Bahir Dar University

Faculty of Civil and Water Resource Engineering

Department of Hydraulics Engineering

MSC THESIS

WATER BALANCE SIMULATION AND OPTIMAL RESERVOIR SIZING FOR SUPPLEMENTAL IRRIGATION IN NORTH WESTERN AMHARA REGION: A CASE STUDY IN GUMARA- MAKSEGNIT SUB WATERSHED

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September, 2015

Water Balance Simulation And Optimal Reservoir Sizing For Supplemental Irrigation in North Western Amhara Region: A case Study in Gumara-Maksegnit Sub-watershed

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THESIS

Submitted to the Faculty of Civil and Water Resource Engineering In partial fulfillment of the requirements for the Degree of Master of Science in Hydraulics Engineering

Bahir Dar University

Bahir Dar, Ethiopia

September, 2015

DECLARATION

I, the undersigned, declare that the thesis comprises my own work. In compliance with internationally accepted practices, I have dually acknowledged and refereed all materials used in this work. I understand that non-adherence to the principles of academic honesty and integrity, misrepresentation/ fabrication of any idea/data/fact/source will constitute Sufficient ground for disciplinary action by the university and can also evoke penal action from the sources which have not been properly cited or acknowledged.

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Bahir Dar University

Faculty of Civil and Water Resource Engineering

Department of Hydraulic Engineering

Modeling water balance in water harvesting system for supplementary irrigation in North western Amhara Region: A case study in Gumara-Maksegnit Sub-watershed

By: Amare Tsige Genet

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Bahir Dar

Dedicated to my family: those who pay a lot for my success, i truly thank you all

ABSTRACT

Understanding the behavior of water harvesting systems and accurate model simulating are crucial for effective management and utilization of its water resources and its optimal storage size design in the Ethiopian highland. This study was conducted with the main objective of developing water balance model for water harvesting structure and to find the optimal reservoir size and reliability of the system that maximize the net economical return . The study was conducted in a small watershed located about 45 km southwest of Gondar. Gumara maksignt, a critical watershed in Lake Tana basin and its sub watershed which defined artificially were instrumented with automatic rain gauge to measure rainfall and rectangular weirs to measure sediment concentration and runoff at two nested locations in 2014. Rate of sedimentation, runoff prediction and useful life time of the reservoir were estimated using Surish, modified rational and Varshney Method respectively. Water balance of the pond was analyzed based on behavioral analysis using excel and water balance principles. Modified rational method predicts runoff with Nash Sutcliff coefficient range from 0.75-0.91. The results showed that the adopted behavioral analysis water balance model can be successfully applied to generate optimal reservoir sizing and reliability with demand driven operating policies for a one-year period for different inflows and sediment rates resulting from climate changes and different levels of crop ,land and catchment characteristics. The proposed model implement under normal rainfall year, using pepper as dominant crop and the results showed that the required optimum reservoir size is 296 m^3 with 100% reliability. It also gives 106.8%, 41 and 5year of marginal rate of return, age and payback period respectively for 0.2 ha of land. However, for wet years the reservoir capacity can drops up to 148 m^3 with 50% reliability. In contrast, for dry years the reservoir capacity rises to 444 m^3. Water balance procedure is relatively easy to apply and can be used as a decision support tool for effective management and utilization of water resources and optimal reservoir size design.

Keywords— Water harvesting, modeling, reservoir size, reliability, runoff, Supplemental irrigation and water balance

ACKNOWLEDGEMENT

First and for most, i would like to thank the almighty GOD for his mercy and blessings in all my life.

The author gratefully acknowledges the ERA, BDU, ARARI, GARC , AARC and ICARDA.

I would like to express my sincere thanks to my advisor, Dr. Seifu Admassu Tilahun for his guidance and consistent advice that enabled me to produce this work within the required period of time. He has tirelessly guided and encouraged me compilation of my thesis work.

The research for this MSc thesis was made possible through the fund support of ICARDA and special tanks for project coordinator Dr. Wondimu Bayu for providing and assisting all the necessary things.

I am deeply indebted to Dr. Birru Yitaferu. He makes my life easy.

In the complex task of doing this thesis research, i have been greatly assisted by several individuals: GARC and AARC soil and water research directorate staff (especially Baye, Negus, Ertiban, Desalgn and Mengistu)

Therefore, I am greatly indebted. Greatest gratitude go to Atkilt, Negus, Ertiban, Muluken, Andualem, Dres, Teme, Mitku, Mesinbet, Solomon, Damtie and Tade for their friendliness, hospitality and encouragement.

I like to extend greatest thanks to all my school teachers and mates. I was so much benefited from their experience and professional.

All my family who were the source of inspiration in motivating me to pursue higher studies,

Finally, I extend the largest thanks to my caring and wise wife, Sr. Saba Assime, who always fills the gap in all my weaknesses, who shared all my pains and persuaded me not to give up every time life gets hard, is a special gift from God and generally in all our family and home affairs during my study period, which would otherwise had impact on my work.

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LIST OF ACRONYMS

AARC Adet Agricultural Research Center

ARARI Amhara Regional Agricultural Research Institute

BCR Benefit-Cost Ratio

BoA Bureau of Agriculture

CCAR Catchment Command Area Ratio

CHR Cost per Harvested Runoff

CSA Central Stastical Agency

CWR Crop Water Requirement

ERHA Ethiopian Rainwater Harvesting Association

ETB Ethiopian Birr

FAO Food and Agricultural Organization

FFW Food-for-work

GARC Gondar Agricultural Research Center

GPS Global Positioning System

ha hectare

ICARDA International Center for Agriculture Research in the Dry Areas

IWMI International Water Management Institute

m.a.s.l. Meters above sea level

MRM Modified Rational Method

MRR Marginal Rate of Return

MUSLE Modified Universal Soil Loss Equation

NRCS Natural Resource Conservation Service

SER Storage to Excavation Volume ratio

RHE Runoff Harvesting Efficiency

RMSE Root Mean Square Error

RSE Runoff Storage Efficiency

RWH Rain Water Harvesting

SCRP Soil Conservation Research Program

SI Supplemental Irrigation

SPAC Soil Plant Atmospheric Continuum

UN OCHA United nation Office for the Coordination of Humanitarian Affairs

USBR United State Bureau of Reclamation

USLE Universal Soil Loss Equation

WP Water Productivity

1. INTRODUCTION

1.1. Background

The history of rainwater harvesting practices in Ethiopia dates back to 560 BC during the Axumite Kingdom. The application of rainwater-harvesting techniques as alternative interventions to address water scarcity in Ethiopia was recently started through government-initiated soil and water conservation programmers'. It was started as a response to the 1971–74 droughts with the introduction of food-for-work (FFW) programs, which were intended to generate employment opportunities to the people affected by the drought ERHA (2003).

Ethiopia is not a country poor in water. The challenge is keeping and preserving the precious resource, when it falls abundantly from the sky and then to store it and distribute it wisely for efficient use when the rains stop. Annual rainfall in the country ranges between 2700 mms in the south-western highlands and less than 200 mms in some parts of the northern and south-eastern lowlands with a further decrease to 100 mm in the north-eastern lowlands ERHA (2003). Ethiopia's mean annual rainfall reaches approximately 1090 mm Rami (2003). However 70% of the total arable land in Ethiopia receives an annual rainfall of less than 750 mm, while an estimated 110 billion cubic meters of rainwater annually are lost through surface runoff. This is the equivalent to a one meter deep square pond with sides of 330km or a full river ten meters deep, 100 meters wide and a hundred and ten thousand kilometers long. The areas with an annual rainfall of 500–750 mm are believed to support optimum levels of agricultural activities, if the annual rainfall distribution is undisturbed and proper land management is applied Rami (2003).

Most areas with low rainfall suffer from low and unstable crop yield.. In these low rainfall areas, the water use efficiency is extremely low since most of the rainwater is lost by soil surface evaporation and/or runoff. Therefore, the productivity of the land and water are both low. As reported by many investigators that use of water harvesting, the productivity of the rainwater can be significantly improved, through concentrating the rainwater on part of the land. Often, supplementary irrigation to rain fed crops at critical depletion could substantially improve yield Hachum et al (2007). Hence, storage of runoff and its provision for varied uses constitutes an important pillar for the development of the water deficit areas Boufaroua *et al.*, (2013).

Many investigators showed that annual rainfall variability in Amhara and Tigray is high with 20%-40%. Like in most other regions, the amount of rainfall is not the main problem; but collection and storage is the issue. Extension experts also propose household ponds and shallow wells for irrigation in the production of fruits, cash crops and vegetables, which should help the individual farmer to obtain additional income and increase household consumption. The idea is to start growing vegetables during the rainy season, and then - with the help of irrigation - extend the growth period into the dry season when crops receive good prices. Vegetable growing with simple bucket irrigation is feasible for a plot size of 150-200 m^2 only. Limiting factors are the labor force of the farmer, the availability of water from ponds and the vegetation period of different crops Ramie, (2003).

Selection of high value crop, efficient lifting device, irrigation method and irrigation scheduling are essential for increasing the overall efficiency of pond irrigation systems. The most important aspect of operations is to release of the right quantity of water at the right time to irrigation areas and decrease field application loss to achieve greater benefits.

Considering the above facts water harvesting structures are a viable option in the dry areas Oweis et al (2001). If properly planned, designed and implemented, they improve rainwater use efficiency, agricultural development, and environment. However, unless selection is based on maximizing water use efficiency, they might not be the best option. If RWH is to become a more widely used method of water supply, a simpler and more generalized method of storage design would be valuable. Examining the behavior of the system, and specifically, the relationship between the storage, demand, collection area, and reliability is crucial designing the storage.

1.2. Problem statement

There is a need to improve and augment current water resource management and development activities in areas with heavy degradation and low productivity, particularly in Ethiopia, where it is generally believed that only five percent of surface water is utilized Weiß and Schaldach, (2008).

In areas where surface water must be stored for later uses in irrigation and other purposes, a system for determining a reservoir water balance and reservoir's size must be employed. The proper sizing of this reservoir must start by considering all inflows to and outflows from it.

1.3. Objective

The general objective of the study was to develop water balance model for water harvesting structure and to find the optimal reservoir size and reliability of the system that maximize the net economical return. Specific objectives include:

- To assess and develop rainfall-runoff-sediment relationship
- To develop optimum reservoir sizing using a spreadsheet based daily water balance model
- To assess reliability, efficiency and feasibility of the reservoirs in the study area.

2. LITERATURE REVIEW

2.1. Water balance of the pond

2.1.1. Optimal reservoir sizing

Modeling RWH shall incorporate operational parameters such as rainwater use efficiency (i.e., runoff capture, and water savings efficiency) and also design parameters such as the ratio of tank volume divided by catchment area and rainwater demand divided by catchment area Mun and Han (2012). The issue of scale and evaluated annual rainwater utilization potential (including runoff capture and water savings) using building type and an "equivalent building" concept through analysis of existing databases and a RWH model Belmeziti et al. (2013) .One limitation of behavioral simulations is the assumption of climate stationary.

Several investigators have performed optimization and/or economic analysis of RWH. Chiu et al. (2009) conducted a cost benefit analysis of water and pumping energy costs for RWH in a hilly portion of Taiwan and found the optimal storage tank size per residence ranged from 5 to 10 m^3, depending mainly on residence size; unit costs savings were in excess of solar powered systems. Imteaz et al. (2011) used a daily water balance model to optimize tank size for large roof catchments in Melbourne, Australia and he evaluated different climatic conditions and water rates and subsequent predicted effects on investment payback, which was found to range from 15 to 21 years. In another study in Barcelona, Domènech and Saurí (2010) found that RWH could meet many domestic indoor and outdoor demand needs, but often had extremely long payback periods due to high capital outlays.

A simulation model for determining the optimum reservoir size for supplemental irrigation under rainfed farming conditions based on linear programming technique held in Iraq Hacume et al (2007), results showed that the required harvesting area is about 75% of the total area of land, and the required reservoir volumeis about 111 m3/ha of the total field area . These optimal values occur at a 87.5% fulfillment of the maximum demand rate. other study by Mohamed et al (2014) also held to optimize reservoir in sudan , the required optimum cultivated area to safely cultivate is about 2000 ha, and the required reservoir volume is about 29.23 Mm3 per ha of field area. These optimal values of reservoir capacity, minimum silt load and maximum age occurs at maximum demand rate of a crop mix of 25% sorghum, and 75% sesame.

To simulate the impact on water supply and runoff reduction on a watershed scale Steffen et al., (2013) and Walsh et al., (2014) conducted using SWMM. Steffen et al. (2013) estimates water supply and runoff capture benefits in 23 cities in four regions across the US. Non potable demand reductions of 30 to 50% were achieved with small (190 L) storage barrels. Runoff reductions of approximately 20% were achieved in the arid West, and smaller amounts in more humid regions. Walsh et al. (2014) evaluated RWH implementation in the Chollas Creek watershed of San Diego, CA. The authors simulate the drain delay of storage tanks, and found that control of this delay increased runoff reduction variability.

The selection of time scale for modeling RWH is important; finer time scales may limit data source availability, while coarser scales may make some hydrologic processes moot. A variety of time steps have been used for RWH, ranging from 5 to 6 min Sample and Heaney, (2006) to daily Imteaz et al., (2011). For water supply uses within a given range of storage sizes and demands, Fewkes and Butler (2000) demonstrate that a daily time step is acceptable. However, Coombes and Barry (2007) found that time steps larger than 1 h tended to underestimate yield. On balance, considering data availability applicability to both water supply and runoff capture, and a wide variability in demand and storage scenarios an hourly time step appears to be a reasonable compromise.

Even if there is much research in optimization, all focus on roof top and indoor use. There are a study limitation in small catchment for optimizing reservoir size of pervious land and outdoor demand especially in Ethiopia. Therefore the extent of optimizing reservoir size based on irrigable land size, selection of crop, efficient irrigation methods and a better field application efficiency is crucial task.

Farmers must support by better water management knowledge and technology to enhance for better performance of the schemes, such as introduction and/or expansion of efficient technology. In addition, conducting this study will help to have feasible and applicable recommendation.

2.1.2. Determination of reservoir capacity

There are 3 approaches to determine the capacity of a reservoir.

1) Mass curve (Ripple diagram) method;

2) Sequent-peak algorithm;

3) Operation study;

The storage capacity of a reservoir is very important since the main function of a reservoir is storage of water

Generally a mathematical computerized model based on Mass balance (behavioral analysis) technique has been presented here to optimize the size of a storage reservoir for supplemental irrigation. A previous study in this field by J.Carty and C.Cunnane (1990) revealed that the behavioral analysis method resulted in the lowest bias and standard error of results and therefore are most accurate. The data requirements for this method are flow, evaporation, precipitation, other loss and demand. The outputs are the capacity and reliability. The advantages are it can be used for final design and simulate the behavior of the reservoir during operation.

Operation study

Simulation models are based on mass balance equations and take into account all processes and losses. Simulation based techniques are called Behavior Analysis

It is presumed that the reservoir is adequate if the reservoir can supply all types of demands under possible losses such as seepage and evaporation.

Mass Balance Equation of Reservoirs

$S_{t-1} + Q_t - R_t - L_t = S_t$ ---2.1

Where St-1 is storage at end of previous time interval

S_t is storage at end of current time interval

Q_t is inflows at current time interval

R_t is release at current time interval

L_t is loss (evap/seepage) at current time interval

Reservoirs have a fixed storage capacity, K, so

$S_t <= K$ for each interval

It is used to determine the required capacity, define the optimum rules for operation, select the installed capacity for powerhouses, make other decisions regarding to planning

It is carried out only for an extremely low flow period and presents the required capacity to overcome the selected drought; for the entire period and presents the power production for each year and reliability of reservoir yield

Reliability

Sample et al. (2013) used reliability metrics for water supply to assess performance of simulation run. Reliability metrics vary from 0 to 1. Volumetric water supply reliability was defined as the ratio of sum of yield to the sum of total demand for entire record to time T ($length^3$)

2.1.3. Methods of determining when to irrigate

Proper irrigation management requires that growers assess their irrigation needs by taking measurements of various physical parameters. Some use sophisticated equipment while others use the tried and true common sense approaches. Whichever method used, each has its merits and limitations.

In developing any irrigation management strategy, two questions are common: "When do I irrigate?" and "How much do I apply?"

There are 3 important major irrigation methods

1. Soil moisture techniques: The "Feel Method", Neutron Probe, Electrical Resistance, Soil Tension and New Technology

2. Plant indicators

3. Computerized irrigation scheduling

Among the above different methods computerized *i*rrigation scheduling method CROPWAT 8.0 was selected. The main reasons are: it is freely available, easily to use, widely used in Ethiopian agriculture research institute and it also for preliminary design of irrigation project , GARC verify the model in the field and recommended using pepper as a test crop in the watershed and it is developed based on penman-montieth formulation. The penman – montieth formulation is regarded as a good estimator for a wide variety of climatic conditions. The United Nations food agriculture organization (FAO) adopted the P-M method as global standard to estimate reference crop (ETo) from meteorological data

Computerized irrigation scheduling

The use of computer programs to help schedule irrigation was introduced in the 1970's. However, only recently with the introduction of fast, personal computers have they begun to gain wider acceptance. Several methods can be used to determine crop water use and help growers schedule irrigation. The most common is to use an equation to calculate the water use or evapotranspiration (ET) for a reference crop and relate that to other crops. ET refers to water loss from soil evaporation and plant transpiration. In the beginning of a crop's growing season, the plants are small and most of the water loss is through soil evaporation. As the plants grow and a canopy develops, the soil becomes shaded and most of the water loss is through plant transpiration.

Reference equations include alfalfa-based equations (ETr) and grass-based equations (ETo). There are several equations, each with its own advantages and disadvantages. In Arizona, the Modified-Penman equation is widely used. This equation uses weather data to predict the water use of grass. Other equations used with some success are the Blaney-Criddle, Jensen-Haise, and Hargreaves.

Equally important as the crop curve in irrigation scheduling are the soil water parameters. The PAW of the soil must be known as well as the FC.

In its simplest form, irrigation scheduling is a checkbook balance system. For most crops in Arizona, the soil is at 100% moisture, or very near, at planting time or just after planting. Then, using ETo equations with crop coefficients, the daily crop water use can be determined. This is subtracted from the total water in the soil and then new soil water content is determined. This continues until the amount of depletion of PAW in the soil reaches a predetermined setting (the MAD). For many crops, the MAD is set to 40-50% in the root zone of the crop. Some crops, such as vegetable crops, are more sensitive to large fluctuations of soil moisture and the MAD are set to lower levels.

CropWat 8.0

CROPWAT 8.0 is a decision support tool developed by the Land and Water Development Division of FAO in 2006. It is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. it can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rain fed and irrigated conditions

Calculation procedures - All calculation procedures used in the model are based on two FAO publications of the Irrigation and Drainage Series, namely, No. 33 titled "Yield response to water" (1979) and No. 56 "Crop Evapotranspiration - Guidelines for computing crop water requirements" (1998). The development of irrigation schedules is based on a daily soil-water balance using various user-defined options for water supply and irrigation management conditions. Data input & output - In order to run properly, model needs some data inputs, namely: climatic and rainfall data, crop characteristics and soil features. As a starting point, and only to be used when local data are not available, it includes standard crop and soil data. When local data are available, these data files can be easily modified or new ones can be created. Likewise, if local climatic data are not available, these can be obtained from the climatic database, CLIMWAT, containing date from more than 5000 stations worldwide. After all inputs have been correctly introduced, the software gives some important outputs, such as reference evapotranspiration, effective rainfall, net and gross irrigation requirements. After CWR has been calculated, CROPWAT 8.0 can simulate different types of irrigation scheduling, mainly depending on the user desired option: by changing the Irrigation timing (irrigate at critical depletion, irrigate at user defined intervals, irrigate at given yield reduction, etc..) and Irrigation application (fixed application depth, refill soil to field capacity, etc..) the user can find the more suitable irrigation scheduling for the specific situation.

2.1.4. Important parameters and major component of RWH systems

2.1.4.1.<u>Surface water input and output</u>

The data requirements for water balance method are surface flow, evaporation, precipitation, other loss and demand.

Precipitation

Direct precipitation is an important component of the water balance. Depending on the atmospheric conditions, precipitation occurs as rain, snow, hail, or various other forms. Rainfall is relatively easily measured in principle and, hence, is usually the most accurately measured term in the water balance equation. However, precipitation may have significant spatial variability, even over a relatively small area. Therefore, accurate determination of event-by-event precipitation inputs requires multiple precipitation gauges distributed over the study area.

Rainfall is often described by meteorologists as a very noisy phenomenon. In other words, it can vary a great deal not only on very short timescales, but also over very small distances. For instance, a thunderstorm may deluge one location for a few minutes then cease abruptly, while just next door they receive no rainfall whatsoever. Average annual rainfall can vary over quite short distances due to a variety of local factors, for instance the nearby topography. Considerable variation in rainfall can occur within a relatively short distance, especially where the topography is steep and mountainous. Rain may fall in heavy, localized storms and therefore rainfall even in a small area, may be highly variable and unpredictable

Spatial variability in rainfall is very high. Although rainfall is strongly correlated at distances of less than 4 km, the average daily rainfall can differ more than 25% within this range. Locally, significant correlations were found with aspect, slope and altitude. These trends are significant in wet months. In the dry seasons, rainfall seems to be much more erratic Guido et al (2006).

Evapotranspiration

Water is transferred from ponds to the atmosphere by direct evaporation from the water surface and transpiration by emergent plants. The two processes are driven by the same meteorological factors and are commonly lumped together as evapotranspiration (ET).

Surface runoff inflow

Surface runoff is water, from rain, snowmelt, or other sources, that flows over the land surface, and is a major component of the water cycle.

Surface runoff outflow

Surface runoff outflow is water, from rain, snowmelt, runoff or other sources, that flows over the reservoir/storage and spillway component, and is a major component of the water balance

Seepage describes the slow movement of water through small openings and spaces in the surface of unsaturated soil into or out of a body of surface or subsurface

Water use describes the total amount of water withdrawn from its source to be used. Measures of water usage help to evaluate the level of demand from industrial, agricultural, and domestic users.

Water consumption is the portion of water use that is not returned to the original water source after being withdrawn. Consumption occurs when water is lost into the atmosphere through evaporation or incorporated into a product or plant (such as a corn stalk) and is no longer available for reuse.

2.1.4.2. Major Components of Rainwater Harvesting Systems

Rainwater harvesting includes all methods of concentrating, diverting, collecting, storing, and Utilizing/managing runoff for productive purposes. Irrespective of the technique used to collect and store water or the ultimate use of the water, all water-harvesting systems have the following components shown in figure

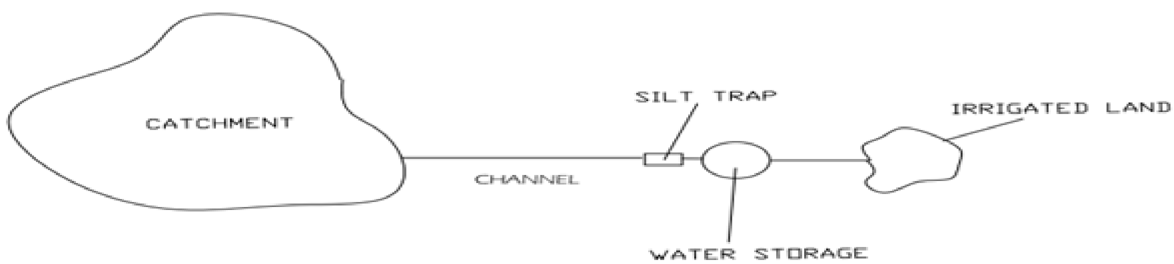


Figure 2. 1: Components of rainwater harvesting system

Catchment Area

Catchment is an area where rainwater is concentrated and contributes some or all its share of rain water to a target area. It can be agricultural, rocky or marginal land, or even a rooftop or a paved road. The rainwater harvested from catchment area should be proportional to command land. The only requirement for a catchment surface is that it has to be impermeable and does not seriously contaminate the water. Ground catchment systems are cheaper than roof catchments and water can be collected from larger area. The size of the catchment area can be determined by using the following equation Gould and Peterson, (1999) and BOA, (2013)

A= 1000 V/PK --2.2

Where, A - catchment area, m^2 V – Water storage capacity, m^3

P – Annual rain fall, mm K – Runoff coefficient for a given catchment

Runoff Delivery Systems

In order to convey runoff from the catchment to the storage, some sort of delivery system is normally required. The diversion channel leading runoff from the ground catchment area to the silt trap and into the tank should be made of compacted earth, or lined with cement or other materials.

Silt Trap or Sediment Pond

It is used to allow the sediment which is being carried in the runoff from the catchment area to settle. Its size is determined according to sediment characteristics and flow discharge. If a lot of sediment is expected, a two-chamber silt trap is recommended - one chamber to catch sand, and the second one to trap finer material. A filter mesh is used to trap leaves, twigs and other debris before the water drains into the tank. It is dug at least 3m away from the storage tank to prevent water from over topping during heavy rains and damaging the tank BoA, (2013).

Storage Facility

It is the place where runoff water is stored from the time it is collected until it is used. Different size and shape of surface and sub surface storage structures are available. Storage tanks and ponds are the common ones. The choice of suitable and cost effective rainwater harvesting tank having appropriate volume needs careful consideration of the existing catchment area, rainfall conditions and the amount of water required. Field experience has shown that universally ideal rainwater harvesting tank design does not exist. Local materials, skill and costs, personal preference and other external factors may favor one design over another Gould and Petereson,(1999).

For trapezoidal

$$V = \frac{H}{3}\left(At + Ab + \sqrt{(At + Ab)}\right) -------------------- 2.3$$

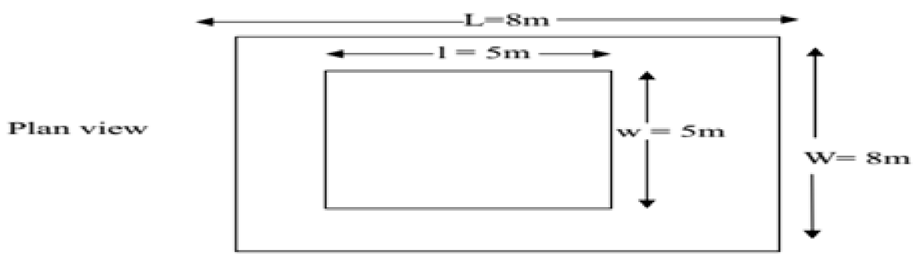


Figure 2. 2: Top view of trapezoidal pond. Source BOA , (2013)

Discharge Channel (pipe) or Spillway

Discharge Channel (pipe) or Spillway is an integral part of the storage pond/tank to ensure that over topping of the embankment is avoided and excess floods flows disposed of safely from storage.

Command Area

The size of the command area depends upon the amount of water harvested from the runoff area. Many water harvesting systems are established merely by estimating the ratio of catchment and command area BOA, (2013).

2.2. Water management

In the moisture deficit areas, water, not land, is the most limiting resource for improved agricultural production. Maximizing water productivity, and not yield per unit of land, is therefore a better strategy for semi-arid area farming systems. Under such conditions, more efficient water management techniques must be adopted. In the semi-arid environments, most of the rainwater is lost by evaporation; therefore the rainwater productivity is extremely low. Water harvesting can improve agriculture by directing and concentrating rainwater through runoff to the plants and other beneficial uses. It was found that over 50% of lost water can be recovered at a very little cost. However, socioeconomic and environmental benefits of this practice are far more important than increasing agricultural water productivity Oweis (2006)

In drought-prone areas where water is a limited resource, it is not always feasible to apply the amounts of water required for achieving maximum yields. For these areas the concepts of deficit irrigation was developed by Moshel and Mikael (1995). Water stored in tanks or ponds can become more effective by applying it at the critical stages of growth rather than by the conventional irrigation schedules. Due to the limited volumes of water harvested and stored compared with crop water requirements, improved benefits of these systems can be derived by incorporating efficient water application methods such as drip irrigation Eyasu (2006) and manually operated lifting devices for taking water from storage. The use of drip irrigation system permits reduction of water loss (up to 50%) and can increase the yield per unit of land by up to 100% compared with surface irrigation systems Cowater International Inc, (2003).

FAO (1989) indicated the problems irrigated agriculture being face in the future. One of the major concerns is the generally poor efficiency with which water resources have been used for irrigation. A relatively safe estimate is that about 40 percent or more of the water diverted for irrigation is wasted at the farm level through either deep percolation or surface runoff Yusuf et al. (2004).

Water management in the rain-fed agriculture is also inefficient. Soil evaporation accounts for 30-50% of the rain fall. Surface runoff is often reported to account for 10-30% of rain fall. The characteristics in dry land of frequent, large and intensive rainfall, results in significant deep percolation amounting to some 10-30% of the rain fall. The result is that productive green water flow as transpiration in general is reported to account for merely 5-10% of rain fall. The rest, between 70-90% of rainfall is lost from cropping system as non productive green water flow (soil evaporation) and as blue water flow (deep percolation and surface runoff) Regasa et al (2006).

Optimization of irrigation water management is necessary for structural (irrigation system design), economic (saving water and energy), and environmental reasons (salt accumulation in soil surface and agro-chemicals leaching into ground water) Annandale et al., (1999). Irrigation improves yield, not only by direct effect on mitigating water stress, but also by encouraging farmers to invest in inputs like fertilizers and improved cultivars, in which they are otherwise reluctant to invest due to uncertainty of crop production under rain fed conditions Smith, (2000) Supplemental irrigation (SI) is a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in the dry rain fed areas. The impact of SI goes beyond yield increases to substantially improve water productivity. Both the productivity of irrigation water and that of rainwater are improved when both are used conjunctively Thiebe et al., (1999).

Optimal SI in rain fed areas is based on the following three basic aspects: Water is applied to a rain fed crop that would normally produce some yield without irrigation, since rainfall is the principal source of water for rain fed crops, SI is only applied when rainfall fails to provide essential moisture for improved and stable production. The amount and timing of SI are scheduled not to provide moisture-stress-free conditions throughout the growing season, but to ensure a minimum amount of water available during the critical stages of crop growth that would permit optimal instead of maximum yield.

The selected crop by farmers, ICARDA and GARC to cultivate with supplementary irrigation in the study area was Hot pepper. Hot pepper (Capsicum spp.), commonly known as chili, is the world's third most important vegetable after potatoes and tomatoes in terms of quantity of production.

2.3. Performance evaluation factors

The main purpose of performance evaluation is to identify deficiencies and recommend improvements to be made to promote and uphold efficiency and effectiveness of a system (Molden et al, 1998). The performance of a system is usually measured using its efficiencies. The efficiency of the rainwater harvesting system is often composed of the runoff harvesting efficiency, runoff storage efficiency and system efficiency (Gary, 1994). The performance can be evaluated by its water productivity, sedimentation rate and economic efficiency (Arega, 2003).

i) **Runoff harvesting efficiency (RHE):** can be measured as the ratio of the amount of water harvested or input to the storage and the amount of runoff available in the catchment.

ii) **Runoff storage efficiency (RSE):** is the ratio of the amount of runoff available in the storage to the amount of runoff input, which actually gets into the storage unit.

iii) System efficiency: It measures the effectiveness of the whole system that indicates how much of the runoff produced on the catchment of rainwater harvesting systems is consumed or irrigation or any other purpose. It is calculated as follows (Suresh, 1997)

$$SE = \frac{water\ consumed}{Total\ runoff} ---------2.4$$

iv) **Storage to Excavation Volume Ratio (SER):** If the ratio is one, then the storage is least economical (the storage holds equal volume of water to that of excavated).

v) Water productivity (WP): is the ratio of the physical yield of a crop (kg) and the amount of water consumed (m3), including both rainfall and supplemental irrigation (Arega, 2003).

vi) **Benefit-Cost Ratio (BCR):** It is essential that the costs of a project be at least balanced by its benefits. A feasibility study should be conducted with due consideration to financial analysis. Economic feasibility is a very important factor in its acceptance by population. If the initial investments are considered as a subsidy to the community without an expected economic return and only operation and maintenance costs are to be covered by the beneficiaries, rainwater harvesting systems can be economically viable and attractive to the beneficiaries. In the case where all costs are to be recovered from the project returns, it is essential that the project benefits offset these costs (Gittenger, 1982).

The project to be economically feasible, the benefit cost ratio should be more than one. To calculate the benefit-cost ratio, all inputs and outputs should be identified, quantified and valued (Gittenger, 1982). Total cost is the sum of investment and annual cost items. Investment costs involved in the erection of the systems prior to the actual supply of the water and annual costs or expenditure that will be important to keep the system in operation after construction has been completed.

vii) **Cost per harvested runoff (CHR)**:- It is a measure of economical viability of the structure and used as a comparative analysis (Theib, 1999).

$$CHR = \frac{Construction\ cost}{Water\ harvested\ in\ storage} \text{--} 2.5$$

2.4. Estimating useful life of reservoirs

Sedimentation in reservoirs is a problem for which an economical solution has not yet been discovered. Disintegration, erosion, transportation and sedimentation are the different stages leading to silting up of reservoirs.

The life of the storage and time for de- silting can be determined by knowing the sedimentation rate. The sedimentation rate is expressed in terms of percent of annual capacity of reservoir lost expressed by the formula (Suresh,1997).

$$S = \frac{Sa}{C} * 100 -----------------------------2.6$$

Where S= annual loss of reservoir capacity, % Sa = annual deposition of silt C= reservoir capacity

The trap efficiency of the reservoir is the ratio of sediment caught in the storage and total load entering with the runoff. The efficiency of the silt trap (%) can be calculated with this equation (Suresh, 1997 ; USBR,1977):

$$Silt\ trap\ effciency = \frac{S1 - S2}{S1} * 100 ---------------- 2.7$$

Where, S1- the sediment entered in to the silt trap S2 – the sediment discharged out of the silt trap

The useful life of a reservoir is taken till its capacity is reduced to about 20% of the designed capacity. Among the common methods used to estimate the use full life of a reservoir is Varshney (1974) Method.

1. First of all, the basic minimum requirement of water is fixed up, that is considered sufficient to cater to the needs of the primary use through the cycle of the driest years, offsetting the seepage, evaporation and any other loss.

2. The reservoir capacity is divided into intervals of 10%.

3. Trap efficiencies for each capacity is determined.

4. The volume of sediment deposited per year is then calculated.

Volume Deposited/ year = Annual Sediment transport X Trap efficiency-------------------------2.8.

5. The volume interval (i.e. 100% of the capacity) is divided by the sediment deposited to get the number of years to fill these volume intervals of 10% capacity.

6. The procedure is repeated and the number of years is added until 80%, 70%, ---20% reservoir capacities is remaining.

7. The period when the project fails to meet the minimum basic demand originally fixed, is considered as the "useful life" of the project.

2.5. Measurement and estimation of flow

Discharge data are essential for the estimation of loads of sediment or chemical pollutants exported from a river or stream. The depth of flow (m or ft) is most commonly measured as stage, the elevation of the water surface relative to an arbitrary fixed point. Stage is important because peak stage may exceed the capacity of stream channels, culverts, or other structures, while both very low and very high stage may stress aquatic life. In a particular location, stage is often measured relative to a fixed point using a staff gage, a rigid metal plate graduated in meters or feet attached to a secure backing and located in a part of the stream where water is present even at low flows. During installation, staff gages are usually related by survey to a fixed reference (e.g., a bridge deck) so that the elevation of the gage can be checked periodically and re-established if it has been disturbed.

Among different methods of measuring discharge, rectangular weir is commonly used. Weirs are typically installed in open channels such as streams to determine discharge (flow rate). The basic principle is that discharge is directly related to the water depth (h); h is known as the "head." Rectangular weir equation is:

$$Q = 2.95Ce(b + Kb)(h + Kh)^{1.5} ------------------- 2.9$$

Where Q = Discharge (L/T0,Ce = Discharge coefficient , h= Head (L), b= width(L), Kb and Kh account for effects of viscosity and surface tension (L)

The sum b+K_b is called "effective width" and the sum h+K_h is called "effective head." The value for g is 9.8066 m/s^2 and K_h=0.001 m. C_e is a function of b/B and h/P, and K_b is a function of b/B. Our "Solve for Flowrate" calculation is analytic, but our "Solve for Head" and "Solve for Notch Width" calculations require numerical solutions since C_e and K_b cannot be computed directly, as they are functions of h and/or b.

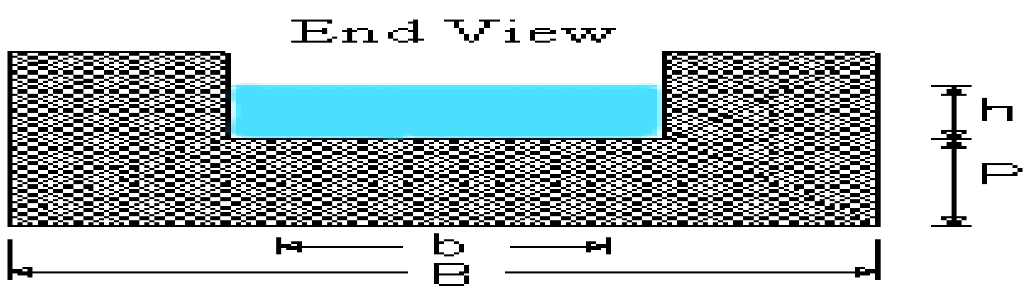


Figure 2. 3: rectangular weir

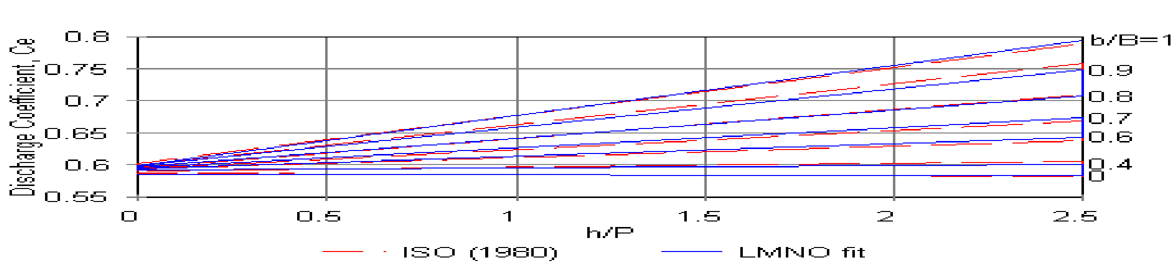


Figure 2. 4: Rectangular weir discharge coefficient

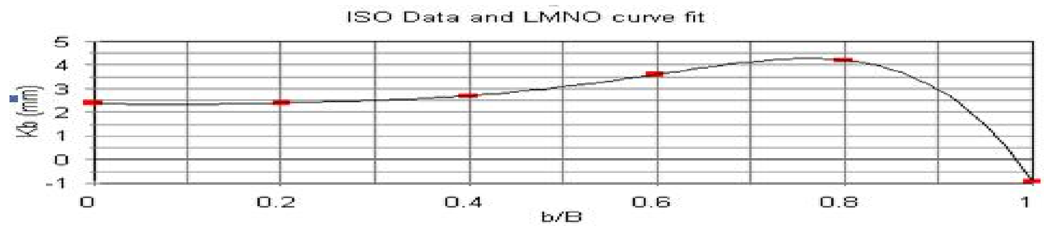


Figure 2. 5: Kb for rectangular weir

2.5.1. Rainfall-runoff models

In the Ethiopian highland, efficient management of rainwater for increasing water availability to the crops during the growing seasons, and collection of the excess rainwater by water harvesting techniques with the view to develop water resources in the region on a long term basis, is essential Selamyihun, (2004). In the Ethiopian highlands, the predominant source of water is rainfall. However, due to temporal and spatial variation in the occurrence of rainfall, about 32 percent of land is moisture deficit. Rainfall is generally lower than 600 mm/year. Rainfall is highly variable, and the land is moderately to highly degrade. These areas are often vulnerable and degraded, and constrained by low productivity and overpopulation. Here, irrigation could secure food production, improve livelihoods, and increase food resilience IWMI (2010).It is estimated that 4 to 5 percent is irrigated, with existing equipped irrigation schemes covering about 640,000 hectares. This means that a significant portion of cultivated land in Ethiopia is currently not irrigated IWMI (2010)

A review by Easton et al. (2012) in blue Nile basin shows that investigate run-off response patterns, discharges in the Anjeni, Andit Tid and Maybar catch-ments were plotted as a function of effective rainfall (i.e. precipitation minus evapotranspiration, P - during the rainy and dry seasons. As rainfall continues to accumulate during the rainy season, the watershed eventually reaches a threshold point where run-off response can be predicted by a linear relationship with effective precipitation, indicating that the proportion of the rainfall that became run-off was constant during the remainder of the rainy season. For the purpose of this study, an approximate threshold of 500 mm of effective cumulative rainfall (P E) was deter-mined after iteratively examining rainfall/run-off plots for each watershed. The proportion Q/(P - E) varies within a relatively small range for the three SCRP watersheds, despite their different characteristics. In Anjeni, approximately 48 per cent of late season effective rainfall became run-otf, while ratios for Andit Tid and Maybar were 56 and 50 per cent, respectively Liu et al., (2008).There was no correlation between biweekly rainfall and discharge during the dry seasons at any of the sites. Despite the great distances between the watersheds and the different characteristics, the response was surprisingly similar

To further investigate the hydrological response in the blu nile basin the infiltration rates are compared with rainfall intensities in the Maybar, Andit tid, Anjeni and Debrimawi watersheds, where infiltration rates were measured by Derib, 2005, Engda 2009, Easton et al, 2012 and Tilahun et al., 2013 respectively.

A review by Awulachew et al. (2009) shows that the number of models simulating the discharge from watersheds in the Blue Nile and other river basins in Ethiopia and Africa has increased exponentially in recent years. Most of these models were originally developed for applications in temperate regions. They range from relatively simple engineering approaches such as the Rational Method (Desta 2003), to more complex models such as SWAT (Setegn et al. 2008), Water Erosion Prediction Project (WEPP) (Zeleke 2000), the Agricultural Non- Point Source model (AGNPS) (Haregeweyn and Yohannes 2003; Mohammed et al. 2004), and water balance approaches (Ayenew and Gebreegziabher 2006;Kim and Kaluarachchi 2008).

The RM has been applied to many different watersheds around the world and for different purposes and in some cases subjected to different modifications. However, the application of MRM in grazing ecosystems has not been reported yet. Further, many studies have been conducted about the application of the RM and calibration of its parameters for Ethiopian conditions, while no application of MRM has been documented so far. Here the authors decide to use MRM considering the availability of data and catchment size because MRM develop for detention and retention of runoff volume and it also applicable for hydraulic design of storage for small watershed.

2.5.2. Modified Rational Method

The modified rational method (MRM) is a method to parameterize simple runoff hydrographs. The MRM produces a runoff hydrograph (and volume) while the original rational method produces only the peak design discharge. The rational method was originally developed for estimating peak discharge for sizing drainage structures, such as storm drains and culverts. The MRM, which has found widespread use in engineering practices since the 1970s, is typically used to size detention/retention facilities for a specified recurrence interval and allowable outflow rate. The MRM was developed with the intent of using the rational method for hydraulic structures involving storage on small watersheds. The MRM hydrograph for the case when the storm duration is less than the time of concentration of the drainage area (Theodro etal 2011) and stated that Qp can be calculated using Equation

$$Q = CIA\frac{D}{360Tc} -2.10$$

Where

Q = Peak discharge, cms C = Rational method runoff coefficient
i = Rainfall intensity, mm/hour A = Drainage area, hectare

D = runoff duration (minute) Tc = Time of concentration (minute)

Time of Concentration

The time it takes for runoff to travel from the most hydraulically distant point in the watershed to a point of interest.

Three Components of the Segmental Time of Concentration Method

1 Sheet Flow: “Sheet flow is flow over plane surfaces. It usually occurs in the headwater of streams.”The most sensitive component of the TC.. The maximum sheet flow length should be no greater than 125 to 150 ft.

$$t1 = \frac{5.48(nL)^{0.8}}{P^{0.5}S^{0.4}}$$ ---2.11

Where

t_1 =overland sheet flow runoff travel time, min

n= Manning rougness coefficient, dimensionless

L= length of the flow path. M (max. L should be 100m)

P = 2 year, 24 hr rainfall, mm S= ground slope, m/m

2) Shallow Concentrated Flow: "After a maximum of 300 feet, sheet flow usually becomes shallow concentrated flow."Note: This 300 ft. value has since been revised down to a maximum of 150 ft. on very uniform surfaces.

t_2= L/(60V) --2.12

V= $4.9178S^{0.5}$ ---2.13

t_2=shallow concentrate flow runoff travel time , min L= length of flow path, m

V= shallow concentrated flow runoff travel time, min L=length of flow path, m

V=shallow concentrate flow velocity, m/s S= surface slope, m/m

3) Channel Flow: Channel flow occurs within swales, channels, streams, ditches and piped storm drainage systems. Velocities are computed for channel flow based upon Manning's open channel flow equation.

Q= $AR^{0.67}S^{0.5}/n$ --2.14

V= Q/A ---2.15

R=A/P ---2.16

t_3=L/(60V) --2.17

Q= channel flow rate, m^3/s V= average velocity flow , m/s

A= channel cross sectional area, m^2 P = wetted perimeter of channel, m

S= channel bottom slope, m/m n= manning roughness coefficient for channel

L= length of flow path, m

Total Time of Concentration: The time of concentration along our sample hydraulic path is simply the sum of the travel times for the overland flow, shallow concentrated flow, and channel flow

$t_c = t_1 + t_2 + t_3$ --2.18

2.6. Measurement and estimation of soil erosion

Data on soil erosion and its controlling factors can be collected in the field or, for simulated conditions, in the laboratory Hudson, (1982) and Morgan, (1995). Whether field or laboratory experiments are used depends on the objective. For realistic data on soil loss, field measurements are the most reliable because condition vary in both time and space, it is often difficult to determine the chief causes of erosion or to understand the process at work Hudson, (1982). Field experiments on large plots are required for evaluating farming practices such as area closure and terracing. Although there is little uniformity on the size of plots for this type of experiment, they are generally in the range of 6 to 13 m wide and 15 to 32 m long Morgan, (1995). Even if most experiment conducted in the previous range, here we are trying to conduct in the range of 0.6 to 2 ha of runoff catchment. In general, the measurement requires funds, long years and well-trained personnel. Consequently, adapting simple empirical model is an option for planning Hudson, (1982).

Sediment concentration and load at the outlet were always higher than the concentrations at upstream Tilahune (2012). This indicates that there are hotspot sediment source areas close to the river channel and at the outlet in contrast to the upslope areas reported by Mekonnen and Melesse (2011) in Debrmawi watershed. The drop and subsequent low sediment concentration at the end of the rainy season is also reported in Tigray, in the northern part of Ethiopia by Vanmaercke et al. (2010), they argued that lower concentrations of sediment are due to sediment depletion. Others (Descheemaeker et al., (2006); Bewket and Sterk, (2003) suggested that the lower sediment concentrations are a result of the increased plant cover. Sadeghi et al (2007 b) argued due to decrese of transport capacity by surface runoff.

The Modified Universal Soil Loss Equation (MUSLE)Williams (1975) was developed as a watershed-based model to estimate the sediment yield produced by each individual storm event. He developed the following revised form of the USLE using 778 storm-runoff events collected from 18 small watersheds with areas varying from 15 to 1,500 ha Williams and Berndt (1977) and called it the modified universal soil loss equation (MUSLE).In the MUSLE, the rainfall (R) factor is replaced with a term that combines storm runoff volume (Qv in m3) and peak runoff rate ($q_p$in m3/s),and interprets the other USLE factors (soil erodibility: K factor, slope steepness and length: LS factor, crop management:C factor, and conservation practices: P factor) on a watershed-wide and individual storm event basis.

The runoff factors represent the energy used in transporting as well as in detaching sediment, which acts as the best indicator for predicting the sediment yield of each individual storm event Foster et al. (1977); Hrissanthou (2005). The accuracy in estimating sediment yield, especially for micro watersheds, is increased by eliminating the sediment delivery ratio Williams and Berndt (1977).

The resulting under- and over-estimation of MUSLE model, depend on various site specific conditions, for instance rainfall characteristics, Sadeghi et al. (2007b) reported MUSLE under-estimation sediment yield in watershed scale. The same author in the same year reported over-estimations Sadeghi et al. (2007a) and Somnuck et al (2014), and did not need any modification to the model Sadeghi and Mizuyama (2007).

The MUSLE has been applied to many different watersheds around the world and for different purposes and in some cases subjected to different modifications. However, the application of MUSLE in grazing ecosystems has not been reported yet. Further, many studies have been conducted about the application of the USLE and calibration of its parameters for Ethiopian conditions, while no application of MUSLE has been documented so far.

2.6.1. Modified Universal Soil Loss Equation

The MUSLE (Williams 1975) is calculated as:

Xt = 11.8 KLSCP (Qv*qp)^0.56 --2.19

where Xt is the sediment yield from a rainfall event in metric tons, Qv is the runoff volume (m3), qp is the peak runoff rate (m3 s_1), K is the soil erodibility in Mg MJ_1 mm_1, LS is the slope length and slope steepness factor (dimensionless), C is the crop management factor (dimensionless), and P is the conservation practice factor (dimensionless). Analysis of LS factors in the original MUSLE Model

Slope steepness (S) and slope length (L) or LS factor is the topographic factor.

L Factor (length)

$L = (\lambda/72.6)^{m}$ --2. 20

λ: the horizontal projection in feet

$$M = \frac{\beta}{1+\beta} - 2.21$$

$$\beta = \left(\frac{sin\theta}{0.0896}\middle|(3(\sin\theta)^{0.8}) + 0.56)\right) - - - - - - - - - - - - - - - - 2.22\right)$$

θ: slope angle *for moderate ratio of sheet to rill erosion; for low ratio of sheet to rill erosion β/2 and for high ratio 2βis used

S Factor (steepness)

(slope angle θ ≥9%)

$$S = 16.8\sin\theta - 0.5 -2.23$$

(slope angle θ< 9)

$$S = 10.8\sin\theta + 0.03 - 2.24$$

The K-factor accounts for the influence of in-situ soil properties on soil loss in upland areas. The factor represents an integrated average annual value of the total soil and soil profile reaction to various hydrologic and geomorphic processes, to include soil detachment, transport, localized deposition and infiltration.

The LS factor incorporates the topographic effects of slope length (L) and steepness (S). Slope length is the horizontal distance from the origin of overland flow to the point on the landscape where either (1) the slope gradient changes significantly enough to initiate deposition, or (2) runoff becomes concentrated in a defined channel. Steepness is the percent change in elevation divided by the change in horizontal distance across the slope length, L.

C factor values are determined by surface and sub-surface vegetative effects, to include residue cover, canopy cover, canopy height, surface roughness, and biomass. These sub factors can reduce the impact of raindrops and slow the movement of water across the landscape. Both the physical effects of agricultural cropping techniques, and their seasonality, are considered.

The P factor accounts for conservation practices used on the landscape to mitigate erosion. These practices include contouring, strip cropping, terracing and sub-surface drainage. If there are no practices in the study area (e.g., natural conditions), then a P-factor value of 1.0 is used. All of the factors are dimensionless, with the exception of R and K.

2.7. Model calibration and validation

Model calibration is the process of changing parameter values to obtain simulated results that most closely reflect recorded values. Model verification involves checking the validity of the parameter values for a period not originally simulated. The general approach to calibration is one of trial-and-error in which various values for each parameter are tried, their effects are noted, and appropriate changes are made to improve agreement between simulated and recorded values Morgan, (1995); Johnson, (1998).

The statistical criteria select for comparison of the performance of the model in predicting discharge will be the Nash-Sutcliffe coefficient, E, a dimensionless indicator widely used to evaluate hydrological models Nash and Sutcliffe, (1971), Coefficient of correlation, R2, and root mean square of error (RMSE). The Nash Sutcliffe coefficient (E) calculates as:

$$E = 1 - \frac{\sum_{i=1}^{n}(Si - Oi)^2}{\sum_{i=1}^{n}(O - O*)^2} \text{---------------------} 2.25$$

Where O* is the average measured discharge, Si is the simulated discharge for each time step, O i is the observed discharge value, and n is the total number of values with in the period of analysis. Along with the coefficient of correlation, the Nash-Sutcliffe coefficient (E) is a measure of statistical association, which indicates the percentage of the observed variance that is explained by the predicted data. The Nash-Sutcliffe coefficient, also known as the efficiency criterion, is perhaps the most common measurement method in the hydrological literature for evaluating the performance of a model MacLean, (2005). E values can vary from zero to one, with one indicating a perfect fit while zero indicates that the model is predicting no better than using the average of the observed data. Legates and McCabe (1999) in Harmel and Smith (2007), mentioned that E is better suited to evaluate model goodness-of-fit than the coefficient of determination, R2, because R2 is insensitive to additive and proportional differences between model simulations and observations. Slope and y-intercept**-** A slope of 1 and y intercept of 0

However, like R2, E is overly sensitive to extreme values because it squares the values of paired differences, as shown in equation above.

The root mean square error, RMSE, is well-accepted absolute error goodness of-fit indicator that describes differences in observed and predicted values in the appropriate units Legates and McCabe, (1999). It is calculated as

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Si - Oi)^\wedge 2} ----------------2.28$$

Where all the terms have the same meaning as the above Equations

3. METHODOLOGY

3.1. Site description

The Gumara-maksegnit watershed research site, named after the district Macksignit and river Gumara, it lies in the critical part of the Lake Tana basin of the North West Amhara region of Ethiopia. The 53.7 km² watershed drains into the Gumara-Maksegnit River, which ultimately reaches Lake Tana. The watershed is located at about 45 km southwest of Gondar town and cross by Maksignt – Belesa district road; it is located between 12° 24’ and 12° 31’ north and between 37° 33’ and 37° 37’ east. The altitude of the study area ranges 1933m to 2852m above mean sea level (Figure 3.1).

The area had a temperature ranging from 11 to 32 ºC. The total annual rain fall varies from 500 – 733 mm with annual mean of 621 mm. Average annual rainfall varies over quite short distances due to a variety of local factors, such as nearby topography which is steep and mountainous.

Woretwe runoff catchment of approximately 2.09 ha catchment size, its lowest elevation is 2052 m.a.s.l at the pond and maximum 2100 m.a.s.l at the peak with average land slope of 22.8%. Annual rainfall in 2014 was 603mm. Land use land cover indicated that 73.7% of catchment was shrub and bush land and the rest was natural grass. The conservation practice of the area were a little to null, woretawe catchment adopted seasonal area closure from cattle from June to October first.

Ambachewe runoff catchment of approximately 0.62 ha catchment size, its lowest elevation is 2010 m.a.s.l at the pond and maximum 2034m.a.s.l at the peak with average land slope of 5.8%. Annual rainfall in 2014 was 506mm. Land use land cover indicated that 100% of catchment was free grazing natural grass land. The conservation practice of Ambachewe catchment was null (Figure 3.2).

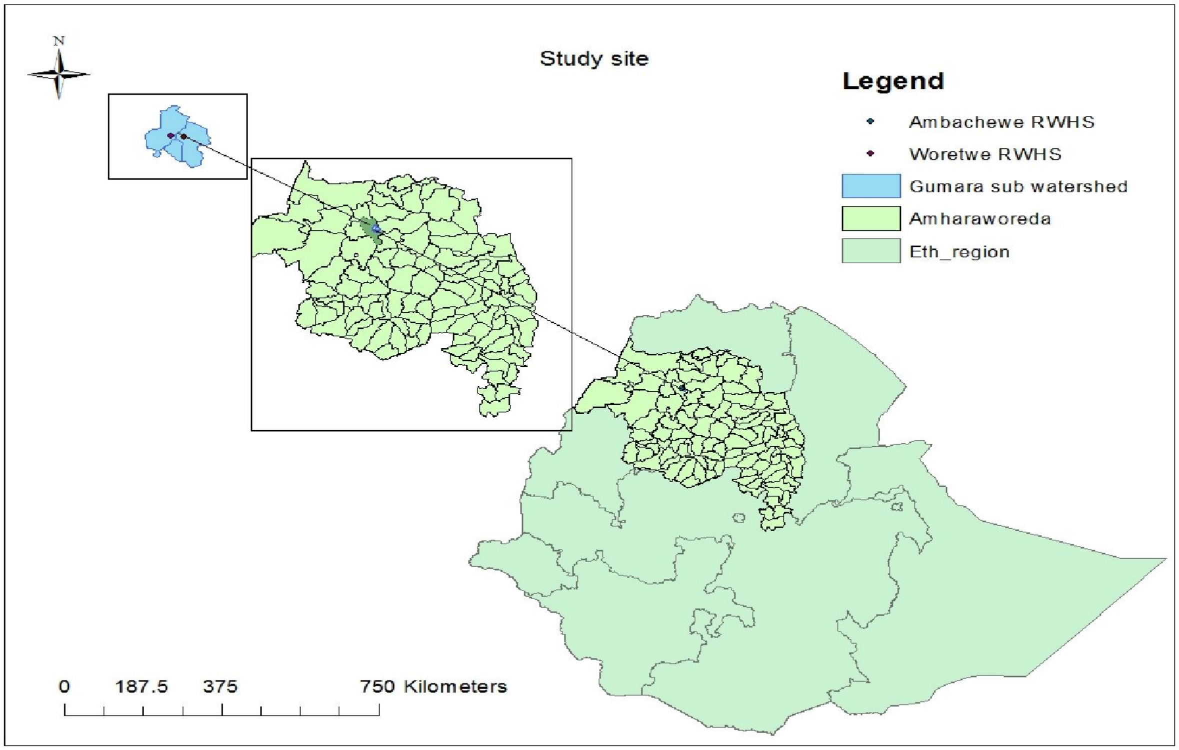


Figure 3. 1: Location map of the study area

A B

Figure 3. 2:A) Runoff catchment of Ambachewe (B) Runoff catchment of Woretwe in August 2014

3.2. Data collection and methodology

Field work was carried out during the summer of 2014 in the watershed. Rainfall and evaporation were measured through the crop length of growing period; runoff discharge and sediment concentration were also monitored at two gauging stations at the outlet of the two sub-watersheds. Installation and running costs were collected from GARC and ICARDA. In addition current market price and other relevant data collected from respective office of maksignit district and project (Appendix Table 8).

3.2.1. **Sample size and sampling methods**

During field observation/assessment period water harvesting structure selection was done based on the criteria of accessibility, live fence, capacity of pond , farmers cooperation ,cost and current status of the pond. Accordingly; two reasonably water harvesting structures were selected among four namely (**Weretaw's and Ambachew's** water harvesting structures**),** which is about three kilo meter far apart. The two water harvesting structure have 8m*8m top width, 5m*5m bottom width , side slope of 0.5m:1m(H:V) and the capacity of the pond is 129m^3.This study was takes place on two reasonably delineated runoff areas contributing water to the reservoir inside Gumara-Maksegnit watershed.

3.2.2 **Metrological data**

The **rainfall data** were recorded in the watershed at five minute intervals with an automatic tipping bucket rain gauge and measuring from June 1 to October 28 in 2014 and another 19 manual rain gauges from June 21 to September 20 in 2014. All rain gauges were distributed throughout the watershed; two were purposively at the water harvesting structure. From continuous readings of the automatic rain gauge, rainfall characteristics like amount, intensity, and duration were determined. Average annual rainfall data were used for modeling purpose; it was from 10 manual rain gauges which showed better correlation with measured discharge than other readings. The seasonal monthly rainfall trend of woretwe and Ambachewe sub watersheds were also showed in 2014 rainy season (Figure 3.3, Appendix figure 1).

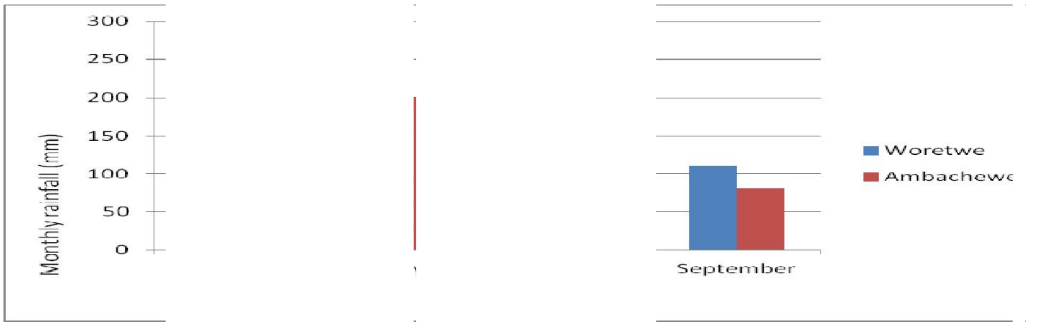


Figure 3. 3: Monthly rainfall distribution of the two sub watershed

Evaporation data were recorded using galvanized barrel (local pan device) from July 4 to October 27and then calibrate using koga metrological station .Calibration result shows local pan over estimate on average of 1.058 than standard pan material and finally adjusts the pan data using 0.7 pan coefficients. The evaporation trend of the watershed for the rainy season was in the range of 1.41-4.35 mm/day (Figure 3.4).

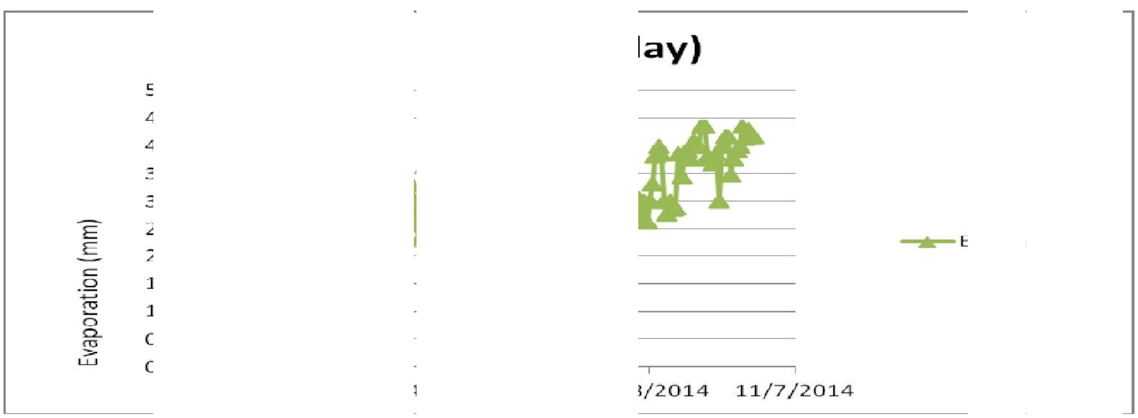


Figure 3. 4: Evaporation trend of the watershed for the main growing season

3.2.3 Gauging station

Sub-watersheds: Concrete weirs at the two outlet of the sub watershed were constructed by GARC Research Center in 2013. Sub-watersheds from each weir were defined using GPS tracking in the field. The size of the sub-watershed areas were 2.09 and 0.62 ha at Woretwe and Ambachewe respectively. The areas of the sub-watersheds were used to calculate runoff depth at the outlet of the watersheds.

The runoff stage: recording stations were located at the inlet and outlet (inlet of pond) of silt trap. The depth of runoff stage was taken manually from July 11 to August 31 and August 2 to September 13, 2014 for Ambachewe and Woretwe respectively. Runoff in the diversion channels lasted a few days for Ambachew where as lasted full of July at Woretwe due to lining material problem.

Sediment concentration : one-liter grab samples for sediment measurement were taken every 10 minutes for inlet of silt trap and 20 minute for the first and sampling rate decreased to 30 minute for second for silt trap outlet. Together with the sediment samples, velocity and runoff depth were measured to determine the total runoff and to estimate the suspended sediment carried by the flow at that specific time interval. Using stopwatch and silt trap the velocity were determined volumetrically during each runoff collection.

The amount of sediment load within the sample were determined by oven drying the one liter grab samples then weighing the oven dried soil. Total soil losses for those sampling intervals were then calculated by multiplying total water flow per time by the sediment concentration determined form the one-liter sample. Bed load calculated 10-15% of suspended load. Total load was summation of bed and suspended load.

Seepage and spill *data* were determined by water level of the pond using installed graduate staff gauge at middle of the pond daily based.

The river stage-discharge relationship was determined using stage discharge and volumetrically methods. Twenty two stream gauging measurements (13 for calibration and 9 for validation) were carried out for different river water stages/height to develop the rating equation and the rating curve. Figure 3.5 presents the relations between measured stream stage and calculated flows with 0.98 E. Using the developed rating equation/ rectangular weir is

$q_o=0.65Ce\ L_wH_w^{1.5}$ ---3.1

Where q_o= peak outflow discharge (cms) , Ce= discharge coefficient (figure 2.6)

L_w= weir crest length (m)

H_w= head over weir crest (m)

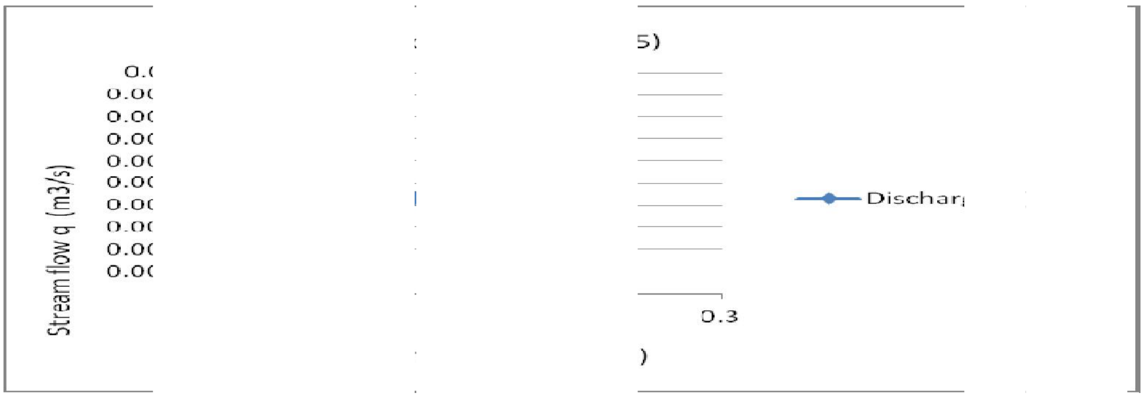


Figure 3. 5: stream stage-discharge rating curve of rectangular weir

3.2.4. Laboratory data

Moisture content and textural composition soil samples were collected from the runoff catchment and command area and it was analyzed in the laboratory. Soil moisture contents were determined using the simple gravimetric method. Texture composition identification was analyzed using hydrometer and textural triangle. Pressure plate was used for determining field capacity and permanent wilting point. A cylindrical core sampler of 98.2 cm3 were used to take samples without disturbing the natural structure for the purpose of analyzing soil bulk density. The soil bulk density was calculated by dividing the mass of the oven-dried sampled soils with the volume of the cylindrical core (Appendix Table 2).

3.3. Simulation Model

A mathematical computerized model based on Linear Programming technique has been presented here to optimize the size of a storage tank or reservoir for supplemental irrigation depending on runoff volume.

The model described here analyzes the relationship between moisture added to the soil, through precipitation and runoff that is required for crop growth. The daily rainfall data available for the record years are used in estimating the value of runoff volume for rainy days.

Daily runoff occurs when the daily rainfall exceeds threshold depth value which in turn depends on the characteristics of the catchment area, mainly slopes and surface conditions.

Runoff predictions: The validity of modified rational method (MRM) was tested for predicting the runoff of the sub watersheds. It is given in the form of

$$Q = CIA\frac{D}{360Tc} - 3.2$$

Where

Q = Peak discharge, cms C = Rational method runoff coefficient
i = Rainfall intensity, mm/hour A = Drainage area, hectare

D = runoff duration (minute) Tc = Time of concentration (minute)

An analysis of the rainfall-runoff relationship and subsequently an assessment of relevant runoff coefficients were based on actual, simultaneous measurements of both rainfall and runoff in the study area. The runoff coefficient from an individual rainstorm is defined as runoff divided by the corresponding rainfall both expressed as depth over catchment area (mm)

The objective function is to maximize the total return by considering the benefit per unit mass of yield per unit of planting area, losses for not cropping (harvesting) area under rainfed conditions, and reservoir cost per unit volume. The total cost of a reservoir includes itsconstruction, lining cost and cost of inlet and spillway structure, therefore the objective function in terms of benefits will have the following form:

Maximize total benefit $C_{TB} = Y.C_y.A_r – Ca.Ac – C_r.V_r$ --3.3

in which:

C_{TB} = Net yearly benefit,

Y= Yield per unit area,

C_y= Return per unit mass of yield,

A_r= Cropped area (Target),

C_a = Cost per unit harvesting area, reflects yearly loss of rain fed production per unit area of catchment,

Ac = Catchment area,

Cr = Cost per unit volume of reservoir, includes its construction, lining cost and cost of inlet and spillway structure.

Vr = Volume of reservoir.

This function is subject to a number of constraints that must be considered. The first constraint in the reservoir routing (volume balance in cubic meter) equation, for variable intervals is given in equation 3.4. The main assumption is that flow and demand will repeat them in the future.

Mass Balance Equation of Reservoirs

$S_{t-1} + Q_t - R_t - L_t = S_t$ --3.4

Where St-1 is storage at end of previous time interval

S_t is storage at end of current time interval

Q_t is inflows at current time interval

R_t is release at current time interval

L_t is loss (evap/seepage) at current time interval

Reservoirs have a fixed storage capacity, K, so

$S_t <= K$ for each interval

Sediment predictions: The validity of MUSLE Williams (1975) was tested for predicting the sediment load of the sub watersheds. It is given in equation 2.19

Irrigation demand

Irrigation demand was estimated using CROPWAT 8.0. The validity of the model was verified in the field by GARC 2013/14 rainy season and they recommend 2/3 of the model output (Appendix Figure 2).

The selected crops were pepper, carrot, cabbage and Swiss chard. Based on farmer perception and the significance difference of supplementary irrigation with rain fed, green pod pepper was selected among those crop types as dominant crop. We use furrow irrigation because it is suitable for a wide range of soil types, crops and land slopes, needs low investment cost and maximum values of furrow length are given for reasonably efficient irrigation.

3.4. Data checking

The reliability of all recorded data such as rainfall and runoff were cross-checked with automatic rain gauge and water level depth of pond. Runoff stage readings, and suspended sediment weights data events at which the runoff height was beyond the rating equation were also avoided.

3.5. Data analysis

Analyses were undertaken based on water balance model (Behavioral analysis) using an Excel 2010/VBA-based modeling tool. This tool implements the water balance design methods and also includes the facility to calculate volumetric reliability, the whole life cost, pay-back-period and cost-benefit of a RWH system (with mains top-up) in comparison with an equivalent loss land value (see section 2.3).

The statistical criteria select for comparison of the performance of the model in predicting discharge and sediment were the Nash-Sutcliffe coefficient, E, a dimensionless indicator widely used to evaluate hydrological models Nash and Sutcliffe, (1971), Coefficient of correlation, R2, and root mean square of error (RMSE) as mentioned in equation 2.25 and 2.26.

4. RESULT AND DISCUSSION

The following paragraphs summarize the findings of the site inspection and analysis result

4.1. Rainfall intensity and soil infiltration rate

Rainfall intensity, one of the factors affecting runoff, is a very important parameter to model rainfall-runoff relationships especially in areas where infiltration excess runoff is expected Beven, (2004). Two hundred sixty four recordings of one hour interval rainfall intensities with a maximum intensity of 44 mm hr-1were recorded during the period of the study. Rainfall intensities greater than 12.12 mm hr-1 occurred only 9.4% of the time in 2014. The largest intensities occurred in August. For example in 2014, from 24 events that are greater than 12.12 mmhr-29.1% of the events occur in July while 54.2% is in August and 16.6% in September. Soil infiltration rate of the watershed is compared with the exceedance probability of the rainfall intensity as shown in (Figure 4.1). The steady state infiltration rates ranged from 12.1 to 210 mm hr-1(Appendix Table1). This finding is similar with Maybar watershed Derib, (2005), Andit tid watershed Engeda A. T, (2009), Anjeni watershed Easton et al, (2012) and Debrimawi watershed Tilahun et al., (2013), the minimum infiltration rate is exceeded 9, 8, 6 and 3% of the time respectively. Even if loam soil infiltration rate are in the range of 10-20 mm/hr, this low infiltration rate (12.12mm/hr) might be caused by the compaction of freely roaming animals for grazing, clay content of the soil and shallow soil depth. Nyssen et al., (2010) behaved similarly when the infiltration rate is reduced or in areas with severe degradation, livestock traffic can cause infiltration excess run-off.

Figure 4. 1: The exceedance probability of the average intensities and basic infiltration rate

4.2. Run-off from two rectangular weir

A total of thirteen, and nine average runoff depth for which both rainfall and runoff depths were available at Ambachewe and Woretwe weir respectively.

Since analysis of the rainfall-runoff relationship and subsequently an assessment of relevant runoff coefficients should best be based on actual, simultaneous measurements of both rainfall and runoff in the project area. A runoff coefficient was calculated for each storm and averaged for each month with a correlation (R2) of 0.78 and 0.96 for Ambachewe and Woretwe sub catchments respectively.

Table 4. 1: Average runoff coefficient of the two sub watershed in 2014 rainy season

	July	August	September
Woretwe	-	0.18	0.14
Ambachewe	0.6	0.25	-

The runoff coefficient showed decreasing trend Unlike Tilahun (2012) indicating that rain water infiltration increase through time during rainy season. No data were available for July and September for woretwe and Ambachew sub catchments respectively. The average run-off measured on two sub catchment showed that Ambachewe catchment had higher run-off losses than those with woretwe catchment. This might be formation of a thin but dense and compacted layer at the surface, low time of concentration and low slope for Ambachew. Well vegetation coverage which increase infiltration capacity of the soil, high slope steepness and length and high time of concentration for woretwe. it is commonly accepted that, a steep slope causes an increase in the lateral hydraulic conductivity of the soils, and thus these soils maintain a greater transmissivity than small slopes, and are able to conduct water out of the profile faster, reducing run-off losses. This is similar with Bayabil et al, (2010) , Nyssen et al. (2010) and Tilahune et al, (2014) .

Apart from the above-mentioned site-specific factors which strongly influence the rainfall-runoff process, it should also be considered that the physical conditions of a catchment area are not homogenous. Even at the micro level there are a variety of different slopes, vegetation covers etc. Each catchment has therefore its own runoff response and will respond differently to different rainstorm events.

4.3. Runoff predictions

In this section the authors going to see whether the modified rational equation can predict the runoff response, where runoff is produced from land through the rainy season. In addition we test whether runoff is related to storm duration and time of concentration and have the ability to improve runoff predictions.

The statistical measures used to evaluate the efficiency of the model during both calibration and validation of rectangular weir equation was the Nash- Sutcliffe efficiency coefficient (E), trend correlation coefficient (R^2) and root mean square error (RMSE). The statically value that indicate the model efficiency to predict discharge during calibration and validation are present in (Figure 17)

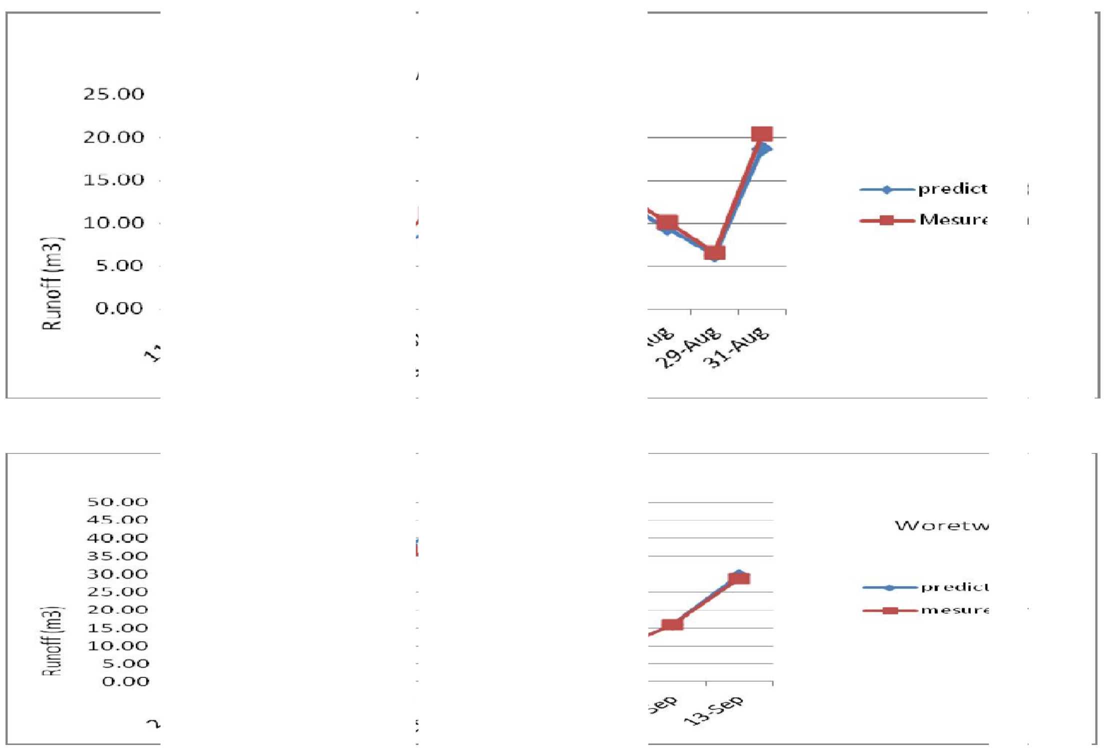


Figure 4. 2: Comparison of predicted and measured runoff volume of Ambachewe and Woretwe sub catchment for eventual time step

There are different factors that influence sample value of NSC, RMSE and R2 which includes the sample size, outliers, bias in magnitude, topography of gauge, time-offset bias of hydrograph models, and the sampling interval of hydrological data McCuen et al., (2006) .However, the calculated Nash-Sutcliffe coefficient, Root Mean Square Error and the coefficient of correlation, of observed and simulated runoff was 0.75, 2.11 and 0.8 respectively for Ambachewe and 0.91, 5.12 and 0.9 for Woretwe which indicates a “very good” model performance according to the ratings of Saleh *et al.*(2000) for daily runoff data. This noticeable model performance showed probably due to the applicability of the model to estimate the runoff despite the small data size.

For some storm event when its duration is less than time of concentration the MRM under estimate the runoff yield at woretwe sub catchment. Unlike woretwe, Ambachewe sub watershed, MRM over estimate the runoff yield regardless of increment and decrement of storm duration against time of concentration. Hence MRM and RM gives more or less similar result this might be most storm duration equivalent with time of concentrations, it needs further investigation (Appendix Table 7).

4.4. Runoff -Sediment concentration and load trend

Sediment concentration shows increasing trend in July similar to the runoff and it will peak around end of July and first August and then decrese in August like runoff on Ambachew sub catchment. For Woretwe, Sediment concentration of august shows the same trend with runoff and reverse in September as shown figure below. Major reason might be vegetation, unstable soil, transport capacity and drainage length. This finding is similar with other works. The drop and subsequent low sediment concentration at the end of the rainy season is also reported in Tigray, in the northern part of Ethiopia by Vanmaercke et al. (2010), they argued that lower concentrations of sediment are due to sediment depletion. Others Descheemaeker et al., (2006); Bewket and Sterk, (2003) suggested that the lower sediment concentrations are a result of the increased plant cover. Sadeghi et al (2007 b) argued due to transport capacity.

Total sediment load entering to the silt trap and ponds were 1.05 &0.44 tones for Ambachewe and 2.71 and 1.15 tones for Woretwe. As shown in (Figure 4.4-4.6) total sediment load entering to Woretwe was two times that of Ambachewe water harvesting structures. The result of sediment yield assessment showed that there were appreciable spatial variations of sediment yield and over land flow generated in the catchment. The detailed analysis of the two aspects on a catchment is shown on figure below. Even though there were moderate to good cover and management, Woretawe catchment sediment yield were almost twice Ambachewe. This might be small gully close to diversion channel near to the outlet of Woretwe sub catchment. This finding is similar with Tilhune et al (2012) in Debremawi watershed.

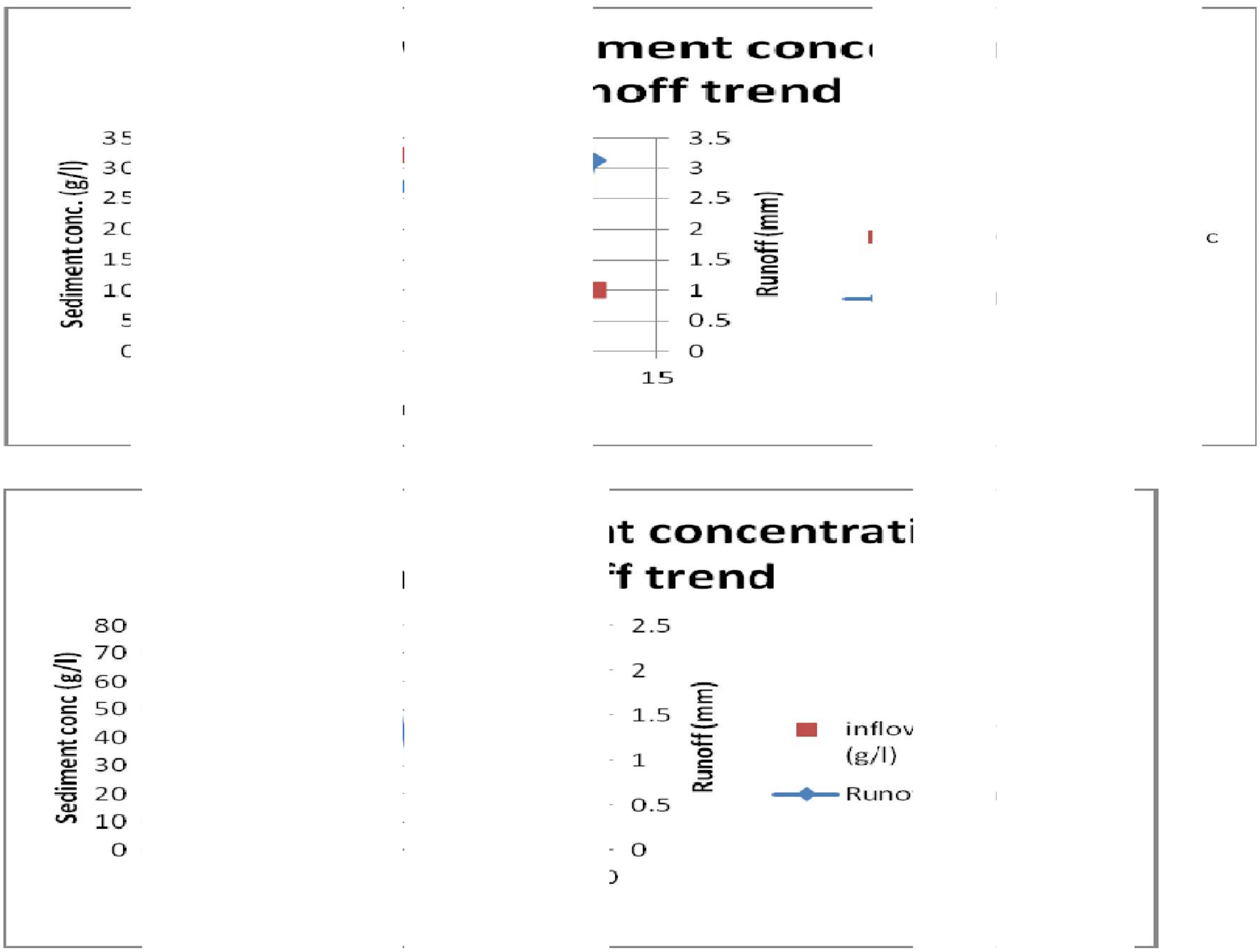
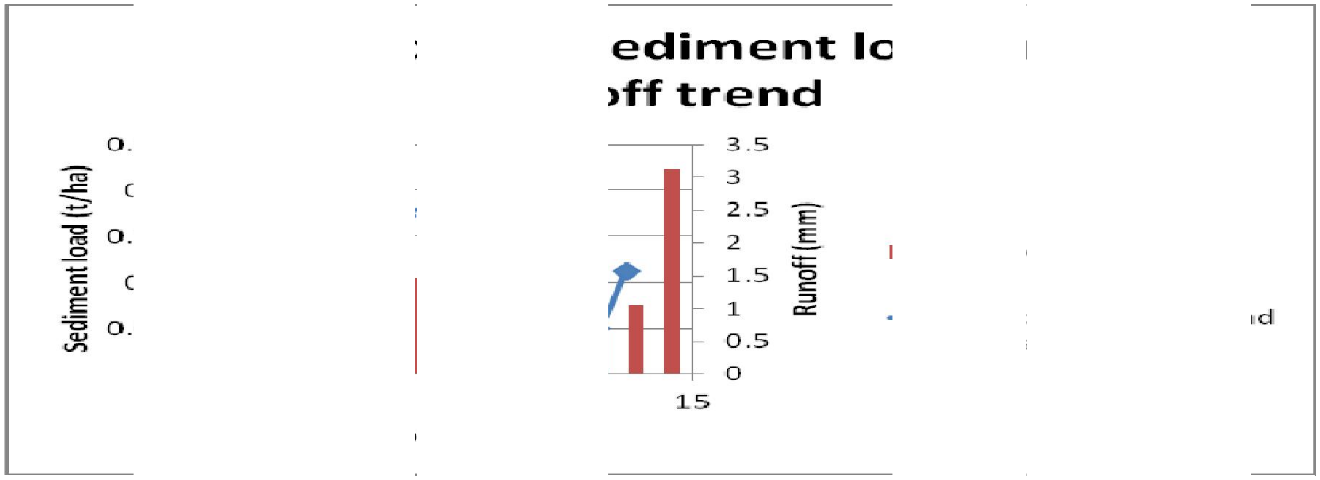


Figure 4. 3: Sediment concentration and storm runoff relationship of 2014 rainy season of the two sub catchment



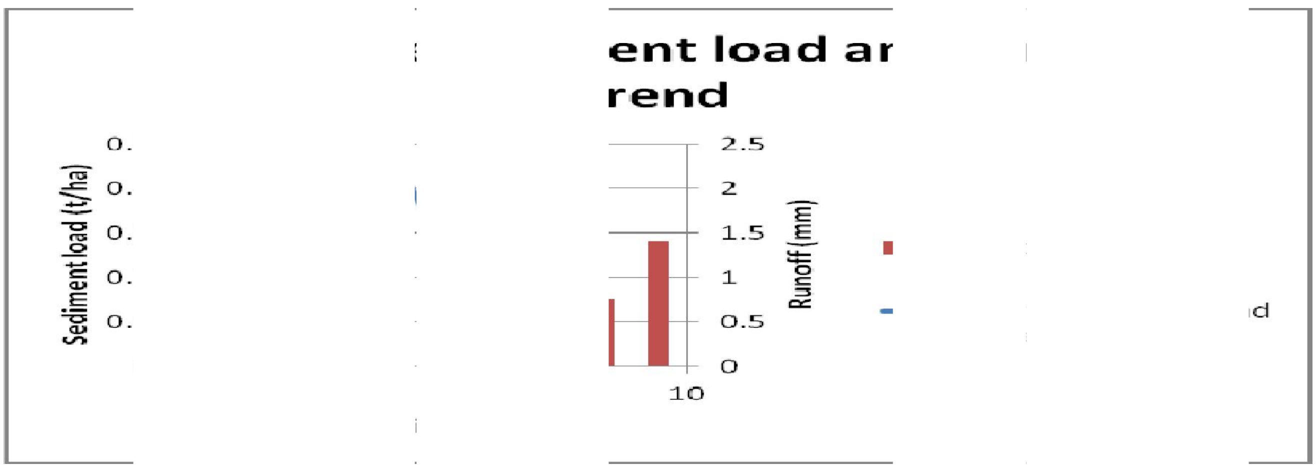
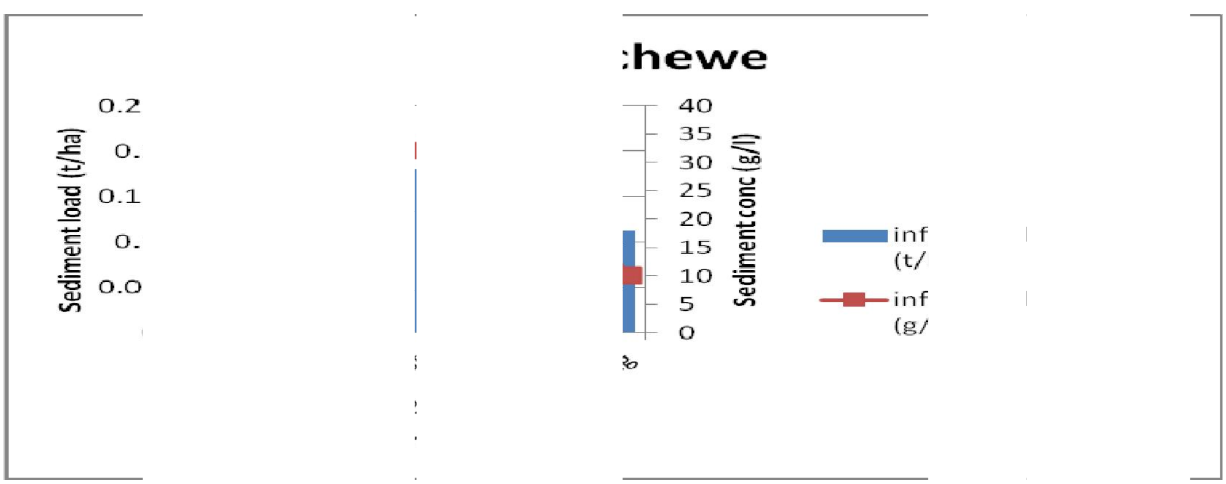


Figure 4. 4: Sediment load and storm runoff relationship of 2014 rainy season of the two sub catchment



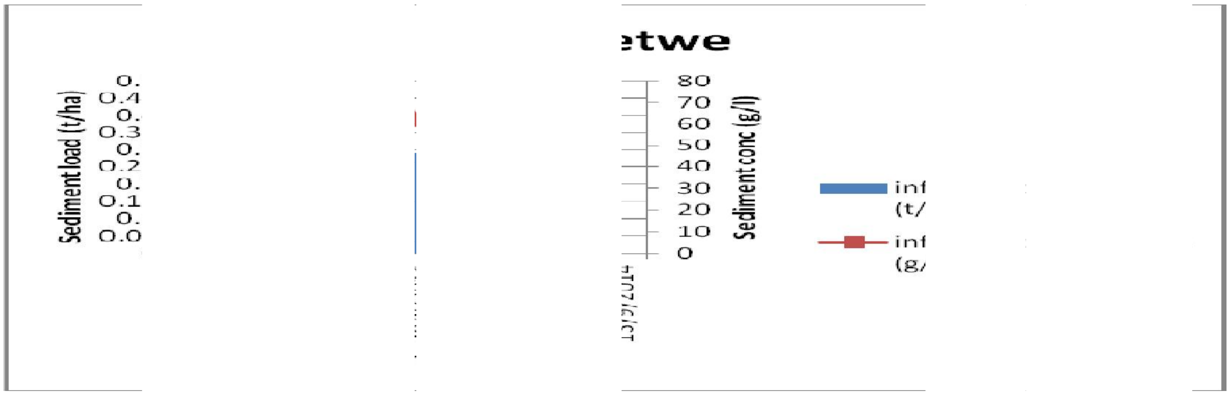


Figure 4. 5: sediment concentrations and the corresponding sediment load at each weir for rainy phases of the monsoon in 2014

4.5. Sediment prediction

Since researching both rainfall-runoff and runoff-sediment relationships were a large task to be accomplished within a short period, here the presented model is a very simple one that will be used as an entry for further sediment modeling research in small runoff catchment. The model framework was formulated based on the hydrology model developed to simulate stream discharge. A result from stream sediment load trend analysis was used to assume the model.

The input parameters for MUSLE were derived from data collected from 13 for ambachewe and 9 for woretawe runoff events. Runoff volume (Qv) and peak discharge (q_p) were measured at the gauge and, other parameter of the area are estimated, the results of which are summarized below

Table 4. 2: summarize the MUSEL parameters

	S (%)	L	LS	K	C	P
Woretawe	22.57	403	42.83	0.14	0.001	0.8
Ambachewe	5.8	257.2	4.04	0.14	0.01	1

Sources:

K Factor based on soil color after Hurni (1985). L and S: Equations after Renard et al. (1997).

C: Values determined by the author basing on SCRP database and by Hurni (1985) for the crops written in italic. P: Values determined by Hurni (1985).

The statistical measures used to evaluate the efficiency of the model during both calibration and validation were the Nash- Sutcliffe efficiency coefficient (E), trend correlation coefficient (R^2) and root mean square error (RMSE). The statically value that indicate the model efficiency to predict sediment during calibration are present in figure below

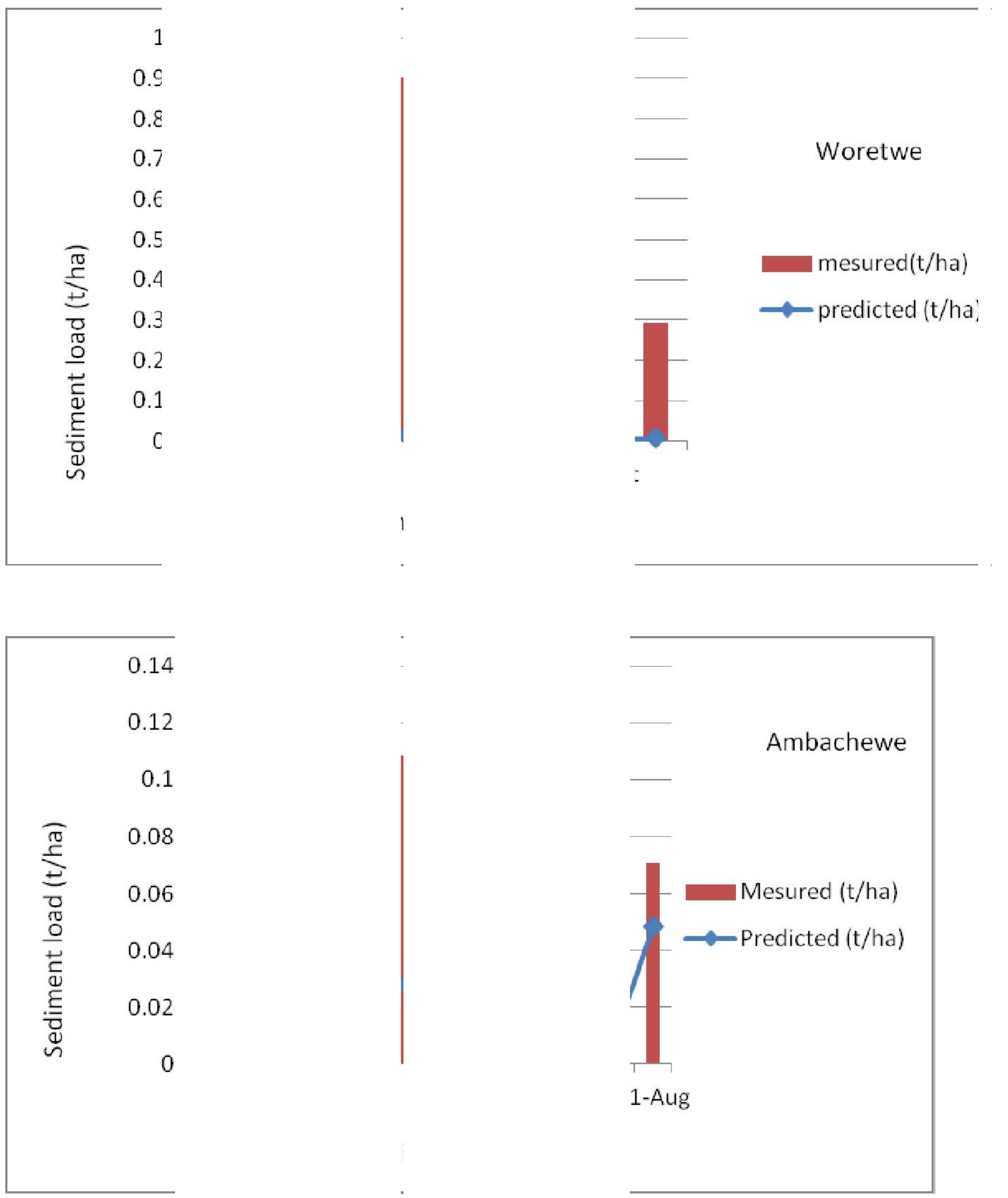


Figure 4. 6: Trend relations between measured and modeled sediment load

There are different factors that influence sample value of NSE, RMSE and R2 which includes the sample size, outliers, bias in magnitude, topography of gauge, and the sampling interval of hydrological data McCuen et al., (2006). However, the calculated Nash-Sutcliffe coefficient, E, Root Mean Square Error, RMSE, and the coefficient of correlation, R2, of observed and simulated runoff is 0.99, 0.18 and 0.59 respectively for Woretwe and 0.99, 0.11 and 0.53 for Ambachewe which indicates a “good” model performance according to the ratings of Saleh et al.(2000) for daily runoff data.

Despite the good fit the model under-predicted sediment concentrations in the two sub watershed. The manually sampled sediment yield was found to be ranged from 1.05 to 2.71 tons while the model predicted 0.225 to 0.215 tons sediment yield for the observed period in 2014 for Ambachewe and Woretwe respectively. Previous studies in Ethiopia had shown that the average annual sediment yield was highly variable because of the variation in topography, land use, climate, soil type, land management and human impact. The results agree with Sadeghi et al. (2007b) who reported the under-estimation of the MUSLE in watershed scale. However, this research contradicts findings that reported over-estimations Sadeghi et al. (2007a) and Somnuck et al (2014), and some applications of MUSLE that did not need any modification to the model Sadeghi and Mizuyama (2007). The resulting under- and over-estimation, depend on various site specific conditions, for instance rainfall characteristics, watershed size, land use; and the reliability of observed sediment data Sadeghi and Mizuyama (2007)

The deviation between the corresponding storm-wise values of measured and estimated sediment yield in the present study can be attributed to the very steep slope of woretwe and very small size of the two watershed (0.62-2.09 ha), which are below the conditions under which the MUSLE Williams(1975); Williams and Berndt (1977) was originally developed and not governed by humid climate. This disagreed with Chang (2006), who stated that the soil loss rates can be evaluated in small basins using the MUSLE. Moreover, it is notable that sediment transport capacity by surface runoff is a key concept in the MUSLE model,which may certainly play a more important role in delivering eroded sediment to the main outlets of the watersheds may also be supposed as other reasons for justification of the existing disagreement.

In the study watershed, the MUSLE model was not calibrated for sediment yield instead after calibrating the model for stream flow the simulated sediment yield output was compared to the observed sediment yield based on the manual bottle samplings (Figure 4.4-4.6). The main reason not able to calibrate sediment parameters in the study watershed was that there was no enough measured sediment data. Although there were manual sediment samplings recorded three times during a runoff event at the outlet gauging station of the study watershed for 13 and 9 days for Ambachewe and Woretwe respectively, the bottle sampling had a huge uncertainty as sediment concentration is not evenly distributed throughout the channel and bottle sampling is just a point data not a continuous datasets and similar with (Addis et al 2014). The main reason saying this are, the bathymetric measurement of the two ponds showed that 0.29 and 0.32 tons for Ambachewe and Woretwe respectively which is close to the predicted value. Sediment yield from upland areas is generally better correlated with observed runoff than with rainfall, although a longer and widespread record of sediment loading is needed to better define the natural condition and the response of sediment yield Williams (1975) may also be supposed as other reasons for justification of the existing disagreement. It needs further investigation.

4.6. Performance efficiency on rainwater harvesting systems

The initial storage capacity lost for the two water harvesting structure were range from 4.5 to 5.6 % of total pond capacity and the rate become decline after the first year. The silt trap efficiency of the two sub watershed were on average 57.8% (57.56-58%) .Based on the survey data for surface area, and the depth of the pond (Appendix Table 3), the dimensional analysis of the pond has been made. The current depth of the pond from the bottom zero point is 3m resulting in the change of storage volume of 129 m^3. By implementing varshney method, useful life of the reservoir at 20% capacity loss is 0.61m depth with 40 year reservoir age (Appendix table 5)

Because of low capacity of stored water in the two ponds, there were little irrigated land and this highly increased the average catchment-command area ratio for ponds. The reason for this was the absence of demand driven and feasibility design. As indicated in (Appendix table 6) and similar with Begashawe (2005) , Eyasu (2006), system efficiency of all ponds were poor because of the total runoff that can be harvested from the catchment was very large compare to the water consumed for irrigation. This indicated that the delineated catchments were more than sufficient or not proportional to crop land or irrigation water requirement. Therefore, the excess runoff coming from the catchment need to divert away from the storage to protect reservoir damage or pass to next reservoir for further production.

The rainwater harvesting systems in the study area, the excavated soil was not used to construct the storage bank to increase the storage volume. Therefore, the storage to excavation volume ratio (SER) was less than one on all schemes, which was the least economical value in line with Suresh, (1997) (Appendix table 6). Considering the community contribution alone, all systems could be economically feasible. From the total initial investment cost, all cost was incurred by donors. The running cost was fully covered by the beneficiaries.

The evaporation loss during the observation period was 22.3m^3 and had little impact on the net harvested water of the ponds. The amount of the evaporation loss is generally related to the surface area of the ponds.

Seepage losses during observation period were 33.5 and 15.5 m^3 for Woretwe and Ambachewe respectively and had little impact on the net harvested water of the pond. The amount of the seepage loss is generally related to the proper lining and efficient seepage reduction material.

However the combine value of seepage and evaporation has clear impact on the net harvested water of ponds. This is similar with Eyasu (2006), protecting the net harvested water from evaporation and seepage loss can increase the irrigated area. The net harvested water of Ambachewe and woretwe ponds were about 73.5% and 67.4% of the total inflow respectively. Therefore lining of the ponds with seepage reduction material and tent for protection of evaporation reduce the loss.

4.7. Water balance case study of the water harvesting structure

Since the study was carried out for a small pond during the 2014 rainy season, few data was collected regarding the subsequent use of the net harvested water. This section attempts to present the general implication of the net harvested water of the ponds at the end of the 2014 rainy season taking the two water harvesting structure in Gumara Macksignt catchment as a case study. The analysis of the water balance was based on Mass balance (behavioral analysis)

Table 4. 3: Water balance of water harvesting structure

	Unit	Woretwe	Ambachewe
Inflow			
Surface Runoff	m^3	172.37	143.62
Rainfall to pond	m^3	38.592	32.38
Outflow			
Evaporation from pond	m^3/season	22.49	22.49
Seepage	m^3	33.49	15.5
Spill out	m^3	35	0
Demeaned	m^3	444	444
sediment deposition	m^3	2.2	0.84
Motor pump safety	m^3	5	5
Change in Storage	m^3	-331.218	-311.83

The seasonal water deficit of the pond was in the range of 312-331 cubic meters, on average 322 cubic meters which compensated from other source. This implies the conventional pond size (129 m^3) is not sufficient to satisfy the outdoor demands of the client, so that developing new optimal pond size is crucial task to answer the above questions. These findings are in line with Rami, (2003) and Arbo (2013)

4.8. Model Application Results

The design of RWH systems in two distinct small watersheds has been evaluated using behavioral analysis water balance model. The simulation model is run for different degree of water availability to crop by supplementing the rainwater to different levels varying from only rain fed to 100% crop water requirement. As the level of water availability to crop is increased, the land lost (storage structure) area increases while the cropped area decreases.

4.8.1. Water balance

The gross irrigation demand of pepper in the main season found to be 296 m^3 with 100% volumetric reliability where as the office of agriculture run with 129 m^3 with 43.58% reliability.

Table 4. 4: Storage yield relationship

Storage (m3)	0	43	86	129	172	222	240	296
Reliability (%)	0	14.52	29.05	43.58	58.10	75	81.08	100

The RWH system implementer agency recommended a storage pond size of 129 m3, which is 43.58 % of the demand for pepper, representing benefit cost ratio less than one (compared to the value of lost land due to construction).

The results showed that the most important factors that determine the required harvesting area, command area and reservoir size are the unit cost of command area and unit cost of reservoir volume. For the maximum demand rate (100% crop water requirement satisfaction), the required reservoir volume was about 444 m^3 per 0.2 ha. The demand rate was gradually decreased to about 33.3% of crop water requirement to study its effect on storage size and it found to be 148 m^3 The optimal benefit was obtained for the demand rate of 66.67% satisfaction of the maximal value of demand rate (which is usually called the crop water requirement), the required reservoir volume was about 296 m^3 (Appendix Table 4).

The results also showed that if the reservoir is designed at a lower probability level of assured rainfall and runoff, it will have a larger capacity and lower chance of being filled up to its full capacity. On the other hand, a reservoir designed on a higher probability level of assured rainfall will have a lower storage capacity but chances of being filled to full capacity will be greater and thus the expected cost of reservoir will be higher.

4.8.2. Economic evaluation

Partial budget analysis was done for the pod yield of pepper. The partial budget analysis was done using the method straight line depreciation. The life span of the constructed pond was estimated about 41 years. So by using this method (straight line depreciation method), the cost of pond construction was calculated for one year. The result showed that, 0.67 &0.59 of crop water requirement for supplementary irrigation gives MRR greater than one respectively (Table 4.5).

Total costs did not include maintenance costs. Cost of maintenance especially for geo-membrane lining is very high due to highly sensitivity nature and its thickness. It was assumed that geo membrane cost will last for at-least 5-10 years. However, that is not true in reality. The geo membrane linings have been changed each year (cost of replacing one geo membrane lining for one pond is about 4700 ETB).

Before the construction of the rainwater harvesting systems, the land was used for rain-fed crop production and it was not economically viable for lower size despite large size and the finding is similar with Rami 2003.

Table 4. 5: Economic analysis

CWR	**Rain fed**	**1/3 CWR**	**0.5 CWR**	**0.54 CWR**	**0.59 CWR**	**2/3 CWR**	**CWR**
Land size (m2)	**2000**	**1856**	**1830**	**1823.5**	**1817**	1804	**1711**
water demand	**0**	**129**	**222**	**240**	**259**	**296**	**444**
Mean yield (kg/area m2)	1328	1530	1661.6	1694.5	1727.4	1793.2	1541.6
Total Revenue (10 birr/kg)	13280	15300	16616	16945	17274	17932	15416
Total costs (birr/area)	2500	2320	2287.5	2279.375	2271.25	2255	2139
Gross field benefit (birr/area)	107	1298	14328.	14665.	15002.	1567	1327

	80	0	5	63	75	7	7
Total costs that vary (birr/area)							
Fertilizer							
Urea	140	129.92	128.1	127.645	127.19	126.28	120
dap	90	83.52	82.35	82.0575	81.765	81.18	77
Present value investment cost with 10% discount rate and 5 year payback period	0	2695.67	3097.26	3307.45	3518.78	3937.54	5907
diesel and oil/season	0	400	400	400	400	400	600
maintenance costs	0		0		0		
water application labor	0	180	203	219	236	270	405
Total	230	3489.11	3910.71	4136.153	4363.735	4815	7109
Net benefit (birr/area)	10550	9490.89	10417.79	10529.47	10639.02	10862	6168
Marginal cost(birr/area)		3259.11	3680.71	3906.153	4133.735	4585	6879
Marginal net benefit(birr/area)		2200	3548.5	3885.625	4222.75	4897	2497
MRR (%)		67.50	96.41	99.47	102.15	106.8	36.29

5. CONCLUSION

A simulation model for determining the optimum reservoir size for supplemental irrigation under rain fed farming conditions based on linear programming is presented. By implementing the proposed model (behavioral analysis), under normal rainfall year, using important input parameters and types of crops grown in Macksgnit to Arbye belesa district, the results showed that the required optimum reservoir size is 2969 m^3 for more than 41 years of age pepper as dominant crop, with 106.8%, 100% & 5 year MRR, reliability & payback period respectively for the average land size of 0.2 ha and alternatively 259 m^3 with 102.2%, 87.7% & 5 year MRR, reliability & payback period respectively. However, for wet years cultivated area increase or the reservoir capacity drops to 148 m^3 with 40 years, 71.6% 50% age , MRR, reliability respectively. In contrast, for dry years the cultivated area is decrease or the reservoir capacity rises to 444 m^3 with 42 year age.

The behavioral analysis method water budget procedure is relatively easy to apply and can be used as a decision support tool for effective management and utilization of water resources and optimal storage size design.

The simulation test and analysis described in this study was based upon the main assumption of flow and demand will repeat them in the future. Further research is required to investigate long-term historic flow and water consumption of irrigation in the water deficit areas of Ethiopia. And on the basis of new data, the calculation storage capacity and reliability then could be examined and modified.

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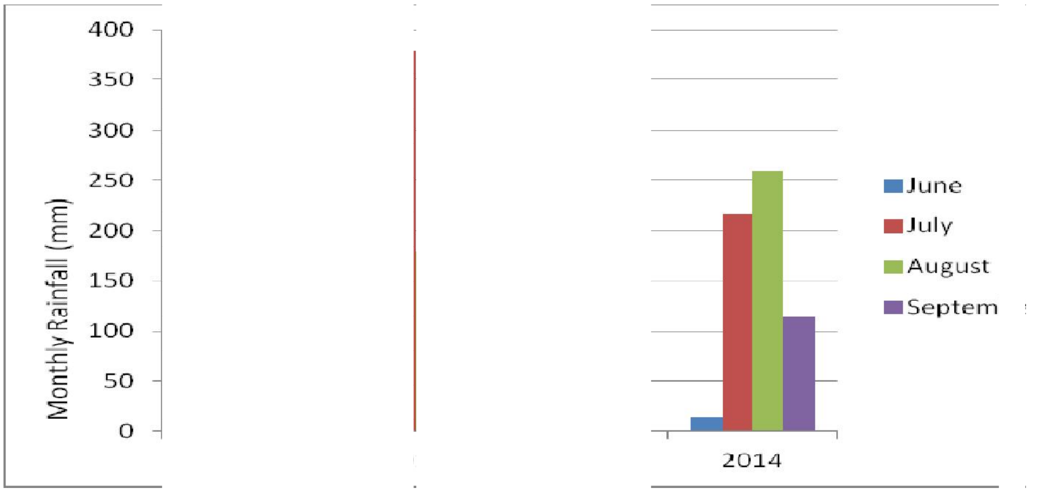
APPENDIX



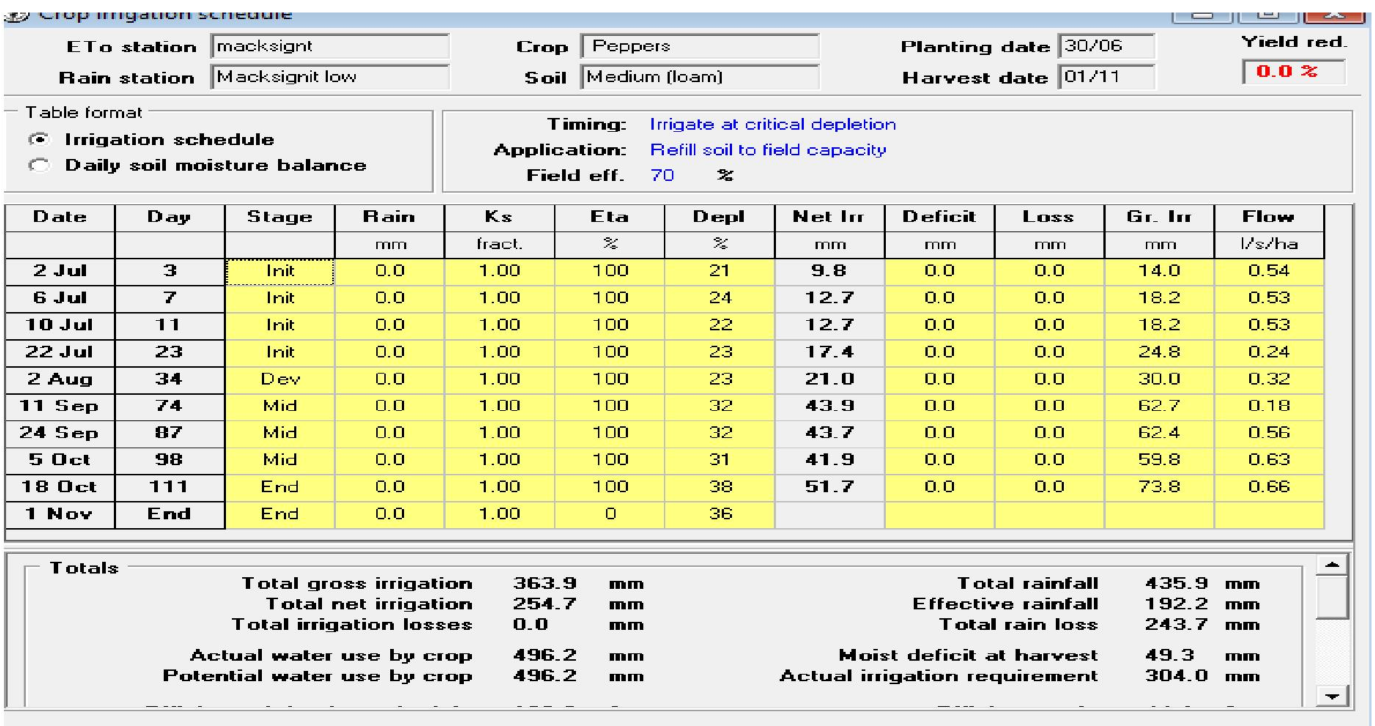
Appendix Figure 1: Rainfall of the specific watershed

Appendix Table 1 : infiltration test data

reading	time diff	cumulative time	water level reading		infiltration	infiltration rate	infiltration rate	cumulative infiltration
h :m: s	minute	min	before filling mm	after filling mm	mm	mm/min	mm/hr	mm
2:46:40	0	0		100				
2:48:40	2	2	93	93	7	3.5	210	7
2:50:40	2	4	83	100	10	2.5	150	17
2:55:40	5	9	87	87	13	1.444444	86.66667	30
3:05:40	10	19	73	103	14	0.736842	44.21053	44
3:15:40	10	29	91	91	12	0.413793	24.82759	56
3:25:40	10	39	81	101	10	0.25641	15.38462	66
3:45:40	20	59	88	88	13	0.220339	13.22034	79
4:05:40	20	79	72	95	16	0.202532	12.1519	95
4:25:40	20	99	75		20	0.20202	12.12121	115

Appendix Table 2: Soil analysis result for cropwat input

Code	%Clay	%Silt	%Sand	Remark	PWP %	%FC	AW
Ambachew silt trap	39	46	15	Silty clay loam	23.98	40.92	16.94
Woreta Silt trap	31	32	37	Clay loam	18.05	31.00	12.95
Ambechewe catchement	20	41	39	Loam	15.2	29.7	0
Woretawe runoff catchement	25	38	37	Loam	18.30	31.55	13.25
Ambechew irrigation	31	40	29	Clay loam	20.74	37.56	16.82
Woretawe Irrigation	43	36	21	Clay	25.755	40.867	15.11


Crop irrigation schedule

ETo station macksignt
Rain station Macksignit low
Crop Peppers
Soil Medium (loam)
Planting date 30/06
Harvest date 01/11
Yield red. 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at critical depletion
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
2 Jul	3	Init	0.0	1.00	100	21	9.8	0.0	0.0	14.0	0.54
6 Jul	7	Init	0.0	1.00	100	24	12.7	0.0	0.0	18.2	0.53
10 Jul	11	Init	0.0	1.00	100	22	12.7	0.0	0.0	18.2	0.53
22 Jul	23	Init	0.0	1.00	100	23	17.4	0.0	0.0	24.8	0.24
2 Aug	34	Dev	0.0	1.00	100	23	21.0	0.0	0.0	30.0	0.32
11 Sep	74	Mid	0.0	1.00	100	32	43.9	0.0	0.0	62.7	0.18
24 Sep	87	Mid	0.0	1.00	100	32	43.7	0.0	0.0	62.4	0.56
5 Oct	98	Mid	0.0	1.00	100	31	41.9	0.0	0.0	59.8	0.63
18 Oct	111	End	0.0	1.00	100	38	51.7	0.0	0.0	73.8	0.66
1 Nov	End	End	0.0	1.00	0	36					

Totals

Total gross irrigation 363.9 mm
Total net irrigation 254.7 mm
Total irrigation losses 0.0 mm
Actual water use by crop 496.2 mm
Potential water use by crop 496.2 mm

Total rainfall 435.9 mm
Effective rainfall 192.2 mm
Total rain loss 243.7 mm
Moist deficit at harvest 49.3 mm
Actual irrigation requirement 304.0 mm

Appendix Figure 2: irrigation scheduling of pepper for 2014 rainy season

Appendix Table 3: depth area volume relationship of collected water level data

	Woretwe			Ambachewe		
date	depth	Area	volume	depth	Area	volume
31	0.93	37.09	28.69			
1-augst	1.2	40.6	38.98			
2	1.21	40.73	39.38	1.28	41.64	42.2
3	1.22	40.86	39.78	1.51	44.63	51.86
4	1.58	45.54	54.92	1.75	47.75	62.59
5	1.6	45.8	55.81	1.9	49.7	69.63
6	1.6	45.8	55.81	1.91	49.83	70.11
7	1.86	49.18	67.73	1.93	50.09	71.07
8	1.87	49.31	68.21	1.96	50.48	72.52
9	1.86	49.18	67.73	1.96	50.48	72.52
10	2	51	74.47	1.97	50.61	73.01
11	2	51	74.47	1.97	50.61	73.01
12	2	51	74.47	1.96	50.48	72.52
13	1.98	50.74	73.49	1.97	50.61	73.01
14	1.97	50.61	73.01	1.97	50.61	73.01
15	1.96	50.48	72.52	1.95	50.35	72.04
16	1.95	50.35	72.04	1.93	50.09	71.07
17	1.94	50.22	71.56	1.92	49.96	70.59
18	2.2	53.6	84.48	1.94	50.22	71.56
19	2.2	53.6	84.48	1.96	50.48	72.52
20	2.2	53.6	84.48	1.98	50.74	73.49
21	2.2	53.6	84.48	1.97	50.61	73.01
22	2.2	53.6	84.48	1.97	50.61	73.01
23	2.2	53.6	84.48	1.97	50.61	73.01
24	2.2	53.6	84.48	1.98	50.74	73.49
25	2.2	53.6	84.48	2	51	74.47

26	2.2	53.6	84.48	2	51	74.47
27	2.38	55.94	93.88	2.53	57.89	101.99
28	2.38	55.94	93.88	2.5	57.5	100.35
29	2.36	55.68	92.82	2.47	57.11	98.71
30	2.5	57.5	100.35	2.9	62.7	123.05
31	2.52	57.76	101.44	3	64	129
1-Sep	2.82	61.66	118.37	3	64	129
2	2.82	61.66	118.37	2.8	61.4	117.21
3	2.82	61.66	118.37	2.82	61.66	118.37
5	2.84	61.92	119.53	2.8	61.4	117.21
6	2.84	61.92	119.53	2.8	61.4	117.21
7	2.84	61.92	119.53	2.82	61.66	118.37
8	2.83	61.79	118.95	3	64	129
9	2.83	61.79	118.95	2.82	61.66	118.37
10	2.83	61.79	118.95	2.8	61.4	117.21
11	2.82	61.66	118.37	2.8	61.4	117.21
12	2.82	61.66	118.37	2.8	61.4	117.21
13	2.8	61.4	117.21	2.8	61.4	117.21
14	2.8	61.4	117.21	3	64	129
15	2.82	61.66	118.37	2.81	61.53	117.79
16	2.8	61.4	117.21	2.8	61.4	117.21
17	2.82	61.66	118.37	2.82	61.66	118.37
18	2.8	61.4	117.21	2.8	61.4	117.21
19	2.82	61.66	118.37	2.8	61.4	117.21
20	2.82	61.66	118.37	2.8	61.4	117.21
21	2.8	61.4	117.21	2.7	60.1	111.48
22	2.8	61.4	117.21	2.7	60.1	111.48

Appendix Table 4: Water balance model based on behavioral analysis

Date	ETo(mm/day)	ET pond (m3)	DE m3	RF pond(m3)	runoff (m3)	sj	Sj+1
6/30/2014	2.31	0.11		0.31	7.28	2.03	9.51
7/1/2014	3.16	0.10		0.13	7.08	9.51	16.62
7/2/2014	3.64	0.13	25.62	0.23	12.35	16.62	3.45
7/3/2014	3.31	0.15	0.00	0.13	6.88	3.45	10.31
7/4/2014	3.31	0.14	0.00	0.21	10.87	10.31	21.25
7/5/2014	2.71	0.14	0.00	0.41	21.48	21.25	43.00
7/6/2014	2.86	0.11	33.31	0.68	35.76	43.00	46.02
7/7/2014	2.33	0.12	0.00	0.85	45.22	46.02	91.97
7/8/2014	3.31	0.10	0.00	0.76	40.07	91.97	132.71
7/9/2014	2.71	0.14	0.00	0.31	16.15	132.71	149.02
7/10/2014	3.06	0.11	33.31	0.46	24.25	149.02	140.31
7/11/2014	2.86	0.13	0.00	0.52	27.60	140.31	168.29
7/12/2014	2.80	0.12	0.00	0.50	26.57	168.29	195.24
7/13/2014	3.31	0.12	0.00	0.56	29.75	195.24	225.44
7/14/2014	1.59	0.14	0.00	0.12	6.43	225.44	231.85
7/15/2014	2.44	0.07	0.00	0.45	23.80	231.85	256.03
7/16/2014	3.16	0.10	0.00	0.53	27.92	256.03	284.38
7/17/2014	2.66	0.13	0.00	0.81	42.78	284.38	327.83
7/18/2014	3.00	0.11	0.00	0.52	27.60	296.00	324.00
7/19/2014	2.83	0.13	0.00	0.38	20.17	296.00	316.42
7/20/2014	3.31	0.12	0.00	0.49	25.79	296.00	322.16
7/21/2014	2.18	0.14	0.00	1.01	53.26	296.00	350.13
7/22/2014	2.71	0.09	30.32	0.10	5.27	296.00	270.96
7/23/2014	3.31	0.11	0.00	0.47	24.64	270.96	295.95
7/24/2014	1.99	0.14	0.00	0.44	23.09	295.95	319.34

7/25/2014	2.55	0.08	0.00	0.34	18.01	296.00	314.27
7/26/2014	3.31	0.11	0.00	0.42	22.13	296.00	318.44
7/27/2014	1.94	0.14	0.00	0.62	32.81	296.00	329.29
7/28/2014	3.13	0.08	0.00	0.88	46.70	296.00	343.50
7/29/2014	3.16	0.13	0.00	1.23	65.16	296.00	362.26
7/30/2014	3.00	0.13	0.00	1.05	55.38	296.00	352.30
7/31/2014	1.41	0.13	0.00	0.32	17.05	296.00	313.24
8/1/2014	2.77	0.06	0.00	0.35	9.67	296.00	305.96
8/2/2014	2.44	0.12	36.60	1.19	33.34	296.00	293.81
8/3/2014	1.72	0.10	0.00	0.95	26.53	293.81	321.19
8/4/2014	1.94	0.07	0.00	0.43	11.92	296.00	308.27
8/5/2014	2.13	0.08	0.00	1.10	30.72	296.00	327.73
8/6/2014	1.94	0.09	0.00	0.78	21.93	296.00	318.62
8/7/2014	1.59	0.08	0.00	0.78	21.95	296.00	318.65
8/8/2014	2.44	0.07	0.00	0.63	17.77	296.00	314.34
8/9/2014	2.31	0.10	0.00	0.50	14.07	296.00	310.47
8/10/2014	2.36	0.10	0.00	0.09	2.45	296.00	298.44
8/11/2014	2.44	0.10	0.00	0.42	11.68	296.00	308.00
8/12/2014	2.44	0.10	0.00	0.63	17.50	296.00	314.03
8/13/2014	3.64	0.10	0.00	0.07	1.84	296.00	297.80
8/14/2014	3.64	0.15	0.00	0.29	8.04	296.00	304.17
8/15/2014	2.91	0.15	0.00	0.16	4.56	296.00	300.57
8/16/2014	2.71	0.12	0.00	0.56	15.80	296.00	312.24
8/17/2014	2.88	0.11	0.00	0.58	16.18	296.00	312.64
8/18/2014	2.49	0.12	0.00	0.67	18.80	296.00	315.35
8/19/2014	2.71	0.11	0.00	0.26	7.29	296.00	303.44
8/20/2014	2.86	0.11	0.00	0.36	10.05	296.00	306.29
8/21/2014	2.57	0.12	0.00	0.33	9.16	296.00	305.37
8/22/2014	2.71	0.11	0.00	0.23	6.32	296.00	302.43

8/23/2014	2.60	0.11	0.00	0.10	2.84	296.00	298.83
8/24/2014	3.00	0.11	0.00	0.30	8.39	296.00	304.58
8/25/2014	2.52	0.13	0.00	0.28	7.76	296.00	303.91
8/26/2014	2.18	0.11	0.00	0.37	10.28	296.00	306.55
8/27/2014	2.57	0.09	0.00	0.13	3.55	296.00	299.58
8/28/2014	2.44	0.11	0.00	0.44	12.36	296.00	308.69
8/29/2014	2.18	0.10	0.00	0.74	20.81	296.00	317.45
8/30/2014	2.71	0.09	0.00	0.55	15.27	296.00	311.73
8/31/2014	2.71	0.11	0.00	0.52	14.64	296.00	311.05
9/1/2014	2.31	0.11	0.00	0.18	3.39	296.00	299.46
9/2/2014	2.44	0.10	0.00	0.41	7.67	296.00	303.99
9/3/2014	2.18	0.10	0.00	0.26	4.88	296.00	301.03
9/4/2014	2.94	0.09	0.00	0.28	5.18	296.00	301.36
9/5/2014	3.00	0.12	0.00	0.15	2.81	296.00	298.84
9/6/2014	2.71	0.13	0.00	0.88	16.44	296.00	313.19
9/7/2014	2.77	0.11	0.00	0.24	4.53	296.00	300.66
9/8/2014	2.08	0.12	0.00	0.22	4.19	296.00	300.30
9/9/2014	2.66	0.09	0.00	0.19	3.54	296.00	299.64
9/10/2014	3.31	0.11	0.00	0.19	3.62	296.00	299.70
9/11/2014	3.00	0.14	76.51	0.09	1.62	296.00	221.06
9/12/2014	2.71	0.13	0.00	0.37	6.88	221.06	228.18
9/13/2014	2.86	0.11	0.00	0.27	5.09	228.18	233.42
9/14/2014	3.06	0.12	0.00	0.06	1.04	233.42	234.40
9/15/2014	2.71	0.13	0.00	0.62	11.62	234.40	246.52
9/16/2014	3.00	0.11	0.00	0.01	0.18	246.52	246.60
9/17/2014	2.63	0.13	0.00	0.25	4.59	246.60	251.30
9/18/2014	3.00	0.11	0.00	0.10	1.82	251.30	253.10
9/19/2014	3.31	0.13	0.00	0.00	0.00	253.10	252.98
9/20/2014	3.81	0.14	0.00	0.00	0.00	252.98	252.84

9/21/2014	3.99	0.16	0.00	0.00	0.00	252.84	252.67
9/22/2014	3.85	0.17	0.00	0.00	0.00	252.67	252.51
9/23/2014	3.00	0.16	0.00	0.00	0.00	252.51	252.34
9/24/2014	2.77	0.13	76.16	0.00	0.00	252.34	176.05
9/25/2014	3.00	0.12	0.00	0.00	0.00	176.05	175.94
9/26/2014	2.86	0.13	0.00	0.00	0.00	175.94	175.81
9/27/2014	2.88	0.12	0.00	0.00	0.00	175.81	175.69
9/28/2014	3.85	0.12	0.00	0.00	0.00	175.69	175.57
9/29/2014	3.44	0.16	0.00	0.00	0.00	175.57	175.40
9/30/2014	3.88	0.15	0.00	0.00	0.00	175.40	175.26
10/1/2014	3.92	0.16	0.00	0.00	0.00	175.26	175.09
10/2/2014	3.78	0.17	0.00	0.00	0.00	175.09	174.93
10/3/2014	4.10	0.16	0.00	0.00	0.00	174.93	174.77
10/4/2014	3.99	0.17	0.00	0.00	0.00	174.77	174.60
10/5/2014	3.99	0.17	73.02	0.00	0.00	174.60	101.41
10/6/2014	4.35	0.17	0.00	0.00	0.00	101.41	101.24
10/7/2014	4.35	0.18	0.00	0.00	0.00	101.24	101.06
10/8/2014	3.81	0.18	0.00	0.00	0.00	101.06	100.87
10/9/2014	3.78	0.16	0.00	0.00	0.00	100.87	100.71
10/10/2014	3.67	0.16	0.00	0.00	0.00	100.71	100.55
10/11/2014	3.85	0.16	0.00	0.00	0.00	100.55	100.40
10/12/2014	3.00	0.16	0.00	0.00	0.00	100.40	100.24
10/13/2014	3.99	0.13	0.00	0.00	0.00	100.24	100.11
10/14/2014	4.17	0.17	0.00	0.00	0.00	100.11	99.94
10/15/2014	4.17	0.18	0.00	0.00	0.00	99.94	99.76
10/16/2014	3.47	0.18	0.00	0.00	0.00	99.76	99.59
10/17/2014	3.78	0.15	0.00	0.00	0.00	99.59	99.44
10/18/2014	3.92	0.16	90.04	0.00	0.00	99.44	9.25

Appendix Table 5: The useful life of the pond for wet, average and dry season

Wet season					Average				Dry season			
year	Volume (m^3)	yearly loss(m3)	Depth (m)	%	Volume (m^3)	yearly loss(m3)	Depth (m)	%	Volume (m^3)	yearly loss(m3)	Depth (m)	%
	148.00		3.00	100.00	296.00		3.00	100.00	444.00		4.00	100.00
1	135.30	12.70	2.74	91.42	277.80	18.20	2.82	93.85	419.80	24.20	3.78	94.55
2	132.60	15.40	2.69	89.59	272.40	23.60	2.76	92.03	411.80	32.20	3.71	92.75
3	129.90	18.10	2.63	87.77	267.00	29.00	2.71	90.20	403.80	40.20	3.64	90.95
4	127.20	20.80	2.58	85.95	261.60	34.40	2.65	88.38	395.80	48.20	3.57	89.14
5	124.50	23.50	2.52	84.12	256.20	39.80	2.60	86.55	387.80	56.20	3.49	87.34
10	111.00	37.00	2.25	75.00	229.20	66.80	2.32	77.43	347.80	96.20	3.13	78.33
15	97.50	50.50	1.98	65.88	202.20	93.80	2.05	68.31	307.80	136.20	2.77	69.32
20	84.00	64.00	1.70	56.76	175.20	120.80	1.78	59.19	267.80	176.20	2.41	60.32
25	70.50	77.50	1.43	47.64	148.20	147.80	1.50	50.07	227.80	216.20	2.05	51.31
30	57.00	91.00	1.16	38.51	121.20	174.80	1.23	40.95	187.80	256.20	1.69	42.30

35	43.50	104.50	0.88	29.39	94.20	201.80	0.95	31.82	147.80	296.20	1.33	33.29
36	40.80	107.20	0.83	27.57	88.80	207.20	0.90	30.00	139.80	304.20	1.26	31.49
37	38.10	109.90	0.77	25.74	83.40	212.60	0.85	28.18	131.80	312.20	1.19	29.68
38	35.40	112.60	0.72	23.92	78.00	218.00	0.79	26.35	123.80	320.20	1.12	27.88
39	32.70	115.30	0.66	22.09	72.60	223.40	0.74	24.53	115.80	328.20	1.04	26.08
40	30.00	118.00	0.61	20.27	67.20	228.80	0.68	22.70	107.80	336.20	0.97	24.28
41	27.30	120.70	0.55	18.45	61.80	234.20	0.63	20.88	99.80	344.20	0.90	22.48
42	24.60	123.40	0.50	16.62	56.40	239.60	0.57	19.05	91.80	352.20	0.83	20.68
43	21.90	126.10	0.44	14.80	51.00	245.00	0.52	17.23	83.80	360.20	0.75	18.87

Appendix Table 6: Performance Efficiency on rainwater harvesting systems

	Ambachew	Woretawe
Rainfall (mm)	506.00	603.00
Inflow (m3)	143.61	172.00
Catchment area (m2)	6200.00	20900.00
Runoff coefficient	0.42	0.16
Runoff (m3)	1317.62	2016.43
Runoff Harvesting Efficiency	0.11	0.09
Seepage loss (m3)	15.50	33.50
Evaporation loss (m3)	22.49	22.49
Water available (m3)	105.62	116.01
Runoff Storage Efficiency	0.74	0.67
System Efficiency	0.08	0.06
Storage Excavated Ratio	0.82	0.90
Water Productivity (kg/m3)	10.34	10.34
construction cost (ETB)	14484.00	14424.00
Cost per Volume of Harvested Runoff (Birr/m3)	137.13	124.33
command area(m2)	1856.00	1856.00
Catchment Command Area Ratio	3.34	11.26
inflow silt(t)	1.05	2.71
outflow silt(t)	0.44	1.15
Silt trap efficiency (%)	58.10	57.56

Appendix Table 7: input data for time of concentration

	Ambachewe	Woretwe	source
n (sheet flow)	0.13	0.24	**(NRCS 1986)**
n(manning)	0.16	0.16	(ASCE) 1992, FHWA 2001, and Chow 1959
s	0.058	0.228	measured
p	34	34	Measured
B	0.4	0	Measured
Y	0.2	0.2	measured
P	1	1	Measured
R	0.12	0.12	Measured
Z	1	1	measured
A	0.12	0.12	Measured
L(Maximum length of flow path)	278.5	420.8	Measured
Tc	28.3	30	Calculated
D	30	27	Measured

Appendix Table 8: Row data for construction cost (source GARC)

No.	Items	Ambachew			Woretwe		
		Qty	Price	Total	Qty	Price	Total
1	**Pond Construction**						
	Excavation	136	30	4080	124	30	3720
	Geomembrane			4760			4760
	Geomembrane layering wage	10	30	300	20	30	600
	PVC pipe	1	111	111	1	111	111
2	**Barrel and its stand**						
	Barrel	2	360	720	2	360	720
	Wood for stand			325			325
	Nail			75			75
	Construction wage			100			100
3	**Silt trap construction**						
	Building bloke	110	12.5	1375	110	12.5	1375
	Cement	3	550	1650	3	550	1650
	Sand			130			130
	Construction wage			500			500
4	**Pedal pump**						
	Pedal pump	1	358	358	1	358	358
Total				14484			14424