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DIPLOMA THESIS

EVALUATION OF RAINFALL AND SURFACE RUNOFF RELATIONSHIP IN AWLALO WATERSHED, TIGRAY ETHIOPIA

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DIPLOMA THESIS ASSIGNMENT

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Environmental Modelling

Thesis title

Evaluation of Rainfall and Surface Runoff Relationship in Awlalo Watershed, Tigray Ethiopia

Objectives of thesis

The research will be conducted with the general objective of estimation and evaluation rainfall and surface runoff for the Awlalo watershed in Western Tigray, Ethiopia, in order to provide answer for the main question of the thesis:
What significantly affects surface runoff generation in the Awlalo watershed?

Specific objectives:
- To assess gathered terrain data from ungauged watershed in order to evaluate the rainfall condition and its effect on surface runoff
- To assess the surface runoff generation process in the watershed
- To estimate the surface runoff by the Soil Conservation Service Curve Number (SCS-CN) approach

Methodology

1. Metrological data collection near the outlet of the watershed (Daily maximum and minimum rainfall, temperature and evaporation)

2. Physiographic data collection from Agricultural office of the area where the research will be conducted

3. Soil infiltration data measure will be conducted at different location of the watershed

4. The Soil Conservation Service Curve Number (SCS-CN) approach with GIS for the surface runoff evaluation

5. Field Observation and Frequent locality observation interview around the watershed

6. General and specific Literature review

The proposed extent of the thesis

60 pages or less in length including tables and figures

Keywords

Rainfall, Surface runoff, Soil infiltration, Curve Number

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BLÖSCHL, G. *Runoff prediction in ungaued basins : synthesis across processes, places and scales.* Cambridge: Cambridge University Press, 2013. ISBN 978-1-107-02818-0.

LOAGUE, K. *Rainfall-runoff modelling.* Wallingford: International Association of Hydrological Sciences, 2010. ISBN 978-1-907161-06-3.

SINGH, V P. – MISHRA, S K. *Soil conservation service curve number (SCS-CN) methodology.* Dordrecht ; Boston: Kluwer Academic Publishers, 2003. ISBN 1402011326.

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Declaration

I hereby declare that the thesis entitled: Evaluation of Rainfall and Surface Runoff Relationship in Awlalo Watershed, Tigray Ethiopia is solely my authorship. Acknowledgement is given to all the literature sources used to support this work. I am duly responsible for any shortcomings in this study.

In Prague on 19.04.2016 Tewelde Lemlem

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Abstract

The watershed developments targets at the prolific use of all the natural resources existing in the whole area from the ridge line to the stream outlet. Commonly in the hydrological studies difficulties encountered in estimation of the surface runoff from the watershed where there is the rainfall record but no surface runoff record. Comparison of surface runoff characteristics with those of watershed characteristics is the basic approach to solution of this problem. The characteristics of watershed that may be highly compared to estimating the volume of surface runoff that will result from a given amount of rainfall are soil cover, soil type and the land use/cover. The study mainly focuses on estimation of the surface runoff for the Awlalo watershed from the rainfall data records of the watershed in around of the watershed area using the Soil conservation Service-Curve Number (SCS-CN) with GIS based approaches. The study area, Awlalo watershed is geographically located in between 13˚ - 14˚N latitude and 39˚ - 40˚30" East longitudes with an area of 350 ha. Different thematic layers such as topo sheet map, land use/cover map, soil map were derived from the digital data such as google earth data and overlaid through ArcGIS software. The estimation and evaluation of the surface runoff for the watershed is carried out using the historic fourteen years (2000 - 20014) monthly and annually rainfall data records of four rain gauge stations in and around the watershed. The computation uses the Soil conservation Service – Curve Number (SCS-CN) method together with the GIS approaches for estimation of the surface runoff. From SCS Curve number, the maximum surface runoff for the watershed was estimated to be 1200.06 mm in the year 2013 and minimum surface runoff of 345.02 mm in the year 2003. The rainfall and surface runoff are strongly correlated with correlation coefficient (r) value being 0.81.

Keywords: Surface runoff, Rainfall, SCS-CN, GIS, Awlalo watershed, Watershed

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1 INTRODUCTION

Ethiopia which is a country of stronghold water source in east Africa and dominated by mountainous topography where the rainfall-surface runoff processes on the mountainous hilly slopes are the source of the surface water for much Ethiopian part (Derib, 2005). First, rainfall influences hydrological responses of a watershed, and this in turn influences soil erosion (Grunwald and Norton, 2000). Consequently, the hydrological processes of different parts of the watershed understanding is crucial to make decisions on water and land resources management.

The difficulties come across in most hydrological studies is the need to estimate and evaluate the surface runoff from the watershed with no record of surface runoff but with records of precipitation. One can overcome such difficulties is by comparing runoff characteristics with those of watershed characteristics. The watershed characteristics are the most important character that should compared to estimating the volume of surface runoff that will result from land use and cover, soil type and amount of rainfall in the watershed area (Dhawale, 2013).

In countries like Ethiopia where the agro-climatic and topographic conditions are too diverse, it is difficult and expensive to measure, collect and store hydrological and related soil loss data. But most physical based models usually have extensive data requirements and it is difficult to build input parameters. Moreover, most of the simple empirical models which have been used to model the relationships of rainfall, surface runoff in Ethiopia today are developed for temperate climates and might not apply for a monsoonal climate. Therefore developing simple evaluation steps or methods that can use easily obtainable data is mandatory for Ethiopia. Hence, this necessitates the estimation and evaluation of rainfall, surface runoff processes through simple, less data demanding and relatively accurate estimation methods. Further evaluating and calibrating the model for other watersheds based on their specific hydrological responses is important to improve the model's applicability for different watersheds of Ethiopian highlands (Tegenu, 2009).

Several land rehabilitation activities like area closures, soil and water conservation and forestation have been implemented by governmental and nongovernmental organizations to reclaim degraded lands. In addition to land rehabilitation activities, household-level water harvesting structures, dams and river diversions have been undertaken to tackle the problem of low agricultural production because of water shortage. But according to Derib (2005), most of these projects were not as successful as expected due to the lack of information on complex rainfall-runoff soil loss processes at the commencement of these projects.

Understanding hydrological processes helps to identify water resource potentials, runoff source areas, and erosion danger zones. This in turn helps with the estimation of runoff and sediment yield, which is the basis for developing planes and managements of watershed that involves water and soil conservation measures (Pandey et al, 2008; Steenhuis et al, 2008). Models help to represent and simulate the actual hydrological processes so that areas most prone to severe damage and in need of greater soil and water conservation measures can be prioritized. This is the key step to better target finite resources for enhanced soil conservation measures.

This diploma thesis will be beneficial in provision of information and hydrological evaluation in future of the rainfall and surface runoff event situations in the watershed area and the approach transferred to other areas. The lack of studies concerning problems of rainfall-surface runoff in the area shows the importance of conducting in depth studies. Knowledge and evaluation of rainfall-surface runoff event can be used to in management regulation, formulation of plans and design of control structures.

The thesis is categorized into six separate chapters. Chapter one deals with the background and problem statement. Chapter two includes objectives and research question. Chapter three reviews related literature. Chapter four presents the methodology, data collection, data evaluation methods and approaches used in this study. The study area description is presented in chapter five. The sixth chapter presents the results and discussions of the study. The final chapter of the thesis includes conclusions and recommendations.

2 OBJECTIVES AND RESEARCH QUESTIONS

2.1 OBJECTIVES OF THE STUDY

As is stated in the chapter Introduction, the availability of surface runoff record is very less in Ethiopia comparing to the rainfall amount and distribution records especially for small and medium watersheds. Since discharge values are necessary for such ungauged watersheds for the different hydrological structures such as medium and small dams, similarly some analytical methods have to be used estimate similarly. Currently many of such different methods and approaches such as empirical equations related to watershed characteristics, runoff and sophisticated physical models of the catchment are applicable.

The research is conducted with the general objective of estimation and evaluation rainfall and surface runoff for the Awlalo watershed in Western Tigray, Ethiopia. The specific objectives of this theses are following:

- To assess gathered terrain data from ungauged watershed in order to evaluate the rainfall condition and its effect on surface runoff
- To assess the surface runoff generation process in the watershed
- To estimate the surface runoff by the Soil Conservation Service Curve Number (SCS-CN) approach

2.2 RESEARCH QUESTIONS

Some of the research questions the paper attempts to address include:

- ✓ What significantly affects surface runoff generation in the Awlalo watershed?
- ✓ How rainfall distribution of the watershed area does relates with the surface runoff generation?
- ✓ Where and when does most of the surface runoff occur in the watershed?
- ✓ What further research is needed to fill in the gap for appropriate understanding of watershed in relation to rainfall and surface runoff?

3 LITERATURE REVIEW

A watershed is the land that covers the area that contributes to the surface runoff in one common point. It is naturally composed of different parts of ecological and physiographic structures. All watersheds has different characteristics of drainage, size, slope, vegetation, geology, climates, soil type, shape, geomorphology and land use and cover. The management and plane of involves the proper use of all land and water resources of a watershed for optimum production with minimum hazard to natural resources. One of the important hydrologic components used in the water resources applications and management planning is runoff. Surface runoff evaluation and estimation is essential for the assessment of water yield potential of the watershed, reducing the sedimentation and flooding hazards downstream, recharging the ground water zones, planning of water conservation measures. Also, it is an important and essential prerequisite of Integrated Watershed Management (Subramanya, 2008).

The rainfall runoff process is a nonlinear, dynamic and complex hydrological process, which is influenced by many interrelated and physical factors. Surface runoff reliable prediction of quantities and rates from lands surface into watercourse and rivers are difficult and time consuming to obtain for watersheds that are ungagged. Due to this many hydrologist have developed models to estimate both human influence on changes in surface runoff more importantly for storm runoff and its subsequent effects on downstream activities (Kumar and Rishi, 2013).

3.1 WATERSHED CHARACTERISTICS

The characteristics of the watershed and its relationship to the water flow are a product of interactions between land and water (rainfall pattern, slop, soil type, land use and land cover, geology) and its use and management. Therefore, watershed is an important water supply and building block factor for integrated planning of land and water use. With the social and economic development human activities and land use change have dramatically affected the watershed runoff generation and flow paths (Xia et al., 2005). Intensive human activities induced changes on runoff are important to well understand its influence on land cover/land use (LUCC) on hydraulic processes of watershed (Liu et al., 2004; Zepp et al., 2005).

Therefore there has been an increasing interest to measure the influences of land use changes on hydrology for watershed management from the perspective of get ahead and decreasing possible environmental impacts.

3.1.1 Watershed Geomorphology

The physical characteristics of the watershed is referred to as watershed geomorphology. Certain physical properties of watersheds meaningfully influences the characteristics of runoff and as such are of great interest in hydrologic analyses. The principal watershed characteristics are:

Area of the watershed

The area of watershed refers also to the drainage area and it is the most important watershed characteristic for the evaluation of the watershed hydrological process. It indicates the volume of water obtained from rainfall. Thus the drainage area is prerequisite as models input from simplest linear prediction equations to complex computer models. We can found the area of the watershed using either by approximate map methods or by GIS once the watershed is defend.

Length of watershed

The distance traveled by surface drainage is referred to as length of the watershed and sometimes more appropriately labeled as hydrologic length. This length is used to compute the watershed travel distance using the time parameter. The watershed length is measured alongside the principal flow path from the watershed outlet up to the area of the basin boundary. The length of the watershed measurement follows a route where the greatest volume of water would generally travel.

Slope of watershed

The momentum of the watershed slope affects the surface runoff. The rate of change of elevation with respect to distance along the principal flow path refers to as watershed slope. The elevation alteration might not essentially be the highest elevation difference within the watershed since the point of highest elevation might occur beside a boundary of the watershed relatively than at the end of the principal flow path. If there is substantial deviation in the slope along the core flow path, it may be preferable to consider several sub-watersheds and estimate the slope of each.

Shape of Watershed

Watershed parameters which shows the watershed shape are used rarely and have a conceptual basis. The shape of the watersheds is different in almost all occurrences and the shape supposedly reflects the way that runoff will blow up at the outlet. A spherical watershed reflects in runoff from various parts of the watershed reaching the outlet at the same time. An elongated watershed have the outlet at the major axis end point and having the same area as the spherical watershed consequently would result the surface runoff to be extended out with time, thus producing a smaller flood peak than that of the circular watershed (Uditha, 2008).

3.1.2 Land use and soil characteristics of watershed

Volume and time of the surface runoff is affected by both land use/land cover and soil characteristics. During a rainstorm, flow from an impervious, sharply sloped and plane surface make a little obstruction and no loss to the flow. In comparison, of flow along grassy hill of the same size will produce obstruction and significant loss to the flow due to infiltration. A lot of data and information about land use has been collected for many years and is available from maps or as GIS data sets. Many hydrological investigates deal with evaluating the land use changes effect on runoff. For example, Soil Conservation Service curve number method (SCS-CN) has been functionally applied to extensive range of catchments across the world to assess the effects of land use/land cover change on surface runoff (Boughton, 1989). Improved computational abilities, in together with digital elevation models (DEMs), digital data on soil type and land use, and GIS tools, are allowing new options for hydrological investigation, assisting us to better recognize the fundamental physical processes underlying the hydrological succession and improve mathematical solution equations representing those processes (Liu,2004).

3.2 RAINFALL-RUNOFF PROCESS

When a rainfall comes, it does not hit the ground surface directly rather it intercepted by trees and other objects above the surface. This is called interception. The difference between the total rainfall and interception is called ground rainfall. When the rainfall intensity increases the interception rate, water starts moving towards the ground and penetrates into soil. The excess rainfall gets collected into the small and large depressions existing in the basin area by rich them to their runoff or overflow levels. This quantity is known as depression storage. If after the depression storage is occupied and filled, the infiltration capacity of the soil exceeds when the rainfall intensity is carry on to go beyond, the difference appears as excess rainfall, which originally accumulated on the ground as surface detention. The stream channel filled water in this routine referred to as surface runoff or as direct runoff. Therefore the store can cause in surface runoff, which can resulted by contributing to excess rainfall, and are simply not debauched in accomplishing the interference, depression storage, and infiltration needs of basin (Garg, 1976).

In order to know how much runoff is being generated from surface water inputs it is required subdividing the water contributions at the earth surface into different components that infiltrate and components that flow overland and directly enter streams. Infiltrated water can follow subsurface paths that take it to the stream speedily, in this case it is called interflow. It can also infiltrate deeply into groundwater, which may sustain the steady flow in streams over much longer period scale which is called baseflow. The routes reserved by water regulate many of the features and characteristics of a landscape, the floods occurrence and size and the strategies required for wise land management.

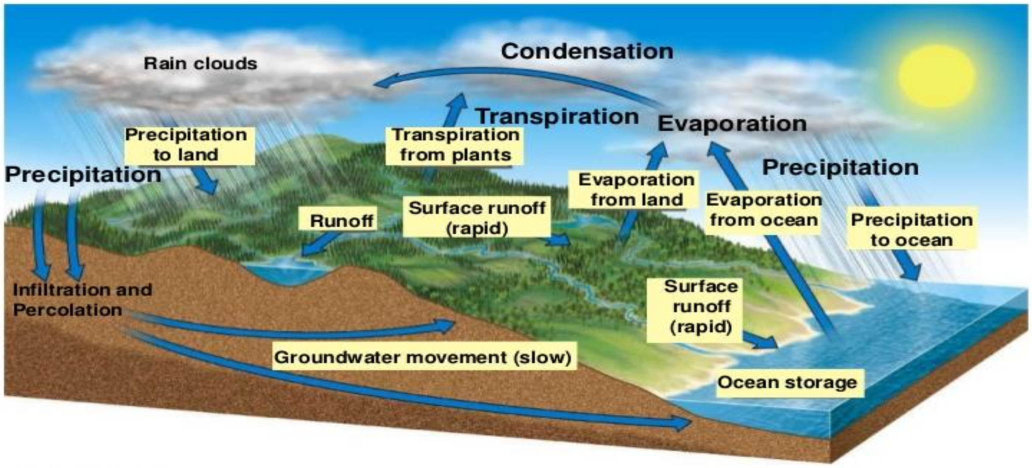


Figure 1: Physical process in rainfall-runoff process

Therefor evaluating and estimating of the rainfall – surface runoff process is therefore important in many flood and water resources problems. Figure 1 demonstrates most the processes involved in the generation of runoff with rainfall (Horton, 1935).

3.3 RAINFALL-RUNOFF RELATIONSHIP

The rainfall-runoff process is one of the important component considered in hydrological cycle, as it determines many of the characteristics of the occurrence and size of floods and landscape characteristics; hence, assessing of the process of the rainfall-runoff and understanding its way of modeling is important for different flood and water resources problems (Tarboton, 2003). In order to create an appropriate hydrological model and evaluation it is important to understand different hydrological process in correct and understandable way to a large number so that the prediction, evaluation and estimation of the hydrological model will be helpful in proper land and water management unit (Bergkamp, 1998).

Surface runoff and rainfall relationship can be considered in three aspects:

- The relation between the amount of rainfall in a given stormflow and the consequently resulting surface runoff
- The relation between the hydrograph of the time distribution and surface runoff
- The relation between rainfall rate of frequency and discharge frequency (Garg, 1976).

3.4 ESTIMATION OF SURFACE RUNOFF

Estimation of surface runoff for hydrologist often encounters difficulties of evaluation for watershed where there is no records of runoff but only rainfall records. Soil Conservation Service (USDA, 1985) curve number method is generally accepted hydrological tool where it requires the uses of land conditions factor called Hydrologic Soil Cover Complex. It is responsiveness to the four watershed properties, i.e. Hydrologic Soil Group, land use, hydrologic condition, and antecedent moisture condition land management , increased its popularity.

3.4.1 Empirical methods for surface runoff estimation

Empirical method include relationships and equations which have been determined using analysis of limited data and the region characteristics, and the method is used to estimate some special probabilistic parameters. Most of these methods are beneficial so, it is not potential to use them for other areas. But, some of these methods have extra extended field and could be applied for same areas by applying some corrections and choosing proper coefficients. There are several empirical evaluating methods which have been developed to estimate and evaluate surface runoff (extra flow). The mentioned methods are divided to four categories including (Bashul, 2002):

Surface runoff coefficient

Another simplest additional method to estimate surface runoff is to use surface coefficient. In other words, in this method the surface runoff estimation is a precipitation percentage considering the parameters affecting runoff.

Relationships between precipitation and runoff

Many of the hydrologist presents their obtained results as some relationships between precipitation and annual surface runoff where constant physical properties of the watershed are considered.

Relationships about annual surface flow shortage

In these relationships it is assumed that, the amount of surface runoff flowing out from concentration point of a watershed is the difference between annual surface flow shortage and precipitation which is affected by some factors like temperature, topography, geology and vegetative cover.

Runoff calculation using physiographic characteristics

Vegetative cover, slope, soil type and length of main waterway are the most important Physiographic characteristics of each watershed that controls factors of potential for producing surface runoff therefore, it is possible to regulate a relationship between the factors mentioned above and a watershed annual surface runoff.

3.4.2 The SCS-CN method

As the result of a large infiltration number tests the CN methodology was originated carried out by SCS-CN at the end of 1930s and beginning of 1940s. To evaluate the effect of soil conservation measures and watershed treatment on the rainfall and surface runoff process tests were applied and conducted. Additionally the outmoded hydrological methods have been used for most of small watersheds that cannot represent the distributed nature of watershed-scale properties of hydrological like land use, slope, and soil type (Herweg and Ludi, 1999). In this situation the Soil Conservation Service Curve Number method (SCS-CN) developed by the USDA-Soil Conservation Service in 1972 (USDA SCS, 1985) is probably a good choice for the estimation of runoff.

The Soil Conservation Service Curve Number method (SCS-CN) model is an empirical approach with the assumptions and few data requirements. Therefore hydrologist have been using this simple method for water management, storm water modeling and runoff estimation for single rainfall conditions for smaller and medium urban and agricultural watersheds (Mishra and Sighn, 2003; Liu and Li, 1994). Some researchers also incorporated the Soil Conservation Service Curve Number method in to GIS based approach system to cover the model applicability to complex watersheds with high temporal and spatial variability in soil and land use.

Although the model is versatile and has been widely used in the world many researchers question its applicability. Johnson (1998), pointed out that the SCS-CN model has been overused and applied to situations and conditions for which it was not designed. Ponce (1996), concluded that this model should not be used for catchments larger than 250 km^2

without catchment subdivision. Apart from scale problems the initial abstraction ratio (the ratio of initial abstraction to maximum potential retention Ia/S) in the SCS-CN model is often set equal to 0.20 according to experimental data obtained in North America but this value has been frequently questioned for its validity and applicability to other regions. Some researchers from china the CN value should be verified before using this model to estimate runoff where the rainfalls are concentrated and intensive much different from those in America (Zhou et al., 2008). In addition runoff has been estimated as well as measured Using SCS-CN in Ethiopia at various temporal and spatial scales from runoff plot to Watershed at Blue Nile, Tekezze, Wabishebele, Awash, and Rift Valley lakes, Giba and May Zeg-Zeg catchment (Zenebe, 2009, Nyssen et al., 2010).

One of the watershed characteristic is the hydrological soil cover complex and the most significant for SCS-CN method. Soils can be classified to their hydrologic-soil provided that they must be independent of watershed slope and cover or both-group.

According to SCS scientist soil can be categorized in to four hydrological groups (A, B, C and D), (USDA, 1985) depend on infiltration soil classification and other criteria. Land cover and land use and treatment classes are used in the preparation of hydrological soil-cover complex which in turn are used in estimating surface runoff. Antecedent Moisture Condition (AMC) is an indicator of watershed availability of soil moisture storage and wetness prior to a storm and can have a significant effect on runoff volume. Identifying its importance, SCS developed a guide for adjusting CN according to AMC based on the total rainfall preceding a storm in period of five day. Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for average, and AMC-III which is for wet condition. The curve number method was originally developed by the NRCS the Soil Conservation Service (SCS) in 1954 to estimate the direct runoff from a single precipitation event on a small agricultural watershed (NRCS, 1997).

The prediction of runoff was developed by the National Resource Conservation Service (NRCS) of the USDA in 1954. The options that are required in generation of the SCS constitute of two input parameters namely the Curve number and the impervious area percentages in the sub basin. In hydrology the curve number describes the infiltration or runoff amount after a rainfall event. The empirical calculations include hydrological conditions such as soil groups and land use. The interpretation is that the CN will reflect the runoff percentage and the higher CN the higher runoff (NRCS 1986).The Runoff equation is illustrated below.

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} \tag{1}$$

Where: Q is the runoff [L]; P = Rainfall [L]; S = Maximum soil Retention [L]

$$S = \frac{1000}{CN} - 10 \tag{2}$$

Where: I_a is the initial abstraction [L] =0.2S

The impervious percentage reflects the part of catchment surface that is impermeable to rainfall water. Different factors influence the impervious percentage such as the population growth, land use, land cover and structures.

4 MATERIALS AND METHODOLOGY

The Figure 2 shows the methodology followed to estimate surface runoff using SCS-Curve Number with GIS based approach. Daily rainfall data of four rain gauge stations in and around the watershed for a period of 2000 to 2014 was used for estimation of surface runoff and rainfall distribution of the watershed area. Surface runoff was estimated with the help of hydrological model using United States Department for Agriculture (USDA) methodology for estimation of surface runoff using SCS-CN (Soil Conservation Service-Curve Number).

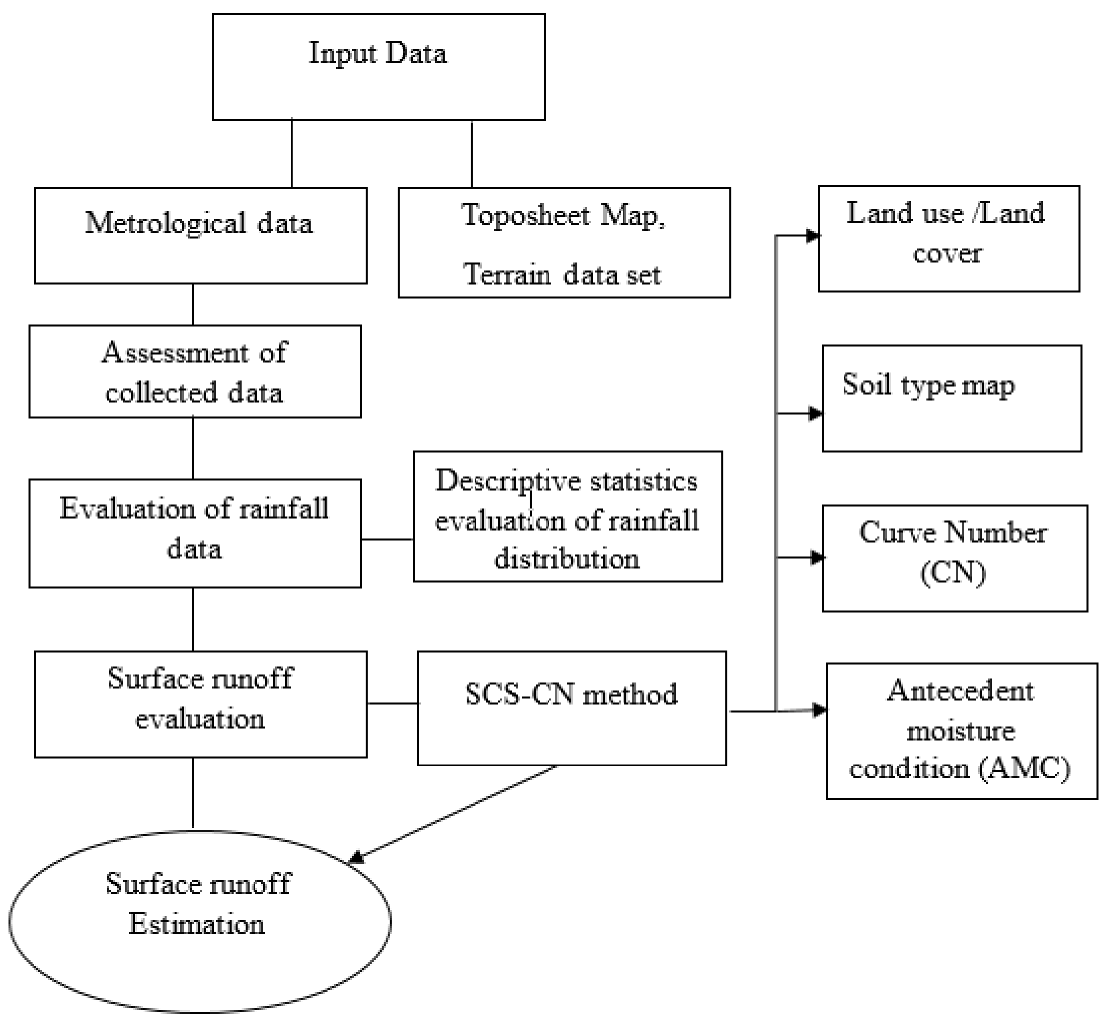


Figure 2: Methodology flow chart to estimate surface runoff using SCS-CN (Source: Author)

4.1 DATA COLLECTION

In order to meet the objectives of the thesis the following data have been collected:

- Rainfall data for the period of 2000 to 2014
- Monthly and Annual Stream Flow (mm) Distribution in the Watershed
- Drainage pattern map, slope map, land use/land cover map and soil type map

4.1.1 Rainfall data

The rainfall data was collected from Tigray Agricultural and rural development documentation office, for the period of 2000 to 2014 (see Table 3) for various rainfall data recording stations of the Awlalo watershed as in Table 2 shown below. The collection point were four stations in and around the watershed area. The rainfall data were recorded on the daily base with less than 24 hour duration. The period of critical rainfall duration were selected for every 30 and 60 minute. As Zhang and Singh (2005) describes the necessary for the long period metrological complete data record which will use as a critical in evaluation and estimation of extreme events.

4.1.2 Monthly and annual stream flow

The monthly and annual stream flow (mm) distribution in the watershed have been carried out from 2000 to 2014. The monthly and annual stream flow record data was statistically computed with descriptive statistics against time period specified. With this the maximum, minimum, average, standard deviation and coefficient of variance have calculated *(see Appendix C).*

Table 1: Rainfall data recording stations

Station Locality Name	Latitude	Longitude
Karo	13º30’31’’	40º07’23’’
Mendi	13º25’19’’	39º30’11’’
Tufa	13º39’01’’	39º17’27’’
Bunka	13º20’33’’	40º33’35’’

Table 2: Monthly and Annual rainfall data for the Awlalo watershed (Source: Tigray agricultural resources documentation)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2011	2012	2013	2014
Jan	0	91	1	5	3	34	0	0	36	41	35	27	0	0
Feb	38	45	22	46	25	25	0	44	1	0	36	0	0	28
Ma	201	7	111	92	99	19	105	83	97	123	38	21	4	206
Ap	94	50	126	48	152	75	76	169	116	84	81	29	147	38
Ma	116	30	24	16	105	74	90	83	239	72	93	41	53	86
Jun	237	23	85	5	69	55	84	82	114	189	33	105	35	46
Jul	347	368	261	364	320	273	435	339	484	246	376	610	407	534
Au	325	455	267	229	470	493	405	420	354	424	509	532	494	391
Sep	236	210	217	245	236	306	282	3	159	134	221	171	318	112
Oct	56	110	98	22	68	74	58	21	45	315	99	321	181	32
No	0	0	1	0	0	29	179	0	48	97	0	0	171	4
Dec	10	0	74	0	145	16	19	56	1	0	0	0	29	21
Σ	166[illegible]	1388	1287	1072	1690	1472	1733	1300	1693	1724	1520	1855	1838	1498

4.1.3 Field Observations and community Questionnaires

Frequently field observations and discussions with the community farmers and technicians who have been collecting data since the establishment of the data collection stations for the watershed. The field observation and group discussion were held for the better understanding of the rainfall-surface runoff processes at different parts of the Awlalo watershed. Among these the reason for the surface runoff in the watershed, where and when the surface runoff occur in the watershed were the discussions. These discussions were positively helpful for the understanding of the surface runoff and to the community near the watershed to express their knowledge, perception and to present their questionnaires in wide. The mostkey understanding and knowledge of community questioners are presented *(in Appendix B).*

4.1.4 Toposheet maps and satellite data

In the present study, the GIS tools technology were used to create a drainage pattern of the watershed, land use and land cover map, slope map and soil cover map. The ArcGIS 10.2 software tool with spatial analysis were used. The starting point of materials were vector base dataset derived from toposheet on 1:50 000 scale from The Tigray Survey office along with the satellite data with the help of google earth were collected to prepare different thematic maps, updating of drainage, land use/land cover information and map, soil type information and map of the Awlalo watershed. The data were manipulated in ArcGIS to provide detailed watershed information.

4.2 DATA EVALUATION

The collected data of the watershed were analyzed with basic statistical description analysis and followed by estimation of surface runoff using SCS-Curve Number with GIS based approach. The following section below discusses in details the above two methods of data analysis for this study.

4.2.1 Descriptive Statistic Evaluation

Correlation coefficient (CC)

In order to show the strong linear relationship between the rainfall amount and surface runoff a correlation variance have been used as basic statistical computation. The main result is called correlation coefficient (R-Value). The more closely the two variables are related in which in our case the rainfall and surface runoff. An R with value 1 indicates regration line perfectly fits the data. For this study case an excel statistical approach has been used to minimize manual error.

The correlation coefficient is given by:

$$R = [1/(n - 1)] \times \sum\{[(x_i - x)/s_x] \times [(y_i - y) / s_y]\} \tag{3}$$

Where R is correlation coefficient; n is number of data, X_i is the X value of data i; X is the mean value of X; Y_i is the Y value of data i; Y is the mean value of Y; S_x is sample standard deviation of X, S_y is sample standard deviation of Y.

Standard Deviation (SD)

In order to know how spread out the rainfall and stream flow data are the standard deviation approach in excel has been used for this study.

$$S_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - \bar{x})^2} \tag{4}$$

Where S_N is standard deviation, N number of data, Xi is the Sample value, X is the mean value of the sample.

More over maximum, minimum and average statistical approaches has been used for this study to produce graphical relationships between the collected data of the watershed.

4.2.2 SCS Curve Number Approach

Antecedent soil water conditions, soil permeability and land use which were the most important watershed properties which are considered in this approach. Estimation of the curve number, the hydrological soil group map showing hydrologic soil groups prepared from GIS data, the land use/land cover were integrated.

Surface runoff is mainly controlled by the initial abstraction, amount of rainfall and moisture retention of the soil. The SCS curve number method is based on the two essential assumptions which are indicated as, the actual surface runoff ratio to the potential runoff is equal to the ratio of the actual percolation to the potential percolation, and the amount of initial abstraction is some fraction of the potential infiltration, water balance equation. In this approach, GIS is used to create a spatial database that characterizes the hydrologic properties of the watershed. GIS system approach have been used to create drainage map, land use and soil coverages of the study area.

$$\frac{Q}{(P - I_a)} = \frac{F}{S} \tag{5}$$

$$F = (P - I_a) - Q \tag{6}$$

Substituting equation (5) in to (6) and by solving:

$$Q = \frac{(P - Ia)^2}{(P - Ia) + S} \tag{7}$$

Where, Q is Surface runoff (mm), P is Rainfall (mm), Ia is Initial abstraction that represents of all the losses before surface runoff starts and its empirical equation is given by:

$$I_a = 0.2S \tag{8}$$

Substituting equation (7) in to (8) and by solving;

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{9}$$

Where S is the potential infiltration after the surface runoff began and is given by the following empirical formula:

$$S = \frac{1000}{CN} - 10 \tag{10}$$

Where the CN is the curve number and is estimated using the hydrological soil group and the Antecedent soil moisture condition (AMC)

The water content in soil with at given time refers to the Antecedent Moisture Condition (AMC). The AMC is determined by the total of rainfall in the period of five day storm preceding. The AMC value is intended to reflect the effect of infiltration on both the rate of surface runoff volume and according to the infiltration curve. An increase in index means an increase in the surface runoff potential. The soil conservation service (SCS) develops three AMC and labeled them as I, II, III, according to rainfall limits for dormant and growing seasons and soil conditions. Classification of Antecedent Moisture Condition is shown in Table 3.

Table 3: Classification of Antecedent soil Moisture Condition (AMC)

AMC Group	**Soil Characteristics**	**Total five day Antecedent Rainfall (mm)**	
		Dormant Season	**Growing Season**
I	Soils are dry but not to wilting point; satisfactory cultivation has taken place	Less than 13	Less than 36
II	Average condition	13-28	36-53
III	Heavy rainfall or light rainfall and low temperatures have occurred within the last 5 days; saturated soil	Over 28	Over 53

The soil conservation service (SCS) established soil classification system that contains of four groups, which are identified according to their minimum infiltration rate as A, B, C, and D. Table 4 shows the hydrological soil group classification. CN values were determined from antecedent moisture conditions and the hydrological soil group and of the watershed. The Curve Number values for AMC-I and AMC-II were found from AMC-II (Chow et al. 1988) by the method of conservation. Table 4 shows the runoff curve numbers (AMC II) for hydrologic soil cover complex. Table 5 also shows the Hydrological Soil Group of watershed.

Table 4: Surface runoff curve numbers for the hydrological soil group A, B, C and D (Source: Chow et al, 1988)

Serial No.	Land use/land cover	Soil group			
		A	B	C	D
1	Agricultural land without conservation	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture Plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub (Stony waste/ rock out crops)	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest Plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road / railway line	98	98	98	98
11	River / stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tank with water	100	100	100	100

Table 5: Hydrological Soil Group (HSG) Classification (Source: Mc. Cuen, 1982 in Chow et al, 1988)

Hydrological Soil Group	**Description**	**Runoff potential**	**Infiltration rate (mm/hr)**
Group A	Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep, well to excessively well drained sands or gravels. These soils have a high rate of water transmission.	Low	>7.5
Group B	Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	Moderate	3.8-7.5
Group C	Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission.	Moderate-high	1.3-3.8
Group D	Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.	High	<1.3

5 DESCRIPTION OF THE AWLALO CATCHMENT

The Awlalo watershed is found in Eastern Tigray regional state province, Ethiopia. It was named after a village found near the catchment, covers a total area of 350 ha, with a hydrological surface area of 250 ha. It is situated 670 km northeast of Addis Ababa adjacent to the Mekelle Adigrat highway at 13˚ -14˚N latitude and 39˚ - 40˚30" East longitudes (see Figure 3 and Figure 4).

Its topography ranges from 3000 meters above sea level (m.a.s.l) near the watershed station in the eastern reach of the unit.

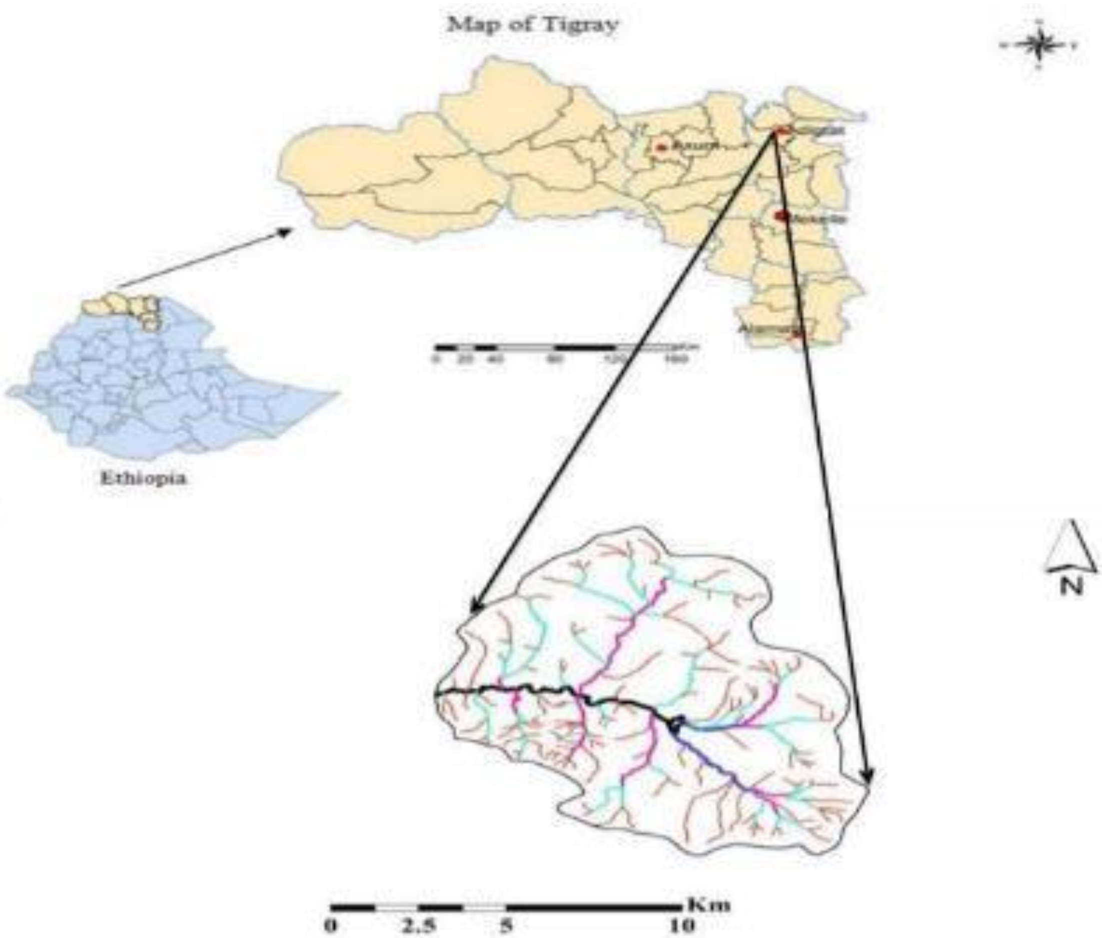


Figure 3: Location map of the Awlalo watershed, Source: (Tigray agricultural studies, 2009)

Figure 4: Photo of the Awlalo watershed (Source: Author)

5.1 PHYSIOGRAPHY AND RELIEF

The Northern part of Ethiopia is known for its mountainous and rough topography, the Awlalo area also shows such pronounced contrasts in the topography. Awlalo watershed consists of small depressed area that extended from South-East to North-West bounded by adjacent highlands. The maximum peak reaches 2560 m above sea level in the Asagulo Ridge, which is found in the Southern part of the study area consisted of the geological Adigrat Sandstone unit. The minimum reading taken at the low land, which is 2140 m above sea level at the central part of the area. Generally, the study area is more of plateau, with an average elevation of 2350 m.

The slope map of the study watershed is grouped in to six classes in percepts. 0% - 3% considered as flat or almost flat), 3% - 8% considered as moderate slopping, 8% - 15% considered as sloping, 15% - 30% considered as moderately steep, 30% - 50% considered as steep and >50% considered as very steep. Most of the area of Awlalo watershed is classified as moderately steep slope. Gentle slopes were designated in the "excellent" group for which the watershed area groundwater management considered as the nearly flat terrain is favorable for more infiltration.

Due to slightly undulating topography moderate slopes are also considered as good in which it gives maximum percolation or runoff partially. The steeps class areas having a great surface runoff with least amount of soil infiltration are regarded as good locations for construction of stop dams for water harvesting or infiltration ponds to recharge the groundwater. The balance between surface runoff response and soil infiltration rates of a terrain is directly controlled by important parameter of slope. High surface runoff production in higher slope regions results in less soil infiltration.

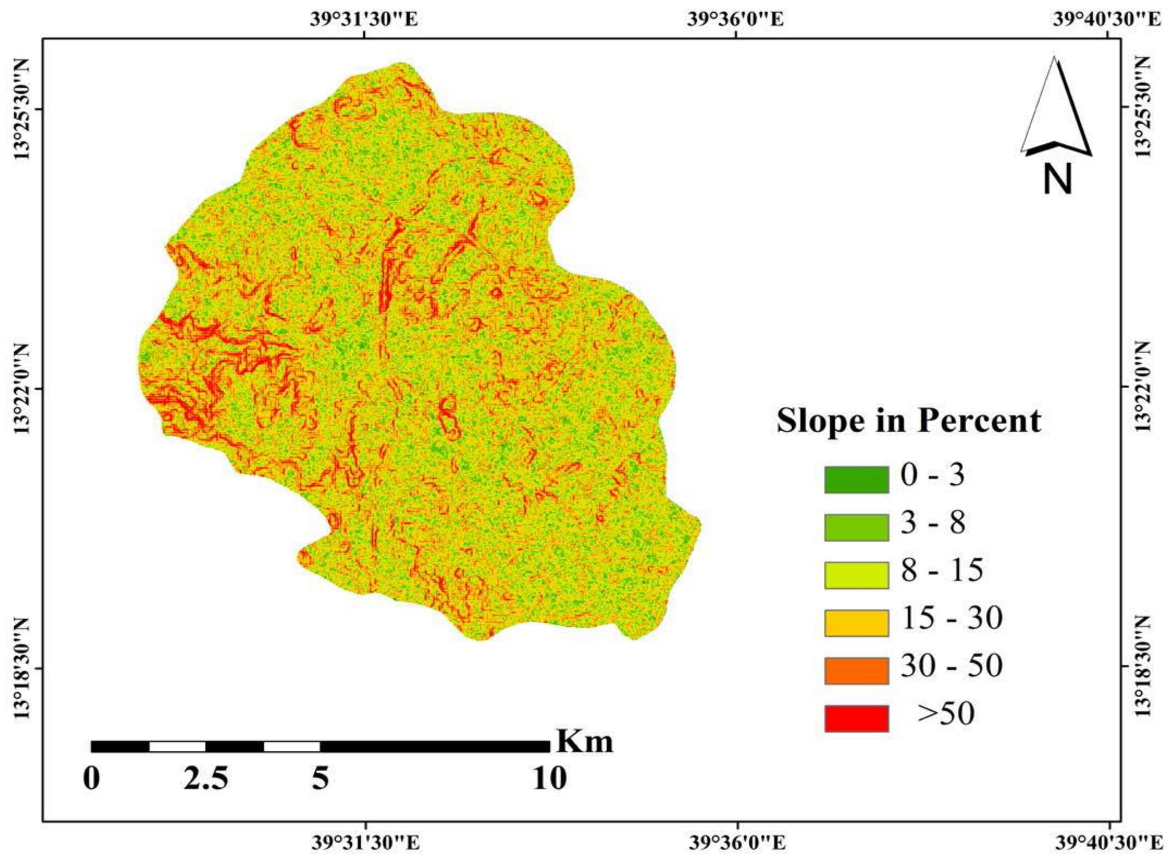


Figure 5: Slope Map of Awlalo watershed (Source: Author)

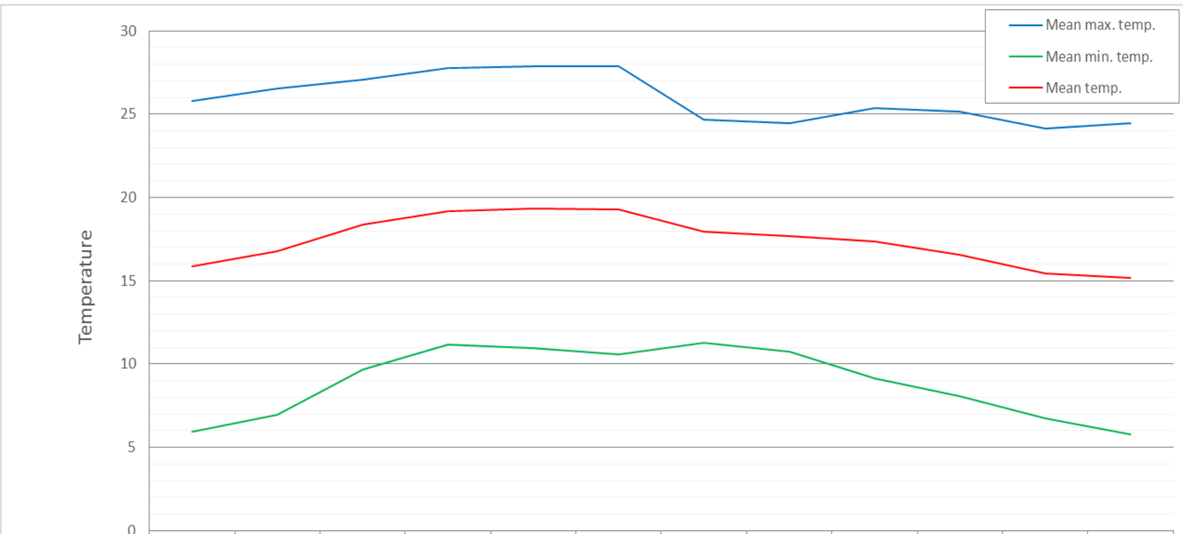
5.2 LOCAL CLIMATE

The Awlalo watershed has a relatively high annual rainfall of 1300 – 1400 mm and remains foggy during most of the rainy season due to its location on the edge of the eastern escarpment where warm air masses rise from the lower plains and condensation begins as soon as the masses reach the colder top of the escarpment (Bono and Seiler, 1984). The smaller (*belg*) rainy season is usually from March to May and the main (*kiremt*) rainy season is from July to October. Krauer (1988) explained that rainfall showers are concentrated around the late evening and after midnight as a result of advective trade winds and a nightly cooling of the air masses. Only recently has drought become more common in the area due to increasing variability of annual rainfall. However, hailstorms and frost are common occurrences and damage crops (Hurni and Grunder, 1986). Recently, the *belg* rains have become unreliable (Holden and Shiferaw, 2000). The year to year monthly rainfall variability for this season, March to April, is very high.

Figure 6: Automatic rain gauge installed at the site's meteorological station (Source: Author)

Temperature data were taken from the Wukro meteorological station, which is 14 km far from the study area from the last 14 years (2000 – 2014).These data is extrapolated to the study area by allowing 0.6°C increment for 100 m depression. The temperature decreases by 2.24°C for 373 m elevation increment. The mean annual minimum temperature of the study area is 8.92°C and the mean annual maximum temperature is 25.9°C. The mean annual temperature of the area is 17.4°C.

In the Awlalo watershed, as in all other places of Ethiopia (Tropical), the altitude of the sun is always high, making solar radiation intense.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Mean max. temp.	25.78	26.56	27.06	27.76	27.86	27.86	24.66	24.46	25.36	25.16	24.16	24.46
Mean min. temp.	5.96	6.96	9.66	11.16	10.96	10.56	11.26	10.76	9.16	8.06	6.76	5.76
Mean temp.	15.87	16.76	18.36	19.16	19.36	19.26	17.96	17.66	17.36	16.56	15.46	15.16

Figure 7: Mean monthly temperature of Awlalo watershed area

5.3 DRAINAGE PATTERN

There are many small intermittent rivers that drain the area. These streams originate from the surrounding highlands. Where the slop is fairly defined as flat the streams are condensed at the upper slops and spare. Most of the steep well-drained areas usually have numerous small streams however the moderate slopes and plain areas have long streams in places. In general, the watershed area is defined by drainage pattern of denderetic. The main sources of supply for the streams are rainfall during the rainy season and to a lesser extent a group of springs that issued at the contacts, through fractures and foliation. The watershed has a swampy area that has an aerial extent of 0.017 Km^2.

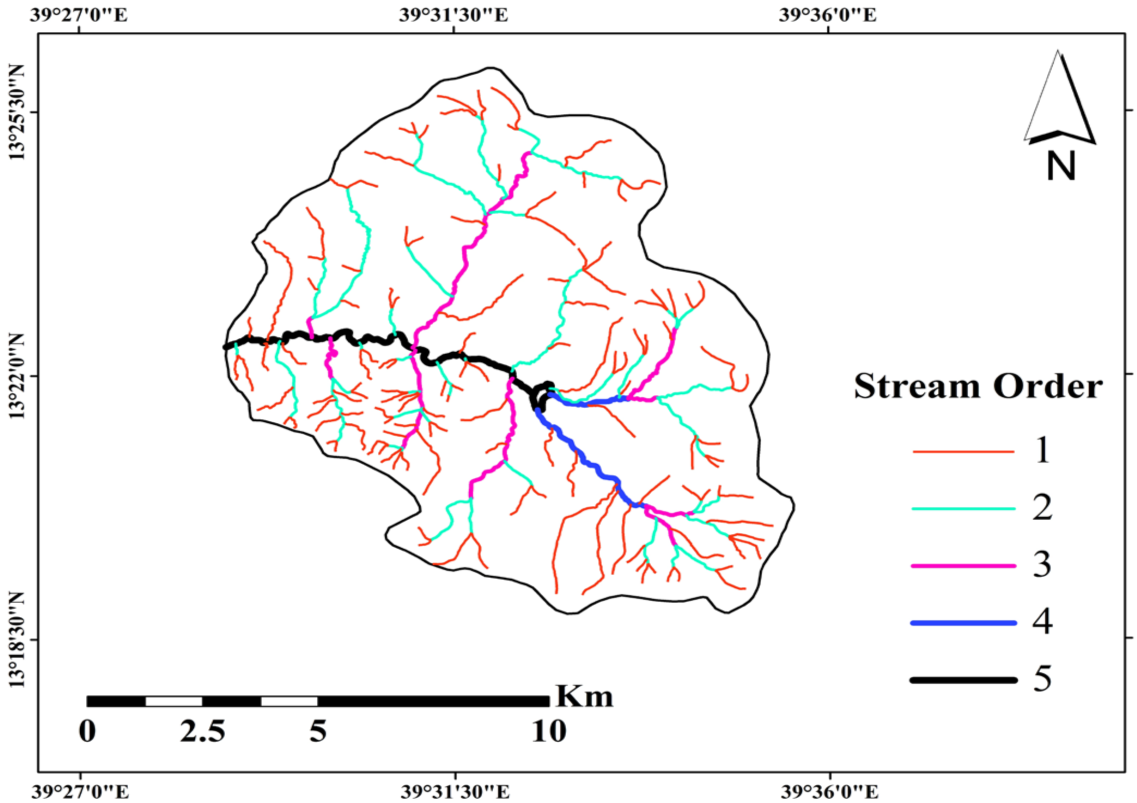


Figure 8: Drainage pattern map of Awlalo watershed (Source: Author)

5.4 SOILS TYPE AND ITS COVERAGE

The soil resource of the Awlalo watershead was classified based on the World Reference Base, WRB soil classification system. Detail on the WRB soil classification system has given on the *(Appendix A).*

The soil types of the Awlalo watershed is described as Pellic Vertisol, Vertic Cambisol, Profoundic Luvisol, Calcaric Regosol, and Haplic Cambisol. The Pellic Vertisol covers 58%, Vertic Cambisol covers 32%, Calcaric Regosol covering 9.5%, Profoundic Luvisol covers 0.8% and Haplic Cambisol which covers about 0.5% of the area. The largest proportion of the watershed is covered by Vertic Cambisol and Pellic Vertisol soil types. The soils are mostly developed under arid conditions at which there is slow weathering process and as a results in very shallow soils are developed in the eastern part of the region. In the higher rainfall areas Cambisols and Vertisols are developed. The majority of the soils of this region are described to be shallow with little soil fertility, high runoff, and low infiltration capacity. Declining soil fertility is particularly severe in Tigray because, according to Mitiku (1996) it is caused by high nutrient losses through extremely low fertilizer, manure inputs and soil erosion.

Table 6: Soil type of Awlalo watershed

Soil Type	Area (km^2)	Area (km^2)	Percentage (%)
Vertic Cambisol	33807163.3	33.8	31.8
Haplic Cambisol	77297.5	0.1	0.1
Pellic Vertisol	61461421.0	61.5	57.9
Profoundic Luvisol	774780.5	0.8	0.7
Calcaric Regosol	10066943.2	10.2	9.5
Total	106187605.4	106.3	100.0

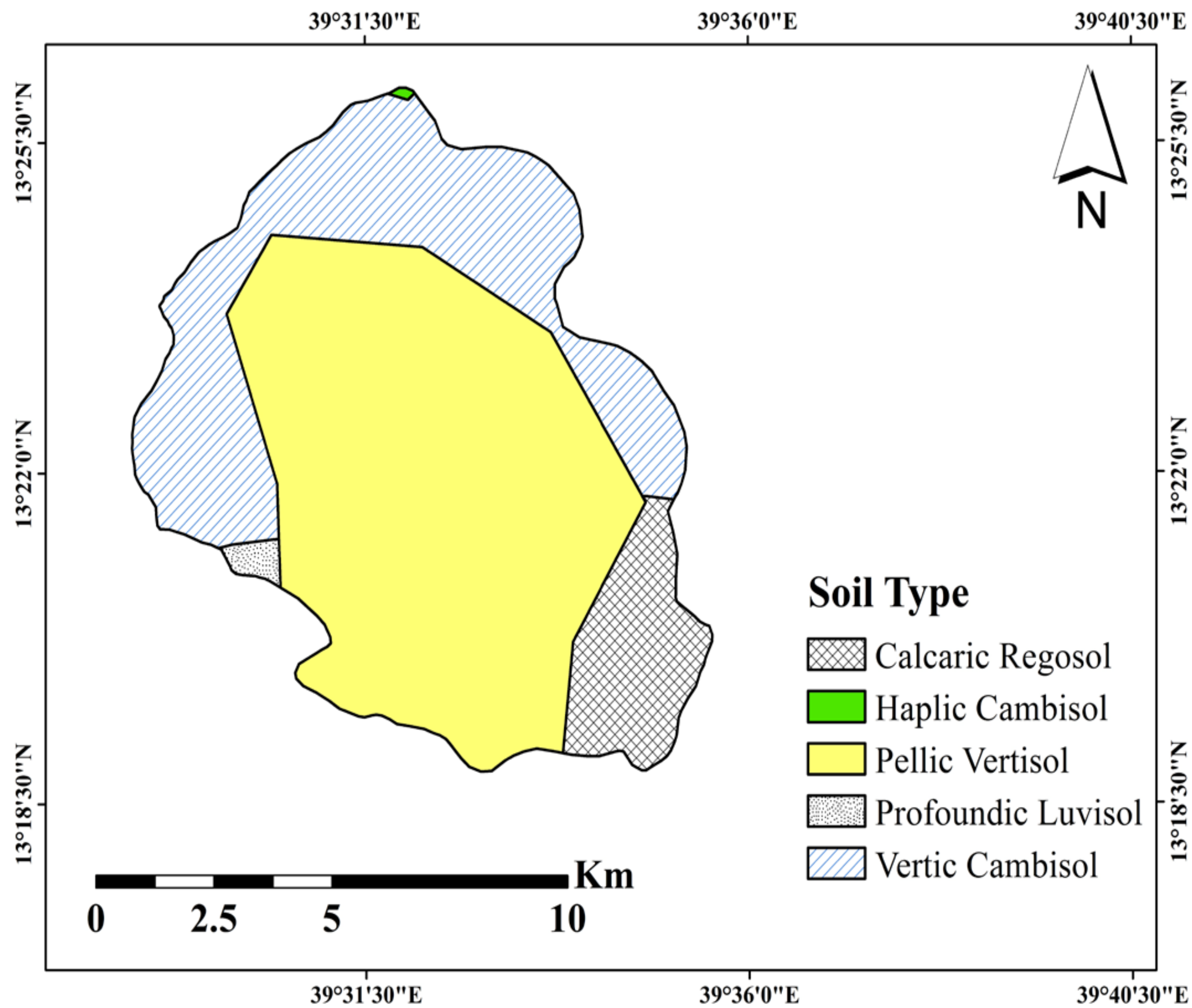


Figure 9: Soil Type Map of Awlalo watershed (source: Author)

5.5 LAND USE/LAND COVER

The figure below indicates the land use land cover map of the watershed which constitutes water body nearly (0.4%), settlement and opens land nearly (11%), shrub and plantation area nearly (13.3%), and cultivated land nearly (76%). The larger portion of the watershed is covered by almost by cultivation land. The most important factors in assessing water resource conditions of the watershed area are land use land cover outline or patterns changes. Due to land use of the practices with higher water necessities and change of climate the water resources are under severe pressure. The consumption of land resource by human activities, particularly agriculture and expansion to urban described by land use outline changes and their estimation (Singh et.al, 2011). Hydrological inferences from land use outlines can help to recognize the changing situation of the demand of water from different activities such as agricultural use, domestic needs and industrialization. Land use outline changes become an important component in hydrological monitoring, modeling and natural resources management in general (Rawat et.al,2013). An analysis of land use changes for hydrologic processes is a major need for the future. Many researchers reported that land use maps are very important inputs for understanding and managing watershed hydrological conditions. Assessment of land use land cover outline of the watershed confirms that the area is most cultivated land, which indirectly supports the future for watershed development and management.

Table 7: Land use/Land cover of Awlalo watershed

Land Use Type	Area (m^2)	Area (km^2)	Percentage (%)
Water body	464565.6	0.5	0.4
Shrubs and plantation	14056567.2	14.1	13.2
Settlement and open land	11153642.4	11.2	10.5
Cultivated land	80663151.6	80.7	75.8
Total	106350130.8	106.3	100

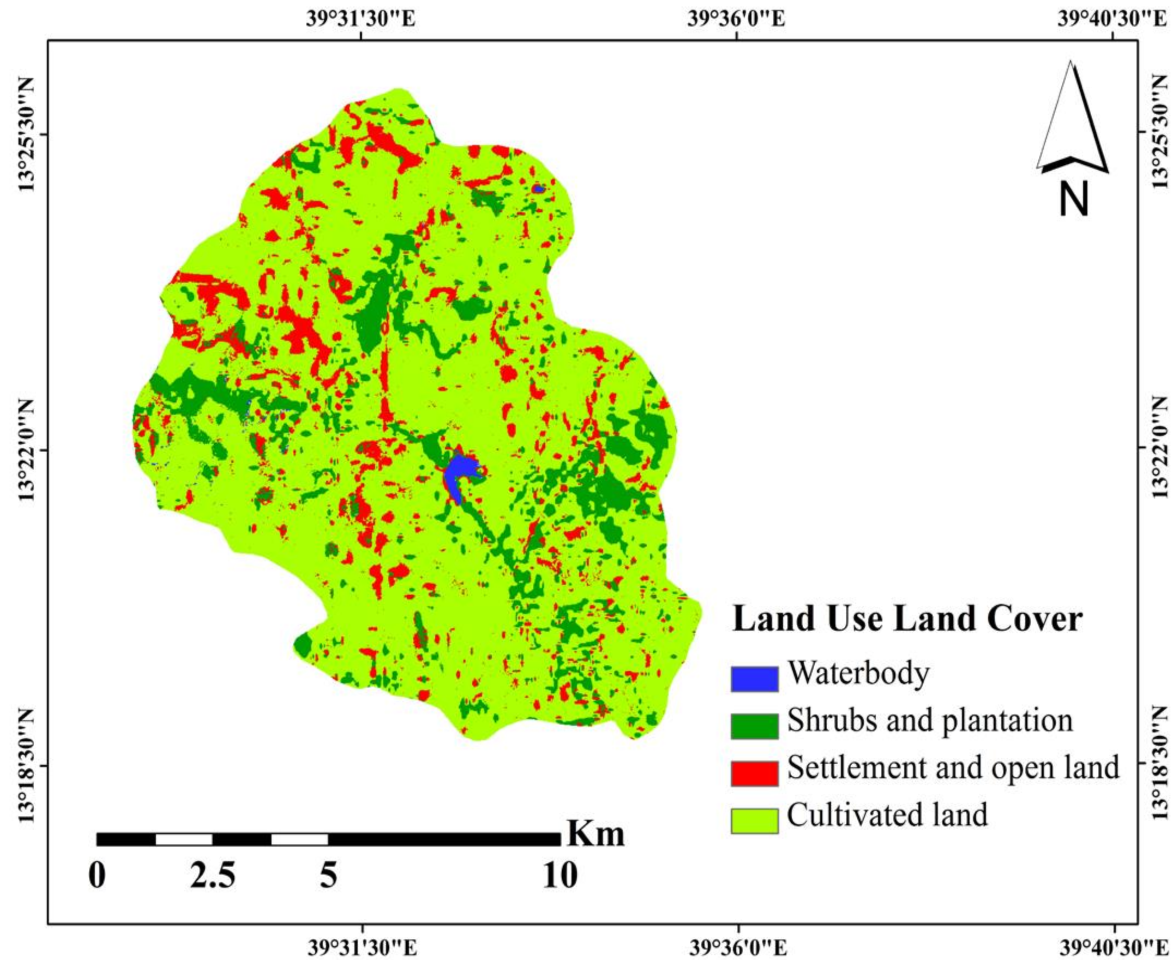


Figure 10: Land use / Land cover Map of Awlalo watershed (Source: Author)

6 RAINFALL-SURFACE RUNOFF IN THE AWLALO CATCHMENT

6.1 BASIC STATISTICAL ANALYSIS OF RAINFALL DISTRIBUTION

Monthly rainfall distribution of the Awlalo watershed over fourteen years is presented in Figure 11.

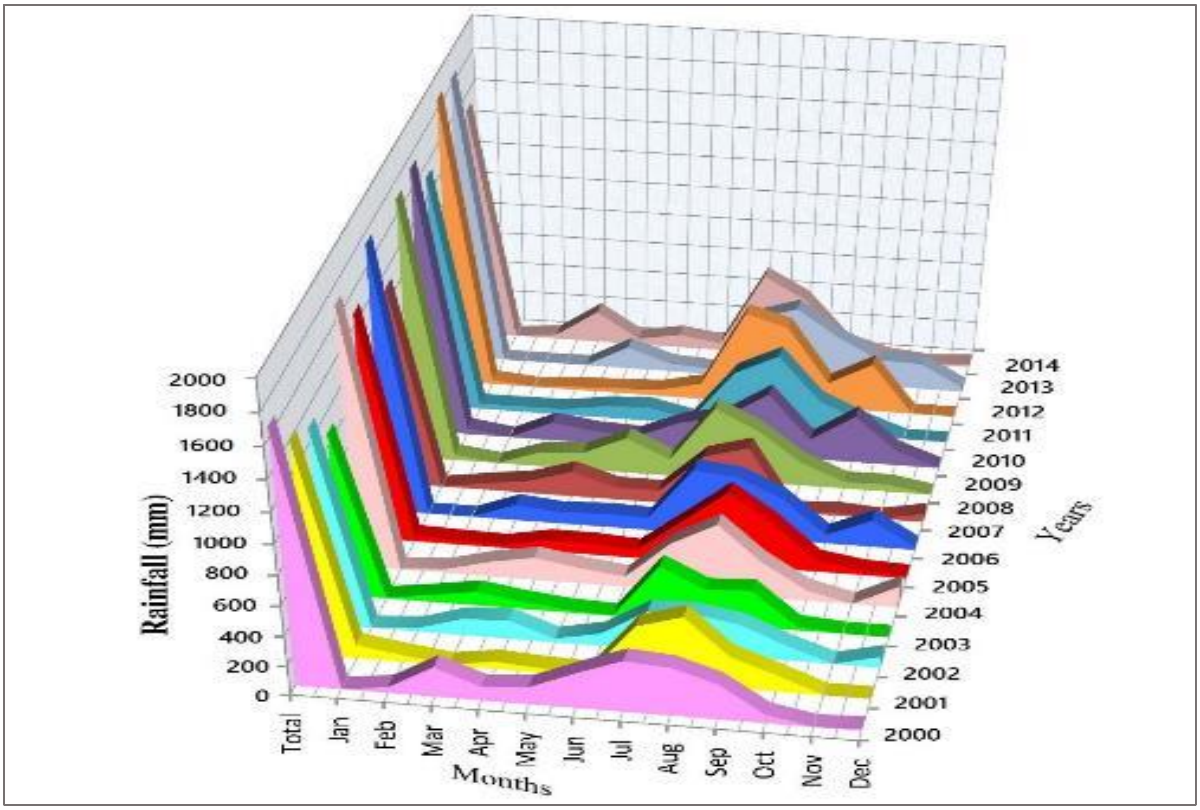


Figure 11: Monthly and annual rainfall distribution for the study area

The tabular form of the rainfall distribution with monthly and annual coefficient of variation is also presented in Table 9 and 10 respectively. From rainfall analysis results, monthly rainfall distribution for each year is highly variable (coefficient of variation, CV > 30%). Year to year monthly rainfall is also highly variable except in months of peak rainfall, i.e., in July (27%) and August (22%). Although monthly and seasonal rainfall is highly variable, annual total variability is quite low (CV = 15%) with an average amount of 1552 mm and standard deviation of 230 mm. Derib (2005) states annual rainfall with CV > 30% is an indication of high vulnerability to drought. Regardless of the higher year to year and annual monthly rainfall variability, the low variability of total annual rainfall minimizes the risk of drought in the study area. Hurni and Grunder (1986) verified that drought is not a problem in this area because of low variability of annual rainfall. However, from the high variability of year to year monthly rainfall especially that of the short rainy seasons, March to April, the probability of the occurrence of dry spells is increasing. Holden and Shiferaw (2000) also mentioned that the short rainy seasons have recently become more unreliable. High variability in the main rainfall onset and offset seasons also could aggrandize the problem further. Hence, management practices should be sought and used to alleviate the effect of monthly and seasonal variation on land production and productivity. The rainfall pattern of the area is unpredictable. The first week of June to mid of October the rainfall season is good in the area. Meanwhile rainfall until the end of June is considered only as moisturizing of the soil. Continuous and heavy daily rainfall saturate the soil at this time which is not favorable condition for major barely crop and in addition to this it causes soil expansion that creates soil workability. The bad season of rainfall for the community start from the last week of June to first week of September where in most cases the average rainfall season extend from last week of June to last week of September.

Table 8: Monthly rainfall distribution descriptive statistical analysis

	Avg.	**SD**	**CV (%)**	**Max**	**Min**
Jan	19	26	135	91	0
Feb	22	18	84	46	0
Mar	86	65	75	206	4
Apr	92	44	48	169	29
May	80	55	69	239	16
Jun	83	64	77	237	5
Jul	383	104	27	610	104
Aug	412	91	22	532	91
Sep	204	83	41	318	3
Oct	107	99	92	321	21
Nov	38	64	170	179	0
Dec	26	41	155	145	0
Total	1552	230	15	1855	1072

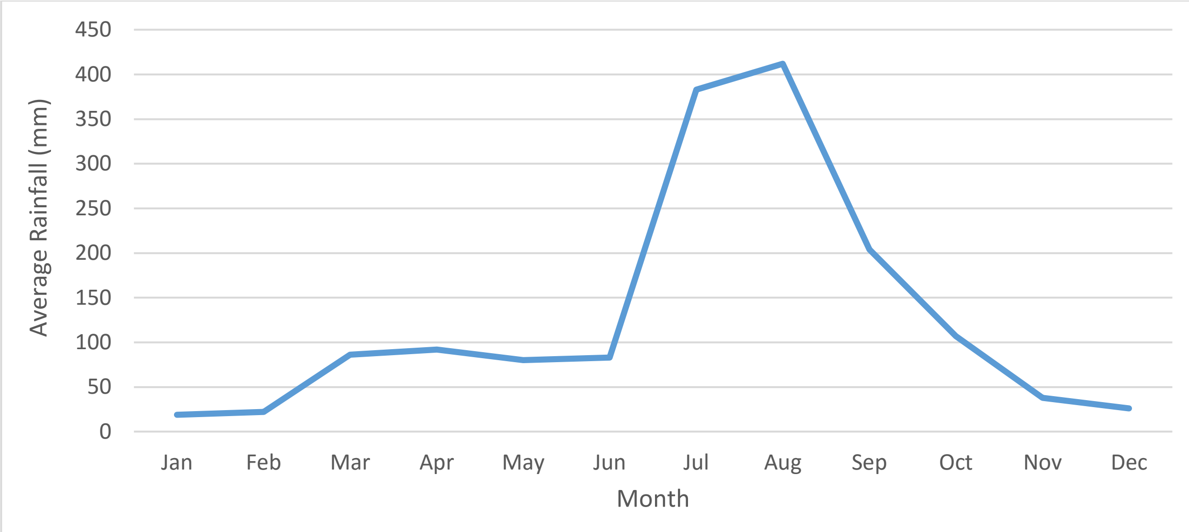


Figure 12: Monthly average rainfall distribution (Source: Author)

Table 9: Annually rainfall distribution descriptive statistical analysis

Year	Total	Avg.	SD	CV (%)
2000	1660	138	126	91
2001	1388	116	151	131
2002	1287	107	95	89
2003	1072	89	122	136
2004	1690	141	140	99
2005	1472	123	152	124
2006	1733	144	151	104
2007	1300	108	137	126
2008	1693	141	149	106
2009	1724	144	129	90
2011	1520	127	161	127
2012	1855	155	216	140
2013	1838	153	170	111
2014	1498	125	171	137

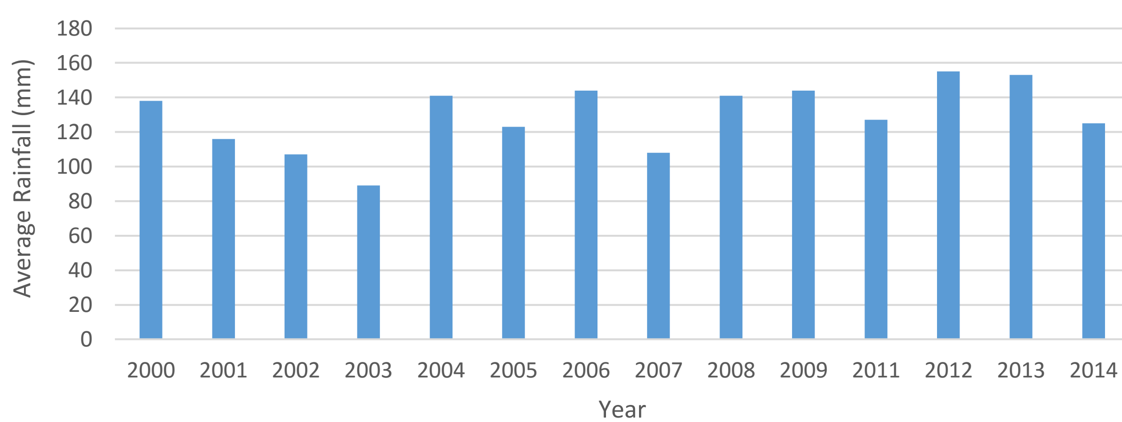


Figure 13: Annual Rainfall Distribution of Awlalo Watershed (Source: Author)

6.2 SURFACE RUNOFF GENERATION PROCESS

In order to determine how long it takes to produce surface runoff the rainfall condition is important to know. Severe rainfall yields higher surface runoff. With heavy rainfall the stream flow changes within very short times, because most of the out rocked areas which produce surface runoff are found on the lower parts of the watershed near by the outlet. This part of the watershed is highly degraded because of continuous annual cultivation during the main rainfall seasons in addition to the melting behavior of its soil, regosols (Figure 9 in Chapter 5). The heavy rainfall seasons of the watershed generated higher surface runoff. As we can see from the above graph of the monthly and annual average rainfall distribution, the period between beginning of June and end of July have sever rainfall more in the lower part of the watershed part which is heavily contribute for the surface runoff generation in the area. The land use/ land cover contributes for the watershed surface runoff as the most of the land is covered with forest like Eyoucalapitos which have contribute to the soil dryness.

Figure 14: Surface Runoff contributing degraded areas near by the outlet 13˚ -14˚N latitude and 39˚ - 40˚30" East longitudes (Source: Author)

Showing the surface runoff contributing degraded areas near by the outlet. The white colored surface shows rock out cropped areas. The muddy surface runoff from these areas reaches to the outlet soon the rainfall starts.

The rainfall usually is peak and saturates the soil in the month of August. This results in high surface runoff generation. Parts of the watershed that produce surface runoff are characterized by high slope, shallow soil depth or totally crop out rocked and eucalyptus plantations while cultivated flat lands with deep soil and bush lands, which dominate the upper watershed, produce the least runoff. Surface runoff concentration increases down the slope at the lower parts of the watershed because of the increase in runoff contributing areas. From direction aspect, the rainfall usually comes from east direction of the watershed and as a result areas which face to the opposite direction gets direct rainfall and produce much surface runoff.

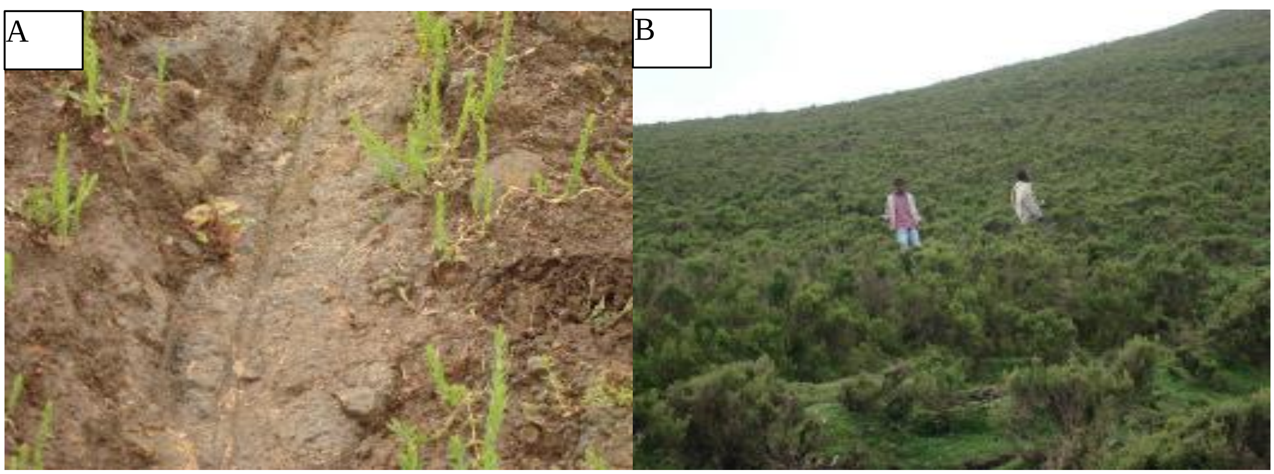


Figure 15: Very shallow depth regosols which produce high runoff (A) and bush lands where there is high infiltration (B) 13˚-14˚N latitude and 39˚- 40˚30" East longitudes. (Photograph source: author)

6.3 ESTIMATION THE SURFACE RUNOFF BY THE SCS-CN APPROACH

From SCS Curve number, the maximum surface runoff for the watershed was estimated to be 1200.06 mm in the year 2013 and minimum runoff of 345.02 mm in the year 2003. Table 4 shows the annual rainfall and runoff for Awlalo watershed for the period 2000 to 2014. Figure 17 shows the rainfall runoff relationship for Awlalo watershed. The rainfall and surface runoff are strongly correlated with correlation coefficient (R) value being 0.81.

Table 10 Annual rainfall and Surface runoff for Awlalo Watershed

Year of Rainfall	Rainfall in (mm)	Surface Runoff (mm)
2000	1660	495.07
2001	1388	610.15
2002	1287	439.87
2003	1072	345.02
2004	1690	934.98
2005	1472	670.57
2006	1733	856.39
2007	1300	570.13
2008	1693	603.07
2009	1724	809.07
2010	1750	1000.04
2011	1520	850.02
2012	1855	1020.03
2013	1838	1200.06
2014	1498	723.09

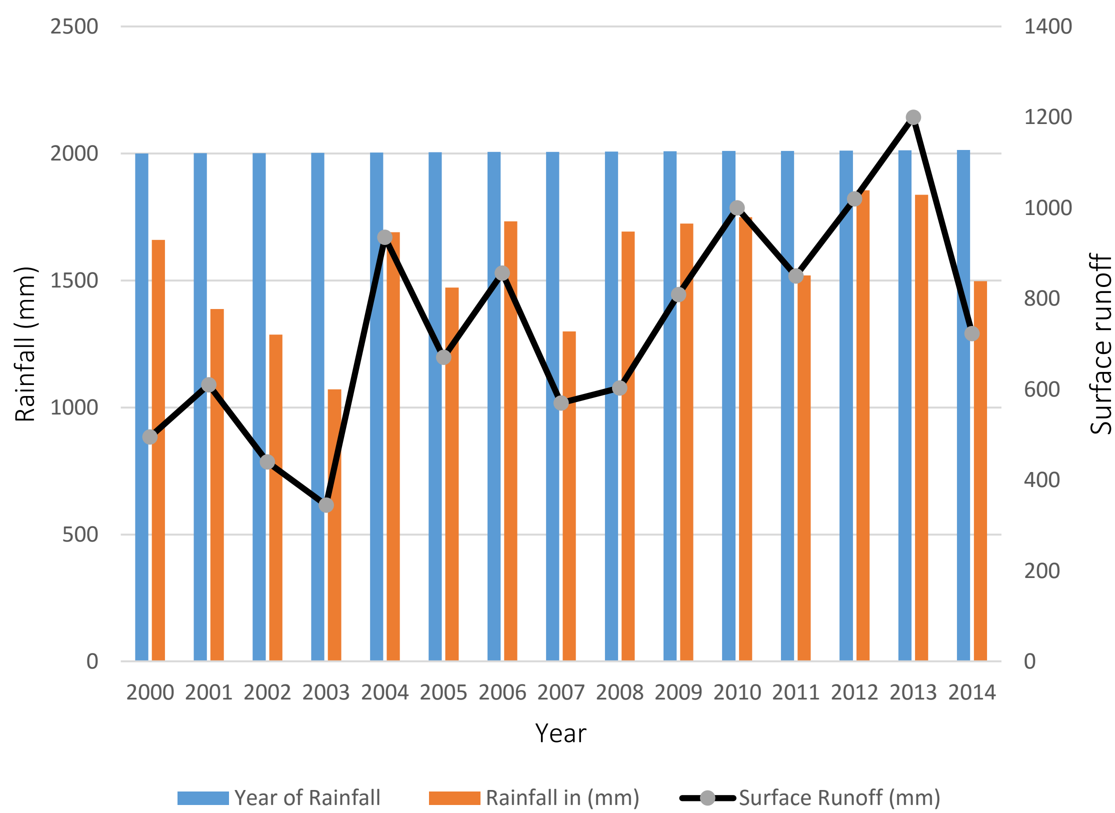


Figure 16: Rainfall and surface runoff relation of Awlalo watershed

As we can see from the above comparison (Figure 16) of the rainfall and surface run off for fourteen years, the amount of the surface run off was increasing and get worst from 2010 to 2014. The amount of surface runoff computed for the year 2003 was 345.02 mm with minimum rainfall amount of 1072 mm in the entire annual period. Coming to the 2007 and 2008 period of rainfall, the amount of surface runoff have been found almost similar which approximately 600 mm where the amount of the rainfall for both year was about 400 mm difference. In the case of the 2009, 2010, 2012 and 2013 period of rainfall season the amount of the surface runoff have been computed and found higher than the other years. We can see from the above comparison graph that between the year 2012 and 2013 the rainfall amount recorded was above 1830 mm which is the highest of all the recorded data and the computed result of surface runoff have been found about 1020 mm.

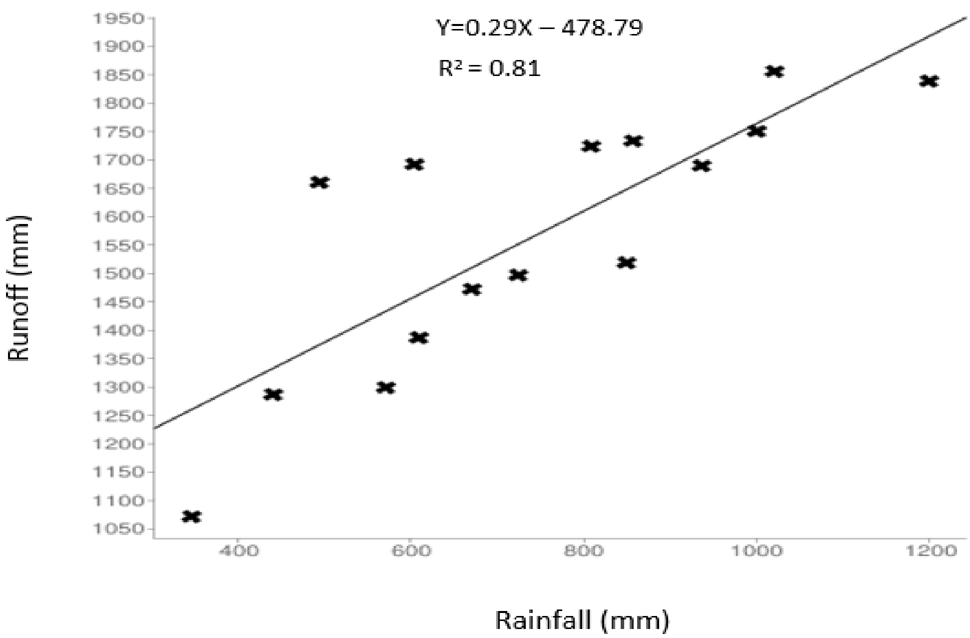


Figure 17: Rainfall and surface runoff correlation graph of Awlalo watershed

6.4 COMMUNITY RAINFALL AND SURFACE RUNOFF QUESTIONERS RESPONSE

According to all the participants of the questioners (farmers and data collector experts) in the watershed area, 95% of the participants agreed rainfall is described by the rain season and very seasonal and heavy rainfall season occurs during June whereas in July is the more sever month that produces soil loss and possibly causes surface runoff before the area get fully saturated. The main cropping/cultivation season is from end of June till the beginning of July where the soil loosely structured and bares at this time. All of the participants answered Yes to the words the question if all rainfall produces surface runoff. The loss structured regosols melt following continuous and heavy rainfall event. From field observation the muddy surface runoff reaches to the stream outlet with in very few minutes. Most of the cultivated land is located in the lower watershed in the main rainfall. 80 % of the farmers mentioned that land covers with Eucalyptus in the lower forest part of the watershed is very dry and produces higher surface runoff. Surface runoff increases down the slope of the watershed. The regosol soils are continually cultivated in the main rain season. The sensitivity of surface runoff is comparatively higher in the lower regosol soil. This is because the regosol is at the watershed and found at the shallow depth with low water holding capacity and melting natures with fine particles easily washed.

6.5 DISCUSSIONS

The pattern of rainfall of the area is very seasonal. A good season of rainfall usually starts from the first week of June to the end of October. But the rainfall till end of June is not higher that the soil moisturizing. It is difficult to know how long it takes for the rainfall to produce surface runoff. This entirely depends on the rainfall amount. In most cases intensive rainfall produces surface runoff. The stream flow may change within very short time of five minutes if there is heavy rainfall due to most of the out rocked area that produces surface runoff are found in the lower watershed outlet. This lower part of the Awlalo watershed is very loss soil due to continuous cultivation. The surface runoff from all parts of the watershed contributing area reaches the outlet within 5-10 minutes. The rainfall is in its peak in August and the soil get fully saturated during this period higher surface runoff produced. Parts of the watershed that generates the surface runoff are described by higher slop, shallow soil depth or totally outcropped. Surface runoff generation in the lower part of the watershed increases its concentration due to the increasing runoff contributing area. From the direction point of view, the rainfall in the watershed comes from the east direction resulting in direct rainfall and generation of surface runoff to the areas of opposite direction. The surface runoff is highly correlated with the rainfall distribution amount of the Awlalo watershed. In the Period 2012 to 2014 was highly increasing the amount of surface runoff comparing the other years. More importantly the between the month of June till July the surface runoff generation from the rainfall can be much considered for the study area. During the period of 2012 the rainfall amount in the watershed was recorded as 1855 mm which is maximum heavy rainfall amount that generates about 1020.03 mm of surface runoff amount in comparison with fourteen years rainfall record of the study area. In 2003 about 1072 mm of rainfall was recorded as minimum amount relatively with the other record and about 345.02 mm of surface runoff have been found by computation which is possibly considered as minimum record of surface runoff in this study area.

7 CONCLUSIONS AND RECOMMENDATIONS

The estimation of the surface runoff using soil conservation service curve number (SCS-CN) method together with GIS based approach can be used effectively as the watershed management. All the factors in the SCS-CN method are geographic factor in character. The geographic nature of these factors helps to integrate the SCS-CN method to integrate with GIS method. The study demonstrates estimation of the surface runoff using SCS-CN method with GIS integrated method for the ungauged watershed. The results obtained clearly shows that the variation of the surface runoff with different soil type and conditions, land use/land cover. The soil conservation service method has been recognized that when applied appropriately for the watershed, could increase the success in delivery of information about surface runoff estimation and evaluation of properties which can be utilized for the proper planning and management determinations through computation of the existing watershed characteristics and factors.

The study shows the amount of seasonal rainfall distribution in the watershed area significantly affects to the generation of the surface runoff. Other factors such as soil type, land use/cover and slope of the watershed area considerably contributes to the surface runoff production. More sever surface runoff generation has experienced in the lower part of the watershed as this part of the watershed is cautiously used in ever rain season cultivation in between June to July. The amount of rainfall distribution of the watershed area which was computed for the surface runoff generation from the past fourteen years shows heavily and concentrated rainfall was increasingly recorded and is major contributor. The statistical computation and correlation of the rain fall amount shows it is strongly related with the surface runoff generation. The rainfall direction is from east part of the watershed where the opposite side area face from easily removable of cultivated soil and generates surface runoff. In other point farmers in this part of the watershed have been using forest plants like Eyucalapitos which causes further dry of the soil. The surface runoff generated in the area have been observed to cause many effects to the watershed area such as decreasing in crop productivity, soil contamination with pesticides, flooding, soil erosion, impact of surface water, ground water, and soil through transport of water pollutants in to the environmental system.

As a recommendation a more comprehensive analysis can be provided with a more comparative statistical procedure of watershed surface runoff estimation and evaluation instead of focusing only with the soil conservation service curve number method. In order to carry out the surface runoff evaluation analysis and overcome the inconsistencies, filling in the gaps such as proper long term rainfall records, precipitation and infiltration rate of the watershed area is recommended. Furthermore land use development controls to prevent affected area and rehabilitate, erosion controls, flood controls and rehabilitation program for the affected area of the watershed should be planned and implemented to prevent the surface runoff in and around the Awlalo watershed area.

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ABBREVIATIONS

A.s.l	Above Mean Sea level
AMC	Antecedent Moisture Content
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
CC	Correlation Coefficient
CN	Curve Number
CV	Coefficient of Variance
DEM	Digital Elevation Model
GIS	Geographic Information System
Ha	Hectares
HSG	Hydrological Soil Group
LUCC	Land Use & Cover Change
NRCS	Natural Resources Conservation Service
RS	Remote Sensing
SCS	Soil Conservation Service
SCS-CN	Soil Conservation Service Curve Number
SD	Standard Deviation
USDA	United States Department of Agriculture
WRB	World Reference Base

APPENDICES

Appendix A: *Guide to Soil classification System and their Code (Source: World Reference Base in soil classification system (WRB), 2014.*

	RSG	Code
1. Soils with thick organic layers:	Histosols	HS
2. Soils with strong human influence –		
With long and intensive agricultural use:	Anthrosols	AT
Containing significant amounts of artefacts:	Technosols	TC
3. Soils with limitations to root growth –		
Permafrost-affected:	Cryosols	CR
Thin or with many coarse fragments:	Leptosols	LP
With a high content of exchangeable Na:	Solonetz	SN
Alternating wet-dry conditions, shrink-swell clays:	Vertisols	VR
High concentration of soluble salts:	Solonchaks	SC
4. Soils distinguished by Fe/Al chemistry –		
Groundwater-affected, underwater and in tidal areas:	Gleysols	GL
Allophanes or Al-humus complexes:	Andosols	AN
Subsoil accumulation of humus and/or oxides:	Podzols	PZ
Accumulation and redistribution of Fe:	Plinthosols	PT
Low-activity clay, P fixation, many Fe oxides, strongly structured:	Nitisols	NT
Dominance of kaolinite and oxides:	Ferralsols	FR
Stagnating water, abrupt textural difference:	Planosols	PL
Stagnating water, structural difference and/or moderate textural difference:	Stagnosols	ST
5. Pronounced accumulation of organic matter in the mineral topsoil –		
Very dark topsoil, secondary carbonates:	Chernozems	CH
Dark topsoil, secondary carbonates:	Kastanozems	KS
Dark topsoil, no secondary carbonates (unless very deep), high base status:	Phaeozems	PH
Dark topsoil, low base status:	Umbrisols	UM
6. Accumulation of moderately soluble salts or non-saline substances –		
Accumulation of, and cementation by, secondary silica:	Durisols	DU
Accumulation of secondary gypsum:	Gypsisols	GY
Accumulation of secondary carbonates:	Calcisols	CL
7. Soils with clay-enriched subsoil –		
Interfingering of coarser-textured, lighter coloured material into a finer-textured, stronger coloured layer:	Retisols	RT
Low-activity clays, low base status:	Acrisols	AC
Low-activity clays, high base status:	Lixisols	LX
8. Soils with little or no profile differentiation –		
Moderately developed:	Cambisols	CM
Sandy:	Arenosols	AR
Stratified fluviatile, marine and lacustrine sediments:	Fluvisols	FL
No significant profile development:	Regosols	RG

Appendix B: *Community Questioners given to the know the relevant perceptions, ideas, and knowledges of the rainfall and the surface runoff around the watershed*

Rainfall characterization

1. How the rainfall does looks like in the watershed area?
   a. Very Seasonal
   b. Uniform and predictable form
2. How do you describe good or bad and average rainfall season?
   a. By the length of rain season
   b. By the number of the rain day
   c. By beginning of rain time
   d. By ending time of the rain
3. When does the rainfall start?
4. When the area does gets enough rainfall or fully saturated?
5. How many days of the rain are required for the soil to get fully saturated?
6. When the rain does usually ends?

Rainfall and surface runoff relation

7. Does all rain produce usually surface runoff? **Yes/No**
8. What kind of rain produce usually surface runoff?
9. How long after rain the surface runoff began?
10. Which week of month the rain usually produces higher surface runoff?
11. What are the reason for this higher surface runoff?
12. Where in the watershed does the surface runoff higher?
    a. Upper, bottom, middle of the watershed slop?
    b. Which direction?
    c. In what kind of land use?
    d. In what kind of soil type?

Appendix C: *Monthly and annual stream flow distribution in the Awlalo watershed*

Monthly and Annual Stream Flow (mm) Distribution for the Awlalo Watershed																	
	Years																
	2000	**2001**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2011**	**2012**	**2013**	**2014**			**Descripti Statistics**		
Total	1134.7	873.8	639.8	761.9	1066.5	638	930.8	855.3	432	506.7	451.2	339.9	**Avg**	**SD**	**CV(%)**	**Max**	**Min**
Jan	13.7	7.7	5.1	10	3.5	5.6	2.3	1	1.3	0.2	0	0.2	719.2	259.1	36	1134.7	339.9
Feb	9.7	4.5	6.8	11.5	4.7	5.1	2.1	0.7	0.2	0.2	0	0.3	4.2	4.4	104.2	13.7	0
Mar	29.9	4.6	15.3	26.7	13.4	2.8	5.1	46.2	0.5	0.3	0.1	14.5	3.8	4	103.9	11.5	0
Apr	43.7	5.4	59.3	31.1	21.1	4.8	4.7	42.5	1.5	0.3	2.6	1.4	13.3	14.5	108.8	46.2	0.1
May	43.7	3.9	8.5	4.7	22.8	5.7	11.7	9.8	9.2	0.2	5.1	2.7	18.2	20.8	114.2	59.3	0.3
Jun	69.4	3	7.5	2	9.3	2.1	9.2	23.2	0.1	3.5	0.1	0.1	10.7	11.9	111.5	43.7	0.2
Jul	272.7	80.3	107.3	114	118.6	27.7	226.3	151.1	117.5	139.9	38.4	125.7	10.8	19.6	181.5	69.4	0.1
Aug	311.7	394.8	186.2	221.1	439.7	289.5	261.5	268.3	211.6	172.1	177.5	161.5	126.6	69.1	54.5	272.7	27.7
Sep	257.4	233.7	147.1	244.8	257.1	239.5	251.2	36.6	61.9	53.1	133.8	32.7	257.9	89.2	34.6	439.7	161.5
Oct	70	120.8	49.2	82.1	90.7	41.3	27.9	200.8	27.4	136.1	59.4	0.7	162.4	95.1	58.5	257.4	32.7
Nov	7.7	9.4	6.5	10.8	3.1	8.4	110.1	63.2	0.6	0.7	33.4	0.1	75.5	55.6	73.6	200.8	0.7
Dec	5.1	5.7	40.9	3.2	82.5	5.5	18.7	11.9	0.3	0.2	0.6	0.1	21.2	33.4	157.6	110.1	0.1
													14.6	24.4	167.3	82.5	0.1
Avg.	94.6	72.8	53.3	63.5	88.9	53.2	77.6	71.3	36	42.2	37.6	28.3					
SD	114.9	123.6	61.7	86.5	133.2	100	106.2	87.5	65.8	66.8	59.2	55.2					
CV(%)	121.5	169.8	115.7	136.2	149.8	188	136.9	122.8	182.9	158.3	157.6	194.9					

Appendix D: *Photographs taken at different parts of the watershed to show the surface runoff is sever causing erosion and soil loss*