ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY (AAIT)

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINEERING

ASSESSMENT OF SURFACE WATER POTENTIAL TO MANAGE FREQUENT DROUGHT DISASTER

(A Case of Dhas District in Borana Zone of Oromia Region, Ethiopia)

By

Alemayehu Worku

Advisor

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June 2019

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APPROVED BY BOARD OF EXAMINERS

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ASSESSMENT OF SURFACE WATER POTENTIAL TO MANAGE FREQUENT DROUGHT DISASTER

(A Case of Dhas District in Borana Zone of Oromia Region, Ethiopia)

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Alemayehu Worku

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University

in Partial Fulfilment of the Requirements for the Degree of Master of Science in Civil and Environmental Engineering

June 2019

Addis Ababa, Ethiopia

ABSTRACT

The study was conducted in Dhas district, which is located in Borana Zone of Oromia region; geographically it is situated 4.00°-4.39°N and 38.39°-39.46° E with altitude range of 1082 – 1666m a.m.s.l. Total area of the district is 3,183.22km^2; its length from West to East is 120 Km and width from South to North is 41km.

There is not any river and gauging station in the district; the study was conducted aiming at estimation of surface water potential of the district and evaluation of its sufficiency for managing of drought disaster in the district. The surface water potential assessment of the district was conducted using SCS model with the aid of remote sensing and GIS. The assessment output was contextualized with the study finding of Genale Dawa integrated Master plan study (Dhas district is located in Dawa sub-basin; finding from separate analysis of Dawa sub-basin was referred).

For the recent land use/ land cover information of Dhas district; satellite images were downloaded from USGS (United States Geological Survey) website with acquisition dates of December 2018, and the image processing was done using ERDAS Imagine 2015. With the aid of HEC-GeoHMS tool that is specifically designed in the ArcGIS environment to process geospatial data, the curve number was generated using the required information (hydrologic soil group, DEM, LULC map).

The district was divided in to twelve sub-watersheds using Global mapped software, and direct runoff estimation was done for each sub-watershed separately; the summation of direct runoff from each sub-watershed was made to get the total direct runoff amount of the district. Thirty years daily grid rainfall data that was collected from NMA was used for the estimation of the direct runoff.

Estimation of runoff volume was computed for all thirty years period, and the estimated minimum and maximum runoff volume were found to be 8Mm^3 and 361Mm^3 respectively. Twenty years of forecast was made to estimate the major requirements in the district. Human and livestock's water requirement estimation based on the population sized of 2039 was computed to be 10Mm^3 / year.

The abundant of estimated runoff volume was evaluated, whether it is enough or not to satisfy the major water requirements in terms of managing the frequent drought disaster. As the analysis shows, Dhas district is having sufficient surface water potential that can be developed for managing of the frequent drought disaster in the district.

This study was conducted focusing only on the available surface water potential of the district, and its sufficiency for managing of the drought disaster in the district. Its finding is also expected to be an entry point for development of the resource in the large scale. But for its implementation, it needs further feasibility and detail studies.

DECLARATION

I hereby declare that; I am the only author of this thesis and it has not been presented for any other degree in any university or collage and all the resources of material used for the thesis have been duly acknowledged.

Name: Alemayehu Worku

Signature: ------------------------------

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LIST OF ACRONYMS

a.m.s.l	Above mean see level
B	Billion
CN	Curve number
DEM	Digital elevation model
E.c	Ethiopian calendar
GIS	Geographical information system
KII	Key informant interview
LULC	Land use land cover
M	Million
MCM	Million cubic metre
MoWIE	Ministry of water irrigation and energy
MoWR	Ministry of Water Resource
NMA	National meteorological agency
NSC	Nash–Sutcliffe efficiency
PEDCo	Planning and economic development commission
PEDO	Planning and economic development office
RS	Remote sensing
SCS	Soil conservation service
SW	Sub-watershed
USGS	United states geological survey
Watbal	Water balance

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1. INTRODUCTION

1.1. Background

Ethiopia has 12 basins; the total mean annual flow from all the 12 basins is estimated to be 122 Bm^3 (MoWR 1999) [A]. Out of the total water resources, about 75% drains to neighbouring countries (MoWR 2001a) [2]. Since almost all river basins originate from the highlands and high rainfall areas, they have huge amount of surface water running in the river basin systems and Ethiopia is considered to be the water tower of the Horn of Africa. This potential is not fully utilized and translated into development because of many factors [3].

The country is divided into 11 climatic zones ranging from equatorial desert to hot and cool steppes, and from tropical savannah and rain forests to warm temperate and cool highlands. The mean annual rainfall varies between about 100 mm in the north-east to 2800 mm in the south-west (Lemma 1996). However, rainfall is generally erratic and irregular. The fluctuation of the rainfall is closely related to the occurrence of the El Niñoouthern Oscillation (ENSO) that occurs on a 2–7-year cycle [2].

The rural people of Borana Zone are very vulnerable to drought. During the drought of 2000, 80% of livestock died. In 2008 a relief program had to supply water and fodder to communities (Angasse A. & Oba G., 2007). Malnutrition is widespread in the Zone as a result of poor access to clean water, low agricultural production, lack of infrastructure and poverty in general (Lasage, A. et al, 2010) [9].

In Borana Zone, drought disaster and flood incidences have been reported at different time. These events looked paradox but need possible solution through proper assessment of water resource potential of the area; surface water potential assessment of the area is part of overall water resource potential assessment of the area.

Currently, the activities that have been intervened in Borana Zone by different bodies are complained as not optimally using the available surface water potential of the area to address the felt need of the community in the area. The surface water potential information of Dhas district as well as Borana Zone enables to manage the frequent drought disaster in the area. This thesis work was done focusing on Dhas district only; only the surface water potential of the district was estimated and only the water demand in the district was evaluated. So, throughout the analysis Dhas district boundary was used as a control volume.

Of course, watershed-based surface water assessment is the usual approach so as to take the upstream and downstream users into consideration. But due to the district not having any river, the matter of upstream and downstream users could not be an issue. A watershed is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir; so, a watershed may comprise of more than one administrative boundary This may have its own impact in terms of managing the resource. Hence, for the sake of its management simplicity district-based analysis was conducted by this study.

1.2. Problem Statement

The livelihood of Dhas district pastoralist community is centring water hence, water resource development of the area to tackle the challenges related to the livelihood system of the community is not questionable. Before implementation of any water resources development project, it is very crucial to do an assessment on the available water resource potential of the area.

There are no any perennial rivers in Dhas district as well as in Borana Zone; only depressions with defined water ways are observed, and hence there is no any stream gauging station and gauged hydrological data in the area.

Due to lack of gauged hydrological data and unavailability of readymade surface water potential information of the area particularly to the Dhas district, it has not been possible to quantify the surface water potential of the district. Most of the development actors intervening in the area are assuming that, the area is not receiving enough rainfall as the result it is not having good surface water potential. Due to this reason, the water resource development activities that have been intervened by different bodies are undermining the available surface water potential of the area.

Dhas district is situated in Dawa sub-basin of Genale Dawa river basin, and Genale Dawa integrated master plan study was conducted. Dawa sub-basin includes wider range of climatic zone; the Dawa river headwaters are located in the Sidamo mountain. Compared to the total Dawa sub-basin, size of Dhas district is very small and accounts for about only 6.64%. The available gauging station (Melka Guba) on river Dawa that is closest to Dhas district shares the total area of 20,098 Km^2 out of which Dhas contributed only 16%. So, using of the observed hydrology data (at Melka Guba staion) for Dhas district is much farther form the reality; not well reflecting the surface water information of Dhas district.

Drought is a common phenomenon in many parts of Borana. The lowland parts are severely affected by recurrent droughts. The rainfall pattern is highly erratic according to the people living in the area, and the rains often do not occur at the expected time. Sometimes the intensity of rainfall is above normal and sometimes it is far below normal. This information was shared during several field interviews with local inhabitants [7].

Dhas district is receiving mean annual rainfall of 523mm. Moreover, excessive rain above the normal and flood incidence is also common in the area. So, there is a possibility of coping the frequent drought disaster in Dhas district through the development of available surface water potential in the district.

Thus, this study was done to fill the gap (making available the surface water potential information of Dhas district) and evaluating the available surface water potential against the water requirement for managing of frequent drought disaster in the district.

1.3. Objective of the Study

The general objective of the research work was to assess the surface water resource potential and water requirement estimation for managing of frequent drought disaster in Dhas district, Oromia Region of Ethiopia.

The specific research objectives are:

- To assess the surface water potential of Dhas district;
- To evaluate amount of water required for managing frequent drought disaster in Dhas district.

2. LITERATURE REVIEW

2.1. General

Surface water is water stored or flowing on the earth's surface. The surface water system continually interacts with the atmospheric and subsurface water systems [14].

A comprehensive assessment of the water resources available in a region or a river basin is essential for finding sustainable solutions for water-related problems concerning both the quantity and quality of the water resources. Research on the development and application of water balance models at different spatial and temporal scales has been carried out since later part of the 19^{th} century [5].

Dhas district is located in the semi-arid zone and is generally drought prone with erratic rainfall. The area is assumed not to having enough rainfall and surface water potential to cope frequently facing drought disaster.

Dhas district is located within the Genale-Dawa River basin; nevertheless, Genale-Dawa river basin integrated resources development master plan is studied, the sub-basin data (the data specific to Dhas district) is not easily available at the required level for planning of local development activities. Hence, it is required to compute the surface water potential of Dhas district. The research finding enables to have specific information regarding Dhas district.

2.2. Surface Water/ Direct Runoff Estimation

The derivation of relationships between the rainfall over a catchment area and the resulting flow in a river is a fundamental problem for the hydrologist. In most countries, there are usually plenty of rainfall records, but the more elaborate and expensive streamflow measurements, which are what the engineer needs for the assessment of water resources or of damaging flood peaks, are often limited and are rarely available for a specific river under investigation. Evaluating river discharges from rainfall has stimulated the imagination and ingenuity of engineers for many years, and more recently has been the inspiration of many research workers [11].

Estimating runoff or discharge from rainfall measurements is very much dependent on the timescale being considered. For short durations (hours) the complex interrelationship between rainfall and runoff is not easily defined, but as the time period lengthens, the connection becomes simpler until, on an annual basis, a straight-line correlation may be obtained. The time interval used in the measurement of the two variables affects the derivation of any relationship, although with continuously recorded rainfall and stream discharge this constraint is removed and only the purpose of the study influences choice of time interval [11].

Until recently, the estimation of runoff as a percentage of storm rainfall was standard practice. The applicable coefficient varies from near zero for a small storm to a relatively high value for a major storm and is dependent upon initial moisture conditions. Although the experienced hydrologist may be reasonably successful in selecting the proper coefficient for each storm, the method is extremely subjective, and its use cannot be advocated for estimating the runoff from specific storms. The coefficient method is still widely used in the design of storm-drainage and small water-control structures and is the basis of design required by many city and county codes [15].

The variation in runoff coefficient with magnitude of storm can be taken into account by graphical correlation of rainfall and runoff. Such relations are typically curved, indicating an increasing percentage of runoff with increasing rainfall. Only a moderate degree of correlation can be expected, however, since variations in initial moisture conditions are not considered [15].

2.3. Initial Moisture Condition

The quantity of runoff produced by a storm depends on (1) the moisture deficiency of the basin at the onset of rain and (2) the storm characteristics, such as rainfall amount, intensity and duration. The storm characteristics can be determined from an adequate network of precipitation gages, but the direct determination of moisture conditions throughout the basin at the beginning of the storm is not feasible. While reliable observation of soil moisture can be made at a point. Also, any complete accountability of moisture within a basin must include consideration of depression and interception storage [15].

Pan-evaporation data are sometimes used in the computation of a moisture index. The most common index is based on antecedent precipitation. The rate at which moisture is depleted from a particular basin under specified meteorological condition is roughly proportional to the amount in storage. In other words, the soil moisture should decrease logarithmically with time during periods of no precipitation [15].

2.4. Surface Retention

Much of the rain falling during the first part of a storm is stored on the vegetal cover as interception and in surface puddles as depression storage. As rain continues, the soil surface becomes covered with a film of water known as surface detention and flow begins downslope toward an established surface channel. En route to a channel, the water is designated as overland flow and up on entering a channel, it becomes surface runoff. That part of storm precipitation which does not appear either as infiltration or as surfaces runoff during or immediately following the storm is surface retention. In other words, surface retention includes interception, depression storage and evaporation during the storm but does not include that water which is temporarily stored en route to the streams [15].

Although the effect of vegetal cover is unimportant in major floods, interception by some types of cover may be a considerable portion of the annual rainfall. Interception storage capacity is usually satisfied early in a storm so that a large percentage of the rain in the numerous small storms is intercepted. After the vegetation is saturated, interception would cease were it not for the fact that appreciable water may evaporate from the enormous wetted surface of the foliage. Once interception storage is filled, the amount of water reaching the soil surface is equal to the rainfall less evaporation from the vegetation. Interception storage capacity is reduced as wind speed increases, but the rate of evaporation is increased. Apparently, high wind speeds tend to augment total interception during a long storm and to decrease it for a short storm [15].

2.5. Soil Conservation Service (SCS) Model

When a storm occurs, a portion of rainfall infiltrates into the ground and some portion may evaporate. The rest flows as a thin sheet of water over the land surface which is termed as overland flow or surface runoff. The yield of a catchment (usually means annual yield) is the net quantity of water available for storage, after all losses, for the purposes of water resources utilisation and planning, like irrigation, water supply, etc. The runoff from rainfall may be estimated by the following methods: (i) Empirical formulae, curves and tables (ii) Infiltration method (iii) Rational method (iv) Overland flow hydrograph (v) Unit hydrograph method (vi) Coaxial Graphical Correlation and API [12]

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The curve number method was developed by the USDA Natural Resources Conservation Service, which was formerly called the Soil Conservation Service or SCS -the number is still popularly known as a "SCS runoff curve number" in the literature. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope plots monitored by the USDA. It is widely used and is an efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area [13]. The US Soil Conservation Service model is widely used for estimating floods on small to medium-sized un-gauged drainage basins [19]

The Soil Conservation service (1972) developed a method for computing abstractions from storm rainfall. For the storm as a whole, the depth of excess precipitation or direct runoff P_e is always less than or equal to the depth of precipitation P; likewise, after runoff begins, the additional depth of water retained in the water shed, F_a, is less than or equal to some potential maximum retention S. There is some amount of rainfall I_a (initial abstraction before ponding) for which no runoff will occur, so the potential runoff is $P-I_a$. The hypothesis of the SCS method is that the ratios of the two actuals to the two potential quantifies is equal [14].

The CN method was originally developed in 1954 by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture, since renamed the Natural Resources Conservation Service (NRCS, 2004). The origins of the methodology can be traced back to thousands of infiltrometer tests carried out by SCS during the 1930s and 1940s at experimental sites (Ponce and Hawkins, 1996; Williams et at., 2012). Although it was originally developed mainly for agricultural watersheds, the CN method has since been adapted for urbanized and forested watersheds (Cronshey et at., 1986). Among the perceived advantages of the CN method are its simplicity, practicality, predictability, stability, reliance on a single parameter, and responsiveness to watershed properties such as soil type, land use, surface condition, and antecedent condition (Ponce and Hawkins, 1996; Yu, 2012). However, the marked sensitivity of runoff estimation to the choice of CN, the lack of clear guidance on how to vary the antecedent condition, the method's variable accuracy for different biomes, and the fixing of the initial abstraction ration of 0.2 have all been cited as weaknesses (Ponce and Hawkins, 1996). The most criticized assumption in the CN method is that the ratio of actual retention to potential retention is the same as the ratio of actual runoff to potential runoff [20].

2.6. Remote Sensing and GIS Method

The success of planning for developmental activities depends on the quality and quantity of information available on both natural and socio-economic resources. It is, therefore, essential to devise the ways and means of organising computerised information system [23].

These systems must be capable of handling vast amount of data collected by modern techniques and produce up to date information. Remote Sensing technology has already demonstrated its capabilities to provide information on natural resources such as crop, land use, soils, forest etc on regular basis. Similarly, Geographic Information Systems (GIS) are the latest tools available to store, retrieve and analyse different types of data for management of natural resources. GIS facilitates systematic handling of data to generate information in a devised format. Thus, it plays an important role in evolving alternate scenarios for natural resources management. Remote Sensing (RS) data and Geographical Information System (GIS) play a rapidly increasing role in the field of hydrology and water resources development [23].

Although very few remotely sensed data can be directly applied in hydrology, such information is of great value since many hydrologically relevant data can be derived from remote sensing information. One of the greatest advantages of using RS data for hydrological modelling and monitoring is its ability to generate information in spatial and temporal domain, which is very crucial for successful model analysis, prediction and validation. However, the use of RS technology involves large amount of spatial data management and requires an efficient system to handle such data. The GIS technology provides suitable alternatives for efficient management of large and complex databases.

Image data have been used as a primary source of natural resources information in thematic mapping which in turn is utilised in various hydrological studies. The remote sensing data provides synoptic view of a fairly large area in the narrow and discrete bands of the electromagnetic spectrum at regular intervals. The space borne multispectral data enable generating timely, reliable and cost-effective information on various natural resources, namely surface water, ground water, land use/cover, soil, forest cover and environmental hazards, namely waterlogging, salinity and alkalinity, soil erosion by water etc. For many hydrological purposes, remote sensing data alone are not sufficient and need to be merged with data from other sources. Hence, multitudes of spatially related (i.e. geographic) data concerning topography, rainfall, evaporation, vegetation, geomorphology and soils have to be considered [24].

GIS for estimation of direct runoff potential: For the estimation of the amount of direct runoff that will be produced from a basin, various hydrologic models are available. Soil Conservation Services (SCS) model is most widely used for the estimation of direct runoff. All the factors of SCS model are geographic in character. Due to the geographic nature of these factors, SCS runoff model can easily be modelled into GIS. In recent years, satellite remote sensing and GIS have emerged as powerful tools for collecting the requisite information on land use and land cover of large areas [21].

Remote sensing and GIS technique is a very reliable alternative or a dependable support system to our conventional way of surveying, investigation, planning, monitoring, modelling, data storing and decision-making process. The synoptic concept of satellite image is fairly easy for identification of the broad physical features such as stream network, land use/land cover, soils surface, water bodies etc. The land use/land cover is an important parameter input of SCS model which could be determined very accurately with help of this technique. With the help of RS, GIS and SCS model it is possible to make management plans for usage and development of watershed. Although Curve number method is empirical approach to determine the runoff depth from the watershed. But it can be useful for estimating the runoff for places which do not have runoff record [21].

2.7. Drought

When we think of severe droughts, usually think of periods of extremely dry weather that persists long enough to cause problems such as crop damage and water shortages. However, the truth is that dry conditions develop for different a reason which is why there is more than one definition of drought. According to David Miskus, a drought expert and meteorologist at the National Oceanic and Atmospheric Administration's Climate Prediction Centre, a drought is caused by not only lack of precipitation and high temperature but also by overuse and overpopulation, and it can occur in virtually all climates [29].

A drought is a period of below-average precipitation in a given region; resulting in prolonged shortage in the water supply, whether atmospheric, surface water or ground water. A drought can last for months or years or may be declared after as few as 15 days. It can have a substantial impact on the ecosystem and agriculture of the affected region and harm to the local economy [28].

Sadly, droughts and their many repercussions, such as extreme famine, have been known to humankind since antiquity and still occur today, with starvation and malnutrition being some of the tragic outcomes in many parts of the world. Between July 2011 and mid-2012, a severe drought affected the entire East Africa region. Said to be "the worst in 60 years", the drought caused a severe food crisis across Somalia, Djibouti, Ethiopia and Kenya that threatened the livelihood of 9.5 million people. Many refugees from southern Somalia fled to neighbouring Kenya and Ethiopia, where crowded, unsanitary conditions together with severe malnutrition led to a large number of deaths. Other conditions together with severe malnutrition led Sudan and parts of Uganda, were also affected by a flood crisis [27].

Despite the extensive modernization of Ethiopia in the last 120 Years, about 80% of the population are peasants who still live from harvest to harvest, and are vulnerable to crop failures [25]. Droughts and floods are known to mankind from time immemorial. They are reported from time to time over different parts of the world. The historical reports of these events are mostly qualitative in nature. Information sources of Africa drouught are mainly local chromicles, archival data, historical texts and literature, traveller's dairies, European settlers' notes, folk songs and so on [26].

In Ethiopia, the National Meteorological Services Agency (NMSA) has attempted to collect and document the history of drought arid famine and their impact on various administrative regions of Ethiopia from vaious documents available nationally and internationally (NMSA 1996a, 1996b); they include some unpublished materials which are locally available in manuscript form. Analysis of the chronological events of Ethiopian droughts/famines have been classified into four parts and the analyst indicates some interesting features [26].

During the period between 253 B.C and the 1st century A.D, one drought/famine was reported every seven years. From the beginning of A.D to 1500 A.D, there were some devastating famines known as ASAH, FASSAS and HGLAH during which millions perished. During this period, 177 droughts/famines, about one in nine years, were reported in the country. Information from 1500 is based on recorded data and hence is more reliable. From the 16th century to the first half of the 20th century, 10, 14, 21, 16 and 8 droughts/ famines were reported respectivly, suggesting 69 events in a period of 450 years. This shows on an average the occurrence of one drought every seven years. The two notorious famines known as QUACHINE and KIFUQEN, which devastated more areas of the country, were reported during this period. The reports from 1950 onwards are well documented and contain interesting scientific data. The analysis of the rainfall data during this period indicates that 18 droughts/ famines were recorded in 38 years, suggesting the occurrence of drought every two years. The highest frequency of drought/ famines occurred in the 2nd century A.D. followed by the first part of the 20th century, and also an increasing trend from the 15th century onwards. The analysis shows that the decade 1970-1979 was the worst period, having seven disaster years [26].

In a gauge-based precipitation data set for 14 Ethiopian rainfal Zones during 1971-2011, 2009 was the second driest year nationally, surpassed only by the catastrophic 1984 drought. In southern Ethiopia, the data indicate that there has been a general decline in precipitation during this period [30].

The fact that the mean annual precipitation in parts of the Ethiopian highlands exceeds 2000mm (Griffiths 1972), may make the impression of Ethiopia as a dry country seem paradoxical. In the other end of the scale, arid/ semi-arid regions in the lowland receive a meager 300mm [30].

Arero and Dhas districts are the most lulnerable in Borana Zone to drought and human-made shocks such as conflicts. Violent conflicts have disrupted pastoral grazing movement patterns and community coping strategies against adversity and drought, thereby increasing their lulnerability to shocks and stresses. There were four episodes of conflict in Arero, Dhas and Moyale districts between 2000 and 2005 (Odhiambo, 2012) including two in Dhas in 2001 and in 2004. Over the past decade, various districts of Borana Zone had been affected by droughts, mainly caused by environmental variability, competition over scarce resources, cattle raids and cunter-raids (Odhiambo, 2012) [9].

2.8. Studies Made Using Similar Approach in Ethiopia

The runoff estimation was carried out for Lake Taba basin using HEC-HMS flood hydrograph package using SCS model and SWAT (Soil Water Assessment Tool) which uses Multi-layer Soil water balance Model. Comparison of runoff estimation using SCS model and Soil Water Balance for Lake Tana basin shows as the estimation by SCS has no exaggerated devation from SWAT model. The total devation of SCS form SWAT was +9% [18].

Table 2-1 Runoff comparison between SWAT and SCS

Sub-basin	Watbal (MCM)	SCS (MCM)
Gilgel Abbay	3729.43	3890.06
Gelda	401.3	474.58
Gumara	1273.26	1388.84
Ribb-shine	686.8	724.04
Arno-Garno	126.01	228.08
Gumaro	191.07	79.93
Megech	360.43	396.3
Ambagenene	232.45	252.62
West Tana	505.11	781.11
Koga	182.13	182.13
Sum	7,688.00	8,397.69

2.9. Previous Studies in the Area

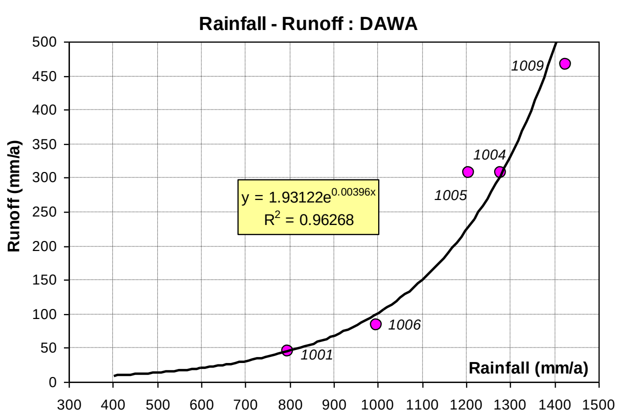

Figure 2-1: Rainfall-Runoff relation for Dawa Sub-Basin

Genal-Dawa river basin is divided in to theee sub-baseins namely Weyb, Genale and Dawa. And Dhas district is located in Dawa sub-basin. Separate analysis was found for the three sub-basins; runoff factors of about 7% were computed in the central parts of Dawa [17].

3. METHOD AND METHODOLOGY

3.1. Description of the Study Area

3.1.1. Location of Dhas district

Due to the rearrangement of districts' boundary, the current boundary of Dhas district was defined in 2017. Dhas District is geographically located between 4.00°-4.39°North latitude and 38.39°-39.46° East longitude with altitude range of 1082 – 1666m a.m.s.l.

Dhas district is surrounded by five districts namely: Wachile in the North, Guchi in the South East, Miyo in the South, Dirre districts in the South West and Dubluk district in the West.

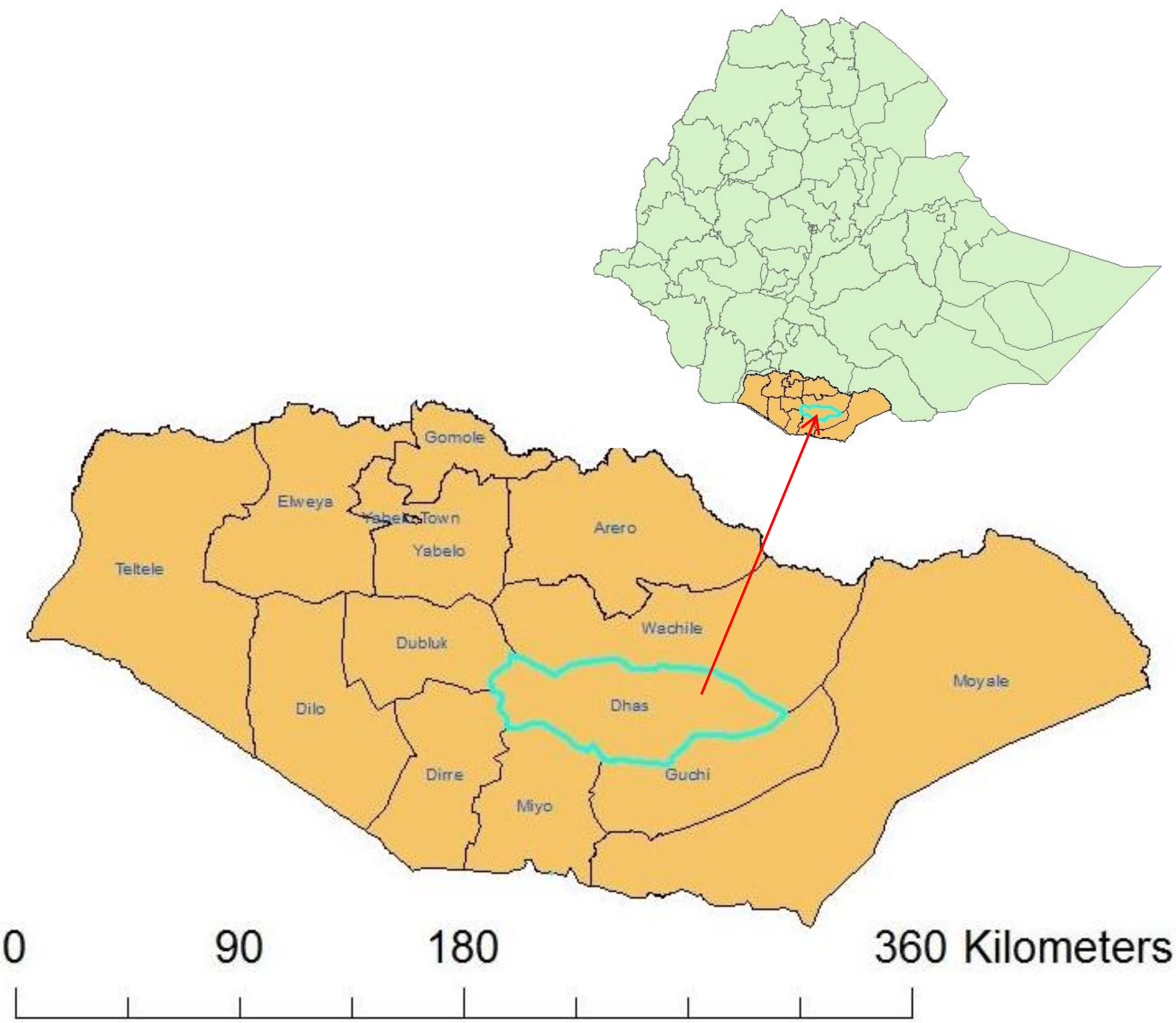

Figure 3-1: Location map of Dhas district

3.1.2. Climate

Dhas district is characterized by bimodal type rain with 55% occurring in the long rainy season “Gena” extending from mid-March to May and erratic short rain season “Haggaya” from mid-September through mid-November. The other seasons are the cool dry season “Adolessa” extending from June to August and the major dry season “Bonna” from December to February.

The mean annual rainfall as computed from the grid data collected form the National Meteorological Agency is 523mm; with the mean monthly maximum of 159mm in April. And the mean monthly maximum and mean monthly minimum temperature is 28.9C° and 16.1C° respectively.

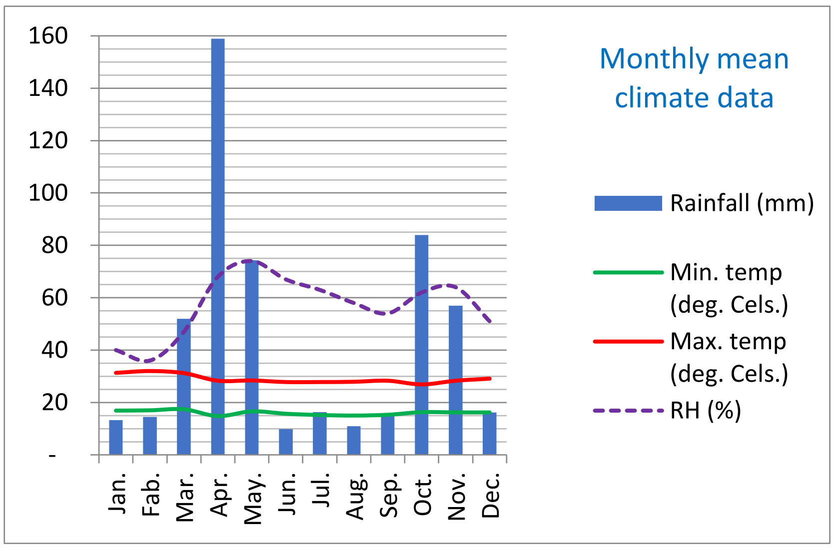

Figure 3-2: Monthly mean climate data

3.1.3. Topography

As of 2017 boundary rearrangement, and the shape file data of the district collected from Oromia Planning and Economic Development Commission, Dhas district stretches over an area of 3,183.22km². From West to East its maximum length is computed to be 120 Km and from South to North its maximum width is computed to be 41km. The altitude ranges from 1082-1666m a.m.s.l, and the topography of the district includes mountain range scattered volcanic cones, creator and gently undulating and flat plains.

The district is mainly divided into 12 sub-watersheds; nine of them draining to the North direction, one draining to the South direction and the remaining two draining to the East direction. But there is no any river in the district as well as the in the Borana Zone.

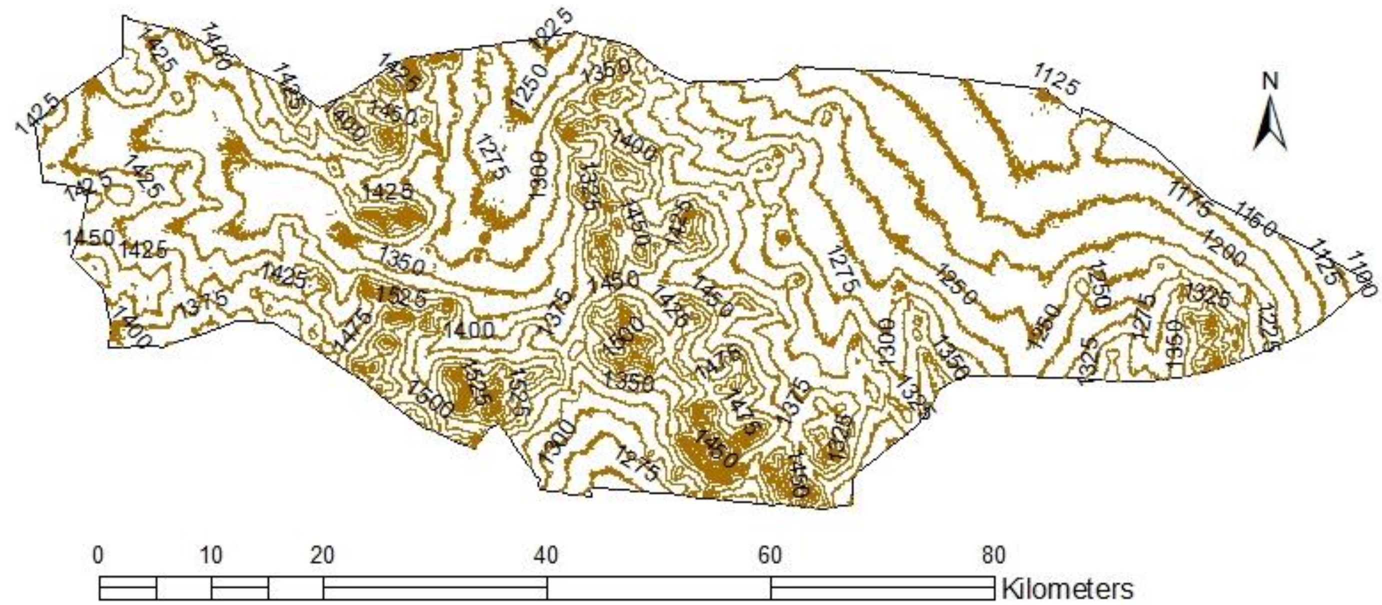

Figure 3-3: Contour map of Dhas district

3.1.4. Land use/ Land cover

Based on the satellite image from USGS (United states geological survey) website with acquisition dates of December 16, 2018 and December 23, 2018, the land use/ land cover of the Dhas district was mainly divided in to four main classes: Grass & Bush land, Forest, Bare land and Water way; each account for 71%, 16%, 5% and 8% respectively.

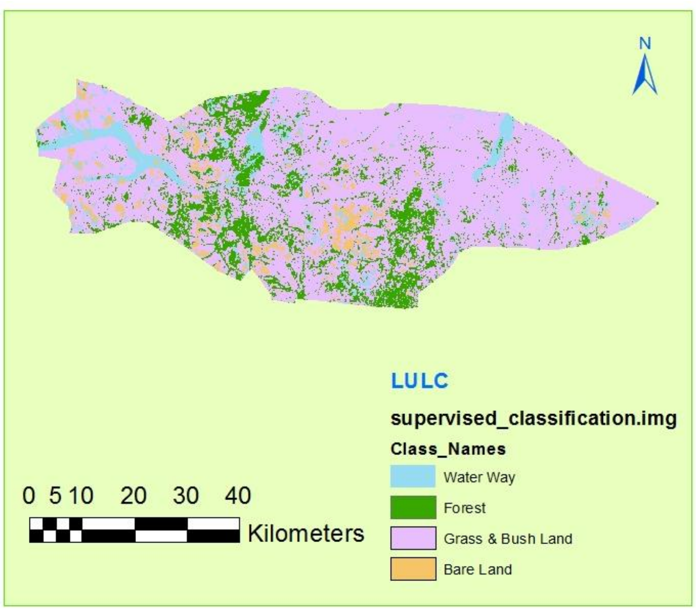

Figure 3-4: Land use/ Land cover map of Dhas district

3.1.5. Socio economy of the population

Dhas district is one of 14 woredas of the Borana zone and divided in to 12 kebele. The district characterized by pastoral livelihood system as a whole. Livestock rearing is the major livelihood of the people living in the woreda. The total human population of the woreda is 59,830 as of 2009 E.c; the average population density is about 19 people/ Km^2 [16].

Borena peoples are mainly pastoralist and their life depend on cattle product. About 96% of Borena pastoral community food either directly or indirectly obtained from livestock and livestock products. The traditional pastoral system in Borena was based on wet season grazing with cattle watering at ponds and dry season grazing close to traditional wells called Ellas. As of 2008 data, the total livestock population was estimated to be about 474,981; out of which cattle, shoat, camel and pack animal share 53%, 33%, 7% and 7% in their respective order [16].

3.1.6. Infrastructure and social facilities

Infrastructure and social facilities in Dhas district are poor; and main water sources are Ellas (traditional water wells) and ponds. Less than 7% (only those living around the district head quarter) of the district population have access to tap water. Based on the information from Borana Zone finance and economic development office, the information is tabulated below:

Table 3-1: Social Facilities as of 2008 E.c

No	Name of kebele	School				Health center human		Animal Health center		Water				
		Sate-llite	1st cycle	2nd cycle	Prepa-ratory	Health Center	Health post	Type C	Type D	Tap Water	Ella	Pond	Cistern	Roof top rainwater harvesting
1	Borbor	4	2	1	1	1	1		1	20	45	5	3	6
2	Tesokelo	4	2				1		-		-	17	2	5
3	Das	8	7	1		1	1		1		16	31	4	11
4	Gayo	2	3			1	1		1		27	41	8	6
5	Anole	4	2	1			1				-	7	1	5
6	HarJarte	1	2				1		1		-	6	4	5
7	Walensu		2				1				-	3	2	4
8	Gerbi		1				1	1			58	7	5	7
9	Meta Arba	3	3				1		1		-	10	3	6
10	Raro	1	2				1		1		-	28	1	6
11	Erder	7	5			1	1		1		6	6	1	7
12	Gorile	1	5			1	1		1		27	45	1	10
	Total	35	36	3	1	5	12	1	8	20	179	206	35	78

Source: - Dhas Woreda Finance and Economic Development office

3.1.7. Major hazards happened in Dhas district

The existence of multiple hazards is normal, inevitable part of the ecological social, economic and political environment in this woreda. Drought, conflict and human and livestock disease outbreak are identified as the main and recurrent hazards affecting their livelihood and lives; vulnerability to this hazard varies based on socio economic status, gender and age [16].

3.1.8. Vulnerability to Recurrent Droughts of Borana Zone

The lowland parts of the zone are severely affected by recurrent drought. The rainfall pattern is highly erratic in the area, sometimes above normal and sometimes far below normal in intensity (Frankenberger T. et al, 2012). The semi-arid savannah landscape of the zone is marked by gently sloping lowlands and flood plains (Lasage et al., 2010) Pastoralists in the zone face drought, pests, diseases, lack of access to improved crops and livestock varieties, and poor market access (Ibid). The Borana Zonal Administration Office emphasized that pastoralists in the zone are vulnerable to shortage of food, loss of livestock, and the need to move to less affected regions of the zone and beyond (Borana Zonal Administration, 2013) [9].

The Ministry of Agriculture (MoA) Regional Pastoral Livelihoods Resilience Project (RPLRP) has reported frequent disasters including drought, floods, and livestock diseases (MoA, 2013). A survey conducted in Borana communities in 2009 found that drought occurred in the zone every 1–2 years, compared to every 6–8 years in the past, evidence that the area is vulnerable to stresses related to climate changes (Riché et al., 2009) [9].

The rural people of Borana Zone are very vulnerable to drought. During the drought of 2000, 80% of livestock died. In 2008 a relief program had to supply water and fodder to communities (Angasse A. & Oba G., 2007). Malnutrition is widespread in the zone as a result of poor access to clean water, low agricultural production, lack of infrastructure and poverty in general (Lasage, A. et al, 2010). Climate change and environmental degradation have given rise to conflicts over declining grazing land. In the pastoralist and some agro-pastoral areas of the zone, human diseases such as malaria and animal diseases such as trypanosomiasis, pasteurolosis, blackleg and anthrax challenge the livelihoods of the communities (Borana Zonal Administration, 2013) [9].

3.2. Materials Used

Different reference materials, data and application software used during the preparation of this study document. Satellite image downloaded from Landsat-7, soil map, DEM with 30m resolution, ERDAS IMAGINE 2015 software, Arc GIS 10.3

software, Google Earth software, Global Mapper software, FAO CROPWAT 8.0 Software, Microsoft application software like Excel, Word, used to do different analysis, illustration and document preparation purpose.

Data and information from different source were also used: grid data for rainfall, temperature, relative humidity, wind speed and radiation; observed data for rainfall, and background information of the study area were used.

Physical observation of the study area, interviewing of different people, study documents from the concerned institution and from the internet were additional supportive information sources.

3.3. Data Collection

3.3.1. Satellite image

The satellite images were downloaded from USGS Landsat 7 with acquisition dates of December 16, 2018 and December 23, 2018 with the path/row of 167/57 and 168/57 respectively. This study was done using Land sat imageries of nine bands to identify LULC in December 2018. The image data files were downloaded in zipped files from the https://www.usgs.gov, United State Geological Survey (USGS) website, and extracted to Tiff format files. Coordinates of the image with path/row of 167/57 is (5.2201, 39.1778); (4.9803, 40.8291); (3.4589, 40.5033); (3.6983, 38.8552), and with path/row of 168/57 is (5.2201, 37.6327); (4.9803, 39.2840); (3.4589, 38.9583); (3.6983, 37.3102).

3.3.2. Meteorology data

a. Rainfall data

The thirty years, from 1987 to 2016, Satellite/ grid daily rainfall data in the form of text was collected from National Meteorology Agency. The rainfall grid interval is 0.0375 degree by 0.0375 degree or with a resolution of ~ 4.1km. Moreover, observed daily rainfall data was collected from the National Meteorology Agency to validate the grid rainfall data. The observed data was available only for two nearby stations namely Chewbet with coordinate of 4.18°N, 38.38°E and Mega with coordinate of 4.07°N, 38.32°E. The data available for Chewbet station is for 30 years (from 1989 to 2018), and for Mega station is for 31 years (from 1988 to 2018). A very nearby class-3 station named Dembel with coordinate of 4.17oN, 39.4oN was indicated on the website of NMA, but practically no information could be found at the NMA regarding that station.

b. Temperature

The 30 years (1987-2016) grid monthly temperature data with 0.0375x0.0375-degree grid interval was collected from NMA. And daily minimum and daily maximum observed data was found only for Mega station.

c. Other climate data

And other climate data (daily data for 29 years; 1987-2015) like relative humidity, wind speed and radiation were downloaded from NASA website with grid interval of 0.5x0.5 degree (https://power.larc.nasa.gov/data-access-viewer/).

3.3.3. Topography and soil data

The shape file for Borana Zone with all of its districts was collected from Oromia Planning and Economic Development Commission in softcopy. The map datum was in WGS84 and with projection coordinate system.

The area of interest, Dhas district, is geographically ranging between 4.00°-4.39°N, and 38.39°-39.46°E hence, the 30m resolution DEM (4°N, 38°E and 4°N, 39° E) files were downloaded from USGS website, and the two DEM files were stitched together with the aid of ArcGIS mosaic tool. The source for raster soil data for the whole country with the hydrologic soil group table was FAO.

3.3.4. District profile and socio economy data

Physical and socio-economic profile for Borana Zone and Dhas district as of May 2009 E.c was collected from Borana Zone Planning and Economic Development Office in softcopy. Human and Animal population data and livelihood system information was part of the document.

3.4. Methods Used

3.4.1. Estimation of surface water potential

The whole analysis of the study was made using the Dhas district boundary as a control volume; only the runoff generated within the district considered and expected demand estimation was also done considering only human and livestock population within the district.

Estimation of Surface Runoff was computed Using SCS Model with the aid of Remote Sensing and Geographical Information System. The latest possible Land use/Land cover map of the whole district was developed with the aid of ERDAS Imagine 2015 using satellite image through cross checking of ground truth (illustrated under section 3.5.1).

The district was divided in to twelve sub-watersheds by making the outlet point of the sub-watersheds at the boarder of the district. And shape file was created for all the twelve sub-watershed areas using global mapper software (shown under section 3.5.2).

Using the developed Land use/Land cover map, Digital Elevation Model (DEM) and soil map of the district, curve number map for normal condition (CN II) was generated for the whole district in the GIS environment. A sub-watershed might comprise several types of curve number; a weighted curve number was computed for each sub-watershed independently (as illustrated under section 3.5.2.d).

Because of the rainfall depth varying considerably across the district, daily areal rainfall depth was computed for each sub-watershed throughout 30 years period.

Based on a five-day antecedent rainfall amount and season category (because of the study area located in semi-arid zone, and also having erratic nature of rainfall, dormant category was considered for the whole analysis) curve number for AMC-I and AMC-III, dry condition and wet condition, respectively were derived from AMC-II CN.

Using the SCS model:

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

$$S = \frac{25{,}400}{CN} - 254$$

<u>Where:</u>

Q = Runoff depth (mm).

S = Maximum recharge capacity.

CN = Curve Number.

P = Rainfall depth (mm).

For the rainfall depth less than or equal to the initial abstraction (I=0.2S), no any runoff would be generated.

The procedure followed for computing of the direct runoff has been illustrated by the flow chart in the next page.

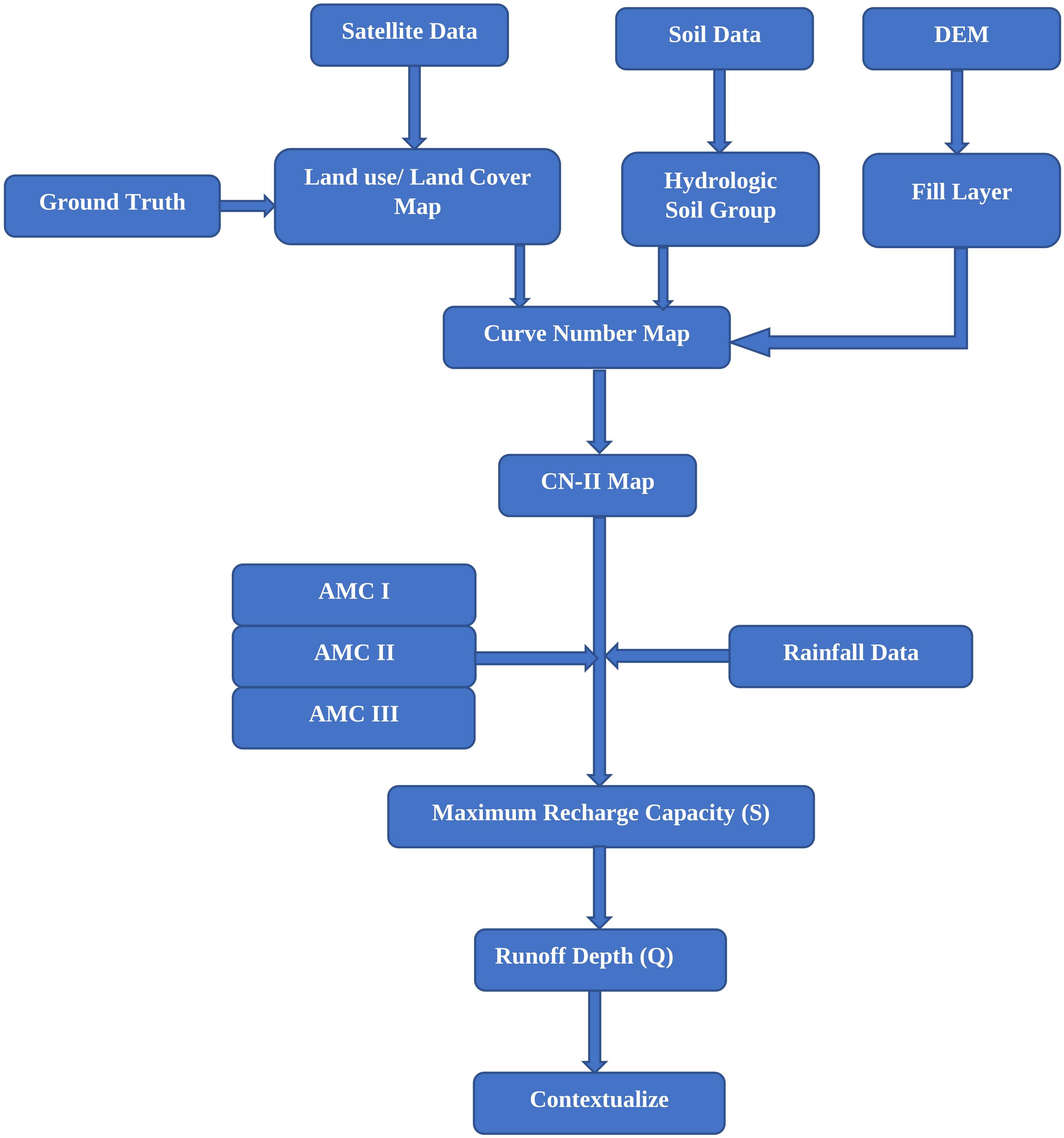

Figure 3-5: Flow chart for estimation of Runoff Depth

3.4.2. Estimation of water demand for managing of drought disaster

Livelihood system for majority of the Dhas district is relying on pastoralism. So, for managing frequent drought disaster, analysis on access to water and animal feed was done. To do the estimates, twenty years of forecast period was used since 2019.

The water demand for domestic consumption was made based on the past and existing water demand trend for rural community, which has been set by the Ministry of Water, Irrigation and Energy. As Alfalfa is widely grown throughout the world as forage for cattle and grown in irrigation, it was considered for estimation of irrigation water requirement.

3.5. Data Preparation and Analysis

3.5.1. Preparation of Land use Land cover (LULC) Map

a. Image pre-processing

The data acquired from the satellite still needs to be interpreted (or analysed) to extract the required information. But to extract the required information, the downloaded images were processed for different corrections and adjustments. As any image involves radiometric errors as well as geometric errors, these errors should be corrected. Radiometric correction is to avoid radiometric errors or distortions, while geometric correction is to remove geometric distortion.

i. Layer Stacking

Stack multiple (usually single band) images as bands/layers into a single output multi-band image file. The downloaded images were in .tiff file format and the stacked layer was saved to an .img file. In order to analyse remotely sensed images, the different images representing different bands must be stacked. This allows different combinations of RGB to be shown in the view. A layer stack is often used to combine separate image bands into a single multispectral image file. Layer stacking is also commonly used to combine image derivatives with spectral bands for further analysis.

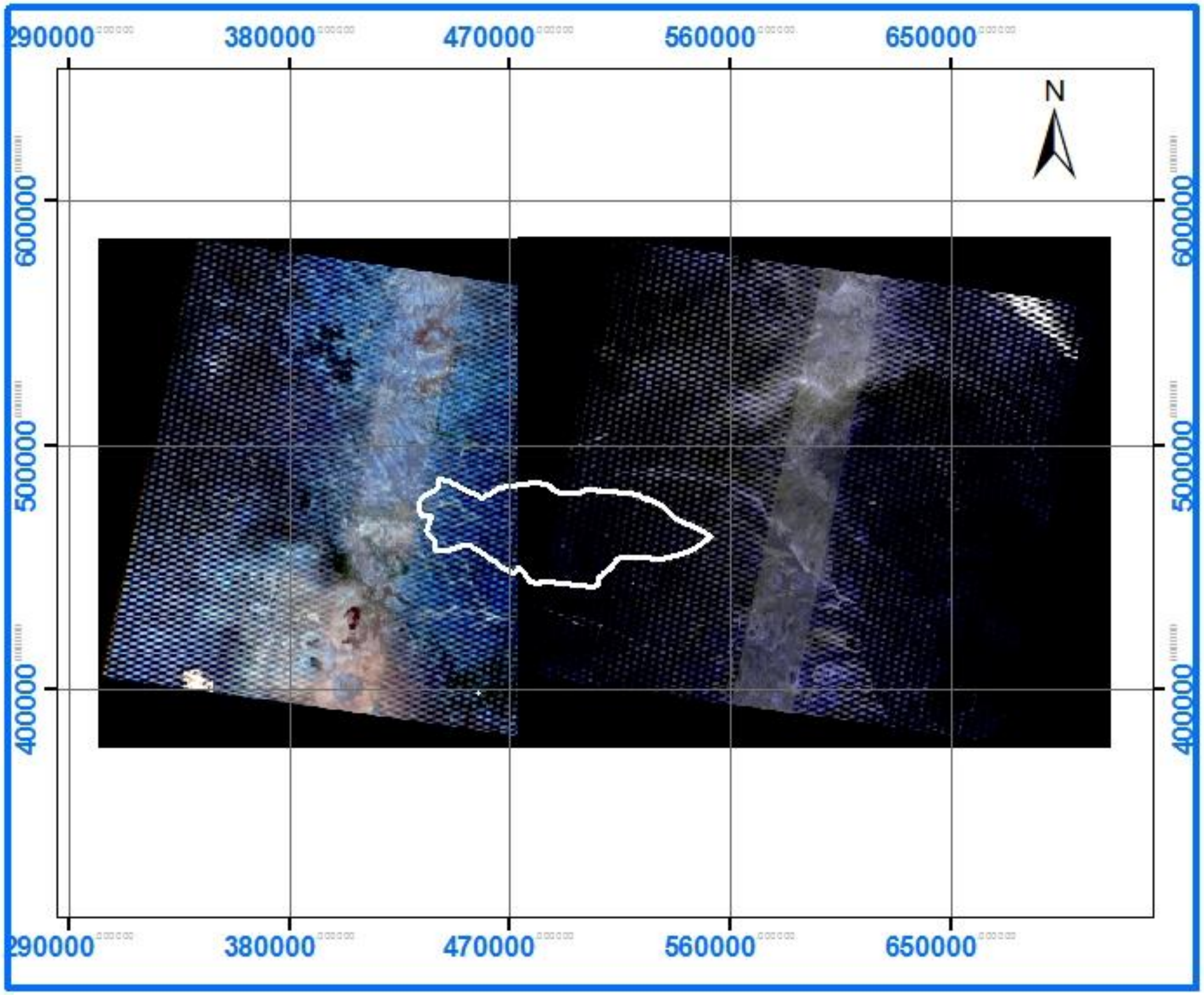

Figure 3-6: Stacked Layer

i. Gap filling

The Landsat 7 satellite was launched in April 1999 with an aim of providing timely and high quality visible and infrared images of the Earth's surface. Unfortunately, the Scan Line Corrector (SLC; an electromechanical device that compensates for the forward motion of the satellite) on Landsat 7's Enhanced Thematic Mapper Plus (ETM+) instrument, failed on 31 May 2003. Consequently, the once spatially continuous fields observed from the sensor were affected by a line-of-sight zig-zag pattern, resulting in large gaps and around 22% of pixels missing in collected data.

Failure of SLC imposed systematic data gaps on retrieved imagery and removed the capacity to provide spatially continuous fields. While a number of methods have been developed to fill these gaps, most of the proposed techniques are only applicable over relatively homogeneous areas. This method is designed to modify neighbouring pixels in a single Landsat 7 SLC-off scene, creating a final aesthetic image. For this study, the gap filling was done using "Focal Analysis"-mean method under special tools of ERDAS IMAGINE 2015 software.

iii. Mosaic images

Since the study area touches two images. i.e. path/rows 167/57 and 168/57, combining those two images to single (tied) colour balanced and compressed ortho-mosaic imagery was done. Satellite imagery that are orthorectified and have an overlapping area can be stitched together to create a seamless mosaic. So, after passing the layer stacking, the two images have been stitched together using ERDAS IMAGINE Software.

iv. Radiometric corrections

When the emitted or reflected electro-magnetic energy is observed by a sensor on board an aircraft or spacecraft, the observed energy does not coincide with the energy emitted or reflected from the same object observed from a short distance. This is due to the sun's azimuth and elevation, atmospheric conditions such as fog or aerosols, sensor's response etc. which influence the observed energy. Therefore, in order to obtain the real irradiance or reflectance, those radiometric distortions must be corrected.

Brightness inversion

Reverse both linear and nonlinear intensity range of an image, producing images that have the opposite contrast of the original image. Dark detail becomes light and light detail becomes dark. So, Brightness inversion was done for the stacked-Mosaicked image with the aid of ERDAS Imagine software.

Histogram equalization

Apply a nonlinear contrast stretch that redistributes pixel values so that there is approximately the same number of pixels with each value within a range. So, Histogram equalization was done for the stacked image that passed under process of Brightness inversion using ERDAS Imagine.

v. Geometric corrections (Georeferencing)

Geometric correction is undertaken to avoid geometric distortions i.e., internal and external distortions from a distorted image, and is achieved by establishing the relationship between the image coordinate system and the geographic coordinate system using calibration data of the sensor, measured data of position and ground control points, atmospheric condition etc. Geometric correction is putting of pixels in their proper map locations. So, geometric correction was checked for processed Landsat 7 image, but no distortion was identified to be corrected; hence, the processed image was adopted as it is regarding the geometric correction.

vi. Sub setting an image

Sub setting allows the amount of date we are working with to be minimized by specifying a particular geographic area (area of interest). So, sub setting is the process of "cropping" or cutting out a portion of an image for further processing. So, sub setting for AoI/ Dhas district was done using Multispectral-Control Points (Keyboard only) tool in ERDAS IMAGINE 2015.

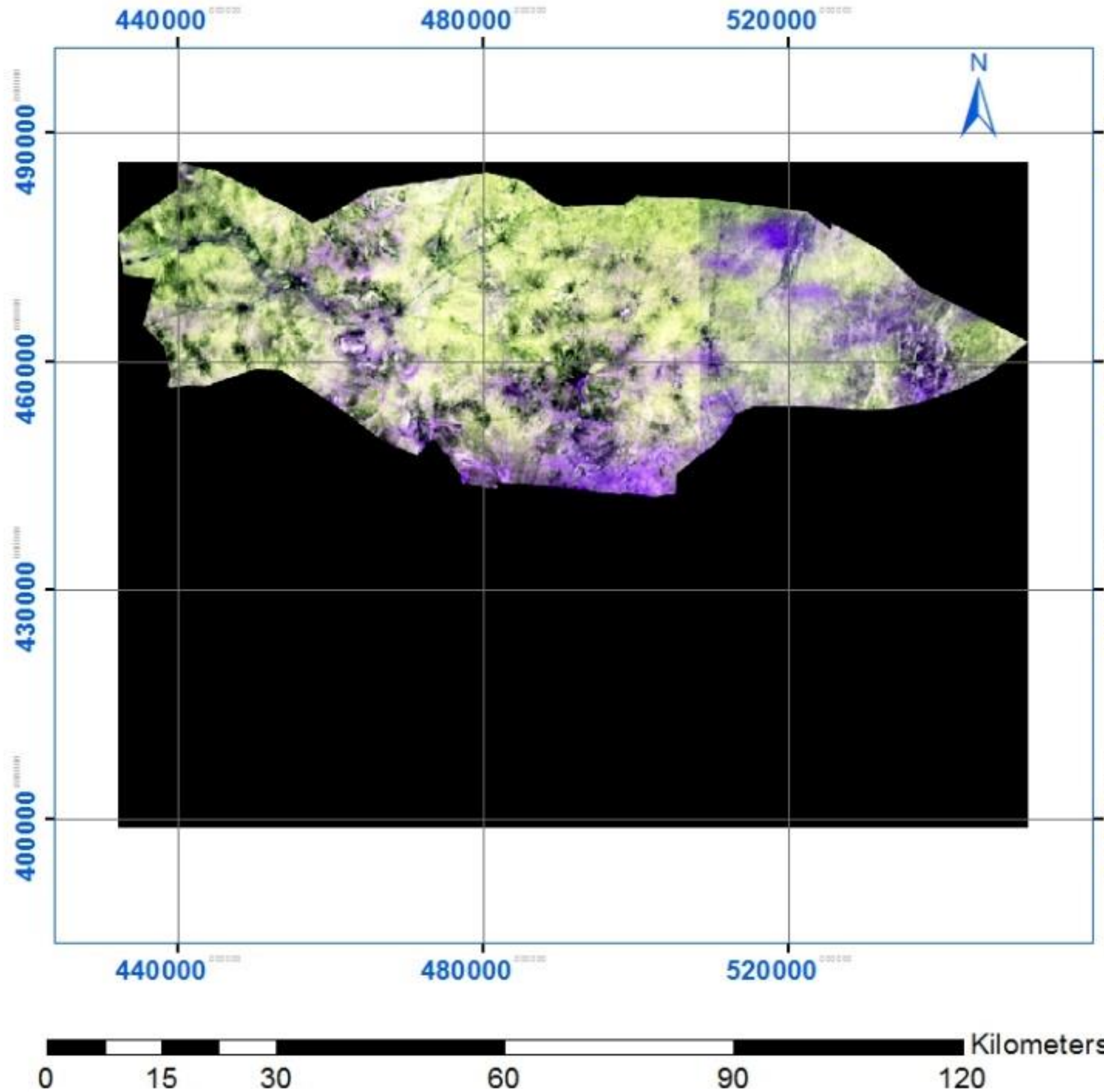

Figure 3-7: Image Sub setting for Dhas district

a. Image Classification

The possibilities for the classification of land cover types depend on the date an image was acquired. This not only holds for crops, which have a certain growing cycle, but also for other applications. Usually, classification is performed with a set of target classes in mind. Such a set is called a classification scheme (or classification system). The purpose of such a scheme is to provide a framework for organizing and categorizing the information that can be extracted from the data. The proper classification scheme includes classes that are both important to the study and discernible from the data on hand. Most schemes have a hierarchical structure, which can describe a study area in several levels of detail.

A number of classification schemes have been developed by specialists who have inventoried a geographic region. For this study unsupervised, supervised and a hybrid of these two classifications were used.

i. Supervised Versus Unsupervised classification

In supervised classification, it is important to have a set of desired classes in mind and then create the appropriate signatures form the data. Someone must also have some way of recognizing pixels that represent the classes that he wants to extract.

Supervised classification is usually appropriate when someone want to identify relatively few classes, when he has selected classification sites that can be verified with ground truth data, or when you can identify distinct, homogeneous regions that represent each class.

On the other hand, if someone wants the classes to be determined by spectral distinctions that are inherent in the data so that he can define the classes later, then the application is better suited to unsupervised classification. Unsupervised classification enables someone to define many classes easily, and identify classes that are not contiguous easily recognized regions.

Supervised classification also includes using a set of classes that is generated from an unsupervised classification. Using a combination of supervised and unsupervised classification may yield optimum results, especially with large data set. For instance, unsupervised classification may be useful for generating a basic set of classes, and then supervised classification can be used for further definition of the classes.

Image classification was done using ERDAS IMAGINE software; initially unsupervised classification was made by classifying the image in to 6 classes. ERDAS IMAGINE uses the ISODATA algorithm to perform an unsupervised classification. ISODATA stands for Iterative Self-Organizing Data Analysis Technique. It is iterative in that it repeatedly performs an entire classification (outputting a thematic raster layer) and recalculates statistics. Self-Organizing refers to the way in which it locates the clusters that are inherent in the data.

Based on the defined unsupervised six classes, corresponding land use land cover was referred/ supervised from Google earth to assign the categories with the aid of ERDAS software. Supervised Classification provides tools for categorizing pixels using interactive supervised techniques. Someone provide examples of what particular classes look like, which are then used by the software algorithms to derive rules for mapping all other pixels into the class values. For this analysis; as it was observed by the unsupervised classification, the land use land cover (LULC) of the Dhas district could be categorized in to four main classes. Accordingly, supervised classification was done by categorising the whole area of the district into four classes. As the result, the land use land cover (LULC) of the study area is as shown below.

ii. Accuracy Assessment

After doing the classification, evaluation of a classified image file (thematic raster layer) was done using Accuracy Assessment tool in ERDAS IMAGINE. And the evaluation was done by class values of randomly selected five points. As the accuracy report and cell report show, the classification was done correctly.

3.5.2. Defining of Watersheds

a. Generation of micro-watersheds

In Global mapper; the micro-watersheds, showing drainage pattern of streams were generated from the stitched DEM. For this study, the stream threshold, number of cells, used is 5000; which is equal to (30*30*5000= 4,500,000 m^2). Stream threshold specifies how much ground area or how many cells the flow must accumulate from for a cell to be considered part of a stream.

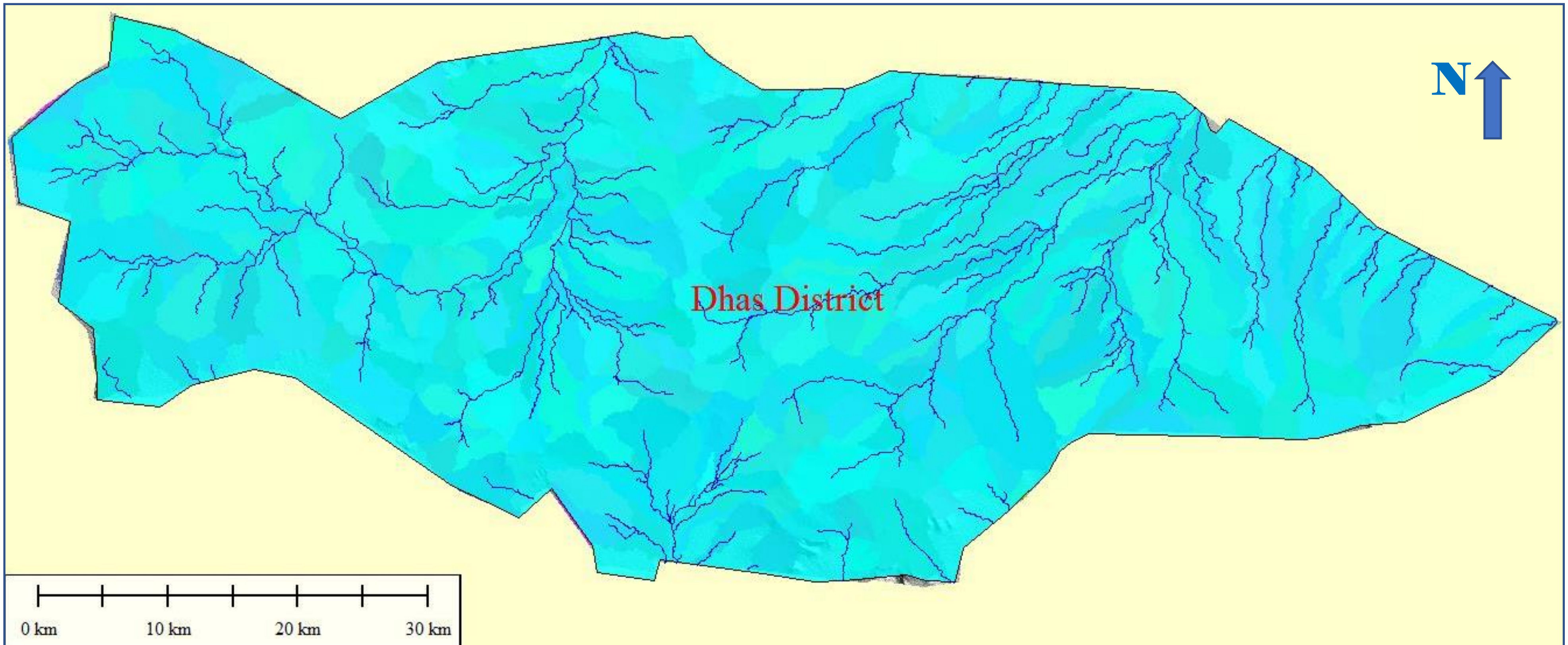

Figure 3-8: Drainage pattern of Dhas district

b. Delineation of sub-watersheds

Using digitizer tool in Global Mapper, sub-watersheds were delineated based on the drainage network developed by the Global Mapper during the generation of micro-watersheds. In total, 12 sub-watersheds each having an outlet at the boarder of the district were delineated.

Of course, there are some areas (estimated to be about 292.7 Km^2 in total or 9.2% of the total area) that have not been part of the 12 sub-watersheds, and not considered in the analysis; these are at the margin of the district and not contributing to the delineated sub-watersheds. Shape file for all the twelve sub-watersheds was also generated with the aid of Global Mapper software.

Except three sub-watersheds, SW-3, SW-10 and SW-12 almost all sub-watersheds are draining to the North and North East direction of the district. SW-3 drains to the south; SW-10 and SW-12 drain to the East direction of the district.

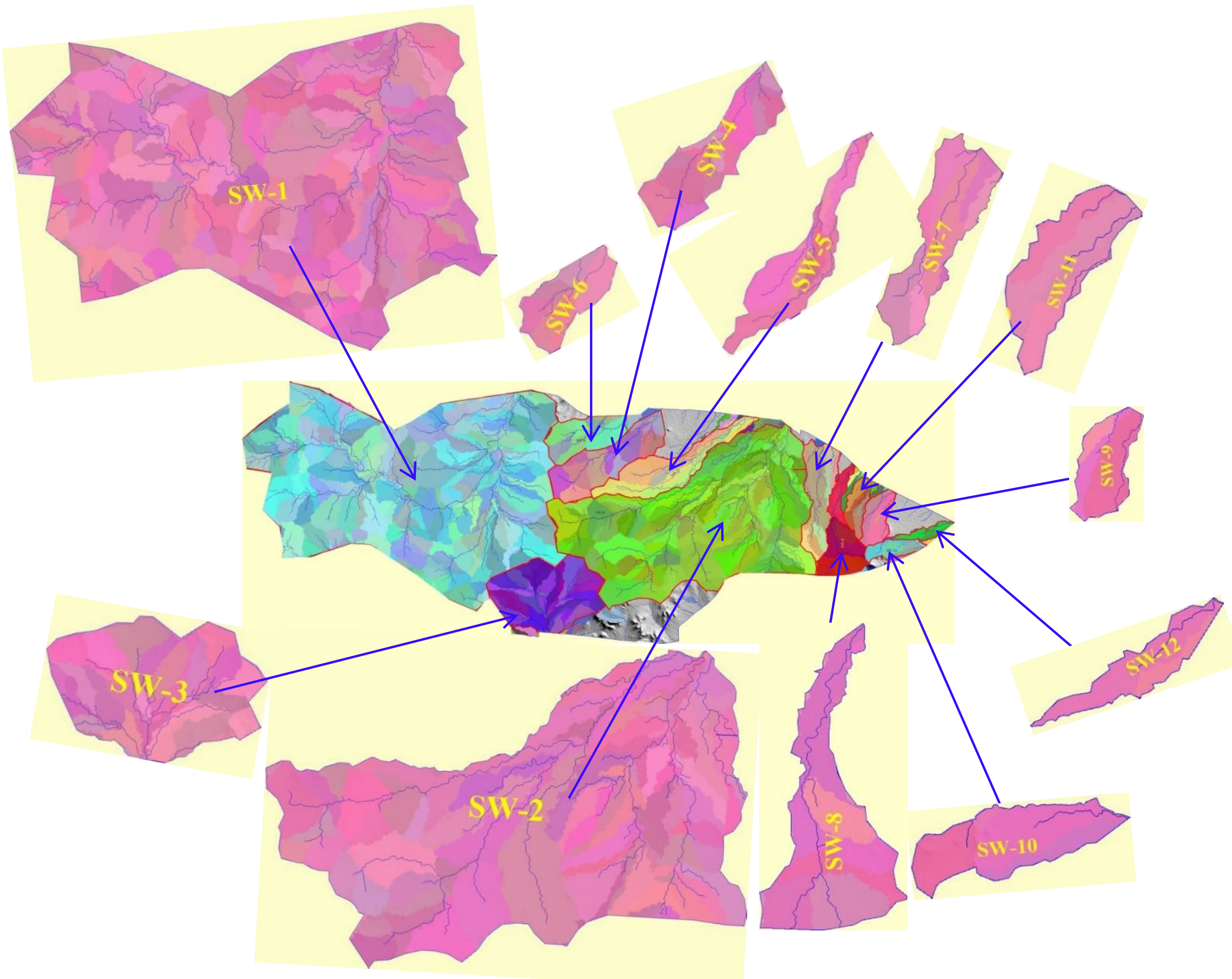

Figure 3-9: Sub-Watersheds

3.5.2. Curve number Generation

a. Preparation of soil data

Land-soil data is one of the most important input data to generate curve number (CN). There are five types of soils in the study area; namely Eurtic Fluvisols, Eutric Cambisols, Chromic Cambisols, Eutric Leptosols and Lithic Leptosols. All soil types were considered for the analysis.

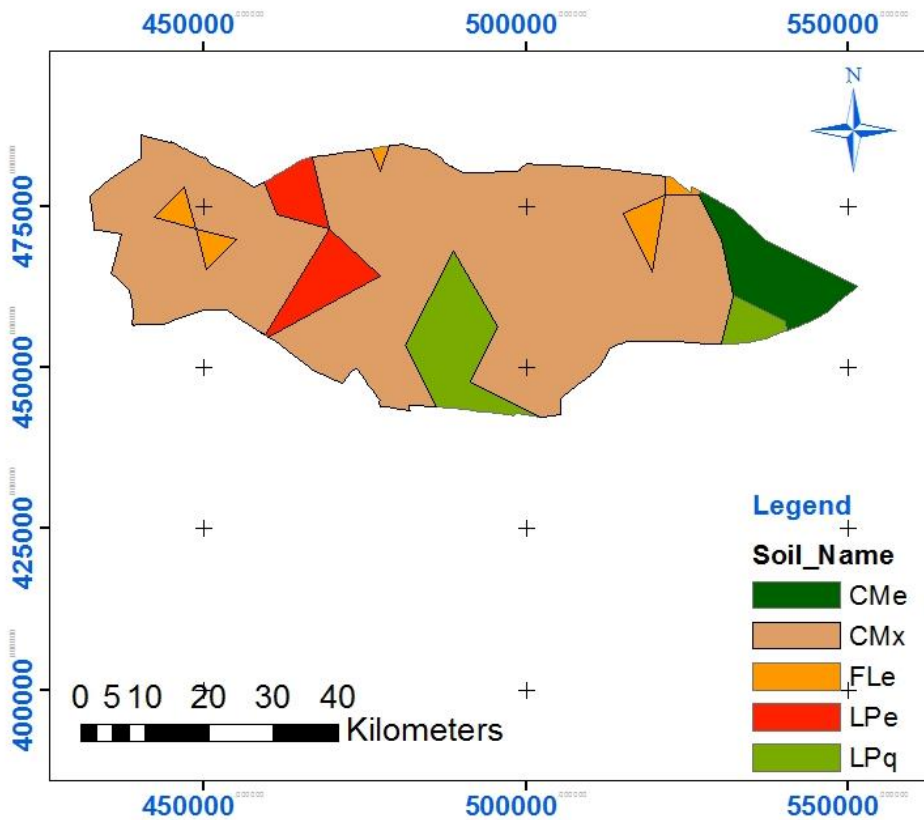

Figure 3-10: Soil map of Dhas district (Source FAO)

As per National Engineering Handbook, hydrologic soil group is determined by the water transmitting soil layer with the lowest saturated hydraulic conductivity and depth to any layer that is more or less water impermeable (such as a fragipan or duripan) or depth to a water table (if present). Accordingly, soils are classified in four hydrologic soil groups A, B, C and D:

Group A: Soils in this group have low runoff potential when thoroughly wet. Water is transmitted freely through the soil. Group A soils typically have less than 10 percent clay and more than 90 percent sand or gravel and have gravel or sand textures. Some soils having loamy sand, sandy loam, loam or silt loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group B: Soils in this group have moderately low runoff potential when thoroughly wet. Water transmission through the soil is unimpeded. Group B soils typically have between 10 percent and 20 percent clay and 50 percent to 90 percent sand and have loamy sand or sandy loam textures. Some soils having loam, silt loam, silt, or sandy clay loam textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group C: Soils in this group have moderately high runoff potential when thoroughly wet. Water transmission through the soil is somewhat restricted. Group C soils typically have between 20 percent and 40 percent clay and less than 50 percent sand and have loam, silt loam, sandy clay loam, clay loam, and silty clay loam textures. Some soils having clay, silty clay, or sandy clay textures may be placed in this group if they are well aggregated, of low bulk density, or contain greater than 35 percent rock fragments.

Group D—Soils in this group have high runoff potential when thoroughly wet. Water movement through the soil is restricted or very restricted. Group D soils typically have greater than 40 percent clay, less than 50 percent sand, and have clayey textures. In some areas, they also have high shrink-swell potential. All soils with a depth to a water impermeable layer less than 50 centimetres.

Table 3-2: Soil description of the study area

Soil Type	Full Name	Hydrologic Soil Group	Soil Description
FLe	Eurtic Fluvisols	C	moderately to poorly drained soils with moderately fine to fine textures (slow infiltration rates)
CMe	Eutric Cambisols	C	moderately to poorly drained soils with moderately fine to fine textures (slow infiltration rates)
CMx	Chromic Cambisols	D	poorly drained soils with very fine texture (very slow infiltration rates)
LPe	Eutric Leptosols	C	moderately to poorly drained soils with moderately fine to fine textures (slow infiltration rates)
LPq	Lithic Leptosols	C	moderately to poorly drained soils with moderately fine to fine textures (slow infiltration rates)

For each sub-watershed, the soil map was digitised using Editor Tool of the ArcGIS; the feature was created for all soil types corresponding to each sub-watershed. After preparing the soil, union/ merging of soil layer with LULC was done in ArcGIS. Union computes a geometric union of the input features (LULC and Soil), and all features and their attributes have been written to the output feature class.

b. Lookup table

HEC-GeoHMS compatible to ArcGIS10.3 was installed to be integrated with the ArcGIS 10.3. HEC-GeoHMS is a set of ArcGIS tools specifically designed to process geospatial data. HEC-GeoHMS looks curve numbers from the lookup table; a lookup table that relates land use and hydrologic soil groups to a curve number.

Table 3-3: Curve number for classified land covers

ObjectID	LUValue	Description	A	B	C	D
1	1	Water Way	77	86	91	94
2	2	Forest	36	60	73	79
3	3	Grass & Bush land	45	57	68	74
4	4	Bare land	77	86	91	94

Source: US EPA Archive Document

c. Fill layer

To generate the curve number in GIS, the Hec-GeoHMS tool integrated in GIS look for Fill layer. The depression less DEM is created by filling the depressions or pits by increasing the elevation of the pit cells to the level of the surrounding terrain. The pits are often considered as errors in the DEM due to re-sampling and interpolating the grid. For example, in a group of three-by-three cells, if the centre cell has the lowest elevation compared to its eight neighbouring cells, then the centre cell's elevation will be increased equalling the next lowest cell. Filling the depressions allows water to flow across the landscape.

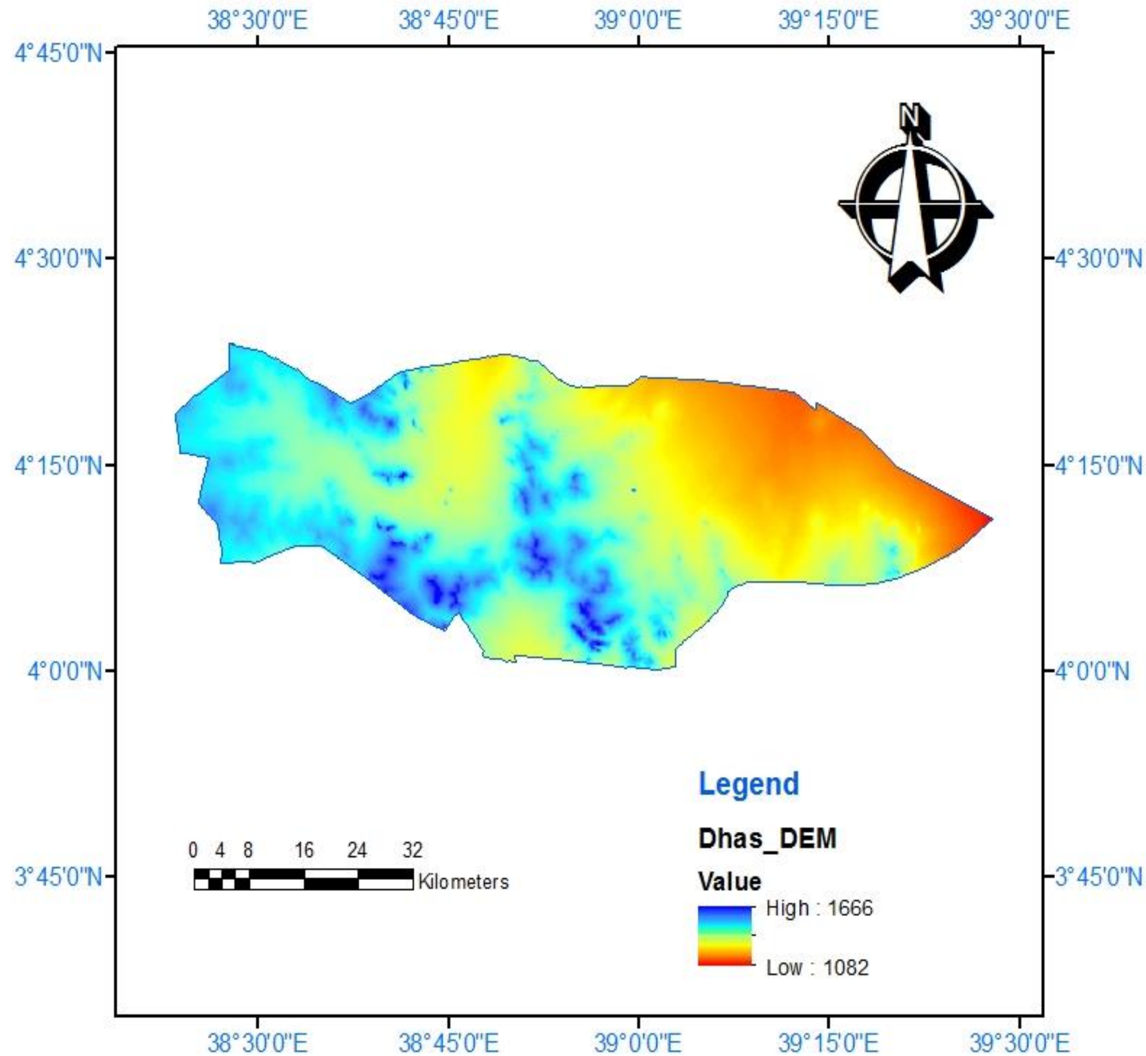

Figure 3-11: Digital Elevation Model (EDM) for Dhas district

Using the merged LULC-Soil layer, Lookup table and fill layer, the appropriate curve number value (CN) was generated in Hec-GeoHMS tool, which was integrated with the ArcGIS 10.3.

d. Weighted curve number for sub-watersheds

Using the developed shape file for each sub-watershed, curve number was also clipped from the district CN for each sub-watershed accordingly. And the area under the curve numbers were computed by using cell count; the area covered by one cell was considered to be (30m x 30m = 900m^2).

And weighted average curve number for each sub-watershed was also computed as follows:

$CN = (\Sigma (CNi \times Ai))/A$

Where:

CN = weighted average curve number.

CNi = curve number from i=1 to any i= N

Ai = area with curve number CNi

A = total area of the sub-watershed.

Table 3-4: Weighted average curve number for sub-watersheds

Name of Sub-Watershed	Perimeter (Km)	Area (Km^2)	CN
SW-1	176.67	1,346.40	78
SW-2	147.73	797.48	76
SW-3	56.11	183.65	75
SW-4	58.33	121.22	75
SW-5	70.75	109.27	75
SW-6	39.13	73.76	75
SW-7	53.62	83.14	74
SW-8	53.66	72.17	71
SW-9	28.14	36.13	73

Name of Sub-Watershed	Perimeter (Km)	Area (Km^2)	CN
SW-10	26.01	24.45	73
SW-11	27.10	28.60	70
SW-12	25.12	14.25	69

These computed weighted average curve numbers are the curve numbers under normal condition (CN II). The appropriate moisture group is based on a five-day antecedent rainfall amount and season category (dormant and growing seasons).

3.5.3. Analysis for rainfall data

Rainfall is a critical input for hydrologic models that predict the makeup of the hydrologic state over land. Because rainfall is intermittent, accurate modelling of the dynamic surface hydrologic state requires accurate rainfall data at the highest possible resolution. The global importance of satellite-derived rainfall has led to the development and accuracy assessment of an increasing number of satellite-based rainfall products to meet the needs of various users.

a. Satellite rainfall data

The collected rainfall grid data for consecutive 30 years, from 1987 to 2016 is full, doesn't have any missing value. Hence, the available 30 years annual rainfall data was tested for outliers' threshold.

$$Y_H = \bar{Y} + K_n S_y$$

$$Y_L = \bar{Y} - K_n S_y$$

Where: Y_H = *high outliers threshold in log units*

Y_L = *low outliers threshold in log units*

$\bar{y}$ = *mean of log transfer values*

Sy = Standard deviation (sample)

Kn= 2.563 for n=30 from table

$$Skewness\ coefficient(Cs) = \frac{n\sum_{i=1}^{n}(yi - y)^3}{(n-1)(n-2){s_y}^3} = 0.16$$

The skew coefficient is between ±0.4 hence, tests for both high and low outliers would be applied before eliminating any outliers from the data set.

$Y_H = 2.7 + 2.563 * 0.087 = 2.92$

X = $10^{2.93}$ = 832mm, which is greater than 777.8 mm. So, it is Ok.

$Y_L = 2.7 - 2.563 * 0.087 = 2.48$

X = $10^{2.48}$ = 302mm, which is less than 342 mm. So, it is Ok.

b. Observed data

Observed data was available for two nearby stations. Before using the available data for any analysis, data completeness and outliers' threshold test was done. Even if many years of stations' data are collected from the NME, more or less complete rainfall data is available for the period of 1990 to 2011. After preparation of the available rainfall data, consistency check was carried out. Accordingly, the rainfall depth of 84.8mm for the year of 1992 eliminated from Chewbet station because of its being below the low threshold, and the rainfall depth of 1528.9mm for the year of 2010 eliminated from Mega station due to its being beyond the high threshold. To keep continuity of the data, arithmetic mean was used to replace the eliminated values.

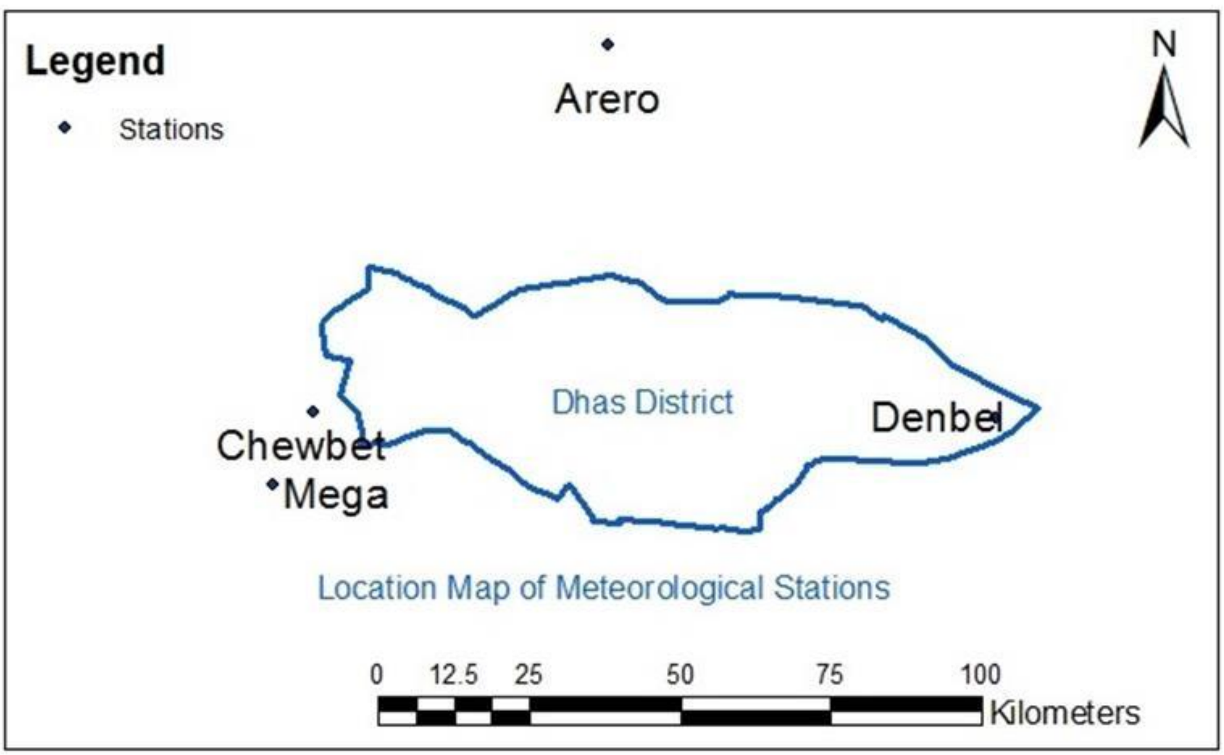

Figure 3-12: Location map of nearby meteorological stations; as of NMA web site

c. Observed versus Satellite rainfall data

In order to check how the satellite rainfall data matches with the ground data, different statistical techniques are used; for this study three techniques (Pearson correlation coefficient, Nash-Sutcliffe efficiency coefficient and Bias) are used.

<u>Pearson correlation coefficient (r)</u>

This test is used to measure the strength of a linear association between the grid/ satellite data and ground station/observed data, where the value r = 1 means a perfect positive correlation and the value r = -1 means a perfect negative correlation. Accordingly, the correlation for monthly mean for the ground/ observed and for the satellite was tested and it was found to be 1. Hence, for the study area the station rainfall data and grid rainfall data have a perfect positive correlation.

$$r = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2}\sqrt{\sum(Y-\bar{Y})^2}}$$

$$Where: X = observed\ monthly\ mean\ data\ and\ \bar{X} = mean\ of\ observed\ monthly\ mean\ data$$

$$Y = satellie\ monthly\ mean\ data\ data\ \bar{Y} = mean\ of\ satellie\ monthly\ mean\ data$$

Table 3-5: Mega-Monthly mean rainfall data

Month	Station Data (mm)	Satellite Data (mm)
Jan	18.73	14.56
Feb	36.58	30.44
Mar	74.31	64.06
Apr	119.34	103.69
May	57.21	47.81
June	20.44	15.63
July	16.13	12.50
Aug	6.56	4.81
Sep	11.70	9.00

Table 3-6: Chewbet-Monthly mean rainfall data

Month	Station Data (mm)	Satellite Data (mm)
Jan	20.11	17.65
Feb	7.93	6.85
Mar	63.94	56.45
Apr	101.84	90.15
May	38.16	33.45
June	3.66	3.10
July	0.79	0.65
Aug	2.67	2.35
Sep	3.39	2.90

Month	Station Data (mm)	Satellite Data (mm)
Oct	83.97	71.44
Nov	57.43	45.31
Dec	38.10	29.44

Month	Station Data (mm)	Satellite Data (mm)
Oct	76.44	67.95
Nov	53.30	45.90
Dec	15.13	13.25

Bias correction for Satellite data

As it is shown, the observed and satellite data have a perfect positive correlation for Pearson correlation coefficient hence, the linear scaling (LS) bias correction method was used for this study so as the monthly mean of corrected values perfectly much with that of the observed ones. It operates with monthly correction values based on the difference between observed and satellite data. The change factor for precipitation is a multiplier that is computed from the ratio of the monthly mean of the observed to the satellite dataset.

$$P_{d,cor} = P_{d,sat} * \left(\frac{\mu(P_{m,obs})}{\mu(P_{m,sat})}\right)$$

Where:

$P_{d,cor} = Corrected\ daily\ precipitation$

$P_{d,sat} = Daily\ precipitation\ from\ satellite$

$\mu(P_{m,obs}) = long - term\ mean\ monthly\ rainfall\ of\ observed\ data$

$\mu(P_{m,sat}) = long - term\ mean\ monthly\ rainfall\ of\ satellite\ data$

Nash–Sutcliffe efficiency coefficient (NSE)

The Nash–Sutcliffe model efficiency coefficient (NSE) is used to assess the predictive power of hydrological models. Nash–Sutcliffe efficiency can range from −∞ to 1. An efficiency of 1 (NSE = 1) corresponds to a perfect match of modelled to the observed data. An efficiency of 0 (NSE = 0) indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (NSE < 0) occurs when the observed mean is a better predictor than the model or, in other words, when the residual variance (described by the numerator in the expression above), is larger than the data variance (described by the denominator). Essentially, the closer the model efficiency is to 1, the more accurate the model is. Threshold values to indicate a model of sufficient quality have been suggested between 0.5 < NSE < 0.65.

$$F = \sum_{i=1}^{n}\left(P_{obs,i} - P_{cor,i}\right)^2 \qquad\qquad F_0 = \sum_{i=1}^{n}\left(P_{obs,i} - \bar{P}_{obs}\right)^2$$

$$Where: P_{obs,i} = Observed\ monthly\ mean\ rainfall$$

$$P_{cor,i} = Corrected\ monthly\ mean\ rainfall$$

$$\bar{P}_{obs} = mean\ of\ observed\ monthly\ mean\ rainfall$$

$$NSE = 1 - \frac{F}{F_0}$$

The NSE for Satellite/raw data and corrected Satellite data of Chewbet station was found to be 0.97 and 1 respectively.

Bias

Bias is a consistent deviation from the mean in one direction (high or low). A normal property of good forecast is that it is not biased. In terms of forecasting, bias is the tendency of the forecast to be either above or below the actual observations. With this concept if the computed bias is +ve, the forecast is consistently too low; if the computed bias is –ve the forecast is consistently too high. The +ve and –ve errors cancel each other out when the bias is computed. Bias is a measure of general tendency of direction of error. Percent Bias (PBIAS) is calculated as the percentage of total error from the total observed.

$$PBIAS = \frac{\sum_{i=1}^{n}\left({P^i}_{obs} - {P^i}_{cor}\right) * 100}{\sum_{i=1}^{n}\left({P^i}_{obs}\right)}$$

For chewbet station, the PBIAS was computed to be 0% and +12% for the corrected and raw data respectively. This shows that the satellite data is consistently low by 12%.

As it is shown, the corrected value for Chewbet station is having 1 NSE or perfect matching and the PBIAS of 0 or optimal value, and the raw data for this station is having NSE of 0.97 and PBIAS of +12%. Still the raw data is reliable to be used as it is without any correction.

Chewbet is the nearest station to the study area and its rainfall situation is also assumed to have resemblance with the study area. So, instead of using Chewbet station data for correction reference of the whole study area, it is better to using the satellite data of the study area without any correction. Moreover, because of the Bias being positive it is just being on the safer side for the assessment of surface water potential. Hence; after doing all this rainfall data analysis, the available 30 years of satellite rainfall data of the study area was used as it was.

d. Rainfall distribution across the district

Using the 30 years grid rainfall data, mean annual rainfall distribution map was developed using ArcGIS special analysis tool. Dhas district is stretched West to East and its maximum length is computed to be 120 Km, and the rainfall distribution varies across the district is varying considerably, the mean annual rainfall across the district ranges from 216mm to 624mm. When we go from West to East across the district, the trend of rainfall is increasing with the highest value at the middle of the district.

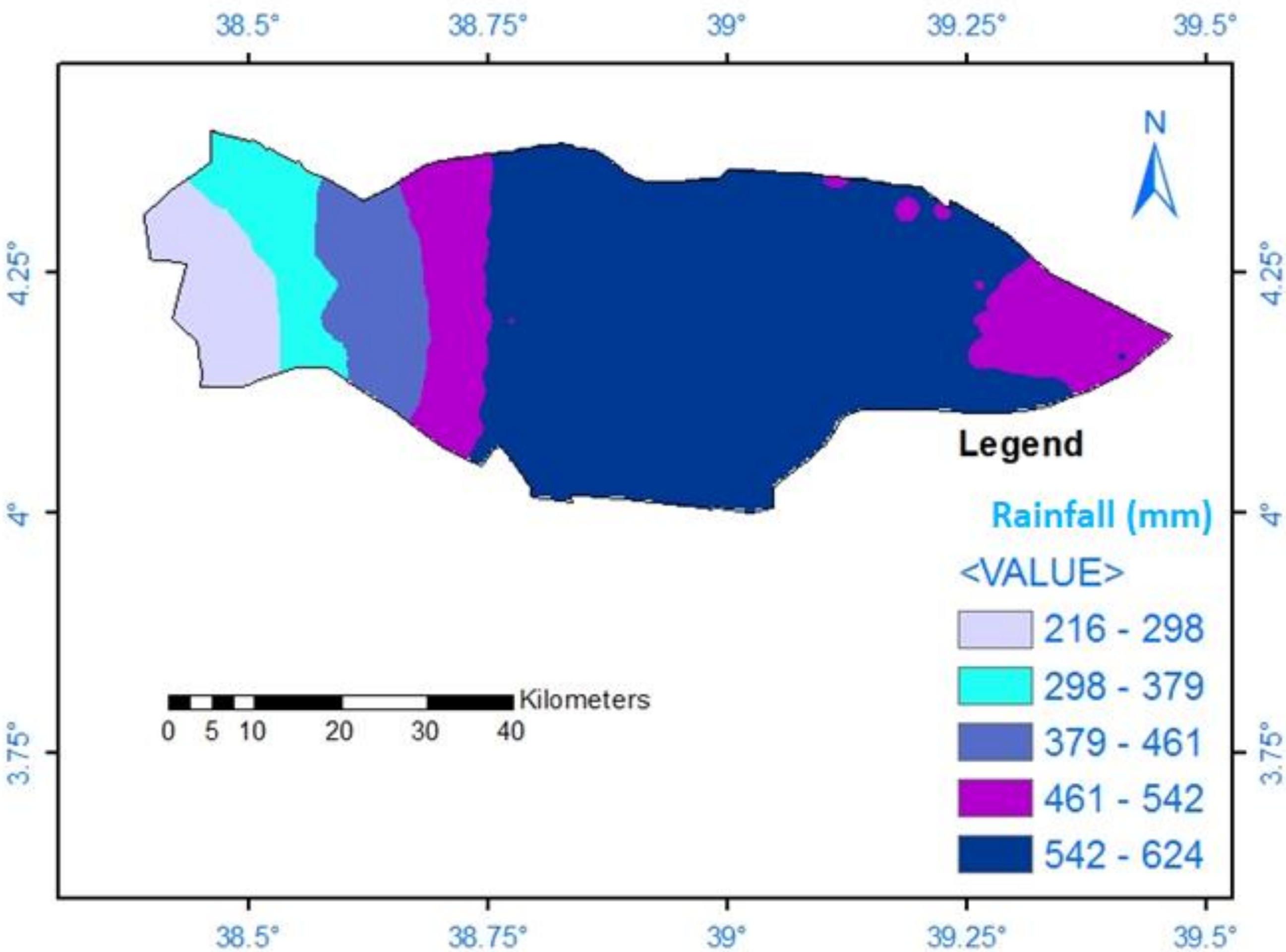

Figure 3-13: Mean Annual Rainfall distribution map of Dhas district

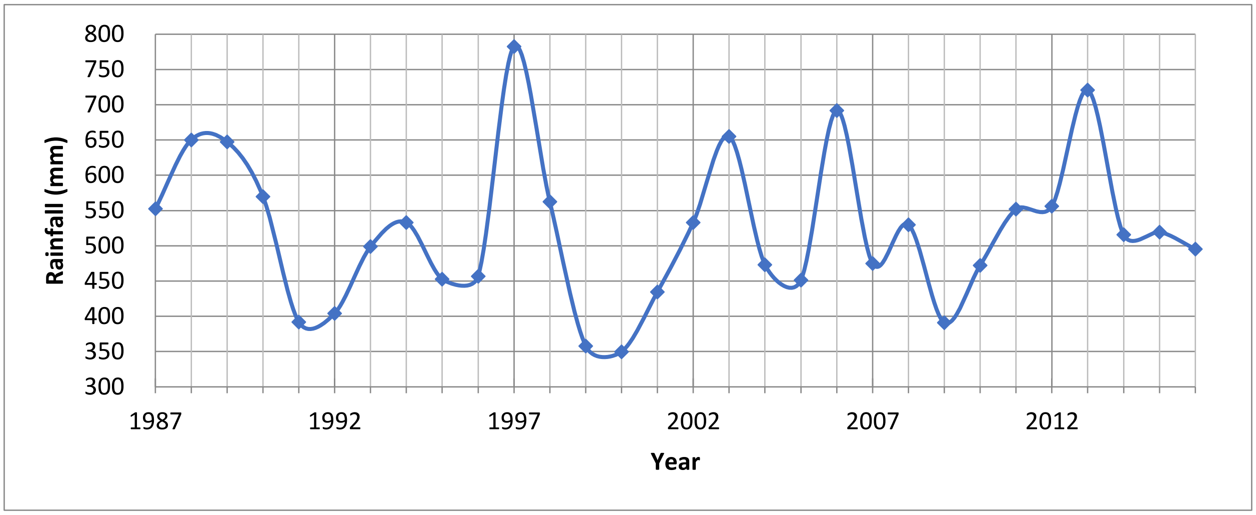

Figure 3-14: Areal-Yearly Rainfall Distribution

e. Dependable rainfall

Dependable rainfall is a key parameter required for different development purposes. It is commonly expressed as exceeded annual rainfall. The computation of this parameter was carried out based on thirty years areal yearly rainfall data of the district.

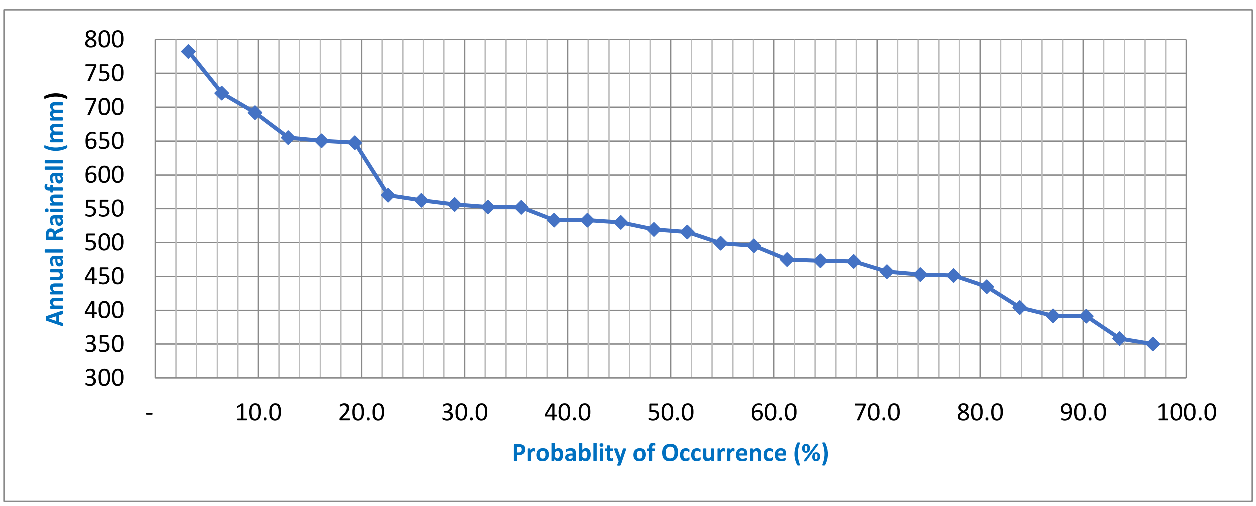

Figure 3-15: Dependable Rainfall

3.5.4. Runoff computation

Estimation of surface runoff is computed using Soil Conservation Service (SCS) model. For the storm as a whole, the depth of excess precipitation or direct runoff Q is always less than or equal to the depth of precipitation **P**; likewise, after runoff begins, the additional depth of water retained in the watershed, $\mathbf{F_a}$, is less than or equal to some potential maximum retention **S**. There is some amount of rainfall $\mathbf{I_a}$ (initial abstraction before ponding or runoff, such as infiltration or rainfall interception by vegetation); historically, it has generally been assumed that I_a=0.2S for which no runoff will occur. So, the potential runoff is $\mathbf{P\text{-}I_a}$. **T**he hypothesis of the SCS method is that, the ratios of the two actual to the two potential quantities is equal, that is:

$$\frac{F_a}{S} = \frac{Q}{P - I_a}; from\ the\ continuity\ principle, P = Q + I_a + F_a$$

From the above:

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

$$S = \frac{25{,}400}{CN} - 254$$

Where,

Q = Runoff depth (mm).
S = Maximum recharge capacity.
CN = Curve Number.
P = Rainfall depth (mm).

The above computed curve number for each sub-watershed is the curve number under normal condition (CN II). The appropriate moisture group is based on a five-day antecedent rainfall amount and season category (dormant and growing seasons).

Table 3-7: AMC category

AMC group	Total 5-days antecedent rainfall (mm)	
	Dormant season	Growing season
I	Less than 13	Less than 36
II	13 to 28	36 to 53
III	More than 28	More than 53

Curve numbers for AMC-I and AMC-III, dry condition and wet condition, respectively are derived from CN AMC-II. So, by considering the daily rainfall and appropriate curve number resulted from the previous 5 days rainfall depth, the direct runoff was estimated.

3.5.5. Computation of water needs

The required annual water volume depends on the water needs, evaporation from the water surface and seepage into the soil or through the storage structure (dam). Water needs for irrigation, domestic uses and livestock is estimated as shown below.

a. Domestic water demand

Total population of the district was estimated to be 59,830 in 2008 E.c. Based on the population growth rate currently used by the Borana Zone Planning and Economic Development Office for the district (2.6%), the population forecast for Dhas district is done.

Table 3-8: Domestic water demand

Year	Population	Water demand (L/c/d)	System loss (%)	Total demand (m^3/year)	Remark
2019	62,982	25	30	747,119	GTP-2; previously it was 15 L/c/d
2029	81,412	35	30	1,352,046	
2039	105,235	45	30	2,247,034	

b. Livestock's' Water demand

As per the information found from Borana Zone Planning and Economic Development office, the current livestock's population is as tabulated below. The forecast for the number of livestock's is also estimated based on the projection used by the office i.e. 0.05% growth rate.

Table 3-9: Livestock's water demand

Year	Livestock	Number of Livestock	Water demand (L/head/d)	Total demand (m^3/Year)	Remark
2016	Cattle	255480	25	6,387,000	Typical
	Shoat	159537	5	797,685	Typical
	Camel	32773	6	196,638	In cold weather, and when green feed is available, the camel may not drink water. In dry seasons camels drink up to 60 L of water every 10 days.
	Pack animal	31187	15	467,805	
	Total			7,849,128	
2019	Cattle	255,863	25	6,396,585	
	Shoat	159,776	5	798,882	
	Camel	32,822	6	196,933	
	Pack animal	31,234	15	468,507	
	Total			7,860,908	
2029	Cattle	257,146	25	6,428,640	
	Shoat	160,577	5	802,886	
	Camel	32,987	6	197,920	
	Pack animal	31,390	15	470,855	
	Total			7,900,301	
2039	Cattle	258,434	25	6,460,856	
	Shoat	161,382	5	806,909	
	Camel	33,152	6	198,912	
	Pack animal	31,548	15	473,215	
	Total			7,939,891	

c. Irrigation Water Requirement

Using the 30 years (1987-2016) monthly temperature data from NMA with 0.0375x0.0375 degree grid interval and other climate data (daily data for 29 years; 1987-2015) like relative humidity, wind speed and radiation from NASA website (https://power.larc.nasa.gov/data-access-viewer/) with 0.5x0.5 degree grid interval potential evapotranspiration was computed. The software used to compute ETo was FAO CROPWAT 8.0 Software (Penman-Monteith method).

Table 3-10: Potential Evapotranspiration for Dhas district

Month	Tmax.(C°)	Tmin.(C°)	RH (%)	Wind (Km/day)	Radiation (MJ/m^2/day)	ETo (mm/day)
Jan	31.3	16.9	40	301	20.64	6.12
Feb	32.0	17.0	36	321	21.87	6.74
Mar	31.2	17.4	47	304	20.77	6.09
Apr	28.3	14.8	68	252	17.95	4.2
May	28.4	16.6	74	254	16.91	3.86
Jun	27.8	15.7	67	298	15.10	3.97
Jul	27.8	15.2	63	341	14.81	4.25
Aug	27.9	15.0	58	373	16.20	4.81
Sep	28.3	15.3	54	348	18.57	5.26
Oct	26.9	16.3	62	280	16.30	4.29
Nov	28.3	16.2	64	269	17.40	4.3
Dec	29.1	16.2	51	286	19.03	5.13
Average	16.1	28.9	57	302	18	4.92

By considering Alfalfa crop, estimation of crop water requirement using FAO CROPWAT 8.0 software estimation was made as shown in the table below. Assuming the overall irrigation efficiency of 42% for furrow irrigation method, gross irrigation requirement is also tabulated below.

Table 3-11: Irrigation water requirement

Month	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Total
Net Irr. Req. (mm)	8	0	43	41	47	101	62	90	140	177	184	170	1,062
Gross Irr. Req.(mm)	20	0	102	97	112	239	148	215	334	420	437	404	2,528

As Alfalfa is widely grown throughout the world as forage for cattle and grown in irrigation, it was considered as source of animal feed for drought period, and also for estimation of water requirement for irrigation. Alfalfa is a perennial forage legume which normally lives four to eight years, but can live more than 20 years, depending on variety and climate. In most climates, alfalfa is cut three to four times a year; for this analysis it is assumed to be cut four times per year. Total yields are typically around eight tonnes per hectare in temperate environments, but yields have been recorded up to 20 t/ha. For this analysis, 14 t/ha was considered.

In Borana area especially in Dhas district, common livestock are cattle, sheep, pack animals, goat, and camel. Because of camel being browsers, they can consume bushes and forest leaves hence, forage production (Alfalfa) is considered for the cattle, shoat and pack animals. Normally, 5 kg/head/day of forage (alfalfa) for cattle and pack animals and 2.5kg/head/day for shoat could be considered disregarding size and other physical and anatomy of animals. But this forage provision is assumed to be a supplementary during drought periods; hence, as it is practically reported during the drought period normally 2.5Kg hay and 0.5kg concentrate per head per day has been provided for cattle. So, for this analysis 3kg/head/day for cattle, 2kg/head/day for pack animals and 1.5 kg/head/day for shoat as supplementary fodder only for drought period was considered (see table 3-11).

Table 3-12: Water demand for supplementary fodder production

Year	Livestock	Estimated # of Livestock	Feed demand (Kg/head/ day)	Total demand (t/month)	Yield (t/ha/ harvest)	# harvests per year	Yield (t/ha/ year)	Req'd land size (ha)	Water demand (m^3/ha/year)	Total (Mm^3/year)
2019	Cattle	255,863	3	23,028	15	4	60	534.86	25280	13.52
	Shoat	159,776	1.5	7,190						
	Pack animal	31,234	2	1,874						
	Total	446,874		**32,092**						
2029	Cattle	257,146	3	23,143	15	4	60	537.54	25280	13.59
	Shoat	160,577	1.5	7,226						
	Pack animal	31,390	2	1,883						
	Total	449,113		**32,252**						
2039	Cattle	258,434	3	23,259	15	4	60	540.24	25280	13.66
	Shoat	161,382	1.5	7,262						
	Pack animal	31,548	2	1,893						
	Total	451,364		**32,414**						

d. Expected Losses

i. Evaporation loss

The two main factors influencing evaporation from an open water surface are the supply of energy to provide the latent heat of vaporization and the ability to transport the vapour away from the evaporative surface. Solar radiation is the main source of heat energy. The ability to transport vapour away from the evaporative surface depends on the wind velocity over the surface and the specific humidity gradient in the air above it [14].

By Genale Dawa Basin study, curves relating annual evaporation (EVAP) and potential evapotranspiration (ETo), with elevation were developed, and site-estimation can be made by simply applying the respective analytical curves, given site elevation (Es):

EVAP = 7419 - 758.4 Ln (Es) for: EVAP (mm/a); Es (m a.s.l)

And to estimate actual evaporation for an open water surface (reservoir), a reduction factor of 80% (equivalent to evaporation pan-coefficient) should be applied.

So, by considering average elevation of the Dhas district (1,374m a.m.s.l), Evap=1,939mm/annum and estimation of actual evaporation from the reservoir will be (0.8*1939= 1,551mm/year). Without determining specific area of storage, the type of storage system and corresponding water surface area, it may be difficult to quantify volume of water that is going to be lost through evaporation. So, for the sake of simplicity an assumption of a single storage reservoir with annual average water depth of 15m was done. The average surface area could be estimated by dividing annual runoff volume to the 15m depth; so, for further simplicity it was accounted as 10% of the stored runoff volume.

ii. Seepage Losses

Seepage loss mainly depends on type of structure used for storage of the runoff (material used to construct the structure, like dam material) and reservoir condition (permeability of the reservoir area and the wetted area). By considering the same assumption made for evaporation loss (15m average water depth) with circular shaped reservoir and considering only a projected area, estimation was roughly made. As the soil data of the area shows, most of the soil is moderately to poorly drained soil with moderately fine to fine textures (slow infiltration rates) hence, permeability of $1x10^{-7}$cm/sec could be used for the analysis. For further simplicity, seepage loss was also estimated to be 0.21% of the stored runoff volume.

As elaborated under a and b above, the summation of domestic and livestock annual water demand was estimated to be 10Mm^3. The water to be allocated for irrigation is, the amount that is in excess of various losses and leftover from domestic and livestock consumption.

So, the amount of water that can be allocated for irrigation with its probability of occurrence has been tabulated below.

Table 3-13: Amount of water available for irrigation with its probability of occurrence

P (%)	3.2	6.5	9.7	12.9	16.1	19.4	22.6	25.8	29.0	32.3	35.5	38.7	41.9	45.2	48.4
Water Available for Irr. (Mm^3)	315	265	215	151	132	131	123	113	113	98	94	87	83	75	74

P (%)	51.6	54.8	58.1	61.3	64.5	67.7	71.0	74.2	77.4	80.6	83.9	87.1	90.3	93.5	96.8
Water Available for Irr. (Mm^3)	65	63	60	58	58	57	56	42	39	35	24	24	15	11	-

As it has been indicated in different documents and also triangulated during the KII, the frequency of drought occurrence has currently increased from the previous 5-6-year interval to 2-3years. Most of the time, short interval droughts are occurring due to the failure of one rainy season; either due to the failure of long rainy season ("Gena") or due to the failure of the short rainy season ("Haggaya").

Table 3-14: Scenario-1 (Drought interval of 3 years period)

Year	Drought interval (years)	Duration of supplementary fodder provision (month)	Yearly Irrigation water demand (Mm^3)	Remark
2039	3	6	40.98	The required fodder amount would be produced and stored in 2 good years

Table 3-15: Scenario-2 (Drought interval of 6 years period)

Year	Drought interval (years)	Duration of supplementary fodder provision (month)	Yearly Irrigation water demand (Mm^3)	Remark
2039	6	12	32.78	The required fodder amount would be produced and stored in 5 good years

To be on the safer side, Scenario-1 was considered for the analysis. As per Scenario-1, the 40.98 Mm^3 irrigation water demand corresponds with the 75% probability of occurrence.

4. RESULT AND DISCUSSION

4.1. Rainfall Situation

The rainfall distribution across the district shows as the central part of the Dhas district is receiving more rain than other parts of the district; five sub-watersheds (SW-2, SW-3, SW-4, SW-5 and SW-6) are belonging to the larger rainfall depth. Hence, it enables to be more productive to focus on these watersheds to get relatively high runoff volume pre-unit area, disregarding other parameters.

The district has bi-modal rainfall pattern (long rainy season from March to May and short rainy season occurs in October and November) with mean annual rainfall of 523mm. Out of this 55% is received in the long rainy season (between March and May). The mean monthly maximum rainfall occurs in the month of April with the value of 159mm.

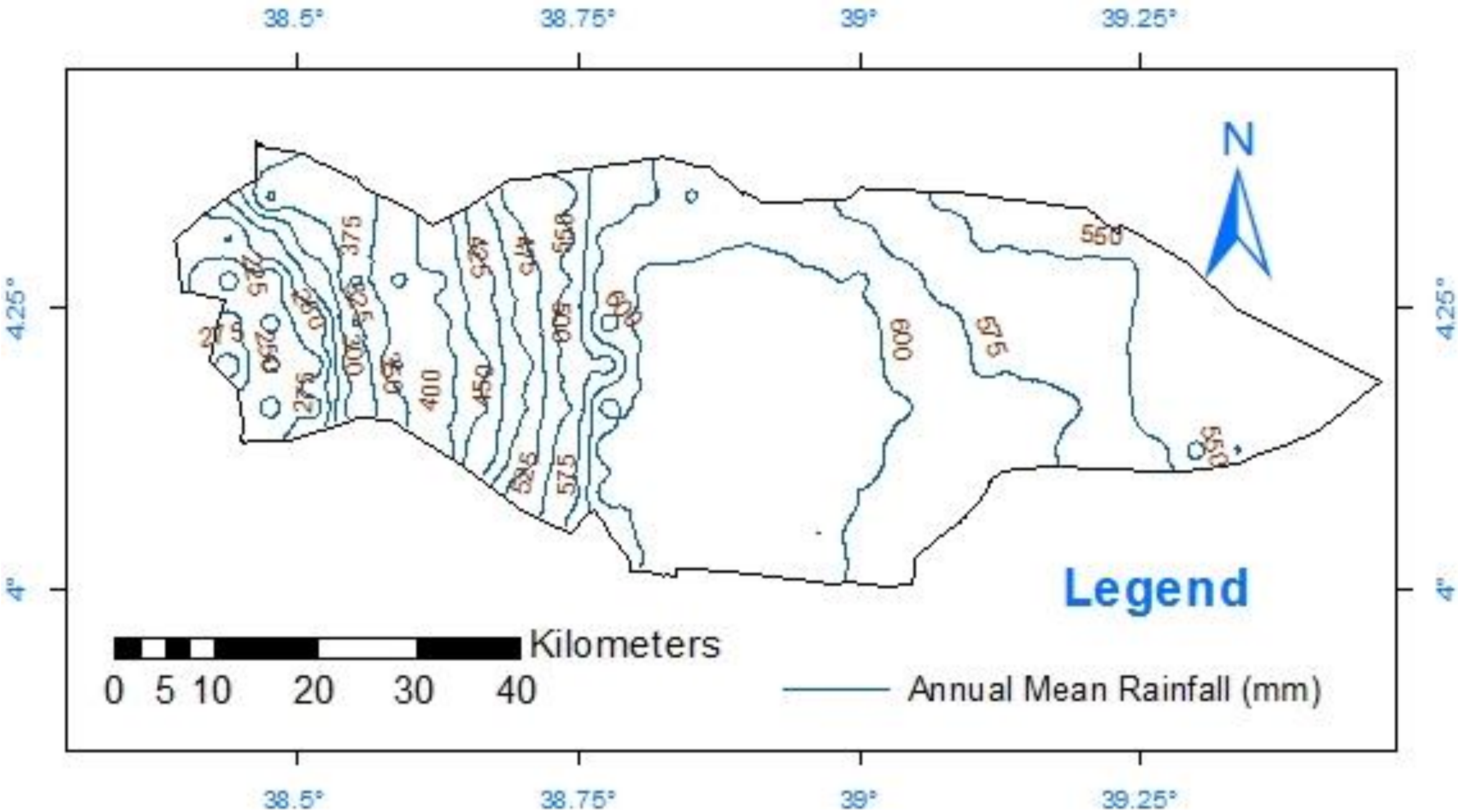

Figure 4-1: Isohyetal map of Dhas district

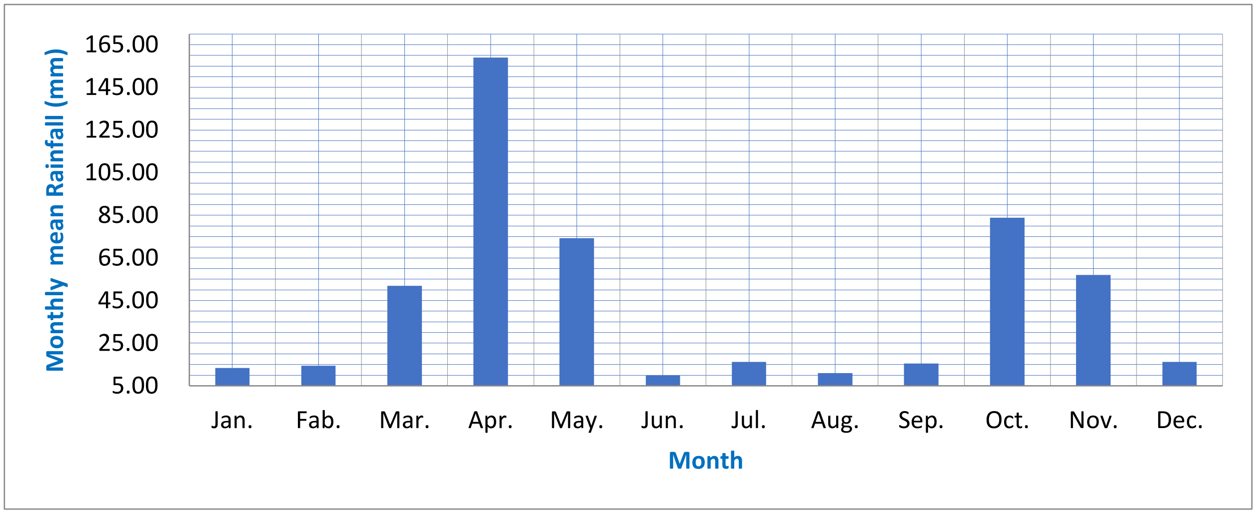

Figure 4-2: Monthly mean Rainfall (mm)

4.2. Watershed Characteristics

Based on the drainage part of the district, the district was divided in to 12 sub-watersheds. Due to their very fragmented nature and difficulty in the analysis, some of the sub-watersheds were not considered in the analysis; out of the total district area this accounted for 9.2% or 292.7 Km2. The computed minimum and maximum sub-watershed size were 14.25 km^2 and 1,346.4 km^2 respectively.

As of December 2018, majority of the area was covered with grass & bush, which accounted for 71% of the total district. Forest, Bare land and Water ways share 16%, 5% and 8% respectively. Settlement areas were not reflected in the LULC; this might be due to two main reasons: (1) because of scattered settlement and very small size compared to the total area, (2) most of the community house roofs are made of soil, in the analysis might be considered as a bare land.

Even if majority of the area's hydrologic soil group is "D", the weighted curve number ranges between 69 and 78. This is due to mass of area (87%) being covered with grass, bush and forest; as of SCS empirical formula, this has much effect in the initial abstraction and consequent runoff depth.

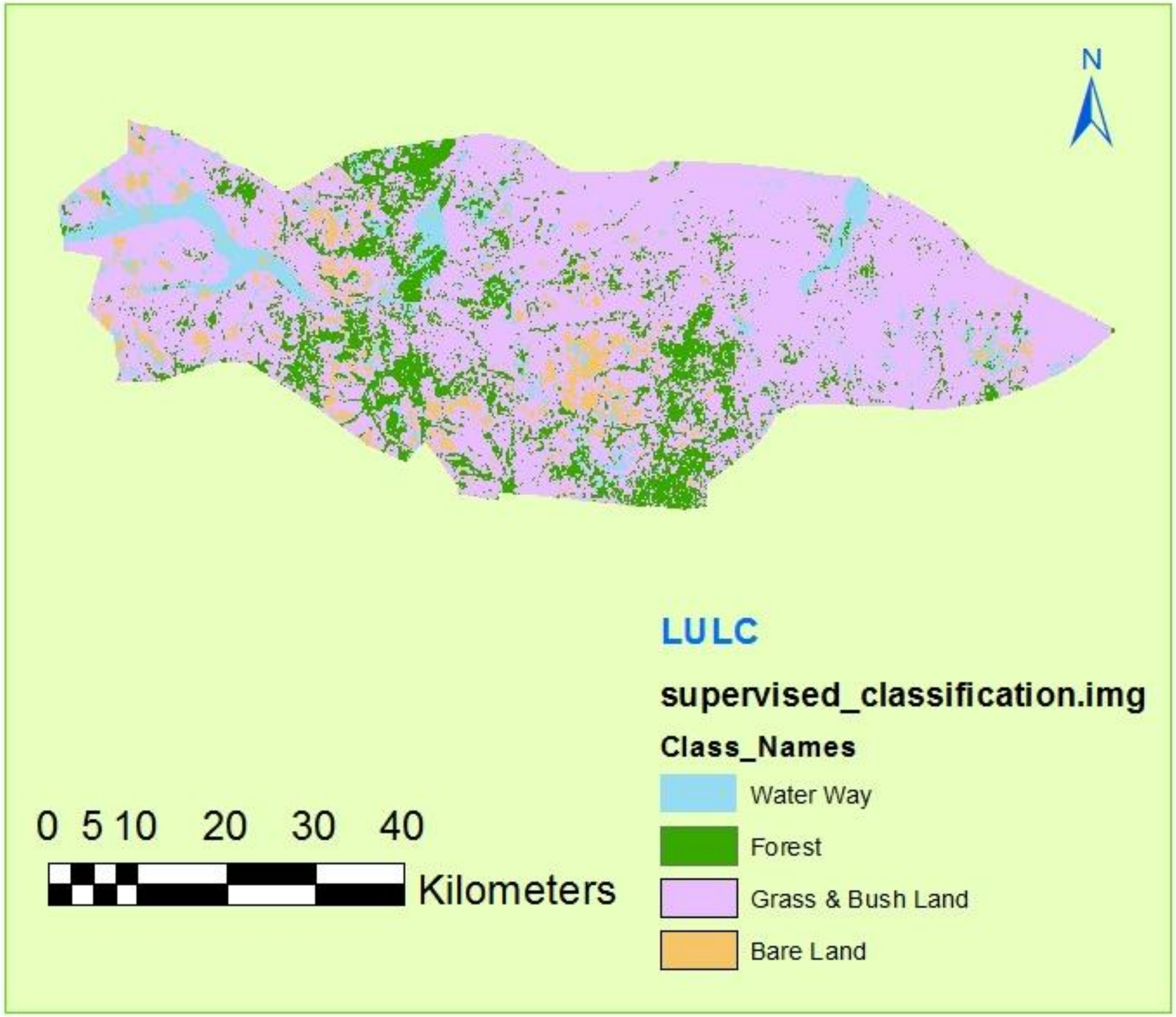

Figure 4-3: Land used Land Cover Map of Dhas District as of December 2018

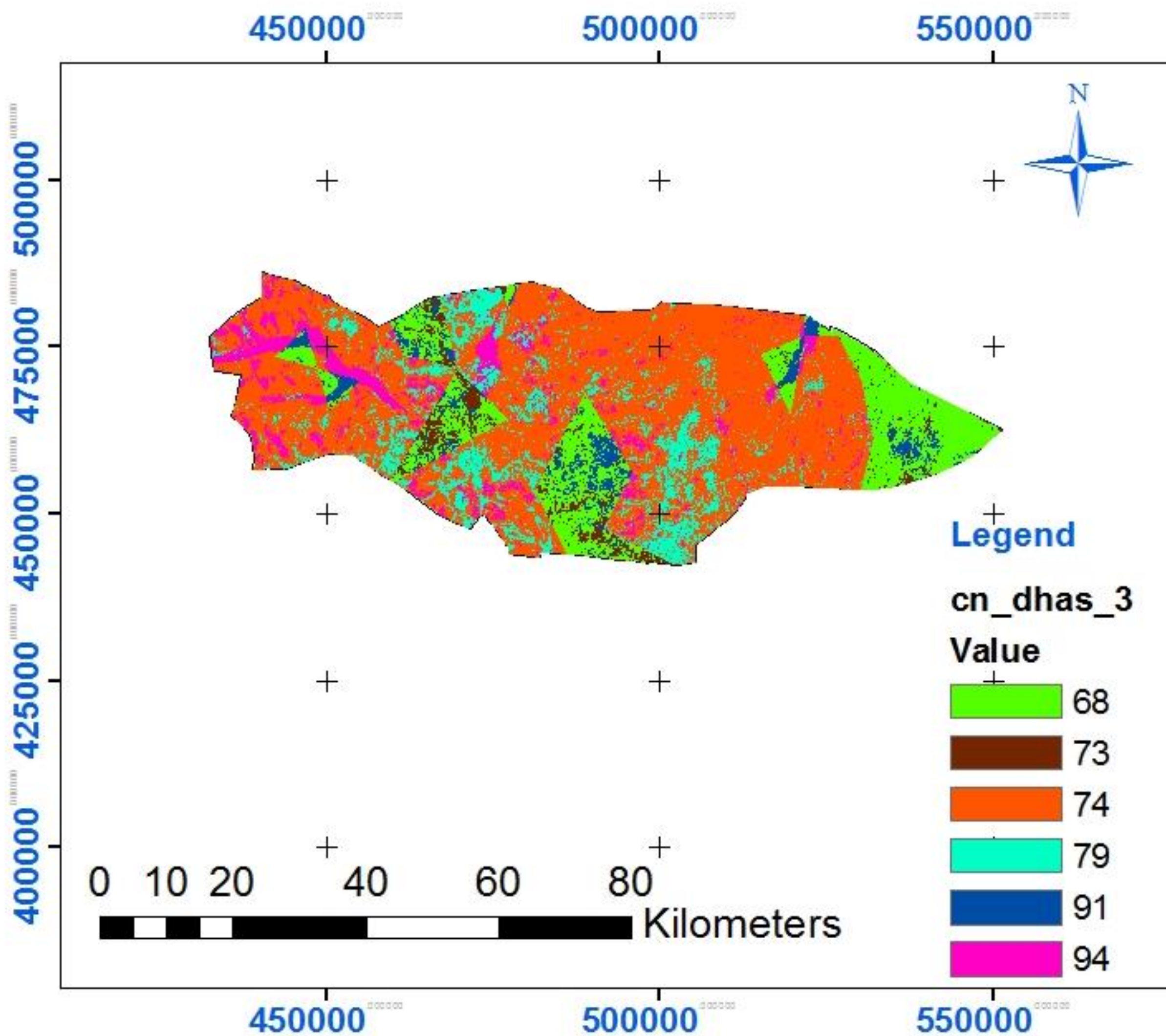

Figure 4-4: Curve Number for Dhas District as of December 2018

4.3. Runoff Volume Estimation

Based on the SCS model, the direct runoff estimation was done for all the thirty years. The maximum estimated runoff volume was 361 Million cubic metre for the year of 1988 and the minimum estimated runoff volume was 8Mm^3 for the month of 1991.

Table 4-1: Estimated direct runoff for all years

Year	Annual Rainfall (mm)	Runoff depth (mm)	Estimated Runoff volume (m^3)	Runoff factor
1987	558.51	47.21	136,456,478.04	0.085
1988	658.13	124.80	360,727,978.40	0.190
1989	655.44	25.18	72,780,977.82	0.038
1990	572.07	28.86	83,406,857.02	0.050
1991	388.86	2.76	7,974,084.54	0.007
1992	409.95	13.06	37,748,524.87	0.032
1993	506.54	26.92	77,805,617.39	0.053
1994	524.48	25.95	75,006,523.16	0.049
1995	454.66	12.97	37,496,740.03	0.029
1996	457.31	9.76	28,213,220.76	0.021
1997	782.58	86.68	250,542,461.27	0.111
1998	568.09	54.47	157,432,642.18	0.096
1999	359.87	7.89	22,815,632.74	0.022
2000	349.10	18.85	54,473,748.95	0.054
2001	432.62	20.14	58,219,273.62	0.047
2002	530.56	32.51	93,982,737.69	0.061
2003	656.37	105.83	305,895,640.39	0.161
2004	478.20	26.32	76,075,612.77	0.055

Year	Annual Rainfall (mm)	Runoff depth (mm)	Estimated Runoff volume (m^3)	Runoff factor
2005	451.58	25.90	74,868,990.94	0.057
2006	693.54	54.17	156,585,036.93	0.078
2007	475.78	37.21	107,567,133.89	0.078
2008	536.44	41.49	119,940,556.54	0.077
2009	391.92	17.22	49,781,276.15	0.044
2010	474.34	32.43	93,727,162.33	0.068
2011	553.38	47.14	136,254,788.79	0.085
2012	563.38	39.98	115,564,082.56	0.071
2013	725.28	61.72	178,408,760.09	0.085
2014	517.63	35.92	103,840,679.85	0.069
2015	523.27	28.20	81,499,966.50	0.054
2016	497.94	51.03	147,489,530.60	0.102

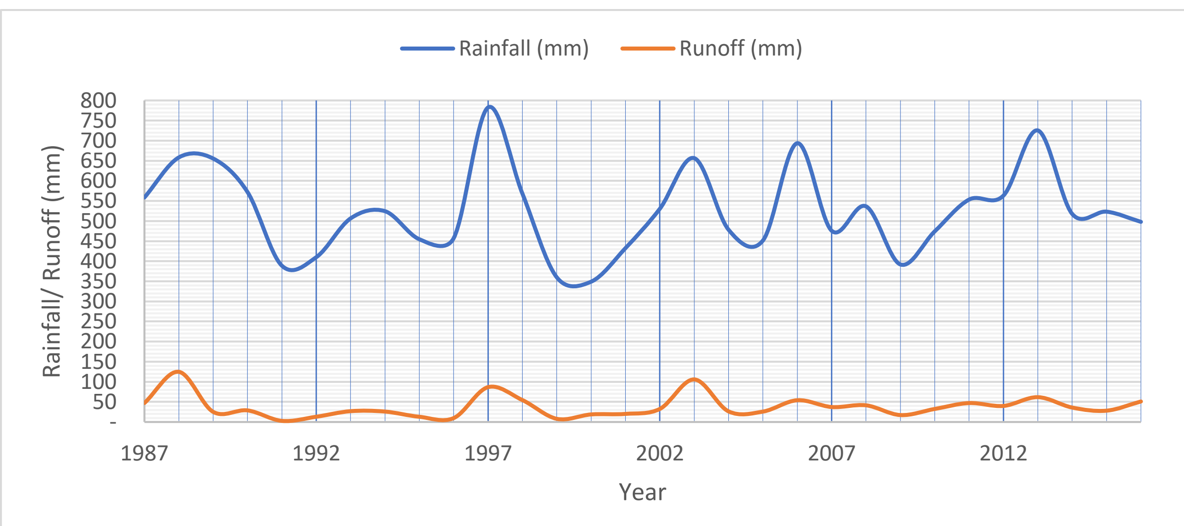

Figure 4-5: Rainfall-Runoff graph

Based on the outputs of runoff depth, runoff factor was computed for each year (last column of table 4-1).

The runoff-factor tells us what portion of the rainfall is changed to direct runoff, and it is computed as the ration of rainfall depth to the runoff depth. As it is shown in the computation, it ranges from 0.007 for the year of 1991 and 0.19 for the year of 1988 with overall average value of 0.068. Runoff factors of about **7%** were computed in the central parts of Dawa (Genale Dawa integrated Master plan study); this is the same as the computed average value of **0.068 (6.8%)** so, the computed runoff depth could be valid.

As the tenets of SCS is based on the theory that for the rainfall depth generating runoff should exceed the initial abstraction, some watersheds didn't exhibit any runoff corresponding to the rainfall of a certain period. For the year of 1991, SW-1 and SW-3 didn't generate any runoff.

Table 4-2: Runoff Volume Estimate for the year of 1991

Name of Sub-Watershed	Area (Km^2)	Annual Rainfall (mm)	Weighted Average (mm)	Runoff depth (mm)	Estimated Runoff volume (m3)	Runoff depth to Rainfall depth ratio
(A)	(B)	(C)	(D) = (B*C)/ Tolal Area	(E) = (P-Ia)^2/ (P+0.8S)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	303	141	-	-	-
SW-2	797.48	456	126	2	1,737,892	0.004
SW-3	183.65	469	30	-	-	-
SW-4	121.22	459	19	5	584,544	0.01
SW-5	109.27	486	18	5	539,660	0.01
SW-6	73.76	473	12	9	635,947	0.02
SW-7	83.14	467	13	18	1,530,430	0.04
SW-8	72.17	461	12	17	1,251,281	0.04
SW-9	36.13	488	6	17	608,215	0.03
SW-10	24.45	497	4	19	469,381	0.04
SW-11	28.6	469	5	14	401,721	0.03

Name of Sub-Watershed	Area (Km^2)	Annual Rainfall (mm)	Weighted Average (mm)	Runoff depth (mm)	Estimated Runoff volume (m3)	Runoff depth to Rainfall depth ratio
SW-12	14.25	495	2	15	215,013	0.03
Total	**2,890.52**		**389**		**7,974,085**	

As per the theory of SCS, the runoff generation is considering the daily rainfall depth hence; only the large annual rainfall depth doesn't necessarily generate large annual runoff. The rainfall distribution also matters; a rainfall concentrating to a shorter period generates better runoff than a rainfall distributed over a longer duration. i.e. due to their yearly distribution nature, two equaled annual rainfall depths may not generate equal amount of runoff from the same watershed area.

This was observed in the runoff analysis of Dhas district. The minimum annual rainfall depth was recorded in 2000 with the magnitude of 349mm, and the estimated runoff depth was 18.85mm. Whereas, the other years having annual rainfall of greater than 349 (1991, 1992, 1995, 1996, 1999, 2009) showed runoff depth of less than 18.85mm.

a. Dependable runoff volume

In terms of surface water development, it needs to concentrate on the reliability of available runoff volume instead of rainfall reliability. Using the generated runoff volume over the district, dependable runoff volume was computed.

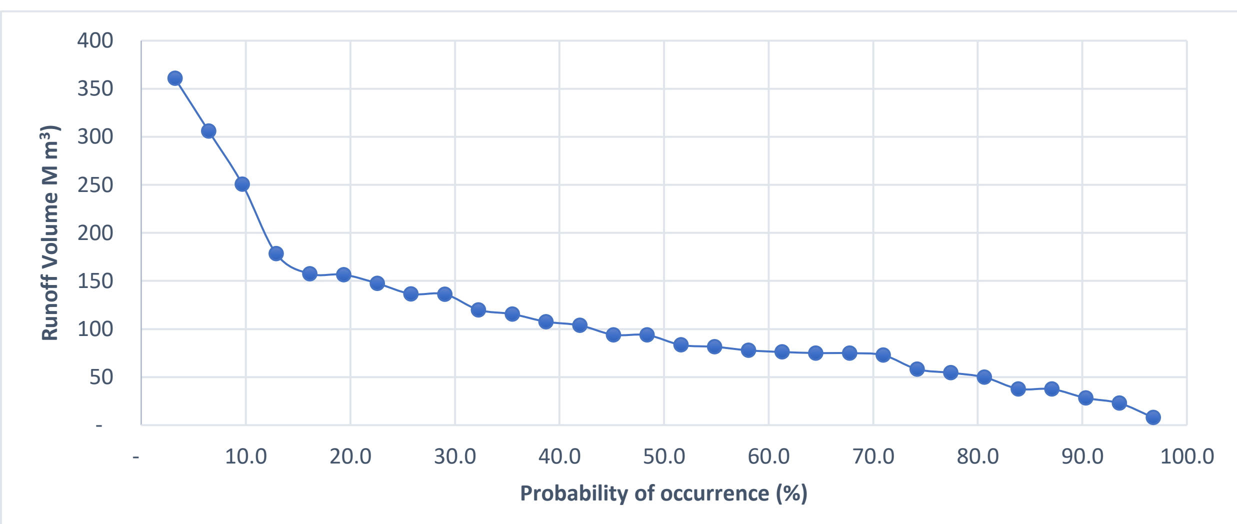

Figure 4-6: Dependable runoff volume over the Dhas district

Table 4-3: Dependable runoff volume

Probability (%)	3.2	6.5	9.7	12.9	16.1	19.4	22.6	25.8	29.0	32.3	35.5	38.7	41.9	45.2	48.4
Gross Runoff (Mm^3)	361	306	251	178	157	157	147	136	136	120	116	108	104	94	94

Probability (%)	51.6	54.8	58.1	61.3	64.5	67.7	71.0	74.2	77.4	80.6	83.9	87.1	90.3	93.5	96.8
Gross Runoff (Mm^3)	83	81	78	76	75	75	73	58	54	50	38	37	28	23	8

The runoff volume with probability of occurrence of 96.8% was corresponding with the rainfall of 90.3% probability of occurrence. The rainfall depth with probability of occurrence of 96.8% was matching with 77.4% probability of occurrence of the runoff volume.

So, as per the analysis relaying only on the dependable rainfall value may not be a guarantee to get the expected dependable runoff volume.

4.4. Water Demand Estimation

The water demands, and expected losses were estimated under section 3. Total expected loss was assumed to be proportional to the total runoff volume i.e. 10.21%. And the total water for domestic consumption and livestock was estimated after 20-year population forecast, as the result it was estimated to be 10Mm^3 per annum.

The water in excess of losses and leftover form domestic and livestock consumptions was suggested to be used for irrigation.

Based on the drought interval of 3 years and provision of supplementary fodder for 6 months period during the drought period, the available water was allocated for fodder production.

After 20 years forecast of animal population, the required amount of animal feed was 32,414 tone/ month. Proportionally, to secure this amount of animal feed for 6 months, total amount of (13.66*6) = 81.96 Mm^3 water was estimated for irrigation. For 3 years of drought interval, there is possibility to produce and store the fodder in two good years; so, the required amount of water for irrigation would be (81.96/2) = 40.98 Mm3/ year.

This 40.98 Mm^3 of water that is in excess of losses and surplus from domestic and animal consumption would correspond with the 75% probability of occurrence. i.e. in three out of four years, there is probability of getting this amount of runoff volume.

The probability of considered drought interval is 33% (once in three years), and the probability of getting the required amount of water for fodder production is 75% (in three out of four years). So, relaying on the available runoff volume is safe.

5. STUDY LIMITATIONS

During the study process, some limitations have been perceived; some of the limitations might affect the study output and the others may affect implementation of study findings:

- Curve number values: it was not possible to get the curve number developed either for the study area or other parts of the country hence, the curve number values used for the study were directly taken for the reference materials. That might affect the computed result by under mining or by exaggeration;

- Rainfall data: observed data was available only for one nearby station (Chewbet); the other one indicated on the website of NMA (Denbel station) could not be found in place. So, data check for grid rainfall data was done based on only Chewbet station. Actually, the Bias analysis for Chewbet station shows, as the grid rainfall data is positively deviated by 12% (PBIAS of +12%). i.e. the grid data underestimated by 12% from the observed. But for the sake of safety, the grid rainfall data for the whole Dhas district was used as it was. So, that might underestimate the computed runoff volume result;

- The study was confined with in the district, and didn't consider any flow coming in or going out of the district over the ground surface; practically this may be a challenge;
- Due to the study being district based, not a watershed based, it was not possible to accommodate all areas of the district while doing the estimation of surface water potential. That was also expected to undermine the total surface water potential of the district;
- The outlet for surface water potential assessment was done at the border of the district hence; command area may not be available within the district, if gravity irrigation system is considered;
- Due to lack of similar studies in the study area, it was not possible to cross check and compare the study result with previous findings. The only study that can represent the study area was Genale-Dawa River Basin Integrated Resources Development Master Plan Study. The analysis done for Dawa sub-basin was used for validation of the study result. Dawa sub-basin comprises of the study area, but not specific to the area of interest.

6. CONCLUSION AND RECOMMENDATION

Currently, Dhas district is habitat for 62,982 human and 479,695 animal population. It is receiving 523mm annual rainfall with its distribution concentrating at the middle part. The district is frequently affected with drought and subjected to relief aid. It has bi-modal rainfall pattern and generates enough amount of runoff volume that can be developed for managing of the frequent drought disaster.

The available runoff volume was found to be abundant enough to satisfying the major requirements after twenty years of forecast (from 2019-1939). And the water in excess of expected losses and surplus from the water requirement of human and livestock was also evaluated to be adequate for production of supplementary animal feed through irrigation.

Normally, the drought in the area occurs due to the failure of one or two of rainy seasons, the prevalence of drought due to failure of one rainy season is high with the interval of about three years. Of course, there is the probability for failure of the two seasons; but the frequency for this is low. The water requirement was made based on the two scenarios. And the one with shorter interval (failure of one rainy season) was found prevailing for the analysis.

The hypothesis that was made during the proposal preparation was "there is possibility of coping the frequent drought disaster in Dhas district through the development of available surface water potential of the district.". The hypothesis is confirmed through the procedural analysis of this study so, it could be acceptable.

The scope of the study was to estimate the available surface water potential of Dhas district considering boundary of the district as a control volume; for its practicality, it needs further detail study in terms of technical feasibility, economic viability, social acceptability, environmental impact and so on.

This study can be an entry point for the development of surface water potential of the area in large scale to coping the frequent drought disaster in the area.

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ANNEXES

Annex A: Figures

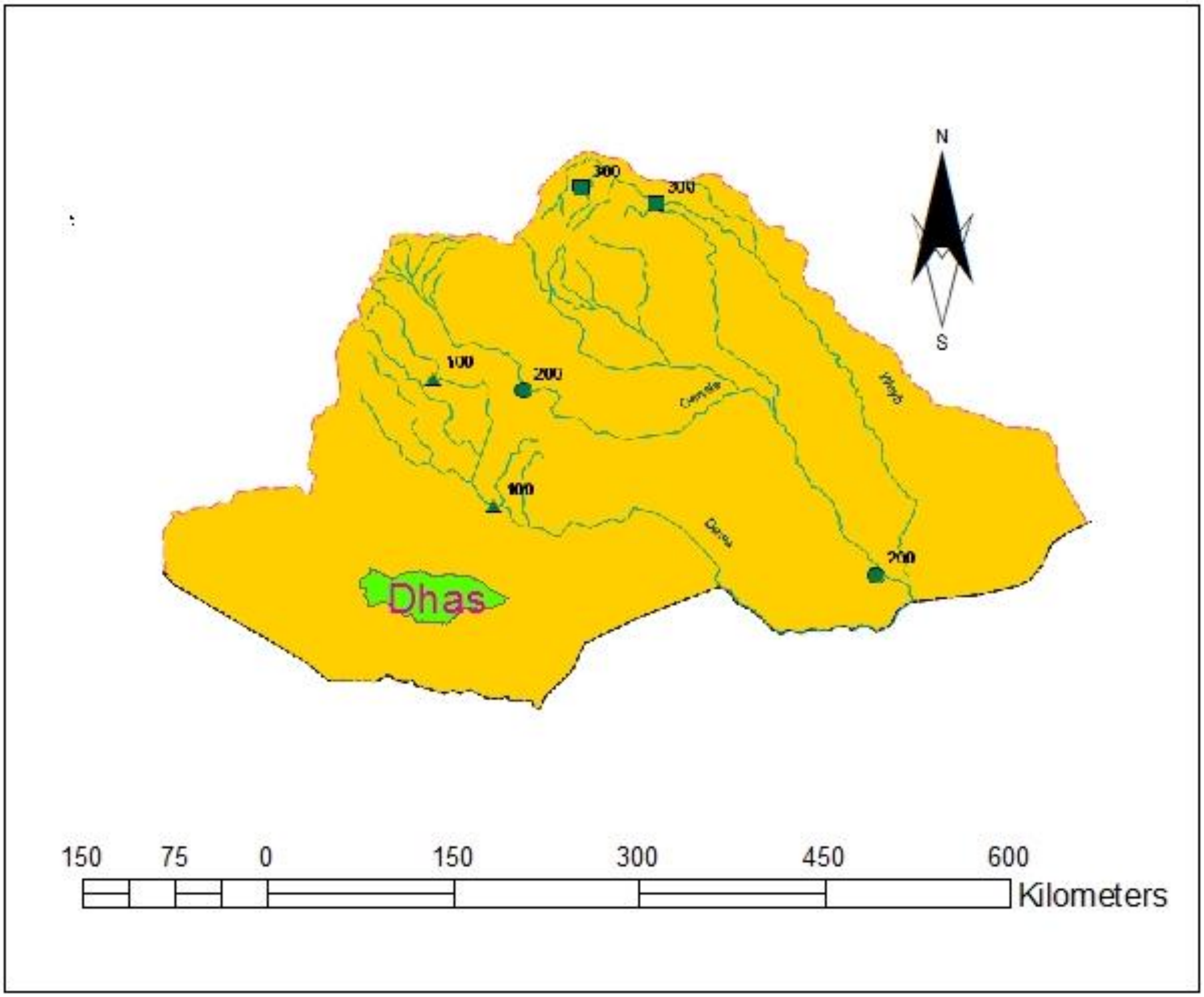

Figure A -1: Location Map of Dhas district in the Genale-Dawa Basin

Annex B: Photos

Figure 7-2: Land Use (grass and bush) of the study area-May 2019

Figure 7-3: Land Use (Bare land/ settlement) of the study area-May 2019

Annex C: KII Interview Guide

Key informant interview guide for analyzing possible options of managing frequent drought disaster

1. General Information.

1.1. Name of interviewed person_________________________________

1.2. Occupation/ Position ___________________________________

1.3. Woreda _____________________ Kebele _______________

2. Common problems in the area related to drought

2.1. How often does the drought occur? ________________________

2.2. What are commonly observed problems related to drought ____________

2.3. What is the main reason for the drought ________________

2.4. What are the coping mechanisms of the community against the drought? ___

3. Surface water potential of the area

3.1. Do you think that the area is receiving enough rainfall?

3.2. Does the area generate much runoff during the rainy season?

3.3. Would it be possible to harvest the direct runoff using storage system?

3.4. If the area is generating considerable amount of direct runoff, does it have any advantage or disadvantage to collecting the runoff in the reservoir?

3.5. If fodder production is practiced in the area, would it increase the resilience of the community?

3.6. What would you suggest against managing of the frequent drought disaster in the area?

Annex D: Runoff Volume Result-All Years

For Year of 1987

SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	553.89	258.00	49.38	66.48	0.089
SW-2	797.48	545.13	150.40	32.08	25.59	0.059
SW-3	183.65	592.07	37.62	65.33	12.00	0.110
SW-4	121.22	592.00	24.83	52.18	6.33	0.088
SW-5	109.27	541.33	20.46	26.55	2.90	0.049
SW-6	73.76	624.25	15.93	84.58	6.24	0.135
SW-7	83.14	589.50	16.96	80.83	6.72	0.137
SW-8	72.17	561.33	14.02	51.28	3.70	0.091
SW-9	36.13	575.00	7.19	74.18	2.68	0.129
SW-10	24.45	546.75	4.62	52.94	1.29	0.097
SW-11	28.60	583.50	5.77	63.43	1.81	0.109
SW-12	14.25	551.00	2.72	50.41	0.72	0.091
Total	2,890.52		558.51		136.46	0.085

For Year of 1988

SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	609.85	284.07	99.90	134.50	0.164
SW-2	797.48	728.58	201.01	164.96	131.55	0.226
SW-3	183.65	757.71	48.14	156.35	28.71	0.206
SW-4	121.22	727.33	30.50	149.85	18.16	0.206
SW-5	109.27	767.67	29.02	170.51	18.63	0.222
SW-6	73.76	633.75	16.17	107.72	7.95	0.170
SW-7	83.14	551.50	15.86	88.86	7.39	0.161
SW-8	72.17	552.67	13.80	78.18	5.64	0.141
SW-9	36.13	537.50	6.72	83.63	3.02	0.156
SW-10	24.45	552.75	4.68	87.55	2.14	0.158
SW-11	28.60	544.50	5.39	71.27	2.04	0.131
SW-12	14.25	562.50	2.77	69.29	0.99	0.123
Total	2,890.52		658.13		360.73	0.190

For Year of 1989

SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	590.81	275.20	20.08	27.03	0.034
SW-2	797.48	725.98	200.29	28.80	22.97	0.040
SW-3	183.65	728.71	46.30	31.83	5.85	0.044
SW-4	121.22	762.50	31.98	40.46	4.90	0.053
SW-5	109.27	751.00	28.39	35.09	3.83	0.047
SW-6	73.76	776.00	19.80	49.32	3.64	0.064
SW-7	83.14	591.00	17.00	16.74	1.39	0.028
SW-8	72.17	604.33	15.09	11.50	0.83	0.019
SW-9	36.13	592.00	7.40	26.65	0.96	0.045
SW-10	24.45	614.75	5.20	19.48	0.48	0.032
SW-11	28.60	587.50	5.81	22.72	0.65	0.039
SW-12	14.25	604.00	2.98	17.15	0.24	0.028
Total	2,890.52		655.44		72.78	0.038

For Year of 1990

SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	495.99	231.03	11.21	15.10	0.023
SW-2	797.48	645.20	178.01	48.81	38.92	0.076
SW-3	183.65	709.07	45.05	56.32	10.34	0.079
SW-4	121.22	639.67	26.83	43.15	5.23	0.067
SW-5	109.27	643.83	24.34	50.39	5.51	0.078
SW-6	73.76	631.75	16.12	44.12	3.25	0.070
SW-7	83.14	574.50	16.52	31.64	2.63	0.055
SW-8	72.17	579.00	14.46	16.93	1.22	0.029
SW-9	36.13	550.50	6.88	13.17	0.48	0.024
SW-10	24.45	540.00	4.57	6.88	0.17	0.013
SW-11	28.60	564.00	5.58	17.23	0.49	0.031
SW-12	14.25	545.50	2.69	4.67	0.07	0.009
Total	2,890.52		572.07		83.41	0.050

For Year of 1991

SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	303.05	141.16	-	-	-
SW-2	797.48	456.45	125.93	2.18	1.74	0.005
SW-3	183.65	468.93	29.79	-	-	-
SW-4	121.22	458.50	19.23	4.82	0.58	0.011
SW-5	109.27	485.83	18.37	4.94	0.54	0.010
SW-6	73.76	473.25	12.08	8.62	0.64	0.018
SW-7	83.14	466.50	13.42	18.41	1.53	0.039
SW-8	72.17	461.33	11.52	17.34	1.25	0.038
SW-9	36.13	487.50	6.09	16.83	0.61	0.035
SW-10	24.45	496.75	4.20	19.20	0.47	0.039
SW-11	28.60	468.50	4.64	14.05	0.40	0.030
SW-12	14.25	495.00	2.44	15.09	0.22	0.030
Total	2,890.52		388.86		7.97	0.007

For Year of 1992

SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	370.33	172.50	2.65	3.56	0.007
SW-2	797.48	445.73	122.97	22.52	17.96	0.051
SW-3	183.65	469.00	29.80	19.77	3.63	0.042
SW-4	121.22	483.67	20.28	27.04	3.28	0.056
SW-5	109.27	481.00	18.18	46.50	5.08	0.097
SW-6	73.76	495.25	12.64	28.23	2.08	0.057
SW-7	83.14	375.00	10.79	11.59	0.96	0.031
SW-8	72.17	386.67	9.65	4.46	0.32	0.012
SW-9	36.13	354.50	4.43	8.96	0.32	0.025
SW-10	24.45	381.50	3.23	9.73	0.24	0.025
SW-11	28.60	365.00	3.61	7.41	0.21	0.020
SW-12	14.25	378.00	1.86	6.85	0.10	0.018
Total	2,890.52		409.95		37.75	0.032

For Year of	1993					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	395.57	184.26	13.69	18.44	0.035
SW-2	797.48	627.90	173.23	35.96	28.68	0.057
SW-3	183.65	617.64	39.24	42.82	7.86	0.069
SW-4	121.22	644.17	27.01	58.25	7.06	0.090
SW-5	109.27	691.17	26.13	75.26	8.22	0.109
SW-6	73.76	590.25	15.06	52.21	3.85	0.088
SW-7	83.14	462.00	13.29	14.44	1.20	0.031
SW-8	72.17	473.33	11.82	13.24	0.96	0.028
SW-9	36.13	458.50	5.73	13.43	0.49	0.029
SW-10	24.45	470.50	3.98	20.20	0.49	0.043
SW-11	28.60	455.00	4.50	12.74	0.36	0.028
SW-12	14.25	464.00	2.29	13.34	0.19	0.029
Total	2,890.52		506.54		77.81	0.053

For Year of	1994					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	436.41	203.28	4.04	5.44	0.009
SW-2	797.48	608.28	167.82	41.80	33.34	0.069
SW-3	183.65	600.14	38.13	46.48	8.54	0.077
SW-4	121.22	546.50	22.92	33.84	4.10	0.062
SW-5	109.27	568.50	21.49	35.71	3.90	0.063
SW-6	73.76	540.25	13.79	53.11	3.92	0.098
SW-7	83.14	644.50	18.54	71.84	5.97	0.111
SW-8	72.17	645.67	16.12	59.57	4.30	0.092
SW-9	36.13	623.50	7.79	58.44	2.11	0.094
SW-10	24.45	626.50	5.30	51.43	1.26	0.082
SW-11	28.60	634.00	6.27	55.65	1.59	0.088
SW-12	14.25	615.00	3.03	37.66	0.54	0.061
Total	2,890.52		524.48		75.01	0.049

For Year of	1995					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	406.24	189.23	9.27	12.49	0.023
SW-2	797.48	484.53	133.68	8.53	6.80	0.018
SW-3	183.65	528.71	33.59	31.49	5.78	0.060
SW-4	121.22	516.83	21.67	37.92	4.60	0.073
SW-5	109.27	507.67	19.19	33.67	3.68	0.066
SW-6	73.76	515.50	13.15	7.86	0.58	0.015
SW-7	83.14	504.50	14.51	17.44	1.45	0.035
SW-8	72.17	484.00	12.08	12.23	0.88	0.025
SW-9	36.13	499.50	6.24	15.78	0.57	0.032
SW-10	24.45	474.00	4.01	8.24	0.20	0.017
SW-11	28.60	501.00	4.96	12.79	0.37	0.026
SW-12	14.25	475.00	2.34	7.25	0.10	0.015
Total	2,890.52		454.66		37.50	0.029

For Year of	1996					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	413.77	192.73	3.02	4.06	0.007
SW-2	797.48	497.03	137.13	14.75	11.76	0.030
SW-3	183.65	475.43	30.21	6.23	1.14	0.013
SW-4	121.22	534.00	22.39	17.71	2.15	0.033
SW-5	109.27	507.00	19.17	12.18	1.33	0.024
SW-6	73.76	547.50	13.97	22.73	1.68	0.042
SW-7	83.14	461.50	13.27	29.42	2.45	0.064
SW-8	72.17	463.00	11.56	21.17	1.53	0.046
SW-9	36.13	470.50	5.88	14.62	0.53	0.031
SW-10	24.45	481.00	4.07	28.25	0.69	0.059
SW-11	28.60	465.00	4.60	22.03	0.63	0.047
SW-12	14.25	472.50	2.33	18.77	0.27	0.040
Total	2,890.52		457.31		28.21	0.021

For Year of	1997					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	651.97	303.69	52.40	70.55	0.080
SW-2	797.48	912.28	251.69	117.57	93.76	0.129
SW-3	183.65	914.79	58.12	149.33	27.43	0.163
SW-4	121.22	861.00	36.11	109.43	13.26	0.127
SW-5	109.27	915.00	34.59	123.66	13.51	0.135
SW-6	73.76	852.50	21.75	106.44	7.85	0.125
SW-7	83.14	835.75	24.04	97.77	8.13	0.117
SW-8	72.17	862.33	21.53	97.92	7.07	0.114
SW-9	36.13	853.00	10.66	100.16	3.62	0.117
SW-10	24.45	913.75	7.73	104.64	2.56	0.115
SW-11	28.60	825.50	8.17	65.31	1.87	0.079
SW-12	14.25	911.50	4.49	66.31	0.94	0.073
Total	2,890.52		782.58		250.54	0.111

For Year of	1998					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	477.99	222.65	26.14	35.20	0.055
SW-2	797.48	642.13	177.16	88.08	70.24	0.137
SW-3	183.65	786.14	49.95	79.11	14.53	0.101
SW-4	121.22	659.33	27.65	72.24	8.76	0.110
SW-5	109.27	648.67	24.52	29.81	3.26	0.046
SW-6	73.76	624.00	15.92	61.79	4.56	0.099
SW-7	83.14	574.25	16.52	93.24	7.75	0.162
SW-8	72.17	569.67	14.22	83.52	6.03	0.147
SW-9	36.13	528.50	6.61	69.25	2.50	0.131
SW-10	24.45	562.75	4.76	66.87	1.64	0.119
SW-11	28.60	542.00	5.36	74.79	2.14	0.138
SW-12	14.25	562.00	2.77	58.56	0.83	0.104
Total	2,890.52		568.09		157.43	0.096

For Year of	1999					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	321.34	149.68	2.12	2.85	0.007
SW-2	797.48	402.33	111.00	13.21	10.54	0.033
SW-3	183.65	385.57	24.50	14.19	2.61	0.037
SW-4	121.22	382.50	16.04	4.54	0.55	0.012
SW-5	109.27	372.50	14.08	4.83	0.53	0.013
SW-6	73.76	402.00	10.26	7.36	0.54	0.018
SW-7	83.14	391.50	11.26	27.02	2.25	0.069
SW-8	72.17	383.33	9.57	19.05	1.38	0.050
SW-9	36.13	378.50	4.73	14.21	0.51	0.038
SW-10	24.45	372.25	3.15	19.50	0.48	0.052
SW-11	28.60	385.00	3.81	13.57	0.39	0.035
SW-12	14.25	362.50	1.79	14.15	0.20	0.039
Total	2,890.52		359.87		22.82	0.022

For Year of	2000					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	288.82	134.53	10.35	13.93	0.036
SW-2	797.48	410.73	113.32	30.80	24.56	0.075
SW-3	183.65	377.79	24.00	26.74	4.91	0.071
SW-4	121.22	413.67	17.35	21.37	2.59	0.052
SW-5	109.27	421.33	15.93	23.95	2.62	0.057
SW-6	73.76	408.75	10.43	17.84	1.32	0.044
SW-7	83.14	375.75	10.81	18.22	1.52	0.048
SW-8	72.17	374.00	9.34	13.94	1.01	0.037
SW-9	36.13	372.00	4.65	21.95	0.79	0.059
SW-10	24.45	376.00	3.18	22.87	0.56	0.061
SW-11	28.60	374.50	3.71	12.35	0.35	0.033
SW-12	14.25	378.00	1.86	22.17	0.32	0.059
Total	2,890.52		349.10		54.47	0.054

For Year of	2001					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	372.39	173.46	6.01	8.10	0.016
SW-2	797.48	490.23	135.25	35.00	27.91	0.071
SW-3	183.65	479.14	30.44	24.45	4.49	0.051
SW-4	121.22	491.00	20.59	42.33	5.13	0.086
SW-5	109.27	492.00	18.60	35.62	3.89	0.072
SW-6	73.76	498.00	12.71	42.75	3.15	0.086
SW-7	83.14	464.00	13.35	23.72	1.97	0.051
SW-8	72.17	468.33	11.69	18.81	1.36	0.040
SW-9	36.13	458.50	5.73	23.46	0.85	0.051
SW-10	24.45	468.25	3.96	21.78	0.53	0.047
SW-11	28.60	459.50	4.55	17.76	0.51	0.039
SW-12	14.25	464.50	2.29	22.99	0.33	0.049
Total	2,890.52		432.62		58.22	0.047

For Year of	2002					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	408.91	190.47	8.40	11.31	0.021
SW-2	797.48	649.70	179.25	56.54	45.09	0.087
SW-3	183.65	653.93	41.55	57.00	10.47	0.087
SW-4	121.22	620.67	26.03	51.38	6.23	0.083
SW-5	109.27	630.17	23.82	52.76	5.76	0.084
SW-6	73.76	613.50	15.66	41.29	3.05	0.067
SW-7	83.14	604.25	17.38	54.57	4.54	0.090
SW-8	72.17	613.33	15.31	51.55	3.72	0.084
SW-9	36.13	581.00	7.26	38.99	1.41	0.067
SW-10	24.45	594.50	5.03	39.47	0.97	0.066
SW-11	28.60	594.50	5.88	36.13	1.03	0.061
SW-12	14.25	592.50	2.92	29.08	0.41	0.049
Total	2,890.52		530.56		93.98	0.061

For Year of	2003					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	541.68	252.32	64.34	86.63	0.119
SW-2	797.48	768.40	212.00	149.73	119.41	0.195
SW-3	183.65	792.36	50.34	153.44	28.18	0.194
SW-4	121.22	747.83	31.36	149.53	18.13	0.200
SW-5	109.27	773.33	29.23	140.79	15.38	0.182
SW-6	73.76	739.50	18.87	136.64	10.08	0.185
SW-7	83.14	704.75	20.27	111.67	9.28	0.158
SW-8	72.17	701.33	17.51	101.67	7.34	0.145
SW-9	36.13	679.00	8.49	128.63	4.65	0.189
SW-10	24.45	676.00	5.72	111.01	2.71	0.164
SW-11	28.60	702.00	6.95	100.72	2.88	0.143
SW-12	14.25	671.50	3.31	85.85	1.22	0.128
Total	2,890.52		656.37		305.90	0.161

For Year of	2004					
SW-Name	Area (Km^2)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm^3)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	422.41	196.76	15.03	20.23	0.036
SW-2	797.48	526.75	145.33	37.96	30.27	0.072
SW-3	183.65	577.71	36.71	34.03	6.25	0.059
SW-4	121.22	522.00	21.89	24.34	2.95	0.047
SW-5	109.27	515.67	19.49	37.90	4.14	0.074
SW-6	73.76	521.50	13.31	33.46	2.47	0.064
SW-7	83.14	501.50	14.42	43.05	3.58	0.086
SW-8	72.17	510.33	12.74	39.55	2.85	0.077
SW-9	36.13	484.50	6.06	32.16	1.16	0.066
SW-10	24.45	497.25	4.21	40.32	0.99	0.081
SW-11	28.60	489.00	4.84	29.09	0.83	0.059
SW-12	14.25	497.50	2.45	24.14	0.34	0.049
Total	2,890.52		478.20		76.08	0.055

For Year of	2005					
SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	379.34	176.70	20.27	27.29	0.053
SW-2	797.48	521.90	143.99	33.47	26.69	0.064
SW-3	183.65	509.00	32.34	37.29	6.85	0.073
SW-4	121.22	559.17	23.45	35.68	4.32	0.064
SW-5	109.27	544.67	20.59	37.79	4.13	0.069
SW-6	73.76	558.50	14.25	32.64	2.41	0.058
SW-7	83.14	458.75	13.20	15.75	1.31	0.034
SW-8	72.17	461.67	11.53	22.07	1.59	0.048
SW-9	36.13	427.50	5.34	2.57	0.09	0.006
SW-10	24.45	436.25	3.69	6.29	0.15	0.014
SW-11	28.60	442.50	4.38	0.25	0.01	0.001
SW-12	14.25	432.50	2.13	1.57	0.02	0.004
Total	2,890.52		451.58		74.87	0.057

For Year of	2006					
SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	577.27	268.89	28.09	37.82	0.049
SW-2	797.48	800.28	220.79	72.97	58.19	0.091
SW-3	183.65	852.93	54.19	104.36	19.17	0.122
SW-4	121.22	788.17	33.05	69.53	8.43	0.088
SW-5	109.27	811.17	30.66	103.87	11.35	0.128
SW-6	73.76	751.75	19.18	62.99	4.65	0.084
SW-7	83.14	744.50	21.41	70.08	5.83	0.094
SW-8	72.17	750.67	18.74	63.89	4.61	0.085
SW-9	36.13	737.00	9.21	58.88	2.13	0.080
SW-10	24.45	750.75	6.35	72.83	1.78	0.097
SW-11	28.60	743.00	7.35	58.68	1.68	0.079
SW-12	14.25	750.00	3.70	67.31	0.96	0.090
Total	2,890.52		693.54		156.59	0.078

For Year of	2007					
SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	440.91	205.38	24.81	33.40	0.056
SW-2	797.48	506.53	139.75	54.24	43.26	0.107
SW-3	183.65	497.64	31.62	34.88	6.41	0.070
SW-4	121.22	539.17	22.61	60.68	7.36	0.113
SW-5	109.27	522.33	19.75	58.17	6.36	0.111
SW-6	73.76	543.00	13.86	53.92	3.98	0.099
SW-7	83.14	477.50	13.73	28.58	2.38	0.060
SW-8	72.17	482.67	12.05	22.62	1.63	0.047
SW-9	36.13	462.00	5.77	31.13	1.12	0.067
SW-10	24.45	493.25	4.17	33.16	0.81	0.067
SW-11	28.60	468.50	4.64	18.89	0.54	0.040
SW-12	14.25	498.50	2.46	23.36	0.33	0.047
Total	2,890.52		475.78		107.57	0.078

For Year of	2008					
SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	467.38	217.70	18.32	24.66	0.039
SW-2	797.48	603.00	166.36	61.31	48.90	0.102
SW-3	183.65	627.21	39.85	66.35	12.18	0.106
SW-4	121.22	648.17	27.18	56.87	6.89	0.088
SW-5	109.27	650.67	24.60	107.54	11.75	0.165
SW-6	73.76	646.75	16.50	75.47	5.57	0.117
SW-7	83.14	504.75	14.52	52.20	4.34	0.103
SW-8	72.17	506.33	12.64	41.55	3.00	0.082
SW-9	36.13	473.00	5.91	29.81	1.08	0.063
SW-10	24.45	475.00	4.02	23.79	0.58	0.050
SW-11	28.60	489.50	4.84	28.75	0.82	0.059
SW-12	14.25	467.00	2.30	11.80	0.17	0.025
Total	2,890.52		536.44		119.94	0.077

For Year of	2009					
SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	326.38	152.03	11.91	16.03	0.036
SW-2	797.48	451.05	124.44	24.54	19.57	0.054
SW-3	183.65	466.57	29.64	25.43	4.67	0.055
SW-4	121.22	469.50	19.69	25.88	3.14	0.055
SW-5	109.27	464.33	17.55	24.45	2.67	0.053
SW-6	73.76	461.50	11.78	33.61	2.48	0.073
SW-7	83.14	414.75	11.93	6.00	0.50	0.014
SW-8	72.17	403.00	10.06	3.16	0.23	0.008
SW-9	36.13	408.50	5.11	7.00	0.25	0.017
SW-10	24.45	418.25	3.54	5.03	0.12	0.012
SW-11	28.60	413.00	4.09	2.68	0.08	0.006
SW-12	14.25	420.00	2.07	2.70	0.04	0.006
Total	2,890.52		391.92		49.78	0.044

For Year of	2010					
SW-Name	Area (Km²)	Annual RF. (mm)	W. Avg. RF (mm)	Runoff depth (mm)	Runoff volume (Mm³)	Runoff factor
(A)	(B)	(C)	(D) = (B*C)/ AT	(E)	(F)= (B*E)	(G) =(E/C)
SW-1	1,346.40	396.85	184.85	12.84	17.29	0.032
SW-2	797.48	548.30	151.27	50.33	40.14	0.092
SW-3	183.65	573.07	36.41	51.09	9.38	0.089
SW-4	121.22	554.50	23.25	71.19	8.63	0.128
SW-5	109.27	553.67	20.93	52.75	5.76	0.095
SW-6	73.76	539.25	13.76	80.07	5.91	0.148
SW-7	83.14	487.50	14.02	32.82	2.73	0.067
SW-8	72.17	493.00	12.31	31.96	2.31	0.065
SW-9	36.13	483.50	6.04	13.40	0.48	0.028
SW-10	24.45	494.50	4.18	17.02	0.42	0.034
SW-11	28.60	489.00	4.84	17.87	0.51	0.037
SW-12	14.25	499.00	2.46	11.49	0.16	0.023
Total	2,890.52		474.34		93.73	0.068

For Year of 2011

SW-Name (A)	Area (Km^2) (B)	Annual RF. (mm) (C)	W. Avg. RF (mm) (D) = (B*C)/ AT	Runoff depth (mm) (E)	Runoff volume (Mm^3) (F)= (B*E)	Runoff factor (G) =(E/C)
SW-1	1,346.40	453.86	211.41	17.08	23.00	0.038
SW-2	797.48	642.40	177.23	80.54	64.23	0.125
SW-3	183.65	685.50	43.55	68.23	12.53	0.100
SW-4	121.22	637.83	26.75	68.36	8.29	0.107
SW-5	109.27	659.00	24.91	78.75	8.60	0.119
SW-6	73.76	615.75	15.71	69.24	5.11	0.112
SW-7	83.14	608.00	17.49	54.02	4.49	0.089
SW-8	72.17	611.33	15.26	50.25	3.63	0.082
SW-9	36.13	590.00	7.37	70.77	2.56	0.120
SW-10	24.45	581.50	4.92	74.19	1.81	0.128
SW-11	28.60	601.00	5.95	41.47	1.19	0.069
SW-12	14.25	572.00	2.82	57.69	0.82	0.101
Total	2,890.52		553.38		136.25	0.085

For Year of 2012

SW-Name (A)	Area (Km^2) (B)	Annual RF. (mm) (C)	W. Avg. RF (mm) (D) = (B*C)/ AT	Runoff depth (mm) (E)	Runoff volume (Mm^3) (F)= (B*E)	Runoff factor (G) =(E/C)
SW-1	1,346.40	519.22	241.85	18.72	25.21	0.036
SW-2	797.48	601.38	165.92	55.69	44.42	0.093
SW-3	183.65	667.64	42.42	74.24	13.63	0.111
SW-4	121.22	640.50	26.86	71.17	8.63	0.111
SW-5	109.27	621.17	23.48	73.20	8.00	0.118
SW-6	73.76	637.00	16.25	82.21	6.06	0.129
SW-7	83.14	521.50	15.00	42.50	3.53	0.081
SW-8	72.17	528.33	13.19	35.32	2.55	0.067
SW-9	36.13	507.00	6.34	35.70	1.29	0.070
SW-10	24.45	524.50	4.44	34.66	0.85	0.066
SW-11	28.60	512.50	5.07	31.32	0.90	0.061
SW-12	14.25	519.50	2.56	35.09	0.50	0.068
Total	2,890.52		563.38		115.56	0.071

For Year of 2013

SW-Name (A)	Area (Km^2) (B)	Annual RF. (mm) (C)	W. Avg. RF (mm) (D) = (B*C)/ AT	Runoff depth (mm) (E)	Runoff volume (Mm^3) (F)= (B*E)	Runoff factor (G) =(E/C)
SW-1	1,346.40	652.54	303.95	30.60	41.20	0.047
SW-2	797.48	793.73	218.98	89.70	71.53	0.113
SW-3	183.65	819.14	52.04	99.35	18.25	0.121
SW-4	121.22	834.50	35.00	81.50	9.88	0.098
SW-5	109.27	813.33	30.75	80.85	8.83	0.099
SW-6	73.76	840.50	21.45	85.00	6.27	0.101
SW-7	83.14	711.50	20.46	102.79	8.55	0.144
SW-8	72.17	706.33	17.64	81.76	5.90	0.116
SW-9	36.13	691.00	8.64	87.83	3.17	0.127
SW-10	24.45	697.75	5.90	71.18	1.74	0.102
SW-11	28.60	707.00	7.00	84.45	2.42	0.119
SW-12	14.25	704.50	3.47	47.10	0.67	0.067
Total	2,890.52		725.28		178.41	0.085

For Year of 2014

SW-Name (A)	Area (Km^2) (B)	Annual RF. (mm) (C)	W. Avg. RF (mm) (D) = (B*C)/ AT	Runoff depth (mm) (E)	Runoff volume (Mm^3) (F)= (B*E)	Runoff factor (G) =(E/C)
SW-1	1,346.40	434.20	202.25	16.41	22.10	0.038
SW-2	797.48	596.53	164.58	63.47	50.62	0.106
SW-3	183.65	591.79	37.60	25.57	4.70	0.043
SW-4	121.22	594.50	24.93	50.49	6.12	0.085
SW-5	109.27	601.17	22.73	62.08	6.78	0.103
SW-6	73.76	575.00	14.67	50.29	3.71	0.087
SW-7	83.14	569.25	16.37	51.47	4.28	0.090
SW-8	72.17	562.00	14.03	33.72	2.43	0.060
SW-9	36.13	574.50	7.18	44.16	1.60	0.077
SW-10	24.45	563.75	4.77	14.55	0.36	0.026
SW-11	28.60	579.50	5.73	32.55	0.93	0.056
SW-12	14.25	565.00	2.79	15.24	0.22	0.027
Total	2,890.52		517.63		103.84	0.069

For Year of 2015

SW-Name (A)	Area (Km^2) (B)	Annual RF. (mm) (C)	W. Avg. RF (mm) (D) = (B*C)/ AT	Runoff depth (mm) (E)	Runoff volume (Mm^3) (F)= (B*E)	Runoff factor (G) =(E/C)
SW-1	1,346.40	469.58	218.73	27.67	37.26	0.059
SW-2	797.48	573.60	158.25	25.38	20.24	0.044
SW-3	183.65	562.29	35.72	24.54	4.51	0.044
SW-4	121.22	582.17	24.41	42.87	5.20	0.074
SW-5	109.27	581.50	21.98	44.47	4.86	0.076
SW-6	73.76	568.50	14.51	40.57	2.99	0.071
SW-7	83.14	552.25	15.88	29.27	2.43	0.053
SW-8	72.17	556.00	13.88	22.06	1.59	0.040
SW-9	36.13	552.00	6.90	24.22	0.87	0.044
SW-10	24.45	557.00	4.71	32.86	0.80	0.059
SW-11	28.60	559.00	5.53	14.23	0.41	0.025
SW-12	14.25	557.50	2.75	23.41	0.33	0.042
Total	2,890.52		523.27		81.50	0.054

For Year of 2016

SW-Name (A)	Area (Km^2) (B)	Annual RF. (mm) (C)	W. Avg. RF (mm) (D) = (B*C)/ AT	Runoff depth (mm) (E)	Runoff volume (Mm^3) (F)= (B*E)	Runoff factor (G) =(E/C)
SW-1	1,346.40	438.95	204.46	30.93	41.65	0.070
SW-2	797.48	555.85	153.36	66.97	53.41	0.120
SW-3	183.65	540.93	34.37	72.01	13.22	0.133
SW-4	121.22	560.17	23.49	72.20	8.75	0.129
SW-5	109.27	550.83	20.82	73.38	8.02	0.133
SW-6	73.76	551.75	14.08	73.42	5.42	0.133
SW-7	83.14	523.50	15.06	68.95	5.73	0.132
SW-8	72.17	536.67	13.40	56.32	4.06	0.105
SW-9	36.13	528.50	6.61	70.92	2.56	0.134
SW-10	24.45	538.00	4.55	78.81	1.93	0.146
SW-11	28.60	520.50	5.15	58.85	1.68	0.113
SW-12	14.25	527.00	2.60	73.82	1.05	0.140
Total	2,890.52		497.94		147.49	0.102