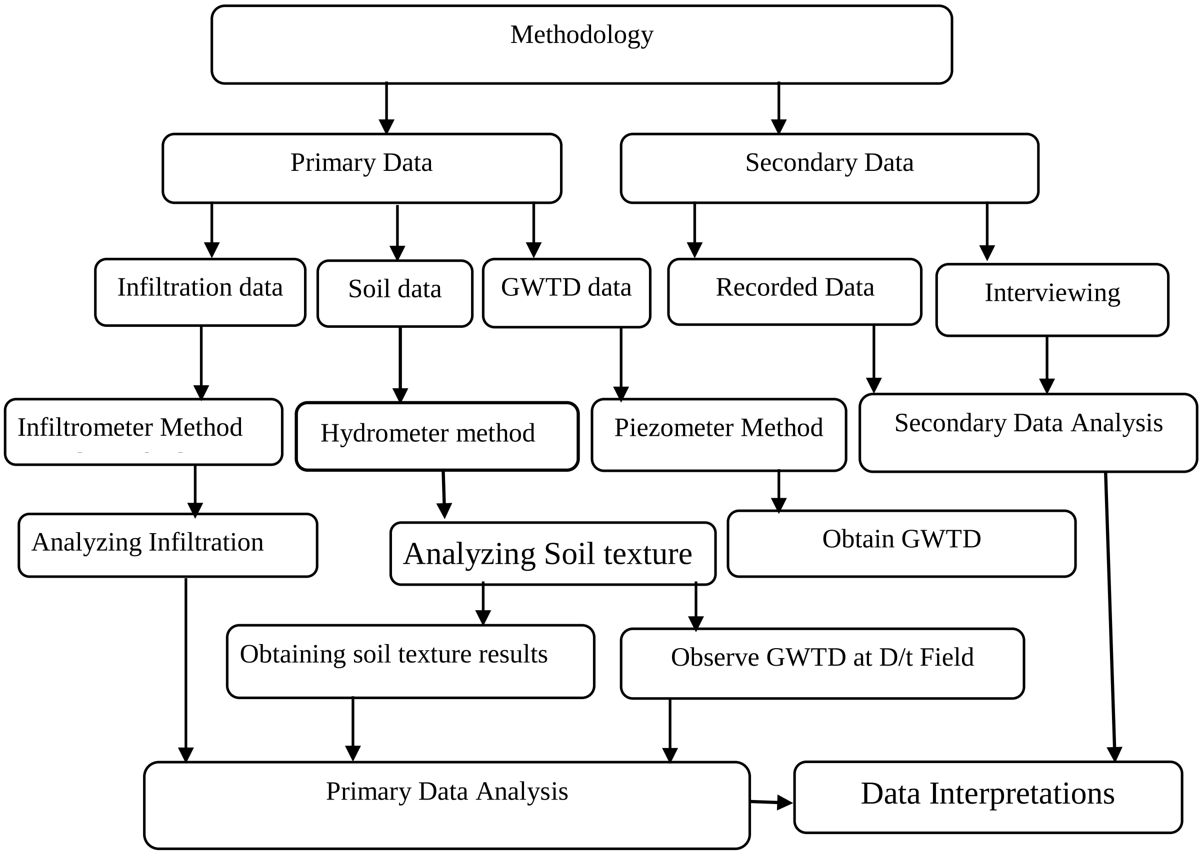

Figure 3.3: Framework of the study

3.3. Primary Data

The primary data were obtained from field test during field work such as expert interview, observation of events in the irrigation systems, soil texture analysis by collecting soil sample. Groundwater table depth by piezometer reading and infiltration rate of the soil by using double ring infiltrometer were primary data obtained. The location of the piezometer, infiltrometer and open pit points were taken using mobile satellite with accuracy less than four.

3.3.1. Soil texture analysis

The disturbed soil sample was collected from the field at depth of 0.8m -1m below the ground surface at five location. This soil sample was excavated at piezometer site by using auger and at the place where infiltration was tasted. ESCRT laboratory has been used to identify the soil texture of the study area. For laboratory textural analysis, 50 g were taken from each sampling area. Samples were air dried at room temperature. All samples were then analyzed for the sand–silt–clay percentages using the hydrometer method.

The hydrometer method is more widely used than the pipette method. This is because of its simplicity, ease and rapidity to use and for most soil fertility evaluation studies this method is sufficient. The density of the soil-water suspension was measured with a Bouyoucos hydrometer that is calibrated to read the density of the soil-water suspension in grams per liter (g/liter), or calibrated directly in percentages. Five field specimens were classified in the soil lab of ESCRT to calculate how much sand, clay, and silt, were in each specimen.

The Apparatus used for the analysis were Weighing balance Multi-mixer (milk shaker), Graduated cylinder (1000ml), Hydrometer (Standard Bouyoucos hydrometer, graduated in g liter^{-1} or percent), Thermometer, Stop watch, Plunger, Oscillatory shaker and Sieve (50 microns and 250 microns).

Dispersing agent: Dissolve 40 g of sodium hexametaphosphate ($NaPO_3$) and 10 g of sodium carbonate (Na_2CO_3) in distilled water in a 1 liter volumetric flask and make to volume with distilled water. Dry the chemicals in oven at 105^oC and cool in a desiccator the day before use.

3.3.2. Procedure of analysis

Weight 50 g soil with the diameter less than 2mm which was not sandy soil in a 1 liter plastic bottle with stopper (Figure 3.4). Add 100 ml of dispersing reagent and shake for 3 hours on an end to end or oscillatory shaker. Transfer the soil and the solution into the cup of a mixer or mechanical stirrer by washing the bottle very well and bring the volume to 500 ml in the cup and stir for 5 minutes.

Figure 3.4: 50 gram of soil and oscillatory shaker

3.3.3. Hydrometer readings

At first step transfer the dispersed soil suspension to a hydrometer jar, washing out the stirrer cup and adjusting the volume in the jar to 1 liter with distilled water and mix with a plunger and measure the temperature of the solution. Then add a drop of amyl alcohol if surface is covered with foam and include blank with distilled water and all the pretreatment received by the sample, but without soil.

After that covered the top of the cylinder tightly with one palm of your hand or a rubber stopper. Shake by inverting the cylinder several times (first energetically so that all the material deposited at the bottom of the cylinder goes into suspension and then slowly) for 30 seconds.

Gently place the cylinder on top of the flat surface (bench) and immediately started the top watch (Figure 3.5).

Then immediately lower the hydrometer carefully into the suspension. Slide the hydrometer slowly into the suspension until it floated (Figure 3.5). Prevent the hydrometer from oscillating. The first hydrometer reading was taken at 40 seconds after the cylinder was set down. This reading measures the percent of silt and clay which was less than 50 microns in suspension. After that remove the hydrometer from the cylinder and measure the temperature of suspension with a thermometer. Then took both hydrometer and temperature readings for the blank too and took the reading on the scale to the nearest 0.5 unit at the top of the meniscus. After the first hydrometer reading at 40 seconds, let the cylinder stand for two hours and took the second reading for both the samples and the blank. Also take temperature readings. The second reading was gives the percent of clay particles less than 2 microns in suspension.

Figure 3.5: Graduated cylinder (1000ml) and hydrometer (g liter^{-1} or percent)

Calculations

Results were corrected to a temperature of 20^{o}C before doing computations. For temperature readings above 20^{o}C correction values were added to the hydrometer reading and for temperature readings below 20^{o}C correction values were subtracted from the hydrometer reading. Temperature correction values are given in Table 3.1. Also correction for compensating for the added dispersing agents was made by subtracting 2 from the hydrometer reading.

Sand = 100 – [(d_1 + 1 – 2) x 100/50] (100/50 to convert sample weight to 100)

Clay = (d_2 – 0.5 - 2) x 100/50

Silt = 100 – (% sand + % clay

Table 3.1: Temperature correction values for hydrometer reading.

Z	Correction value (g/l)
15	-2.0
16	-1.5
17	-1.0
18	-1.0
19	-0.5
20	0.0
21	+0.5
22	+1.0
23	+1.0
24	+1.5
25	+2.0

In order to read the texture triangle, follow the grid line in figure 2.1. The percentage of clay separate was read by following the grid lines in the horizontal direction from left to right. The percentage of silt separate was read by following the grid lines from top right to bottom left.

Lastly the percentage of sand separate was read by following the grid lines from bottom right to top left.

3.3.4. Double-ring infiltrometers

Soil infiltration rate was measured using standard double ring Infiltrometer technique and infiltration rate measurement was taken from three sampling sites in the study field. The double-ring infiltrometer as often being constructed from thin walled steel pipe with the inner and outer cylinder diameters being 30 and 56 cm, respectively. For DRI infiltration, the inner and outer steel rings of 0.3 m and 0.56 m diameter, respectively and 25cm long, were driven concentrically about 0.08 m deep into the soil (Figure 3.6), with minimum soil disturbance and 17cm of the cylinder must be above the ground level.

There are two operational techniques used with the double-ring infiltrometer for measuring the flows of water into the ground. In the constant head test, the water level in the inner ring was maintained at a fixed level and the volume of water used to maintain this level was measured. In the falling head test, the time that the water level decreased in the inner ring was measured. In both constant and falling head tests, the water level in the outer ring was maintained at a constant level to prevent leakage between rings and to force vertical infiltration from the inner ring. Now the selected methods for infiltration measurement was falling head infiltrometer. Soil infiltration rate measurement was taken from three sampling sites in the study field.

Figure 3.6: Double ring infiltrometer at the field 135

We should take care of a ring while it was driving into the ground there may be chance of having hapless connections between the thin wall of a ring and soil.

Here the procedures of double ring infiltrometer with same length were used.

Double ring infiltrometer consists of two cylinders ring tubes with varying inner and outer diameters. Two single cylinders of 30cm & 56cm diameter having a depth of 25cm have been used. The DRI infiltrometer consists of open cylinders, which was driven into the ground. The cylinder was installed by manually impact force vertically inside the soil up to a depth of 8cm. Poured water into outer ring and it allow water to infiltrate as needed. Put a plastic to inner ring and fill water on that for a particular depth. The plastic sheet from the inner ring removed and recording depth with time has been started.

Then, the volume of water infiltrated during time intervals was convinced to an incremental infiltration velocity, here it was expressed in millimeter per hour. Then we have taken initial & final depth of infiltration with a time interval of 10mins (Figure 3.7).

Figure 3.7: Time interval and infiltration rate records

The measurement has been continued until the infiltration rate became constant. For measuring the depth of water in ring we need ruler or scale. A standardized approach was applied at each of the sampling sites according to the method described in (USDA, 1999).

Based on the volume of the rings water was measured out in a measuring cylinder and poured over the rings. The amount of time taken for the water in the inner ring to infiltrate into the soil was noted and the infiltration rate was then computed as (Franzluebbers, 2002).

$$Infiltration rate(\frac{cm}{hr}) = \frac{V}{A*T}$$

Where, V = Volume of water (cm^3)

A= the area of the inner infiltration ring (cm^2)

T = the time recorded (hour).

Limitations of infiltrometer

The ring infiltrometer has certain limitations such as infiltration rate decreases with increase in depth and diameter of infiltration rings. The rate of infiltration increases as the head of water increases in constant head and cannot be used on a sloping soil surface.

3.3.5. Depth of water table

GWTD of Wonji-Shoa sugarcane plantation has been measured through a network of piezometers. The piezometer tubes that has been previously installed in the site of the study has been used (Figure 3.8). The piezometers are all PVC tubes. The piezometer sites were selected purposively in order to cover the range of soil types, water sources and topographic conditions. Water levels are monitored manually using a stick meter by inserting it in the piezometer and obtained results by subtracting depth of stick meter inserted into water from total stick meter inserted into piezometer. Care should take to collect the GWTDs in all the tubes in the minimum possible time, to minimize error. In addition to GWTD measuring using PVC tubes, an attempt should be made to collect ancillary data from different sources through informal and formal discussions. The present and past conditions of the area has been obtained from the elders of the researchers, and previous reports and own personal observation during field visits. The piezometer locations (latitude, longitude) were registered using mobile Geographic Positioning System (GPS) by putting mobile on the top of piezometer and waited it until its accuracy has been came to three. Monthly water table data from available number of piezometer along with their locations were obtained for three months (May to June).

Table 4.6: Waterlogging class for sugarcane crop (Dinka et al., 2014)

Serial number	Mean GWT (cm)	Area		Waterlogging class	
		Ha	%	Kahalown et al. (2005)	FAO/UNEP (1984)
1	20-50	915	15	Sever	Critical
2	50-100	3538	58	Critical	Critical
3	100-150	1037	17	Critical	Moderate
4	150-200	610	10	Moderate	Moderate

Figure 3.8: Installed Piezometer at the Field 50

3.4. Secondary Data Collection

Secondary data were obtained from published journal articles and published thesis paper documents that related to this study. Also from Ethiopian sugar corporation research center and training office detail groundwater study and monthly rainfall data were obtained.

4. RESULTS AND DISCUSSION

4.1. Soil texture

Table 4.1: Result of soil texture analysis.

S/No	lab code	Sampling date	Field No	Soil particles (%)			Soil Texture
				Sand	Clay	Silt	
1	1169/10	06-08-18	163	10	87	3	Clay
2	1170	"	66	10	79	11	Clay
3	1171	"	187	42	38	20	Clay loam
4	1172	"	24	12	72	16	Clay
5	1173	"	135	34	48	18	Silty clay

The hydrometer method was used to separate fines (silt from clay), to compute silt ratio and clay ratio. In the field 163, the percentage of sand was 10%, the percentage of clay was 87%, the percentage of silt was 3%, and so that this specimen was clay soil. In the second, F-66 the percentage of sand was 10%, the percentage of clay was 79%, and the percentage of silt was 11%, so, the second specimen also clay soil. In the third, F-187 the percentage of sand was 42%, the percentage of clay was 38%, and the percentage of silt was 20%, so that by using texture triangle, the fourth specimen was clay loam. In the fourth specimen, F-24 the percentage of sand 12%, the percentage of clay was 72%, and the percentage of silt was 16%, so that by using texture triangle (Figure 2.1), the fourth specimen was clay soil. In the fifth specimen, F-135 the percentage of sand 34%, the percentage of clay was 48%, and the ratio of silt was 18%, so that the fifth specimen was also silty clay soil (Table 4.1).

From this results it was also found that soil conditions effects infiltration rate. In general, fine textured soils have lower infiltration rates than the course textured soils. From the graphs of infiltration rates against time, it was also found that initial infiltration rates were high at the course texture and low at fine texture soils.

4.2. Soil Infiltration Rate

As discussed in literature review, infiltration was the process of water percolating down to the groundwater. The intensity of this process is called the infiltration rate. The infiltration rate is expressed in terms of the volume of water per unit of time [mm/min]. The infiltration capacity of the soil indicates the maximum infiltration rate at a certain moment. Under certain circumstances, it may be necessary to determine the infiltration capacity of the soil, for instance in infiltration areas.

4.2.1. Soil infiltration rate at field 135

At beginning the infiltration rate was high as the soil was in the dry state and slowly as the soil saturated, it decreased and finally got a constant value. This may be attributed to the fact that infiltration rate depends on soil characteristics. At field 135 west there was central drainage structure that made the field was free from waterlogging. Also, since the soil type of this field was silty clay soil, it has higher capacity to transmit water than clay soil type (Appendix table 7). Due to this reason the infiltration rate of the soil at this field was relatively high. The maximum infiltration rate was 9.87mm/hr. and the cumulative in filtration rates of the soil was 39.57mm (Appendix table 7).

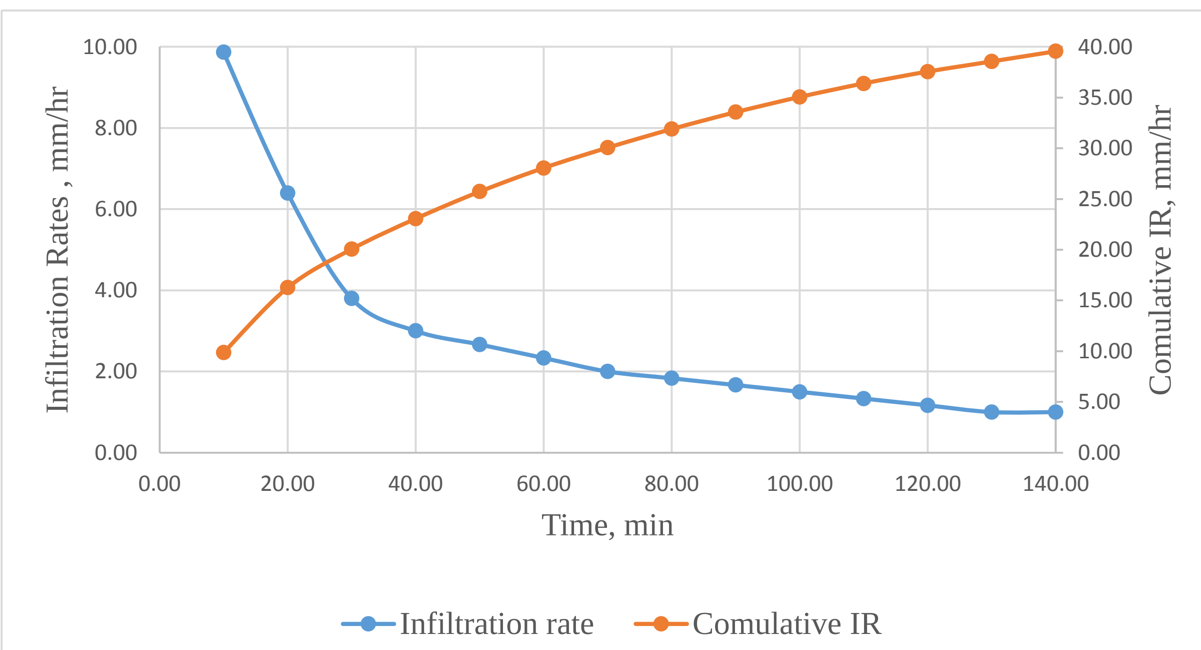

Figure 4.1: Infiltration rate and cumulative in filtration depth of field 135

4.2.2. Soil infiltration rate at field 50

Also at this field in the beginning the infiltration rate was high and slowly infiltrate as the soil saturated it decreased and finally got a constant value (Figure 4.2). This field also have higher GWTD and infiltration rate relative to the other due to occurrence of Geomembrane covered canals around the field. Due to this reason the soil moisture content problem wasn't significantly occurred to the observer. The infiltration rate of the soil at this field has been higher than other field except field 135. The maximum infiltration rates of the soil of this field was 9.17mm/hr. and its cumulative infiltration rate 31.67mm/2hr (Appendix table 8).

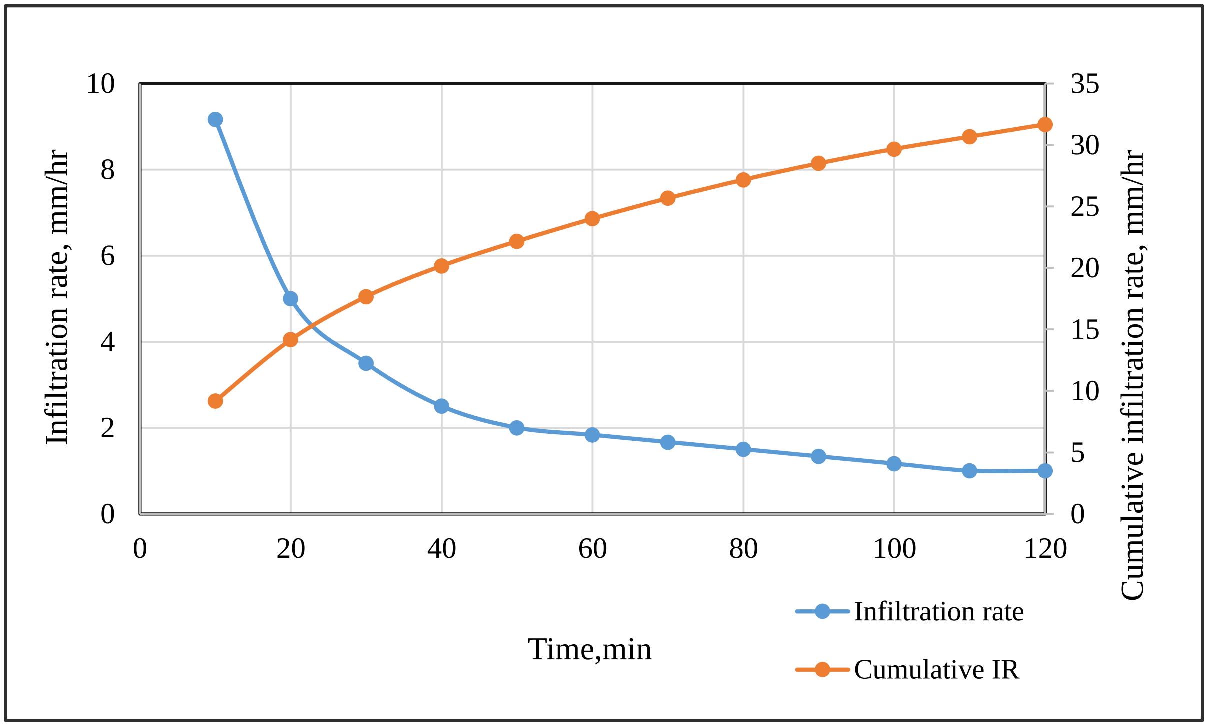

Figure 4.2: Infiltration rate and cumulative infiltration depth of field 50

4.2.3. Soil infiltration rate at field 163

The soil infiltration rates of this field was very low due to high soil moisture content of the area. This area has been highly effected by poor irrigation water management and absence of proper drainage structures and also the soil type at this field was clay soils. So, groundwater depth at this field was shallower than the other. Due to this reason between the farm fields there were ponding water between the field rows.

The maximum infiltration rate of soil in this field was 5.33mm/hr. and cumulative infiltration rate was 27.16mm/2hr (Figure 4.3). Its basic infiltration rate also 1mm/hr. and this shows its infiltration rates were came to constant at 1mm/hr. (Appendix table 6).

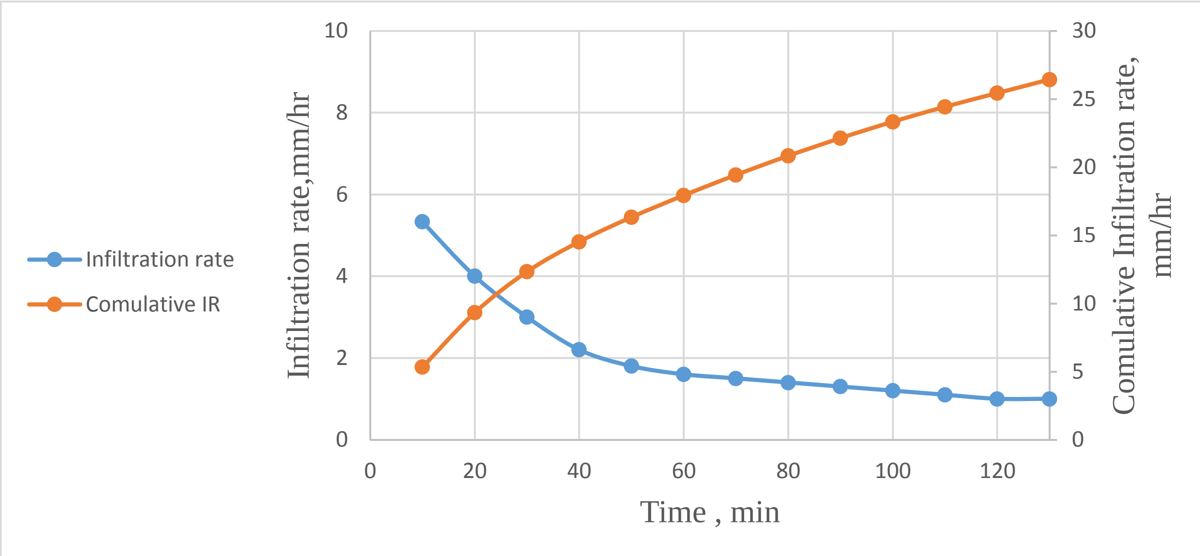

Figure 4.3: Infiltration rate and cumulative in filtration depth of field 163

At the beginning the infiltration capacity was higher and as the time elapsed the soil converted into saturated stage and the infiltration rate was reduce.

The rate of infiltration attained after a sufficiently large time was the basic rate of infiltration which soil becomes saturated. The rate of infiltration decreased with time to a basic rate of infiltration however the cumulative infiltration increased with elapsed time.

The infiltration rates of F-163 and F-135 their cumulative infiltration rates were 26.43 and 39.57mm/2.3hr respectively. This shows surface water has high chance to infiltrate into the soil in F-135 due to the soil type of this field was silty clay soil, groundwater table depth was dipper than other fields and relatively low ability of water to infiltrate into the soil in the F-163 due to its soil type was clay soil and groundwater table depth was shallow. But the groundwater table depth at F-135 was higher/deeper than groundwater depth of F-163 (Appendix table 8). From this it was clear that the problem of waterlogging was not the matter of amount of water infiltrate into the soil but it was the matter of poor surface irrigation management. That means absence of qualified irrigation structure over the field.

Generally, from the measurements that taken in the field, the infiltration of water to the soil got constant after a short time interval due to saturation of the soil (Figure 4.4).

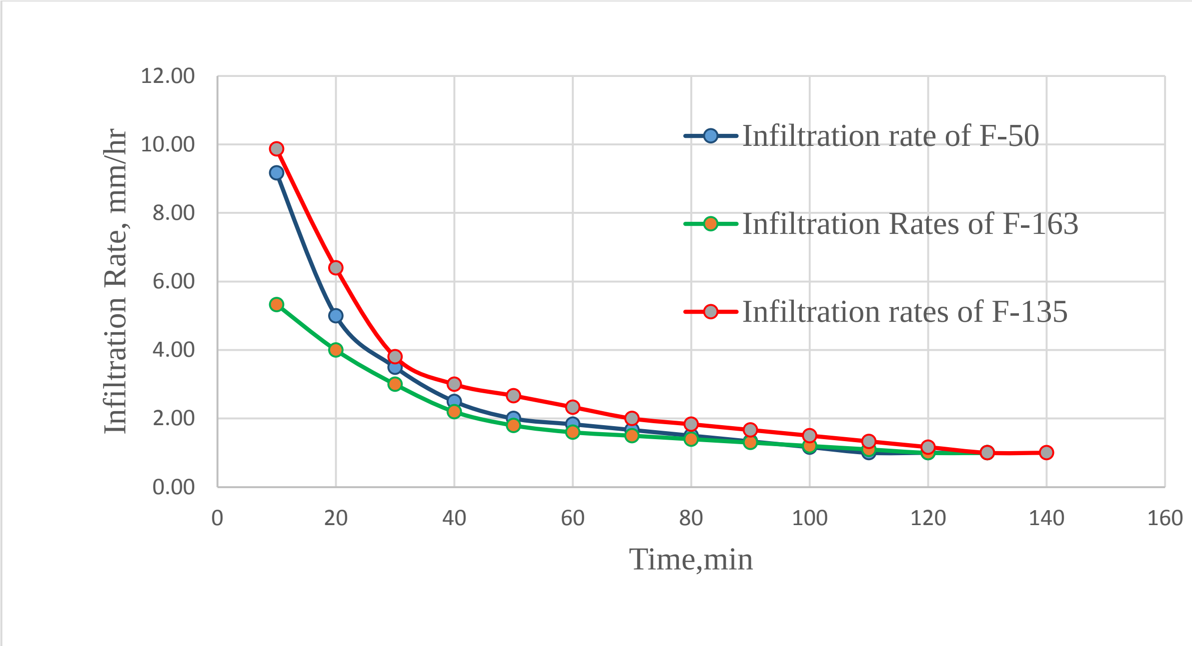

Figure 4.4: Graph of infiltration rate on three fields

4.3. Groundwater Table Depth (GWTD)

The possible sources for groundwater recharge are excess irrigation, plus seepage from the Awash River, leakage from irrigation and drainage canals, rainfall and night storage reservoirs. Owing to this fact, a significant increment in GW levels has been visible during the study period. This was mostly due to the poor performance of irrigation and drainage systems of the area. Seepage from earthen irrigation canals can be a main source for recharging shallow groundwater aquifers (Yosuf, 2015).

4.3.1. Monthly groundwater table depth

Table 4.2: GWTD in different three months

s/ no	Field no	Coordinates (UTM), 2018		Depth of GWT(cm), 2018		
		X	Y	May	June	July
1	24	526402	931965	18	13	9
2	66	523912	928846	34	31	30
3	101	526811	927734	66	65	62
4	50	525824	930406	127	120	114
5	63	526335	923861	36	33	30
6	135	526049	926156	185	164	159
7	163	526360	931845	12	10	8
8	207	524010	928952	22	21	19
Average depth				62	57	54

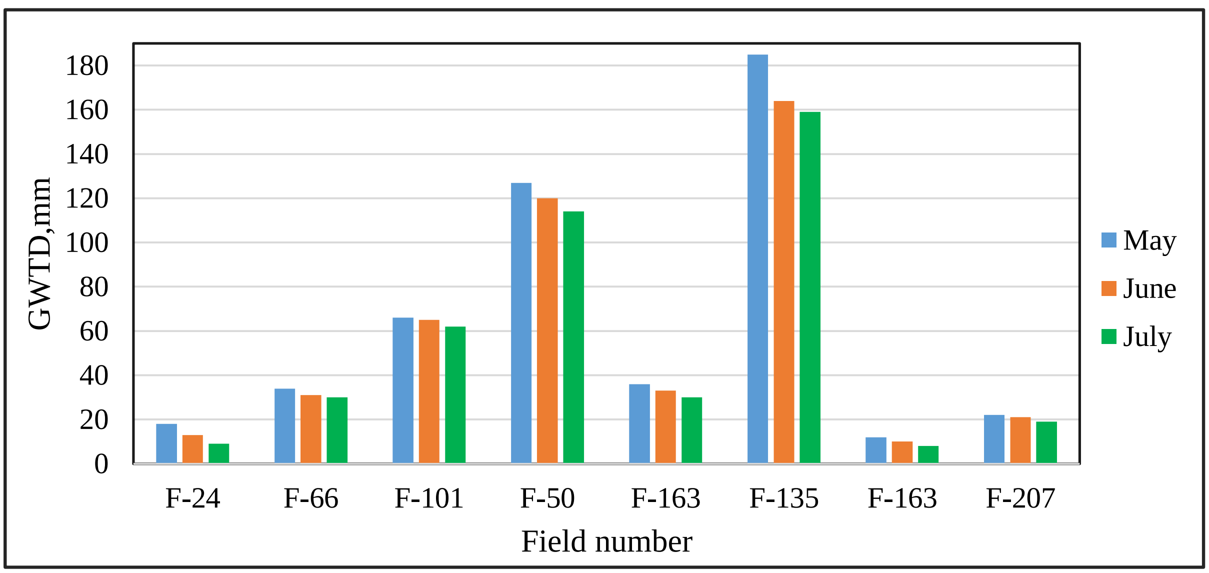

Figure 4.5: GWTD in different three months

The monthly GWTD responses of the 8 piezometers, observed at different parts of the plantation fields, were recorded during the observation period and the GWTD varies from 0.1 m (F-163) and 1.85m depth (F-135). During all the three months, most of the piezometers (except F-50 and F-135) have very shallow GWTD (<1.0 m) below the ground.

In the same period, only piezometer F-135 has GWTD above the critical level (1.5 m) recommended for sugarcane crop. The piezometer F-135 has higher GWTD due to the following reason. The first one was due to presence of central drainage around there and the second reason was no reservoir storage and main canal around the installed piezometer. The piezometer F-163 has lower GWTD due to canal supply at upper elevation and poor drainage canal between the fields.

May

During May the GWT depth varies from 0.12 to 1.85 m, with average value of 0.62 m (Appendix table 8). From May to Jun, the GWT depth value in all selected piezometer sites or irrigated fields showed a slight increment (Figure 4.5) of GWTD due to some amounts of rain fall and over irrigation water (appendix table 5). The average GWTD increment May to June was 0.05m or 50mm. However, GWT depth of the study area, even in May is shallow or less than 2m and much less in some piezometer sites (F-24 and F-63) with GWTD 18 and 12cm respectively. The possible sources for GW recharge during this month might be due to excess irrigation water, seepage from the irrigation and drainage canals.

GWT depth is relatively less shallow in this month compared with all the other months. About 25% of the plantation fields have GWT depth greater than 1 m and 12% of the plantation had GWT depth greater than 1.5 m and found to be safe from significant yield reduction.

The irrigated fields (F-50 and F-135) have relatively deep GWT depths; whereas the irrigated fields (F-24, F-63, F- 207, F-66, F-101, F-163) have relatively shallow GWT as shown on Appendix table 8, which was in line with the topography of the area. This means some of irrigation fields that have shallow GWTD were found at the downstream of the irrigation field, but it does not all downstream irrigation field have shallow groundwater table because, F-135 (West) was found at downstream field but it has higher GWTD relative to the other because of its soil type and proper designed drainage structure .

June

During June the GWT depth varies from 0.1 to 1.64m, with average value of 0.57 m. The irrigated fields (F-50 and F-135) have relatively deep GWT depths; whereas the irrigated fields (F-24, F-63, F- 207, F-66, F-101, and F-163) have relatively shallower GWTD than the May month (Appendix table 8). From June to July, the GWT depth value in all selected piezometer sites or irrigated fields showed a slight increment (Figure 4.5) due to more amounts of rainfall immediately after irrigation water was applied and also due to over irrigation water. The average GWTD increment June to July was 0.03m or 30mm. Due to this reason GWT depth of the study area during this month was shallower or less than 2m in previous month and much less in some piezometer sites (F-24 and F-63) with GWTD 9 and 8cm respectively.

July

The GWT depth during July vary from 0.1 to 1.59 m, with average value of 0.54 m. The GWT depth value in all selected piezometer sites or irrigated fields showed a slight increment (Figure 4.5) of GWTD due to high amounts of rainfall with applied irrigation water to the field before rainfall. GWT depth of the study area in this month was shallower than both GWTD in May and June and much less in some piezometer sites (F-24 and F-163) with GWTD 18 and 12cm respectively. This is because of canal supply at upper elevation and poor drainage canal between the fields and its soil also saturated soil with 10% sand, 87% clay and 13% clay soil which was classified under clay soil in texture.

The possible sources for GW recharge during this month might be expected as excess irrigation water, seepage from the irrigation and drainage canals. But the impacts of rainfall during this month was higher than the two previous months.

This was also mostly due to the application of irrigation water and rainfall at the same day and poor border drainage structure of the field rather than rainfall impacts itself.

4.3.2. Monthly average groundwater table

From the current results the mean average GWTD of the study area ranged between 0.54 m and 0.62 m (Figure 4.6).

Thus, all plantation fields are classified to be shallow (i.e. waterlogged). This shows most of the area has average GWTD less than 1.50 m below the ground surface, hence, classified to be critically waterlogged since they were above the critical depth (1.5 m) recommended for sugarcane crop (Table 4.6).

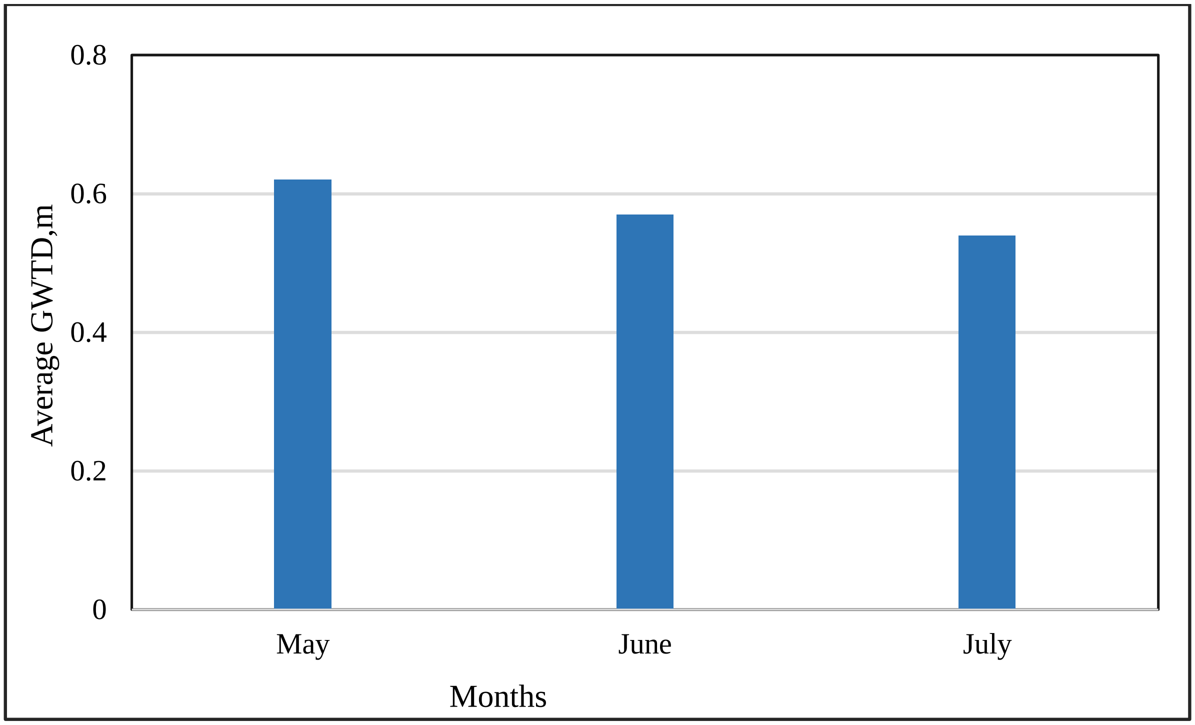

Figure 4.6: Monthly average GWTD, m

4.4. Analyzing Irrigation Water Impacts Based on the Results

According to Megersa et al. (2014) the GWTD during July season was in the range of 0.18 to 0.95 m, with average value of 0.53 m below the ground surface. Almost more than half of the plantation has GWTD less than or equal to 0.50 m. Almost all parts of the cane plantation fields were critically waterlogged (GWTD <1.0 m) during this season. More than 85% of the piezometers have GWTD less than 1.0 m below ground. This implies that the period is characterized by severe waterlogging conditions in the area. These areas of the plantation, have relatively deeper water tables during winter and autumn. Furthermore, these areas, as shown in the stream or runoff network of the area, are known to receive high magnitude of runoff coming from the surrounding plateaus.

From the two results there was waterlogging problems in the plantation area. Megara's (2014) used 35 numbers of piezometer installed in plantation field and now the numbers of piezometer available for instruments were 8 piezometers only. This shows it was difficult to compare each results accurately since piezometers of some area were not available.

But the current study shows evidentially the waterlogging problems comes from poor managements of irrigation practices, some amount of rainfall and high magnitude of runoff coming from the surrounding plateaus during heavy rainy season. This is due to the availability of different structures that prevent high magnitude of runoff coming from surrounding plateaus, like earthen dyke and the other reason is waterlogging problems occurs most of the time but runoff coming from surrounding plateaus comes only during heavy rains especially during August and September.

Also, from the observation and gathering information from WSSE elders the problem of runoff and erosion from the watershed rounded the WSSE field had been insignificant impacts with comparable to the previous one.

Due to this reasons the major causes of rise in GWTD or waterlogging was excess irrigation water in the field. On the other hand the agricultural runoff from the upstream may significantly worsen the downstream areas by rising water table of the plantation fields.

Generally, in the WSSE waterlogging problems was due to poor irrigation water management. The ground water level within the WSSF showed a rising tendency. What has been discussed before and confirmed in the field work were causes high water table and waterlogged fields. The result showed that on some plantation fields the GWT was very shallow or groundwater table less than 2m especially in soils classified as heavy black cotton soils have shallower GWTD than the field that have other soils type. The drainage problems have also become one of the major factors in determining the GWTD of the field. The measurement of GWT of the WSSF showed the maximum GWT depth values in all months.

The average GWT depth for selected irrigation fields varied from 0.54 to 0.62m that had been observed during the field works and confirmed from the results were problems with a high GWT rise and waterlogging condition.

Especially on fields with clayey soils problems with waterlogging have been discovered during the field observation and its trend or extent was confirmed from the results of soil texture analyzed (Table 4.1).

In most irrigated fields downward percolation of irrigation water especially in soils classified as clay soils was so slow that it caused temporary storage within the furrow in some places after irrigation. In some fields like F-163 and F-187, the water was occurred at less than 80cm depth during the soil sample has been taken for soil texture analysis.

4.4.1. Effects of rainfall on ground water table depth

WSSF has a 60 years' rainfall series database from year 1952 to 2012. This database shows that the mean annual rainfall is around 800 mm. There is variability from one year to another. The annual rainfall can be less than 600 mm some years and more than 1000 mm in others.

From data collected of the years 2000 to 2012, it seems that the mean annual rainfall was slightly less than 800 mm. Most of the rainfall is concentrated during the months of July and August (50% of the total annual rainfall) corresponding to the rainy season. Months of November, December and January are very dry with less than 10 mm per month (WSSF, 2013).

The rainfall was in excess in July and August, and not sufficient the rest of the year to supply sugarcane water requirements during the plant cycle (Figure 4.7). Irrigation was necessary to produce sugarcane in this region.

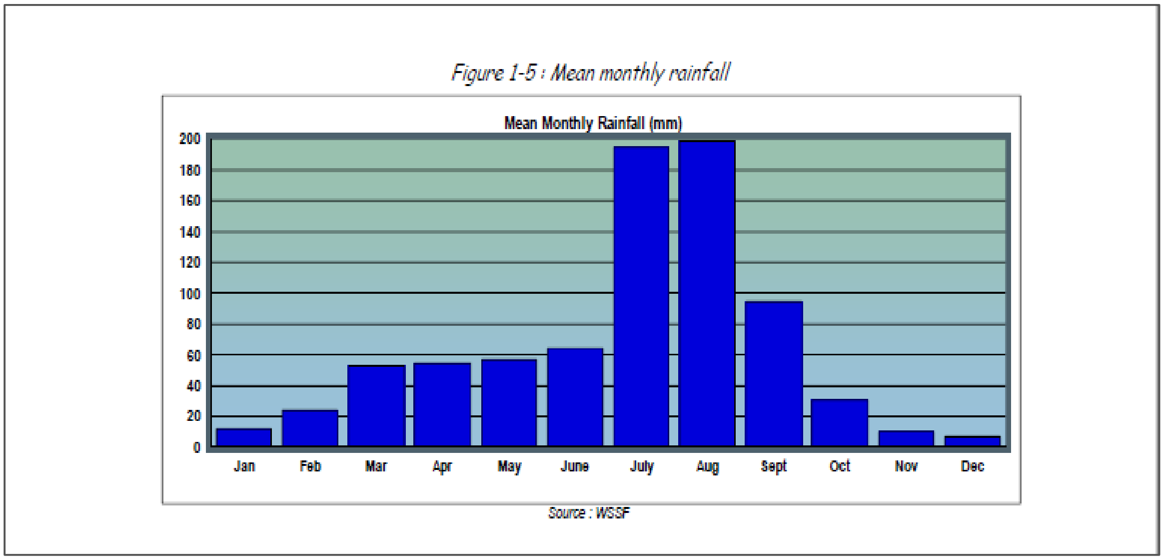

Figure 4.7: Mean monthly rainfall (Source: WSSF, 2013)

In 2018, monthly volume of rain fall was the similarly high concentrated during the months of July and August (Figure 4.8). The volume rainfall in July and August was around 192 and 200mm respectively in 2013 year. The volume rainfall in July was 309 mm in 2018 year and all the other volume of rainfall and occurrences were different from the previous year. This shows the monthly distribution of rainfall in the WSSF was erratic rainfall distribution over the months from year to year.

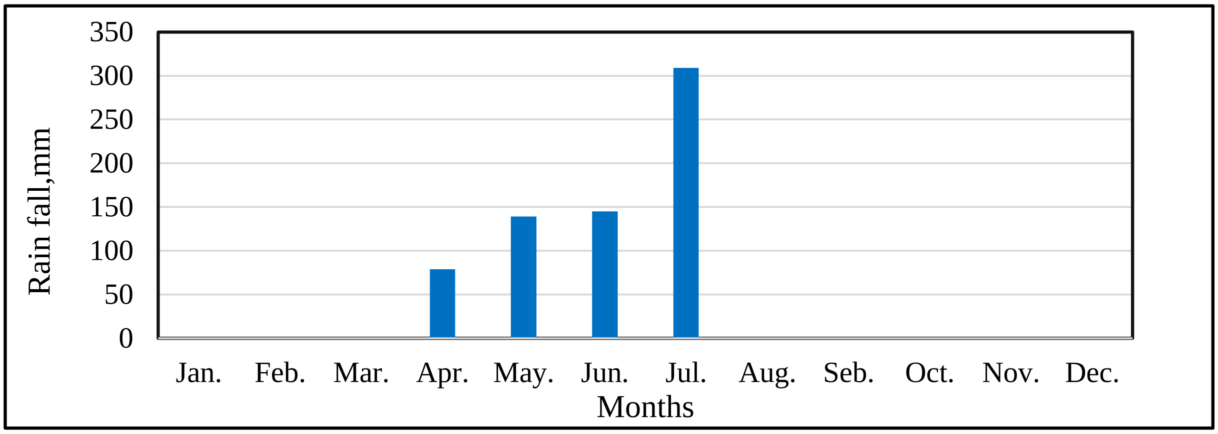

Figure 4.8: Mean Monthly Rainfall, mm, 2018

By comparing the volume rainfall during July in different two years, the volume of the rainfall increased during 2018 by 117mm in July. This shows that the highest volume of rainfall was occurred during July 2018. Hence currently the area has high amount of rainfall relative to 2013 year. Also there was huge difference between June 2018 and July 2018 in volume of rain fall (Figure 4.7 and Figure 4.8). During June and July months the volume of rainfall were 145mm and 309mm respectively. But the average depth of GWT during June and July month were 0.54 and 0.57m. This shows that the difference average depth was only 0.03 m which is not significant change by comparing with the rainfall difference 164mm which greater than twice of volume of rainfall during June month (Appendix table 5). The negative sign shows the groundwater table depth was found under the ground surface. From this results GWTD were rises mostly due to poor irrigation water managements rather than the high volume of rain fall.

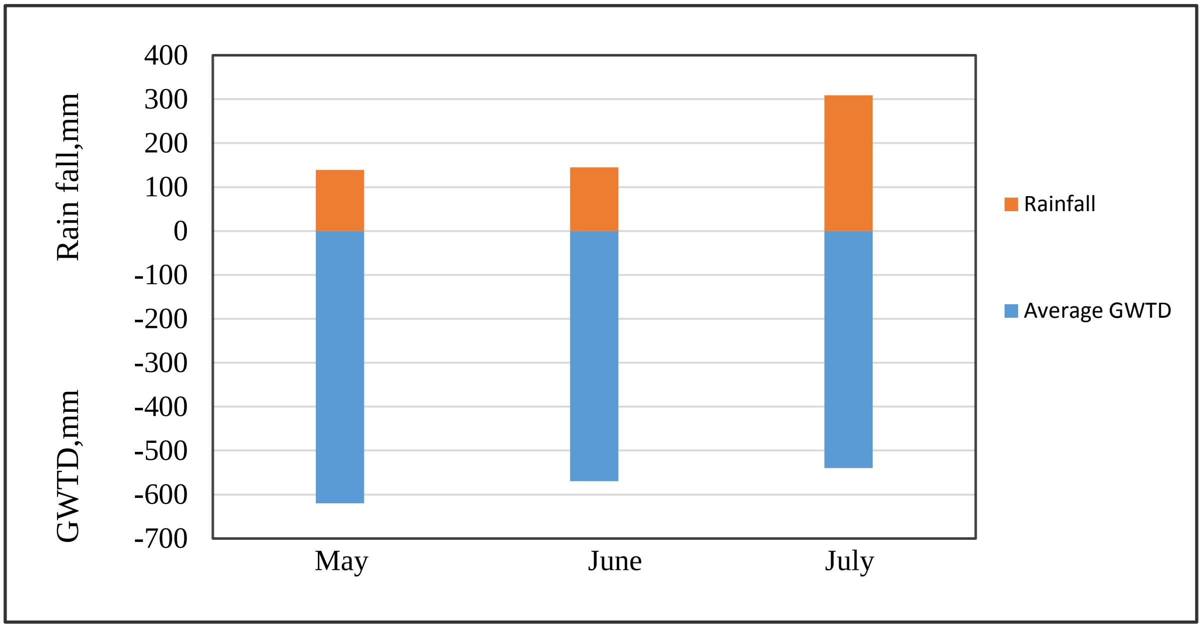

Figure 4.9: Comparison GWTD and rain fall during the three months

In general, the average GWTD in May, Jun, and July were 0.62, 0.57 and 0.54m respectively (Figure 4.6). These values were decreased from May to July due to the increment of volume rainfall (Figure 4.9). GWTD was increased by more amount from May to June and increased from Jun to July by some amount. Even if the values were increased the amount of increment was in small amount. This indicate that the impacts of rainfall was less significant during this months.

4.5. Effects through irrigation canals and drainage structure

The canal is covered with Geomembrane which occurred at field number 50 (Figure 4.10). The GWTD at this field was deeper with compared to the other. This shows the leakage from the canal has high effects on ground water levels. And also the central drainage structures consideration from field 135 gives enough evidence as the groundwater depth was under the impacts of water losses due to in effective canals network structures. Seepage losses may be and have been satisfactorily reduced through the installation of relatively impervious linings or by special treatment of canal sections.

Determination of the need of lining should be based on an analysis of benefit such as water conservation, reduced waterlogging of lower drainage requirements, reduced excavation and right of way cost, lower operation and maintenance costs and structural safety.

4.6. Remedial Measures

As a Remedial measure, in addition to effective irrigation water management, considerable deep drainage in the irrigation fields to keep the waterlogged, make dry irrigated fields by native vegetation around the road and at the border of the field, preventing contribution of recharge from the reservoir to the field by reconstruct reservoirs with concrete materials.

The need for rehabilitating the irrigation system demonstrate that the system has previously not been properly maintained and control structures are frequently reported as being either in a very poor condition or very inoperable. Moreover, addressing of the entire canal network was necessary due to the fact that seepage and leakage are not limited to specific canal category and to some parts of canal network. Most of the canals and canal structures have problems with comparable magnitude.

Rehabilitating of the canal system without any lining materials is much preferable than covering selected canals with geo-membrane. The work must be started from upper reach of the scheme and should go down to smaller canals following topography and discharge capacities. Besides, repairing of water controlling structures at each junction along the way should be carried out simultaneously.

5. CONCLUSION AND RECOMMENDATION

The overarching potential benefit of this study is to contribute to closing knowledge gaps by making available information. It is anticipated that this study will contribute to the foundation of a more robust evaluations of groundwater levels in the area. A better understanding of groundwater levels and recharge patterns in WSSE is critical for development in the country.

The measure of infiltration of water is an important factor for irrigation efficiency, improving the plants water availability, optimizing the crop yields, reducing erosion, and describing the permeability of soil. Soil infiltration rate was measured using standard double ring Infiltrometer technique and infiltration rate measurement was taken from three sampling sites in the study field. The infiltration rates of the soil was different from field to field due to the soil type, water contents of the field, form of drainage and canal structures. In the beginning the infiltration rate is high as the soil is in the dry state and slowly as the soil saturates it decreases and finally gets a constant value (Appendix table 7, 4.2 & 4.3). At field 135 west there was central drainage structure that made the field was free from waterlogging and the infiltration rate of the soil at this field was relatively high. From table 1 the maximum infiltration rate at field 135 was 9.87mm/hr. and the cumulative in filtration rates of the soil was 39.57mm. At field 50 the infiltration rate of the soil has been higher than other field except field 135 due to a canal was covered with Geomembrane.

The monthly GWTD responses of the 8 piezometers, observed at different parts of the plantation fields, were recorded during the observation period and the GWTD varies from 0.1 m (F-133) and 1.85m depth (F-135) for the three months. The mean average GWTD of the study area ranged between 0.54 m and 0.62 m; thus, all plantation fields are classified to be shallow (i.e. waterlogged). This shows most of the area has average GWTD less than 1.50 m below the ground surface, hence, classified to be critically waterlogged since they are above the critical depth (1.5 m) recommended for sugarcane crop (Kahlown et al., 2005). During May month the GWT depth varies from 0.12 to 1.85 m, with average value of 0.62 m. There was some amounts of rain fall over irrigation field. However, GWT depth of the study area, even in May months, is shallow (<2 m) and much less in some piezometer sites (F-24 and F-63) with GWTD 18 and 12cm respectively.

Therefore, the possible sources for GW recharge during this month might be due to excess irrigation water, seepage from the irrigation and drainage canals and leakage from reservoir storage.

Generally, the irrigated fields (F-50 and F-135) have relatively deep GWT depths; whereas the irrigated fields (F-24, F-63, F- 207, F-66, F-101, and F-163) have relatively shallower GWTD (Appendix table 8) for the three months. Evaluating of the groundwater levels on a monthly basis shows that groundwater levels at the selected sites increase in response to poor managements of irrigation water, in effective drainage structures which is covered by grass, leakage and seepages and wet-months precipitation. In some cases, rehabilitating of the canal system without any lining materials is much preferable than covering selected canals with geo-membrane.

The volume of rainfall during Jun and July months were 145mm and 309mm respectively. But, the average depth of GWLD during Jun and July month were 0.54 and 0.57m. This shows that the difference average depth of GWT was only 0.03 m which is insignificant change by comparing with the rainfall volume difference, 164mm which more than twice of volume of rainfall during Jun month. From this results GWTD were rises mostly due to poor irrigation managements rather than the high volume of rain fall.

5.1. Recommendations

The current study clearly recommend that the current situation of groundwater recharge is due to mismanagement of irrigation water, inconsideration of soil type, poor drainage structures and rainfall in some extents were the main causes responsible for the rise and fluctuation of GWTD. This means increasing intensities of irrigation from surface water alone may result in alarming rise of water table creating problems of waterlogging and salinization, affecting crop growth adversely and rendering large areas unproductive. Thus, provide deep vertical border and central drainage can prevent water-logging and salinization.

A necessary data like proper documented data of the surface irrigation designed should be recorded from in every year and to generating new data having both temporal and spatial coverage, the WSSE should be fulfil the standard equipment that used to measure groundwater level.

The soil and amounts of irrigation water that limit infiltration rate and the potential for increasing the GWTD must be considered in any management plan.

Long-term over irrigation had a cumulative effect on the rise of the GWT and could cause waterlogging and associated problems. Thus, efforts on the management of water, especially depth of groundwater should be measured monthly and yearly, in such areas were extremely irrigation water is applied to irrigation field.

In most cases, unfunctional piezometers have been abandoned, but, these piezometers would have substantial importance for groundwater levels study. Thus, protection and management of piezometers is highly recommended.

Foreman of each field should have to consider the topography, soil texture and climatic condition of the area before applied irrigation water to the field.

The work must be started from upper reach of the scheme and should go down to smaller canals following topography and discharge capacities.

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APPENDICES

Appendix Table 1: Double ring infiltrometer (DRI) Location

Field number	Coordinates	
	X	Y
F-163	526335	923861
F-135	526042	9261511
	525820	930402

Appendix Table 2: Open pit location

Field numbers	Coordinates	
	x	Y
F-24	526422	931685
F-66	523932	928866
F-101	528841	927754
F-135	526040	926146
F-163	526330	923856
F-187	524512	928250

Appendix Table 3: Average monthly rainfall

Months	Average monthly rainfall, mm
Jan.	0
Feb.	0
Mar.	0
Apr.	79
May	139
Jun	145
July	309
Aug.	0
Sep.	0
Oct.	0
Nov.	0
Dec.	0

Appendix Table 4: Infiltration rate of F-50, F-163 and F-135

Time ,min	Infiltration rate at F-50,mm/hr.	Infiltration rate at F-163,mm/hr.	Infiltration rate at F-135,mm/hr.
0	0.00	0.00	0.00/
10	9.17	5.33	9.87
20	5.00	4	6.40
30	3.50	3	3.80
40	2.50	2.2	3.00
50	2.00	1.8	2.67
60	1.83	1.6	2.33
70	1.67	1.5	2.00
80	1.50	1.4	1.83
90	1.33	1.3	1.67
100	1.17	1.2	1.50
110	1.00	1.1	1.33
120	1.00	1	1.17
130	1.00	1	1.00
140			1.00

Appendix Table 5: Daily rainfall data

Days	May	June	July
1	6	0.0	9.2
2	4	0.0	30.2
3	0.0	0.0	4.2
4	0.0	0.0	0 .0
5	0.0	0.0	0 .0
6	0.0	0.0	35.0
7	0.0	0.0	0 .0
8	0.0	0.0	0 .0
9	0.0	0.0	27.0
10	0.0	0.0	7.2
11	0.0	15	5.0
12	56.0	0.0	0 .0
13	0.0	30	13.0
14	35.0	0.0	19.0
15	10.0	0.0	7.0
16	0.0	0.0	0 .0
17	0.0	0.0	0 .0
18	0.0	0.0	6.0
19	0.0	0.0	0 .0
20	10	15	10.0
21	0.0	0.0	45.0
22	0.0	0.0	10.0
23	0.0	40	0 .0
24	0.0	0.0	6.4
25	3	0.0	46.0
26	0.0	25.0	0 .0
27	0.0	0.0	0 .0
28	0.0	0.0	0 .0
29	0.0	20.0	15.2
30	15	0.0	0 .0
31	0.0		14.0
	139.0	**145.0**	**309.4**

Appendix Table 6: Infiltration measurement results of field 163

Time (min)	Initial Reading (mm)	Final Reading (mm)	Infiltration Depth (mm)	Infiltration Rates (mm/hr.)	Cumulative IR (mm/2.16hr.)
10	0.00	3.20	31.98	5.33	5.33
20	3.20	5.60	24.00	4.00	9.33
30	5.60	7.40	18.00	3.00	12.33
40	7.40	8.72	13.20	2.20	14.53
50	8.72	9.80	10.80	1.80	16.33
60	9.80	10.78	9.60	1.60	17.93
70	10.78	11.68	9.00	1.50	19.43
80	11.68	12.50	8.40	1.40	20.83
90	12.50	13.30	7.80	1.30	22.13
100	13.30	14.00	7.20	1.20	23.33
110	14.00	14.68	6.60	1.10	24.43
120	14.68	15.30	6.00	1.00	25.43
130	15.30	15.90	6.00	1.00	26.43

Appendix Table 7: Infiltration measurement results of field 135

Time (min)	Initial Reading (mm)	Final Reading (mm)	Infiltration Depth (mm)	Infiltration Rates (mm/hr.)	Cumulative IR (mm/2.33hr.)
10.00	0.00	5.92	59.20	9.87	9.87
20.00	5.92	9.76	38.40	6.40	16.27
30.00	9.76	12.04	22.80	3.80	20.07
40.00	12.04	13.84	18.00	3.00	23.07
50.00	13.84	15.44	16.00	2.67	25.73
60.00	15.44	16.84	14.00	2.33	28.07
70.00	16.84	18.04	12.00	2.00	30.07
80.00	18.04	19.14	11.00	1.83	31.90
90.00	19.14	20.14	10.00	1.67	33.57
100.00	20.14	21.04	9.00	1.50	35.07
110.00	21.04	21.84	8.00	1.33	36.40
120.00	21.84	22.54	7.00	1.17	37.57
130.00	22.54	23.14	6.00	1.00	38.57
140.00	23.14	23.74	6.00	1.00	39.57

Appendix Table 8: Infiltration measurement results of field 50

Time (min)	Initial Reading (mm)	Final Reading (mm)	Infiltration Depth (mm)	Infiltration rate (mm/hr.)	Cumulative IR (mm/hr.)
0	0.00	0.00	0	0.00	0.00
10	0.00	5.50	55	9.17	9.17
20	5.50	8.50	30	5.00	14.17
30	8.50	10.60	21	3.50	17.67
40	10.60	12.10	15	2.50	20.17
50	12.10	13.30	12	2.00	22.17
60	13.30	14.40	11	1.83	24.00
70	14.40	15.40	10	1.67	25.67
80	15.40	16.30	9	1.50	27.17
90	16.30	17.10	8	1.33	28.50
100	17.10	17.80	7	1.17	29.67
110	17.80	18.40	6	1.00	30.67
120	18.40	19.00	6	1.00	31.67