



**ETHIOPIAN INSTITUTE OF
WATER RESOURCES**

**ETHIOPIAN INSTITUTE OF WATER RESOURCE
ENGINEERING AND MANAGMENT**

Research

On

**RAINFALL-RUN-OFF SIMULATION AND MODELING
(THE CASE OF DECHATU WATERSHED)**

**Submitted in Partial Fulfilments of the Requirement for the Award of
Master of Science (MSc) in Water Resources Engineering and
Management**

By

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ABSTRACT

This paper presents an application of surface rainfall run-off simulation using the Hydrologic Modelling System (HEC-HMS). A case study was carried out for the Dechatu watershed, a Rainfall is classified as “bi-modal” with the first significant rains from March to May and the second rains from is July to Septembertypical semi-arid and sub-humid geo-climatic region in eastern Ethiopia Awash River basin. The modeling schemes using mechanism of models provided by HEC-HMS for runoff volume. The modeling results were compared with historical observation data.

Several River Basins (Watershed) across the world have been simulated using hydrological models to understand hydrological processes and the availability of water resource. Some of these basins are ungauged. In this study in order to evaluate the hydrological process of Dechatu Watershed for sustainable management; HEC-HMS 4.2 hydrologic model (with CN) is used to simulate its runoff (Watershed Modelling) was used as an interface to delineate the watershed and generate some input (basins parameters). The CNparameters are computed in HEC-GeoHMS using land use and soil type data.Using the Chi-Squared test ranking, Dengego rainfall data fits Lognormal 3 parameter distribution.

Annual Maximum Daily Rainfall (mm) for selected return periods50years were used for the meteorological inputs. The results showed a total volume of runoff 150.20MM³ during the fifty years of the simulation. The peak discharge was found to be 2,528.7m³ /s and the model evaluation has showed, indicating that the results of the simulation are satisfactory.

List of Figure

FIGURE 1 LOCATION AND MAP OF DECHATU WATERSHED DIRE DAWA ADMINISTRATE.....	6
FIGURE 2. SLOPE MAP OF DECHATU CATCHMENT	7
FIGURE 3. REPRESENTATION OF RAINFALL RUNOFF PROCESS.....	21
FIGURE 4 MODELING APPROACH RAINFALL RUNOFF MODELING	30
FIGURE 5. THE HYDROLOGICAL MODEL IMPLEMENTED IN HEC-HMS.	34
FIGURE 6 MEAN MONTHLY RAINFALL (MM) DENGEGO STATION RAIN FALL.....	34
FIGURE 7. DEM OF DECHATU RIVER WATERSHED AREA	36
FIGURE 8. SOIL MAP OF DECHATU RIVER WATERSHED.....	37
FIGURE 9. LAND USE\LAND COVER MAP 1985. (LANDSAT MSS 1985).....	40
FIGURE 10 LAND USE\LAND COVER MARCH (LANDSAT TM 2000).....	41
FIGURE 11 LAND USE\LAND COVER (LANDSAT ETM + 2014).....	42
FIGURE 12 FREQUENCY ANNUAL DAILY MAXIMUM RF VALUES USING GUMBEL (EV1).....	45
FIGURE 13. GRAIN SIZE FREQUENCY DISTRIBUTION AND MATERIAL AT THE FLOW GAUGE REACH	48
FIGURE 14 DECHATU RIVER FLOW	49
FIGURE 15. LOGNORMAL, GAMBEL, LOG PEARSON III.....	58
FIGURE 16 GRAPH OF DECHATU PEAK FLOOD OF 6 HOUR.....	59
FIGURE 17 PEAK INFLOW & PEAK DISCHARGE.....	60
FIGURE 18. TIME SERIOUS RESULT	60
FIGURE 19. DISCHARGE VS. RETURN PERIOD.....	64

LIST OF TABLESPage

FIGURE 1 LOCATION AND MAP OF DECHATU WATERSHED DIRE DAWA ADMINISTRATE.....	6
FIGURE 2. SLOPE MAP OF DECHATU CATCHMENT	7
FIGURE 3. REPRESENTATION OF RAINFALL RUNOFF PROCESS.....	21
FIGURE 4 MODELING APPROACH RAINFALL RUNOFF MODELING	30
FIGURE 5. THE HYDROLOGICAL MODEL IMPLEMENTED IN HEC-HMS.	34
FIGURE 6 MEAN MONTHLY RAINFALL (MM) DENGEGO STATION RAIN FALL.....	34
FIGURE 7. DEM OF DECHATU RIVER WATERSHED AREA	36
FIGURE 8. SOIL MAP OF DECHATU RIVER WATERSHED.....	37

FIGURE 9. LAND USE\LAND COVER MAP 1985. (LANDSAT MSS 1985).....	40
FIGURE 10 LAND USE\LAND COVER MARCH (LANDSAT TM 2000).....	41
FIGURE 11 LAND USE\LAND COVER (LANDSAT ETM + 2014).....	42
FIGURE 12 FREQUENCY ANNUAL DAILY MAXIMUM RF VALUES USING GUMBEL (EV1).....	45
FIGURE 13. GRAIN SIZE FREQUENCY DISTRIBUTION AND MATERIAL AT THE FLOW GAUGE REACH	48
FIGURE 14 DECHATU RIVER FLOW	49
FIGURE 15. LOGNORMAL, GAMBEL, LOG PEARSON III.....	58
FIGURE 16 GRAPH OF DECHATU PEAK FLOOD OF 6 HOUR.....	59
FIGURE 17 PEAK INFLOW & PEAK DISCHARGE.....	60
FIGURE 18. TIME SERIOUS RESULT	60
FIGURE 19. DISCHARGE VS. RETURN PERIOD	64

Table of Contents

Page

CHAPTER ONE.....	1
1. INTRODUCTION	1
1.1 General Background.....	1
1.2 Scope of the problem.....	2
1.2. Statement of the Problem	3
1.3. Objectives.....	4
1.3.1. Specific objectives of the studies are.....	4
1.4. Research questions.....	5
1.5. Significance of the Study	5
CHAPTER TWO.....	6
2. DESCRIPTION OF THE STUDY AREA	6
2.1. Location.....	6
2.2. Physiography	7
2.3. Climate and rainfall.....	8
2.4. Regional hydrology	9
2.5. Geology	11
2.6 Selection of hydrological model.....	11
2.7. Reason for selection of (HEC-HMS) model.....	12
2.8. Meteorological Data Analysis	13
2.9. Filling Missed Meteorological data's.....	13
2.10. Data Quality Assessment.....	14
2.11. Test for Absence of trend	14
2.12. Test for stationery.....	15
2.13 Test for homogeneity	15
2.14. Test for Consistency	16
2.15. Data Available.....	16
CHAPTER THREE	18

3.0 LITERATURE REVIEW	18
3.1. General.....	18
3.1.1 Model and software description	18
3.1.2 ArcGIS: HEC-GeoHMS	18
3.1.3. Hydrological Modeling	19
3.1.4 Rainfall Runoff Model: HEC-HMS	20
3.1.5. Basin Model.....	22
2.1.6 Flood frequency analysis	24
3.1.7. Previous studies of the area	25
4.5. Runoff Estimation	28
4.0 METHODOLOGY.....	30
4.1 Hydrological Model Development	30
4.2. Terrain Pre-processing	31
4.3. Developing hydrological parameters	31
4.4 Developing HEC-HMS model files:.....	33
4.6. Model Inputs	35
4.7. Digital Elevation Model (DEM).....	35
4.8. Soil Data and Maps (Hydrologic Soil Groups).....	36
4.9. GIS based land use/cover change assessment	39
4.10 Rainfall Frequency.....	44
4.11 Rainfall Frequency Analysis	44
4.12 Rainfall Intensity	44
4.13 Main rivers and run-off characteristics.....	45
4.17. Peak Flow Analysis	50
4.18. Extreme value I distribution	50
4.19. EVI–Gumbel distribution by the method of moments.....	53
4.20 Log Pearson type III distribution.....	54
5.0 Results and Discussion	57
5.1. The Runoff-Volume Models.....	57
5.2. Flood Flows.....	63
5.3. Land use-land cover and changes in Dechatu watershed.....	65
6. Discussion.....	67
7.0 Conclusion	69
Reference.....	71

ABBREVIATIONS

DDAC	Dire Dawa Administrative Council
DD	Dire Dawa
DEM	Digital Elevation Model
E	East
EQN	Equation
ERA	Ethiopian Roads Authority
FUPI	Federal Urban Planning Institute
Geo	Geographical
GIS	Geographical Information Systems
GUI	Graphical User Interface
HEC	Hydrologic Engineering Centre
HMS	Hydrologic Modelling System
Km	Kilometer
M	Million
m	Meter
masl	meter above sea level
mm	millimeter
MoWR	Ministry of Water Resources
N	North
PET	Potential Evapo-Transpiration
RAS	River Analysis System
SCS	Soil Conservation Service
Sec	Second
U.S.	United States
UH	Unit Hydrograph
Yr	year

CHAPTER ONE

1. INTRODUCTION

1.1 General Background

Water is the most vital resource to support all forms of life on earth. It will remain essential for mankind survival and the future development of the world. Water is not evenly distributed over the world by season or location, i.e. global fresh water distribution is neither uniform in space nor in time. Some parts of the world are prone to drought making water scarce and precious commodity, while in other parts of the world it appears in raging torrents causing floods and loss of life and property.

Ethiopia, often referred to as the water tower of East Africa, is dominated by mountainous topography, and the rainfall-runoff processes on the mountainous slopes are the source of the surface water for much of Ethiopia (Derib, 2009), and thus, understanding the rainfall-runoff processes is critical to controlling erosion and enhancing agricultural productivity. The majority of the sedimentation of rivers in the basin occurs during the early period of the rainy season and peaks of sediment are consistently measured before peaks of discharge for a given rainy season (Steenhuis, 2009). In fact, while the primary cause of flooding is abnormally high rainfall, there are many human-induced contributory causes such as land degradation, deforestation of catchment areas, increased population density along riverbanks, poor land use planning, zoning and control of flood plain development, inadequate drainage, particularly in cities, and inadequate management of discharges from river reservoirs (Mulugeta, 2007). In Ethiopia, a research in Awash River basin by (Terefe, 2006) indicates that human factor plays a crucial role in causing frequent flood disasters in upper, middle, and lower Awash. Moreover, projections of flood changes at river basin scale are scarce in the scientific with the alteration of natural environment due to human interventions together with the effects of global climate change, recent years have seen floods to occur more frequently and unpredictably across the globe. Urbanization and changing of demographic features within the river flood plain has led to increased exposure of communities to flood hazard. A model simulation through calibration and validation with measured values (Sultan, 2017). In the absence of extensive field studies and runoff measurements, models have been used to estimate site specific information (Hadadin, 2013) Several approaches can be used to estimate runoff, from simple empirical rainfall-

runoff models to conceptual and highly parameterized process-based models (Haregeweyn, 2016). The common method for predicting event-based surface runoff volume from small watersheds is the Soil Conservation Service Curve Number (SCS-CN) method (SCS 1972).

A rainfall runoff modelling (hydrological) anticipate evaluating the runoff from precipitation in a catchment and hydraulic modelling aims to evaluate magnitude of floods and the area inundated by them. Combination of both will result in runoff simulation and flood inundation levels. The flood at times of unusually high rainy days over top the normal flood ways and create a lot of calamity to the residents of Dire Dawa city. Several flash floods events occurred pass through the city every year, and caused a lot of distraction on properties and people. a major flood swept through Dire Dawa city sequence of floods that occurred in 1981, 1994, 2004, and 2005 (Demessie, 2007; Alemu 2009; DDAEPA 2011) that caused significant fatalities and damages to property, on August 6, 2006, the city of Dire Dawa experienced one of the largest and the most devastating flood ever. The area inundated during the 2006 flood was about 1 km² and 86 % of this area was covered by 1–2 m of water (Alemu, 2009). Although, on the night of 5/6 August 2006, resulting in over 300 fatalities and significant damage to the flood defenses, public infrastructure, housing and livelihoods. Often causing loss of life and damage to property and infrastructure presently in the existing situation like this, it is important to consider major factors that contributed most in the past flood hazard calamities. It has of paramount importance to take notice of these factors to arrive at wise and comprehensive solution towards mitigating the challenge (that is flooding) which is erratic and unpredictable. Such regions are exposed to the hazard that the available fresh water resources fail to meet the water demand in the domestic, agricultural and industrial sectors.

1.2 Scope of the problem

In Africa floods are among the most devastating natural hazards, whereas flash floods are among the greatest hazards arising from tropical cyclones and severe storms. Floods and flash floods cause loss of life, damage to property, and promote the spread of diseases such as malaria, dengue fever, and cholera. From 1,900 to 2006, floods in Africa killed nearly 20 000 people and affected nearly 40 million more, and caused damage estimated at about US\$4 billion (ICSUAfrica, 2007). Water related disasters increased more than four folds in Africa (Adikari, 2008). According to World Bank (2003), in most developing

countries flood disasters still claim tens of thousands of lives each year and destroy livelihoods in an instant

Ethiopia's topographic characteristics has made the country pretty vulnerable to floods and resulting destruction and loss to life, economic, livelihoods, infrastructure, services and health system (DPPC, 2007).

Several factors could be mention as causes of flooding by different writers. Deforestation can impact hydrological processes, leading to localized declines in rainfall, and more rapid runoff of precipitation, causing flooding and soil erosion, a common phenomenon in most parts of Ethiopia (Dagnachew, 2003). On the other hand, the high infiltration rates under natural forests serve to reduce surface runoff and flood response. Certain types of plantation forests may also serve to increase infiltration rates through providing preferential flow pathways down both live and dead root channels. From the theoretical considerations it would be expected that interception of rainfall by forests would reduce floods by removing the proportion of the storm rainfall and by allowing the build-up of the soil moisture deficits (Calder, 1999).

According to (Dagnachewet, 2003), Land-use change due to the expansion of urban areas also affects the ground infiltration rate which in turn gives the way flooding to occur. Land-cover change has one of the causes of flooding phenomenon of the awash basin, which resulted in millions worth of resources lost nearly every main rainy season. Lowlevel vegetative cover could also affect infiltration and could lead to reduced groundwater levels and the base flow of streams. It is obvious that land-cover can affect both thedegree of infiltration and increases runoff following rainfall events (Dagnachewet, 2003)

1.2. Statement of the Problem

High flood, which is normally due to the intensive rainfall in the up lands of the watershed, sparse vegetation cover, steep slopes and low infiltration capacity of the ground surface, which makes the watershed susceptible to soil erosion, sedimentation and run-off contribution to the dawn stream area. (Wale and Mengistu, 2009). In developing countries, studies on ephemeral streams flash floods are uncommon and very few data are available to design appropriate risk mitigation countermeasures and warning systems. Various studies have indicated that it is not unusual to have high flow in the upper catchments and low or

zero flow at the downstream gauges (Renard et al. 1966; Cordery et al. 1983; Walters 1990; Al-Qurashi et al. 2008). Hughes and Sami 1992 studied two events in Cape Province, South Africa, and found that 75 and 22% of the flow volumes were lost to the alluvium and sand channel beds, respectively Ethiopia's topographic and climatic characteristics have made the country vulnerable to high floods that resulted in destruction, casualties and damages to economic, livelihoods, infrastructure, services, and health systems. In Ethiopia, flood disasters and the toll paid in terms of human lives and property damage show an increasing trend (Billi, Alemu and Ciampalini, 2015). Flash floods are formed from excess rain falling on upstream watersheds, flow down-stream with massive concentration, high speed, and typically occur suddenly (Lin, 1999). Heavy downpours in mountainous highlands can lead to surges of water that turn dry river beds or flood plains into raging torrents in minutes. Therefore, the damages of such floods become particularly pronounced and devastating when they pass across or along human settlements and infrastructures. In 2006, the town of Dire Dawa experienced a typical flash flood that, following the heavy rain on the upland areas of eastern Harerge highlands, within a few hours turned the dry bed of the Dechatu River into a swelling and devastating river that caused several casualties and property damage for millions of Euros. The problem of flash floods in the semiarid area of Dire Dawa is not new, but their frequency has significantly increased in the last decades (Alemu, 2009; DDAEPA, 2011). This flood affected more than 117,000 people (i.e., one-third of the town population) and officially resulted in the loss of 256 human lives and 244 missing. It caused also the worst property damages to housing and infrastructures in the town history with an estimated total damage of 10 million USD (Alemu, 2009).

1.3. Objectives

The main objective of this research to estimate the runoff catchment .This study seeks to develop hydrological and hydraulic models for Dechatu River. First objective is to estimate the Run-off modeling of Dire Dawa (Dechatu catchment) develop a physical based hydrological model with HEC-HMS software and simulate the effects of rainfall on surface runoff and flood discharges.

The main objective of this research proposal is to estimate the runoff catchment and intervention scenarios by using, Arc-Hydro, HEC-Geo-HMS, HEC- HMS.

1.3.1. Specific objectives of the studies are

1. To run the applicability of physical based model (HEC- HMS)& to estimate rainfall run-off yield from the study catchment.
2. To characterize the Runoff catchment yield.
3. To assess and evaluate the spatial variability of runoff yield in the watershed and identify priority hot spot areas.
4. To assess the impact of different catchment management interventions on runoff yield.

1.4. Research questions

1. How much Runoff yield estimated from Catchment?
2. Can Watershed management structures reduce the run-off yield in upstream catchment?
3. What is the systematic approach implement for Rain water retention andmanagement?
4. What is the impact of catchment management interventions on runoff yield?

1.5. Significance of the Study

- To understand hydrological processes and the availability ofwater resource.
- Reduced soil erosion from catchment, increased crop yields, improved management of community lands, improved water retention and supply, increased flood concentration time, improved access.
- Flood Protection Works and associated re-settlement and flood zoning.
- Early Warning System and Catchment Monitoring.
- Soil Conservation, Land Management and Rural Infrastructure reduced soil erosion from catchment, increased on-farm crop yields, improved management of community lands, improved water retention and supply, increased flood concentration time, improved access.

CHAPTER TWO

2. DESCRIPTION OF THE STUDY AREA

2.1. Location

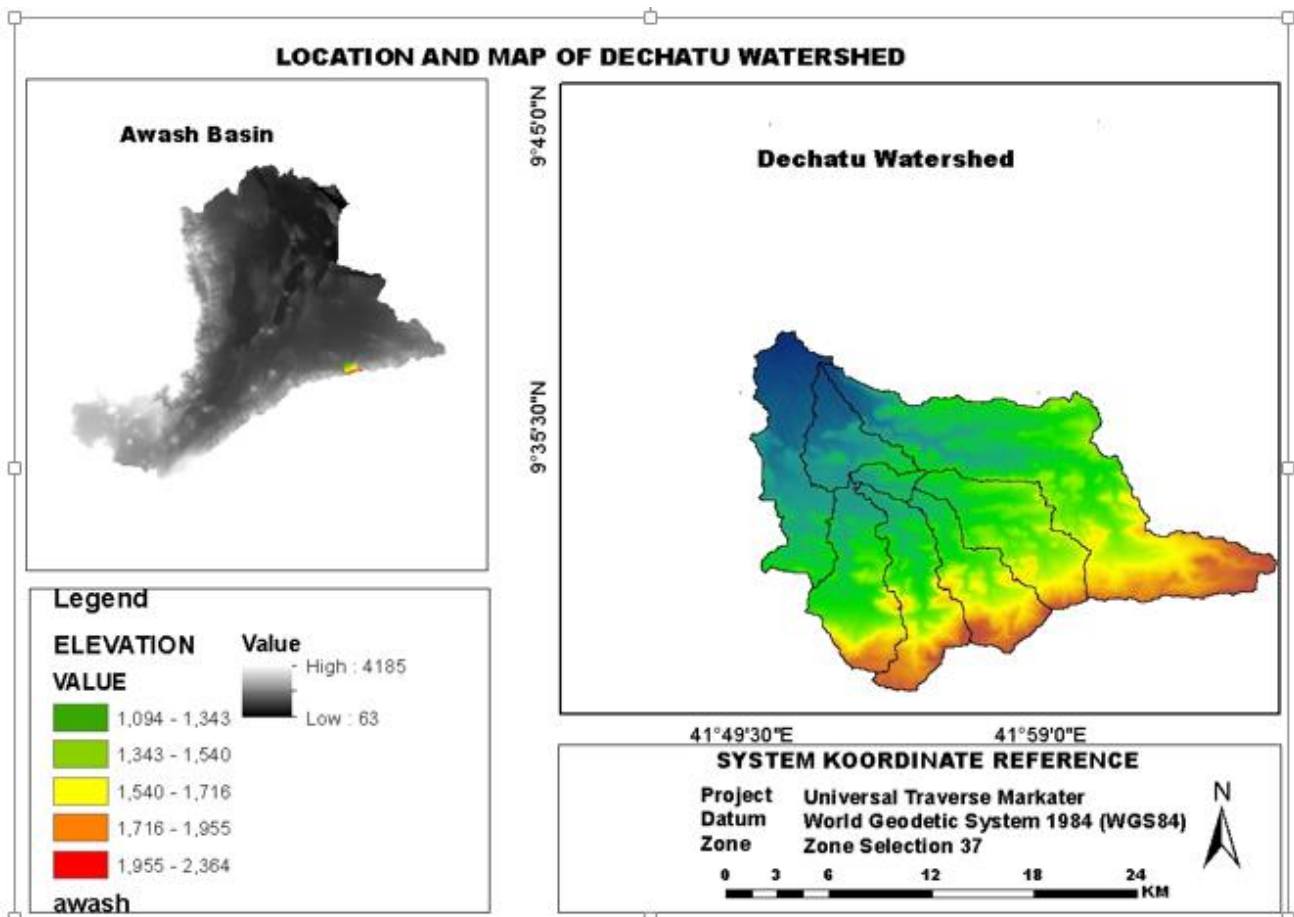


Figure 1 Location and map of Dechatu Watershed Dire Dawa Administrate

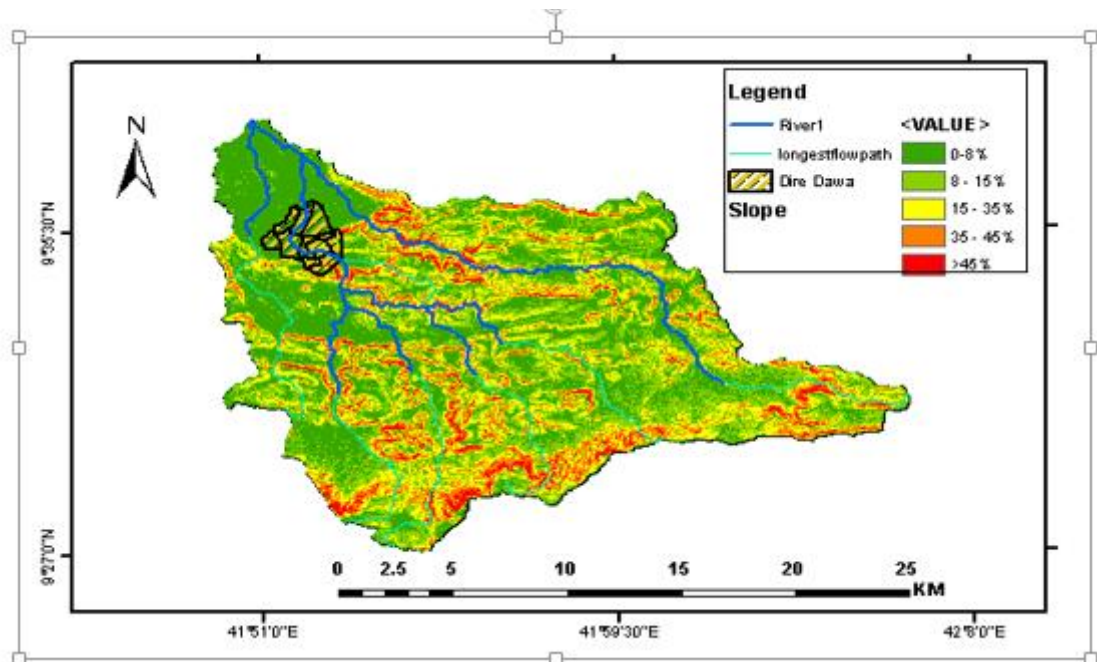
The Dire Dawa Administration is located in the eastern part of Ethiopia between geographic coordinates of $9^{\circ}27'N$ to $9^{\circ}50'N$ Latitude and $41^{\circ}38'$ to $42^{\circ}20'E$ Longitude. The Administration is bordered in the South by the East Haraghe Zone of the Oromia National Regional State, and in the East, West and North by the Shinile Zone of the Somali National Regional State. Dire Dawa city is accessible by airplane, train and cars, and is about 515kms road distance to the east of Addis Ababa and 311 kms to the west of Djibouti port. The total area of the region is about 128,802ha; out of this urban accounts for 2,684ha (2%) and the balance 98% is for rural (IDP, 2006). The total Dire Dawa area can

be divided in to three major areas; the south and south-eastern part of the city is characterized by a chain of mountains and upland at the foot of the mountain chain covering 45%; and low lying flat land (Ephrem, 2006).

2.2. Physiography

The Dire Dawa Administrative Council is generally situated within the altitude range of 950-2,260masl. The study area is characterized by very diverse spatial variation of topographic features. It ranges from very steep high mountains to flat plains with the general topography direction being from south towards the north.

Figure 2.Slope Map of Dechatu catchment



The physiography of The DDAC can be classified in to four major

The mountain ranges: - These mountainous areas are located at the southern, southwestern and southeastern parts of the Council and reach an altitude of some 2,321masl with slopes range of 30-56% and more. The major big waterways start from these mountainous area and most of the cultivable lands are located on the foot-slopes of these mountains and inter-ridge valleys on terraced lands.

The hills: - These are found scattered all over the watershed, with slope ranging between 16 and 30% with very shallow soils and composed mainly of stones and rock out-crops.

The valley bottoms and river terraces: - These are mainly found at the foot slopes of the mountain ranges and the river banks with relatively fertile and deep soils. The slope ranges from 0-5%. These are the units where the rain fed as well as the irrigated crop cultivation are concentrated.

The flat plains: - These are mostly concentrated in the northern, northeastern and northwestern part of the study area at an altitude of some 950 – 1000masl with slope ranging between 0-3 % and mainly used as grazing and browsing of the pastoral livestock types. These areas comprise of severely dissected undulating to rolling areas caused by erosion, especially along wadis (slope 2-8%) in the western plain area of shinile area and moderate to many low to high lying relief hills and rock outcrops in the eastern part especially in Kelead area.

2.3. Climate and rainfall

The climate is warm and dry with relatively low, erratic precipitation which exhibits spatial and temporal variability. The main rainfall mechanism is the Inter-Tropical Convergence Zone (ITCZ). The ITCZ is a low pressure converging zone of the dry tropical easterlies and moist equatorial westerlies. The position of ITCZ as it migrates north-south determines the season of the area. The advance of ITCZ to the north brings the spring rains in March. The Indian Ocean is the moisture source for these spring rains and the main summer rains are derived from the high pressure system from the Gulf of Guinea and Congo basin. The ITCZ returns southward in August and in October restoring the dry season. Rainfall data for the Dire Dawa station cover a 65 year period (1952-2016) and there are few missing data. The Dengego station rainfall record covers 1981 to 2016 with data missing for just 3 years (1992-94). The Kersa station rainfall record is the shortest of the three stations with just 35 years of data available from 1996 to 2016. Useful data are also available for two stations just outside the catchment. The annual average rainfall ranges in Kersa from 317 to 1,038 mm depending on the location and altitude (CRS/Ethiopia: Projects with ECC-SDCOH-Activity Report, November, 2006). The rainfall in Dire Dawa is highly variable from year to year and the mean annual rainfall is between 410 and 800mm (DDA, 2003,

Integrated Resource Development Master Plan study Project ,Volume III ,Water Resources)

The highest maximum daily rainfall recorded at any of the above three stations was at Kersa where 166 mm was measured on 15 April 2001. Very little or no rainfall was measured at the other two stations on the same date. 113 mm was recorded at Dire Dawa on 7 December 2003 in the dry season; again no or little rainfall was registered in the other two stations for the same date. This clearly indicates that extreme rainfall events generally have limited aerial coverage and are relatively unrelated to the amount of annual rainfall. In addition they do not necessarily occur during the main rainy season. Lower (in terms of the depth at any particular point) rainfall events can have much larger areal coverage. Floods generated from such storms will also have longer durations. Mean annual temperature ranges from 20-30°C and as a result potential evapo-transpiration is relatively high at 3,255 mm on average. Relative humidity at 36% and 40% at elevations of 1,200 masl and 1,800 masl respectively is relatively low. Traditionally Dire Dawa is classified between the Kolla and the Dry Weyna Dega agro-climatic zones. Kolla lies within the altitude range 500 to 1500 masl and has an annual rainfall of less than 900 mm. This is primarily found on the gently sloping and plain areas to the foothills and valley bottoms. The Dry Weyna Dega lies in the altitude range 1500 to 2300 masl and has an annual rainfall of 900 to 1400 mm. This zone is found on the Harar Plateau and parts of the escarpment (DDA, 2003, Integrated Resource Development Master Plan study Project ,Volume III ,Water Resources)

2.4. Regional hydrology

The entire Dechatu River watershed area lies in the Eastern Escarpment of the Awash River basin, which is one of the dryer regions of the basin (Figure 1). Since the administration found close to the watershed divide with Wabi-Shebele basin it has only covered small area. The study area is political boundary, the watersheds of the ephemeral streams cross the administration, and in some cases most of their watershed areas are outside the boundary of the administration. There is large topographic elevation difference in a short distance between the highlands and the rift floor. This favors high groundwater recharge in the areas where there are large faults.

The streams draining from the western Hararghe highlands disappear in the rift margin faults. This is clearly visible from satellite images and remote sensing. The presence of thick and wide sand deposits along the stream course may favor indirect recharge (channel losses) from rivers. Groundwater movement in the study area is mainly towards north similar to the surface flow. The main sources of the recharge to aquifer (groundwater replenishment) in basin are subsurface recharge from the escarpment zone, direct recharge from precipitation and recharge through river beds (wadi-gravel) during times of flow and rain events.

The climate of the study region is dominated by various inter factors, but the main factors are the near equator altitude. The year is divided into (Kiremt) from July to mid-October to February, and a "small rainy" season (April). The small rain, originate from the Indian Ocean and are brought by Northwest winds; w the Atlantic Ocean with north 9e northern parts most of location and the three seasons: a main rainy season-September, a dry season (Belg) in hile the heavy rains in the wet season come from-east winds. The southern parts of Council get, on the average, about 800 mm of rainfall per annum, while the northern and north-eastern parts receive about 400 mm annual rainfall. Which flow throughout the year as that of the regions of the country. Only few intermittent and perennial streams pre dominate the natural water flow system of the region. According to the study made by the agricultural development office of the DDAC in the year 1992 EC, the region has over 130 springs with different water discharging capacity and over 44 perennial and intermittent streams. The most important intermittent and perennial streams that drain the Dire Dawa region are Dechatu, Butiji, Lega Hare, Dube, Goro and Elbah WWDSE (2004).

There is large topographic elevation difference in a short distance between the highlands and the rift floor the area to drop its elevation from more than 2,200m at Dhangago to below 1000m at the north part of Shinile. Groundwater movement in the study area is mainly towards north similar to the surface flow. The main sources of the recharge to aquifer (groundwater replenishment) in basin are subsurface recharge from the escarpment zone, direct recharge from precipitation and recharge through riverbeds during times of flow and rain events.

2.5. Geology

The geology of the Administration has been studied or included in the studies conducted during different time periods with different scales and well documented. Some of the major studies include those conducted by the Geological Survey of Ethiopia and mapped at a scale of 1:2000, 000 (Mengesha et al., 1996; Kazmin, 1973), and the National Research Council of Italy done for Ethiopia and Somalia (Merla et al., 1973). These studies, owing to their coarse scale, only provided a broad view of geology of the area. These studies identified three main rock units formed during different periods.

Ethiopian Geological Survey also carried out geological mapping of the Dire Dawa Sheet (NC 37-12) at a scale of 1:250,000, which covered the DDAC up to 42o00' E longitude (Seife, 1985: cited in WWDSE, 2003). Greitze (1961, 1970) prepared a 1:40,000 scale geological map for the central part of the Administration. More recently, the Water Works Design and Supervision Enterprise conducted a study on geology and mineral resources of the Administration. General observation of geology and mineral resources was made, for these are substrates for the formation of soils. In areas where moisture is limiting and the dominant type of weathering is the physical one, the behavior of the local soils is very much affected by the parent material from which it was formed. According to this team, the major rocks identified in the Administration are dominantly granite, limestone, basalt, some unidentified metamorphic looking rocks, and unconsolidated sediments. The granite occupies the higher elevation areas around Dengego, while the limestone occupies extensive area in the lowlands.

2.6 Selection of hydrological model

Each model type serves a purpose, and a particular model type may not categorically be considered more appropriate than others in all situations. Choice of a suitable model structure relies heavily on the function that the model needs to serve.

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always project dependent, since every project has its own specific requirements and needs. Further, some criteria are also user-dependent (and therefore subjective). Among the various project-dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik):-

I. Required model outputs important to the project and therefore to be estimated by the model (Does the model predict the variables required by the project?).

II. Hydrologic processes that need to be modelled to estimate the desired outputs adequately (Is the model capable of simulating single-event or continuous Processes?)

III. Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the project?).

IV. Price (Does the investment appear to be worthwhile for the objectives of the project?).

The selection of model were by considering the above criteria's with inclusive of availability of data, level of application, purpose, required accuracy, space and time scale, catchment area, simplicity, previous trends(studies) in the surrounding area & Ethiopia as a whole. Considering all the criteria's set above data driven model (Artificial Neural network) and physical based models (SWAT) were adopted for this study.

2.7. Reason for selection of (HEC-HMS) model

HEC-HMS model was selected due to the following reasons:-

i. It has been indicated and tested by different researcher and journal paper that the model is calibrated and simulated with satisfactory results on Dechatu catchment.

ii. It has been tested that the model has obvious advantage as a hydrological modeling tool that includes modularity, computational efficiency, ability to predict long-term impacts as a continuous model, and ability to use readily available global datasets, availability of a reliable user and developer support has contributed to its acceptance as one of the most widely adopted and applied hydrological models worldwide.

iii. The model simulates the major hydrological process in the watersheds, less demanding on input data, and it is readily and freely available.

iv. Specifically the model was tested for prediction of runoff yield in Dechatu watershed with satisfying results, since HEC-HMS can be applied for the same land use /land cover and topographical conditions it will have good performance on watershed too. Moreover, projections of flood changes at river basin scale are scarce in the scientific

literature. These same limitations and uncertainties are presently effective also in Ethiopia. In the last decade, an increasing occurrence of floods is reported for Africa in general,

2.8. Meteorological Data Analysis

Meteorological data sets are the key inputs for hydrological modeling purpose, but the selection representative meteorological gauging station depends on the data availability (including existence of enough length of record and distance from the area of interest). Gauging stations were selected based on their relevance for the study. Nevertheless, daily meteorological data for only seven gauging stations were obtained from the Hydrology Department of the Ministry of Water Resources. Locations of these seven gauging stations are as in the Figure. Even if the Model (HEC-HMS) uses the nearest station from the centroid of each sub basin, the other unused station in the model are used for the purpose of filling in missed data and computation of areal rainfall.

Adequate number of gauging stations might have been established in the Blue Nile Basin. However, long records are not available at most of the stations and the reliability of available data is also questionable. The number of operational stream flow gauging stations has increased in recent years (MoWR, 2019). This might have been recorded as good change which may only be increase in number rather than quality oriented improvement. The Hydrological Department under the Ministry of Water Resources is responsible for hydrological and sediment data collection, processing and distribution to the data users.

2.9. Filling Missed Meteorological data's

Complete record of meteorological data is required for hydrological modeling and analysis. There exists small and large duration of missed records in the selected meteorological stations especially on rainfall and temperature. Data for the period of those missing data could be filled using estimation technique. Arithmetic mean, Normal ratio, Regression and distance power method are the most commonly used methods for estimation of missing rainfall & temperature data sets. Depending on the simplicity and length of missing data, regression and distance power method are selected for estimation of missing temperature & rainfall data.

Distance Power Method: The method is easy to use for fill in missing precipitation data (Hubbard, K.G, 1994). It is reliable if only the weather stations are situated inside of 100 Km radius (Tronci N, Molteni F, Bozzini, M, 1986).

The rainfall at a station is estimated as a weighted average of the observed rainfall at the neighboring stations. The weights are equal to the reciprocal of the distance or some power of the reciprocal of the distance of the estimator stations from the estimated stations. Let D_i be the distance of the estimator station from the estimated station. If the weights are an inverse square of distance, the estimated rainfall at point of interest (missed) is: Where P_i and P_A are precipitation at neighboring stations and at the target station respectively D_i is the distance between the target station and the neighboring stations, estimated as: Where X and Y are the coordinates of the station whose data is estimated and X_i and Y_i are the coordinates of stations whose data are used in estimation.

Regression Method: This method of data infilling is applied for gaps having short duration of missing value for temperature and precipitation by considering strong correlation from the existing stations.

2.10. Data Quality Assessment

Engineering studies of water resources development and management depends on hydrological and meteorological data. These data should be stationary, consistent, and homogeneous when they are used for frequency analyses or to simulate a hydrological system. To determine whether the data meet these criteria, the engineer needs a simple but efficient screening procedure statistical variability. Accordingly, in this study, the data quality assessment goes through the following key tests. Rough screening of the data and compute or verify the totals for the hydrological year test for Absence of trend Test for stationery of time series. Homogeneity Test Consistency test.

2.11. Test for Absence of trend

After plotting a time series, one must be sure that there is no correlation between the order in which the data have been collected and the increase (or decrease) in magnitude of those data. It is common practice to test the whole time series for absence of trend.

Accordingly test for absence trend is checked by applying spearman correlation method in this study as it was simple, distribution free and power full for both linear & nonlinear trend. Where n is the total number of sample data's, D is the difference and R_{sp} is spear man correlation coefficient. Here is the rank of the variable and K is chronological transformed series for observation y . The Null hypothesis is finally checked for the acceptance with t-test statics which is described by

2.12. Test for stationery

A time series of hydrological data is strictly stationary if its statistical properties (e.g. its mean, variance, and higher-order moments) are unaffected by the choice of time origin. (By 'unaffected', we mean that estimates of these properties agree within the range of expected. Stationery of time series was checked based upon split-record tests for stability of the variance (F-test) and stability of mean (t-test). The tests for stability of variance and mean verify not only the stationary of a time series, but also its consistency and homogeneity. In the basic data-screening procedure, these two tests are reinforced by a third one, for absence of trend. Although stability of these two properties indicates only a weak form of stationary, this is enough to identify a non-stationary time series or to select those parts of a time series that are acceptable for use. A time series is first divided in to subsets and computation of standard deviation for each subset will be attained first, then variance of the two subsets is checked for the acceptable range for stability of variance.

The t-test for stability of mean involves computing for the two subsets and then comparing the means of two or three non-overlapping sub-sets of the time series (the same subsets from the F-test for stability of variance) A suitable statistic for testing the null hypothesis, $H_0: \bar{X}_1 = \bar{X}_2$, against the alternate hypothesis

2.13 Test for homogeneity

The data qualities with regard to possible temporal and spatial variations or errors should have to be investigated by checking homogeneity and consistency of selected stations. Non- homogeneity is a change in the statistical properties of the time series. Its causes can either natural or man-made. These include alterations to land use, relocation of the observation station, and implementation of flow diversions. Rainbow and non-dimensional plot are the widely used methods for checking homogeneity of time series data's of rainfall.

In this study Absolute homogeneity is checked by rainbow software and relative homogeneity is checked by non-dimensional plot.

In RAINBOW the test for absolute homogeneity is based on the cumulative deviation from the mean and clearly shows the probability of rejecting homogeneity.

There exist two types of homogeneity called absolute homogeneity and relative homogeneity; once the absolute homogeneity of each station alone is checked their relative homogeneity is then checked (by using Non Dimensional Plot) in this study.

2.14. Test for Consistency

A time series of hydro meteorological data is relatively consistent if the periodic data are proportional to an appropriate simultaneous time series.

Double mass curve is a simple, visual and practical method, and it is widely used in the study of the consistency hydro-meteorological data and it was a commonly used data analysis approach for investigating the behavior of records made of hydrological or meteorological data at a number of locations. It is used to determine whether there is a need for corrections to the data to account for changes in data collection procedures or other local conditions. Such changes may result from a variety of things including changes in instrumentation, changes in observation procedures, or changes in gauge location or surrounding conditions. Double mass analysis for checking consistency of a hydrological or meteorological record is considered to be an essential tool before taking it for analysis purpose. This method is based on the hypothesis that each item of the recorded data of a population is consistent. Double mass curve method is adopted for checking consistency of both meteorological and hydrological data.

2.15. Data Available

There are three important rainfall stations within the catchment area, Dire Dawa, Kersa, and Dengego (there are additional rain gauges in adjacent catchments that are relevant to some aspects of the hydrological analysis – see below, Section 3.6). Dire Dawa city is the center of the flood problem at the downstream end of catchment. Dengego is located in the

upper part of the Dechatu catchment near the watershed and Kersa likewise in the Chirecha (Goro) catchment.

CHAPTER THREE

3.0 LITERATURE REVIEW

3.1. General

Simple modeling approaches with a fewer model parameters are generally regarded as an accepted strategy in rainfall-runoff modeling (Nash and Sutcliffe, 1970; Beven 1989, 1993; Jakeman and Hornberger 1993; Jakeman et al. 1990; Young and Beven 1994; McIntyre and Al-Qurashi, 2009). The value of making the model more complex in light of the general data restrictions in arid and semiarid regions is questionable (Al-Qurashi, 2008). Major research priorities toward improved hydrological models for arid regions include improved methods for rainfall observation and modeling. The Soil Conservation Service SCS Soil Conservation Service 1971 curve number CN methodology has been widely used because it represents reliable procedures that have been implemented for many years in different parts of the world. It is computationally efficient and its inputs are generally available. SCS methodology relates runoff to soil type, land use, and management practices. There are many classification schemes of hydrologic models, based on the method of representation of the hydrologic cycle or a component of the hydrologic cycle (Cunderlik, 2003). Hydrologic simulation models use mathematical equations to calculate results like runoff volume or peak flow.

3.1.1 Model and software description

This chapter provides an insight on the theoretical and mathematical background involved behind the software describing the data processing and modelling procedures. Mainly three open source software are used for the project: ArcGIS, Arc Hydro, HEC-GeoHMS and HECHMS is used for hydrologic modelling. While ArcGIS is used as a platform for generating physical basin models for HEC-HMS and geometric model of river using interfacing hydrological extensions HEC-GeoHMS.

3.1.2 ArcGIS: HEC-GeoHMS

HEC-GeoHMS is an interfacing tools between GIS and HEC-HMS. HEC-GeoHMS is a geospatial hydrology toolkit in ArcGIS to create hydrologic inputs that can be directly used with HEC-HMS. It allows to visualize spatial information, extract watershed physical characteristics from DEM (Digital Elevation Model) and GIS data, perform spatial

analysis, and delineate sub basins and streams to develop hydrologic parameters as well as construct inputs to hydrologic models. (Fleming et. al., 2013) HEC-GeoHMS 10.4.2 version was used during this project.

3.1.3. Hydrological Modeling

Hydrological models are characterizations of the real world system. Modeling of the rainfall runoff processes of hydrology is needed for many different reasons the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time Anderson, (M.J. & Burt, T.P). A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small-or field-scale without full incorporation of a watershed.

A watershed model simulates hydrologic processes in a more holistic approach compared to many other models which primarily focus on individual processes or multiple processes at relatively small-or field-scale without full incorporation of a watershed area. Watershed-scale modeling has emerged as an important scientific research and management tool, particularly in efforts to understand and control water pollution. A model is physical or mathematical description of a physical system, including the interaction with its outside world, which can be used to simulate the effects of changes in the system itself or the changes in the condition imposed upon it. The primary features for distinguishing watershed-scale modeling approaches include the nature of the employed algorithms (empirical, conceptual, or physically-based), whether a stochastic or deterministic approach is used for model input or parameter specification, and whether the spatial representation is lumped or distributed

Watershed models can also be categorized as deterministic or stochastic depending on the techniques involved in the modeling process. Deterministic models are mathematical models in which outcomes are obtained through known relationships among states and events. Stochastic models will have most, if not all, of their inputs or parameters represented by statistical distributions which determine a range of outputs. Even though most models are deterministic in nature, stochastic models provide two important advantages. First, their conceptually simple framework makes it possible to describe heterogeneity when there are limited spatial or temporal details. Second, they provide

decision makers with the ability to determine uncertainty-associated with prediction. Empirical models consist of functions used to approximate or fit available data. Such models span arrangements of complexity, from simple regression models to hydro informatics-based models which utilize Artificial Neural Net-works (ANNs), Fuzzy Logic, Genetic, and other algorithms

3.1.4 Rainfall Runoff Model: HEC-HMS

Hydrologic Modelling System (HEC-HMS) is an open source computer software developed by U.S. Army Corps of Engineering’s Hydrologic Engineering Center that helps in simulating the hydrologic cycle (precipitation, evapotranspiration, infiltration, surface runoff and base flow) of a catchment by describing its physical and meteorological properties. A simple schematic representation of rainfall runoff process replicated in HEC-HMS is shown in *figure 3*. Wide options of mathematical models for all the hydrological components that conceptually represent watershed behavior are incorporated in this program. The program uses separate model to represent each component of the runoff process like model to compute runoff volume, model of direct runoff/base flow/ channel flow as well as alternative models to account for the cumulative losses for e.g.: SCS CN loss model. Then, it computes runoff volume by subtracting losses (infiltration, storage, interception, evaporation etc.) from precipitation. HEC-HMS 4.2.1 was used during this research. (Fleming and Brauer, 2016)

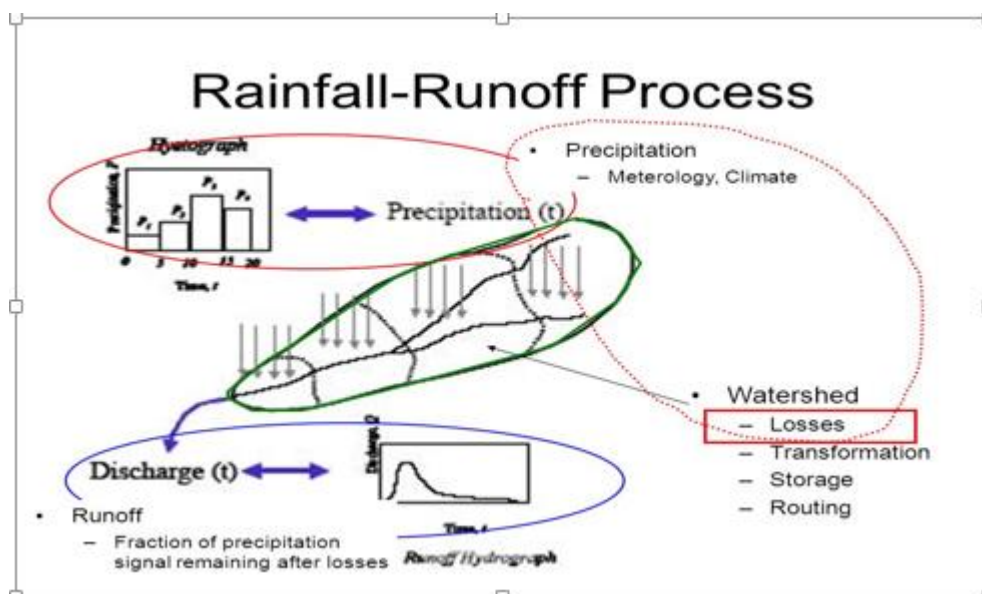


Figure 3. Representation of rainfall runoff process

The HMS is designed to simulate the precipitation-runoff functions of watershed systems. HEC-HMS provides a variety of options for simulating precipitation-runoff processes. In addition to UH and hydrologic routing options, the model implements a distributed runoff transformation that can be applied to gridded e.g., radar rainfall data, and a “moisture depletion” option that can be used for continuous simulations. It is designed to be applicable for a wide range of geographic areas and for solving various possible ranges of problems. These include large river basin water supply and flood hydrology as well as small urban or natural watershed runoff. The resulted hydrographs can be used for studying water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and others. Prior to program execution, three input data sets are required. The first, labeled basin model, contains parameters and connectivity data for hydrologic elements sub basin, routing reach, junction, reservoir, source, sink, and diversion. The second set, precipitation model, contains meteorological data. The final input data set, control specifications, specifies simulation control parameters.

3.1.5. Basin Model

The program uses separate model to represent each component of the runoff process like model to compute runoff volume, model of direct runoff/base flow/ channel flow as well as alternative models to account for the cumulative losses for e.g.: SCS CN loss model. Then, it computes runoff volume by subtracting losses (infiltration, storage, interception, evaporation etc.) The resulted hydrographs can be used for studying water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and others. Prior to program execution, three input data sets are required. The first, labeled basin model, contains parameters and connectivity data for hydrologic elements sub basin, routing reach, junction, reservoir, source, sink, and diversion. The second set, precipitation model, contains meteorological data. The final input data set, control specifications, specifies simulation control parameters.

•**Meteorological Models:**

Information regarding meteorological components such as temperature, precipitation, evapotranspiration, sunshine, humidity, and snowmelt is defined in meteorological model. HEC-HMS provides variety of options to define each meteorological element.

• **Control Specification:**

Starting date and time, ending date and time and computational time step for the simulation are defined in control specification.

• **Time series Data:**

Real time series data for all the meteorological elements defined in meteorological model are fed in this part. Apart from above mentioned meteorological element, discharge data can also be supplied for calibration and simulation of the developed model.

• **Paired Data:**

Meteorological data in tabular/graphical form are supplied as paired data. (Scharffenberger, 2016) In HEC-HMS, the hydrological procedure of changing rainfall into runoff has been represented by four processes: loss, transform, baseflow and transform. These processes are described in following section: HEC-HMS 4.2.1 was used during this studies (Fleming and Brauer, 2016)

• **Transform method**

Transform methods is an approach for computing direct runoff at the outlet of watershed area from the excess precipitation falling over it and this is done based on principles of unit hydrograph. Unit hydrograph can be defined as the runoff hydrograph produced from excess rainfall of unit depth occurring over the watershed. The theories of unit hydrograph are:

- (i) Excess precipitation and runoff produced are directly proportional to each other,
- (ii) Excess precipitation is distributed uniformly with respect to time and space over the watershed area and

(iii) Runoff produced from given excess rainfall is independent of time of occurrence and precedent moisture content (Subramanya, 2008).

The transformation method used for this study was SCS Unit Hydrograph. The resulting runoff hydrograph from this model is described by properties of unit hydrograph using one or more equations of the parameters involved. The peak of unit hydrograph and its time of peak is given by following equations.

Where, U_p = Peak of unit hydrograph, A = Area of watershed, T_p = Time of peak, Δt = Excess precipitation duration and t_{lag} = Basin lag (Feldman, 2000)

Basin lag can be defined as the time difference between the peak of unit hydrograph and centroid of the associated excess rainfall hyetograph which is depicted in the figure 3.3 below?

3.1.6 Flood frequency analysis

Flood frequency analysis is an estimation of how often a certain amount of flow is reoccurring. Such estimation is pre-requisite for carrying out hydraulic computation of river and developing flood inundation map. The analysis is done by fitting a probability model to the sample of annual extreme flood values recorded over a long period of time, for a catchment. The model parameters established can then be used to predict the extreme events of large recurrence interval (Pegram and Parak, 2004). For this project, Gumbel Distribution method has been selected for flood frequency analysis.

Gumbel's distribution is a statistical method commonly used for predicting extreme hydrological events such as floods (Haan, 1977). According to Gumbel, the probability (P) of occurrence of any extreme event is given by the following equation.

$$Q_{surf} = 1.285 \frac{(x - x_0)}{(\sigma_x)} + 0.577 \quad 2.1$$

$$P = (X \geq x_0)1 - e^{-e^y} \quad 2.2$$

$$K = Y_T \frac{(Y_T - 0.577)}{1.2825} + 0.577 \quad 2.3$$

And

$$Y_T = [\ln \ln] \frac{T}{T-1} \quad (2.5)$$

(2.4)

Recurrence interval T is calculated

$$T = \frac{1}{P} \quad (\text{Subramanya, 2008})$$

3.1.7. Previous studies of the area

In the past, flood studies for Dire Dawa town have been done by different organizations before and after the most severe flood event occurred on the fifth day of August 2006.

Dire Dawa administrative council integrated resources development master plan study project (January 2004) this study was conducted before the most severe flood event. it is intensive and consistent study participating Dire Dawa administrative council waters, mines & energy office as a client and water works design & supervision enterprise as a consultant. According to this study, dechatu catchment flood estimation summary is

Table 1. Dechatu catchment flood estimation summery

Catchment	Peak Flood (m ³ /sec) at Various Return Periods					
		50	100	200	500	1000
Dehatu	Rational	863	1082	1143	1330	1936
	Boldakov	792	865	913	985	1009
	SCS	96	105	141	152	156
	Creager	629	715	755	834	1032
Selected peak	Rational	863	1082	1143	1330	1936

The design of flood protection works and spillways, the average values of the Rational, Boldakov and Creager methods are considered. Also the study states, as per the interview of the older people, a flood mark was fixed on the Dechatu River and its flood was estimated as 1170m³.The general comment is that results from different methods shall be compared, not averaged. Usual practice is to use the discharge that best reflects local conditions.

Awash River Basin Flood Control and Watershed Management Study Project (February 2008).”The general comment is that results from different methods shall be compared, not averaged. Usual practice is to use the discharge that best reflects local conditions. This study was conducted after the most severe flood event. The client and consultant are Ministry of Water Resources and Halcrow respectively. This report is not consistent; the data are not commensurate/corresponding/matching and tailored to the methodology. The given data shows that average data for the whole catchment considered as one (lumped). However, the catchment is divided into three sub catchments (distributed) to use HEC-HMS.

- How can we run uniform rainfall data (distributed) across the whole area of three sub catchments without having their specific data (lumped data)?
- The options used for each step to estimate the maximum flood discharge is not clear, Which Metrologic station data used?

- Does the Runoff formed by Localized rain storms? Flooding formed by localized rainstorms: the runoff was mainly generated by infiltration-excess when the flooding had a rapid rise and recession with a single peak value but the total flood volume was small.
- Does the runoff formed by uniform rainfall across the whole area? How much volume of run-off was estimated?
- Flooding formed by mixed rainfalls: the runoff was due to both infiltration- and saturation-excess when the flooding possessed the two previous characteristics.

Even if these questions are not clear in the report, according to this study, Dechatu catchment flood estimation summary is given as follows. The following major points are not clear in the report:

Table 2. Summary of Awash River Basin Flood Control and Watershed Management Study

Return Period(years)	Dechatu Estimated Peak (m3/Sec)	Catchment Discharge
10	901	
25	1166	
50	1368	
100	1582	
200	1750	

4.5. Runoff Estimation

The Curve Number method (SCS, 1972), also known as the Hydrologic Soil Cover Complex Method, is a versatile and widely used procedure for runoff estimation. In this method, runoff producing capability is expressed by a numerical value varying between 0 - 100. In the past 30 years, the SCS method has been used by a few researchers because it gives consistently usable results (Rao et. al., 1996; Sharma et al. 2001; Chandramohan and Durbude, 2001; Sharma and Kumar, 2002 for runoff estimation.

The SCS curve number equation is (SCS, 1972):

$$Q_{surf} = \frac{(R_{day} - I_a)^2}{(R_{day} - I_a + S)} \quad (2)$$

Where Q_{surf} is the accumulated runoff or rainfall excess (mm), R_{day} is the rainfall depth for the day (mm), I_a is the initial abstractions (mm), which includes surface storage, interception and infiltration prior to runoff, and S is the retention parameter (mm). Runoff will only occur when $R_{day} > I_a$. The retention parameter varies spatially due to changes in soils, land use, management and slope and temporally due to changes in soil water content. The retention parameter, S is defined as:

$$S = 25.4 \left(\frac{1000}{CN} - 10 \right) \quad (3)$$

Where CN is the curve number for the day. The initial abstractions, I_a , is commonly approximated as $0.2S$ and equation (2) becomes

$$Q_{surf} = \frac{(R_{day} - 0.2S)^2}{(R_{day} + 0.8S)} \quad (4)$$

Where CN (called the SCS curve number) is used to represent the combined effects of the primary characteristics of the catchment area, including soil type, land use and the previous moisture condition. It takes a value in the range of 30–98.

4.0 METHODOLOGY

4.1 Hydrological Model Development

Rainfall runoff modelling was carried out with the help of HEC-HMS and HEC-GeoHMS a hydrological extension in ArcGIS. Detailed description regarding these software has been done in Section 3.1.2.

An overview of working mechanism of rainfall runoff model is shown with the help of schematic diagram below in figure 4.

The methodology used for carrying out Rainfall Runoff Modelling can be described by categorizing them into two sections, which are as follows:

- Creating Basin Model
- Developing Hydrological Parameters
- Hydrological Modelling
- Creating Basin Model

Basin model was created with the help of HEC-GeoHMS, a hydrological toolkit in ArcGIS.

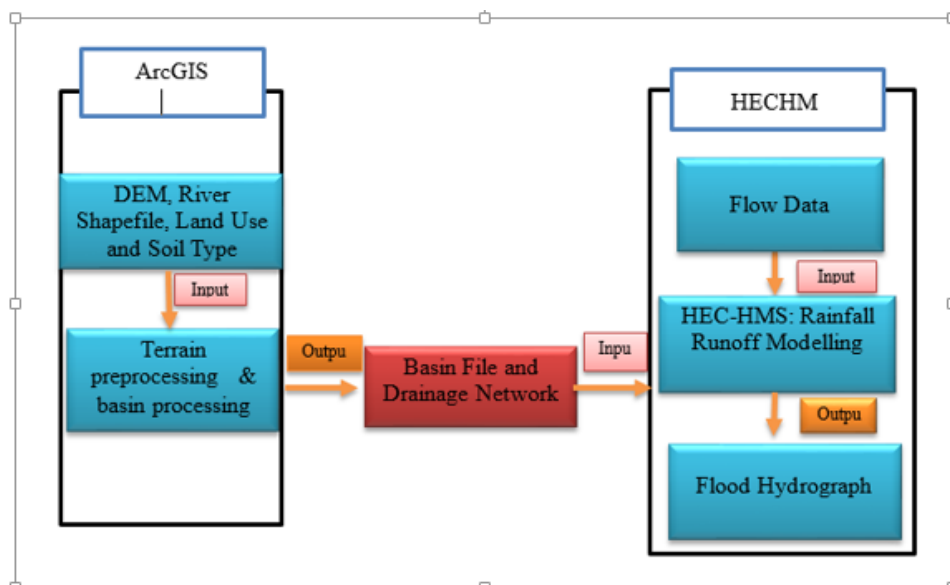


Figure 4 Modeling approach Rainfall Runoff Modeling

4.2. Terrain Pre-processing

Before carrying out terrain pre-processing, the input terrain data DEM was refined using DEM reconditioning. After this process, the DEM was pre-processed in HEC-GeoHMS to derive sub-basins and drainage network of the catchment. The steps included were fill sinks, flow direction, flow accumulation, stream definition, stream segmentation, catchment grid delineation, catchment polygon processing, and drainage line processing and ad joint catchment processing. After terrain pre-processing, HEC-HMS project was created. At first, a project point was defined at the downstream end of the watershed based on which the software delineated the project area. The resulting project area for Dechatu river watershed was 327.3381 km²

Some major characteristics of the basin model for Dechatu are tabulated in Table 4.2 below:

Table 3: Basin Model characteristics

Characteristics	Dechatu Watershed
Basin area (km ²)	327.3381
Number of sub-basin after terrain pre-processing	8
Number of batch points	1

4.3. Developing hydrological parameters

This step parameterizes the values of different hydrological processes involved in modelling. The hydrological parameters were estimated by using the land and soil use data for each sub basin. Different steps involved for developing hydrological parameters are as follows: Select HMS processes: HMS processes for modelling transform, were selected. In this project, same HMS processes were selected for study area which are listed below in **Table 4.3.**

The precipitation data from the three stations were weighted at the center of each sub-basin using Tyson polygon method. The historical precipitation and discharge data show that rainfall and flooding in the Dechatu catchment area present three main characteristics, i.e.:

- Flooding formed by localized rainstorms: the runoff was mainly generated by infiltration-excess when the flooding had a rapid rise and recession with a single peak value but the total flood volume was small.
- Flooding formed by uniform rainfall across the whole area: the runoff was dominated by saturation-excess when the flooding changed little over the period of time and the total flood volume was large.
- Flooding formed by mixed rainfalls: the runoff was due to both infiltration- and saturation-excess when the flooding possessed the two previous characteristics

Table 3 Selected methods for HMS

HMS Processes	Method
Transform	SCS Unit Hydrograph
Routing	Muskingum

CN Lag: This function calculated lag time for transform method based on CN grid. CN grid was generated in ArcGIS using land use and soil cover layers. CN values adopted for different land use type for Dechatu watershed are given in Table 4.4 and Table 4.5 below.

Table 5: CN values adopted for Dechatu

Description	A	B	C	D
	100	100	100	100
Developed areas	61	75	83	87
Pasture	68	79	86	89
Cropland	71	80	87	90
Description	A	B	C	D
Water bodies	100	100	100	100
Developed areas	61	75	83	87
Forest	68	79	86	89
Cropland	71	80	87	90
Barren land	76	85	90	93

For each of the sub-basins and river, physical characteristics were computed based on the refined DEM. The computed characteristics for river included river length and river slope and for basin included basin slope, longest flow path to the basin, basin centroid, centroid elevation and centroidal longest flow path. To calculate basin slope, watershed slope was required which was calculated using Arc Hydro tool. Batch point was one in the Dechatu watershed.

4.4 Developing HEC-HMS model files:

In this step, model files such as background- map file, basin model file and meteorological model file required for HEC-HMS were generated. At first, all the physical characteristic values of reaches and sub-basins were converted to user defined unitary system. In this case, SI system was used. After this HMS basin schematics and legends were added to the basin map. HMS basin schematics included HMS links that represented river and HMS nodes that represented sub-basins and junctions. By adding HMS legend, HMS nodes representing sub-basins and junctions were replaced with HMS legend. Further, coordinates were added to the features in HMS nodes and HMS links.

Finally, background-map file and basin file were created for exporting them to HMS. Gauge

weight method was chosen for creating meteorological model file for basin. For using this method, Thiessen polygon for the available precipitation stations within or in the periphery of the basin area was created in ArcGIS.

4.5. Hydrological Modelling

After completion of building model framework in HEC-GeoHMS, modelling was performed in HEC-HMS by importing files from ArcGIS which were:

- Background- map and river
- Basin file with extension 'Watershed'
- Meteorological files with extensions 'Met' and 'Gage'

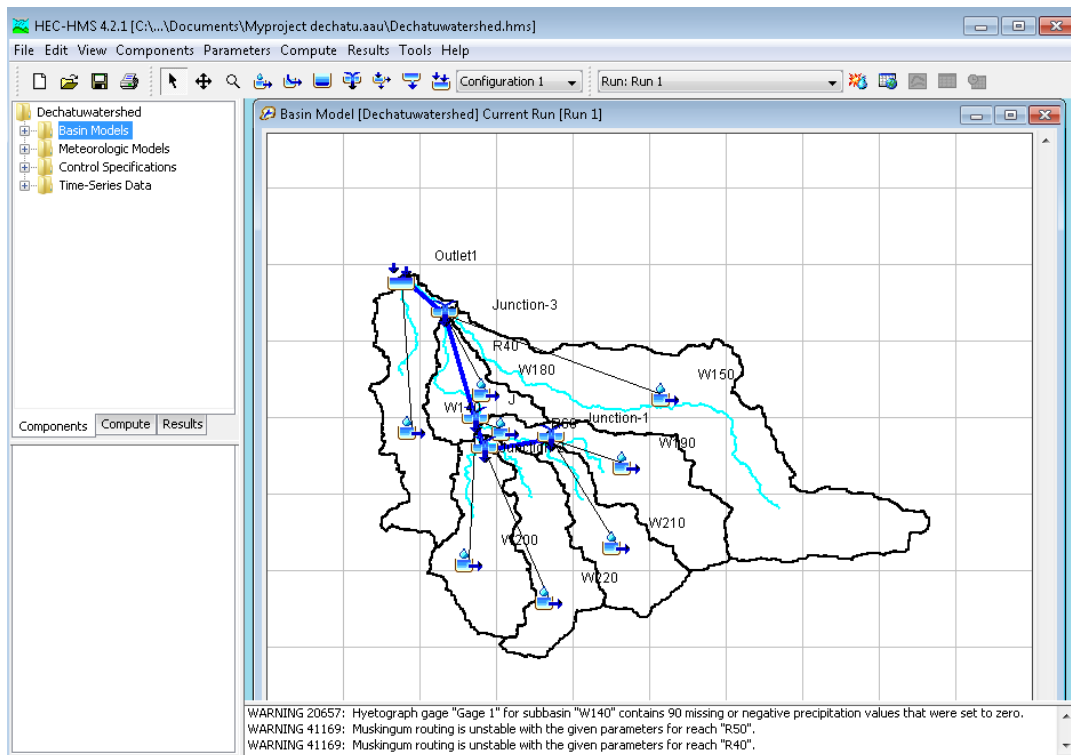


Figure 5. The hydrological model implemented in HEC-HMS.

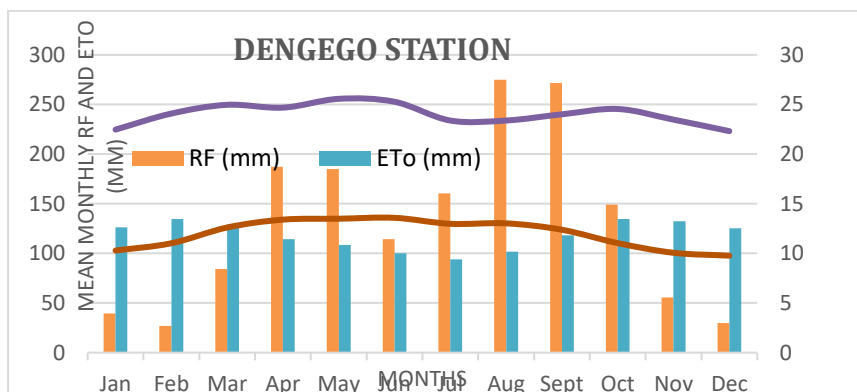


Figure 6 mean monthly Rainfall (mm) Denego Station Rain fall

After the meteorological components were defined, real time series data defining them were entered. Description of all the time-series data entered for both models are given in Section 3.1.2. All time-series data were entered manually for both models. Finally,

simulation run time and computational time step was set in control specification. Control specifications for calibration and validation of bath basins are tabulated in Table 4.7.

4.6. Model Inputs

This chapter gives a detailed overview on data required for the model development and stepwise procedures for the simulation and modelling.

4.7. Digital Elevation Model (DEM)

Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in given area at a specific spatial resolution as a digital file. A digital elevation model is needed for raster-bas hydrological analysis in a GIS. The DEM used in the study was a (30*30 m) made resolution elevation data which was taken from Minister of water GIS department. The DEM was used to generate percent slope values, to automatically delineate watershed boundary, stream networks, and identify gage outlets. It is characterized by chain of mountains that stretch along the south-eastern and western parts bordering Oromia region,

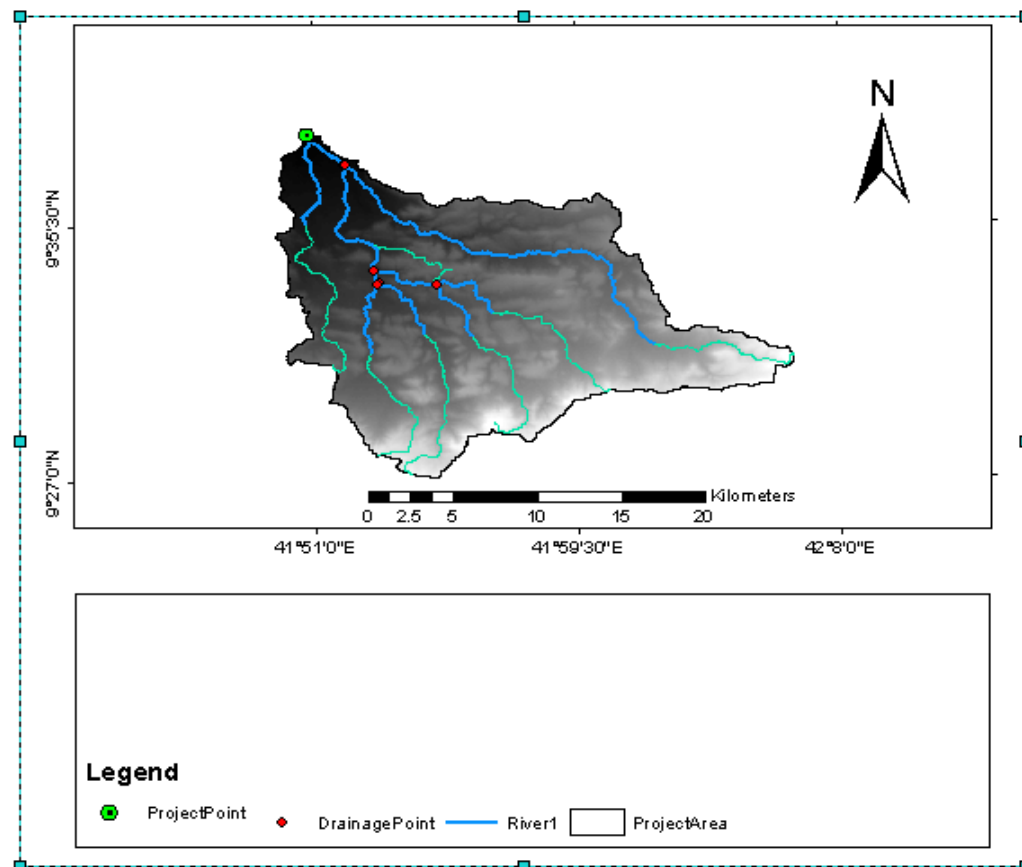


Figure 7. DEM of Dechatu River watershed area

Isolated hills in the low lands and extensive plains surrounded by hilly areas towards the north-western part. DEM (Digital Elevation Model) represented the topographic feature of the study area. For Dechatu, characterized by diverse topographic features 30*30 m resolution clip from an open source, Awash River basin.

4.8. Soil Data and Maps (Hydrologic Soil Groups)

Soil properties influence the relationship between rainfall and runoff by affecting the rate of infiltration. The SCS has divided soils into four hydrologic soil groups based on infiltration rates (Groups A, B, C, and D). These groups were previously described for the Rational Formula (see Section 5.7, Table 5-7).

Consideration shall be given to the effects of urbanization on the natural hydrologic soil group. If heavy equipment can be expected to compact the soil during construction or if grading will mix the surface and subsurface soils, appropriate changes shall be made in the soil group selected. Also runoff curve numbers vary with the antecedent soil moisture conditions, defined as the amount of rainfall occurring in a selected period preceding a given storm. In general, the greater the antecedent rainfall, the more direct runoff there is from a given storm. A five-day period is used as the minimum for estimating antecedent moisture conditions.

Leptosols (15% of area) are mostly found on the mountain and hilly areas and are characterized by very shallow depth. These soils are seldom cultivated, being droughty even with soil conservation measures. They are largely left as open access communal grazing land. The excessively drained Fluvisol (22%), Heptlic Xerosol (55%) and Solonchak (4%) soil types are found on flat, alluvial plains and in valley bottoms and depressions. They are deep with medium to coarse texture. Very small areas of Cambisols are found on the undulating and rolling plains and have moderately deep, medium texture. Antecedent soil moisture conditions also vary during a storm; heavy rain falling on a dry soil can change the soil moisture condition from dry to average to wet during the storm period

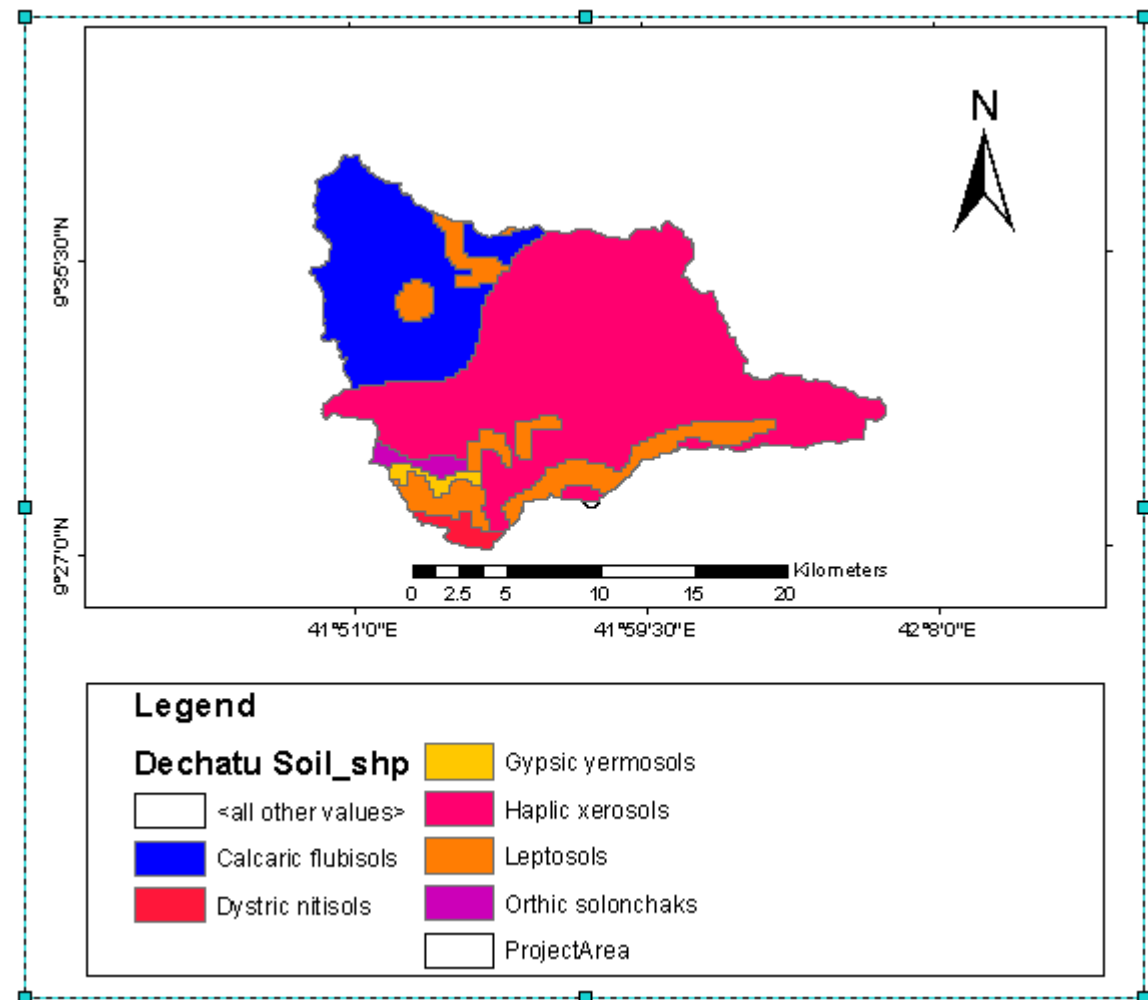


Figure 8. Soil Map of Dechatu River Watershed

Table 6 Soil and area coverage

Sub-Basin Name	Soil Type	Hydrologic Soil Group
W160	Calcaric Fluvisols	B
W200	Dystric nitisols	B
W150	Gypsic yermosols	D
W180	Haplic Xerosols	B
W190	Leptosols	D
W210	Orthic solonchaks	B
W220	Gypsic Yermosols	B
W140		

4.9. GIS based land use/cover change assessment

Runoff is rainfall excess or effective rainfall - the amount by which rainfall exceeds the capability of the land to infiltrate or otherwise retain the rainwater. The principal physical catchment area characteristics affecting the relationship between rainfall and runoff are land use, land treatment, soil types, and land slope.

Land use is the catchment area cover, and it includes both agricultural and nonagricultural uses. Items such as type of vegetation, water surfaces, roads, roofs, etc. are all part of the land use. Land treatment applies mainly to agricultural land use, and it includes mechanical practices such as contouring or terracing and management practices such as rotation of crops.

The SCS uses a combination of soil conditions and land-use (ground cover) to assign a runoff factor to an area. These runoff factors, called runoff curve numbers (CN), indicate the runoff potential of an area. The higher the CN, the higher is the runoff potential.

To assess the land use/cover change, Multi-temporal (Landsat MSS 1985, Landsat TM 2000, and Landsat ETM + 2014) remote sensing data of the area was used. Image enhancement, rectification and classification were also applied on the raw images. The land cover condition of two different periods was spatially compared (1985 to 2000 and 2000 to 2014) and the rate and quantity of change was calculated. Image classification was only used for the extraction of distinct classes or land use/land cover categories from satellite imagery. Ground survey was also made to cross check some of the features identified from satellite image. Detail ground survey was conducted to assess tree species diversity and the status of forests. Based on knowledge of the study area, visual interpretations of imagery and detailed reconnaissance field survey, different land use/land cover categories were distinguished.

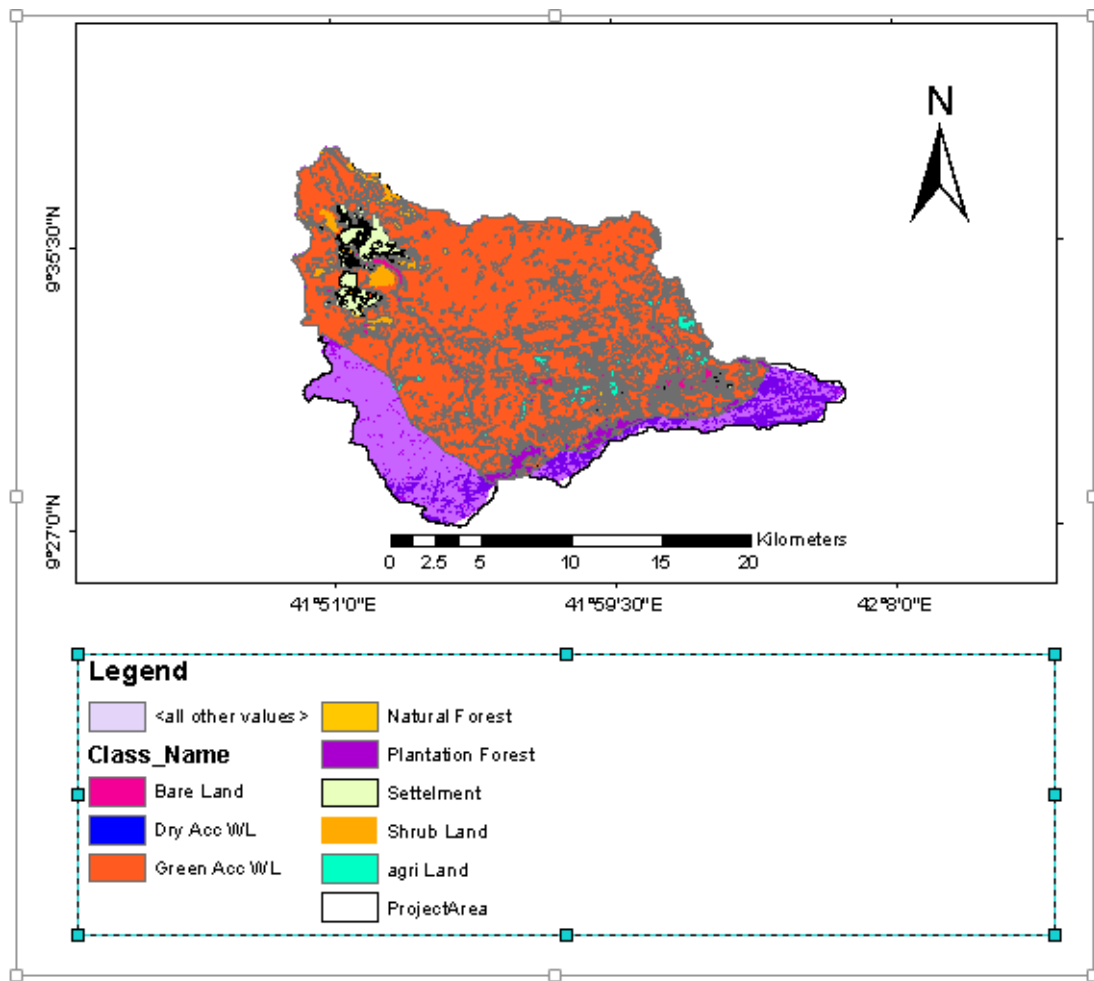


Figure 9. Land use/Land cover Map 1985. (Landsat MSS 1985)

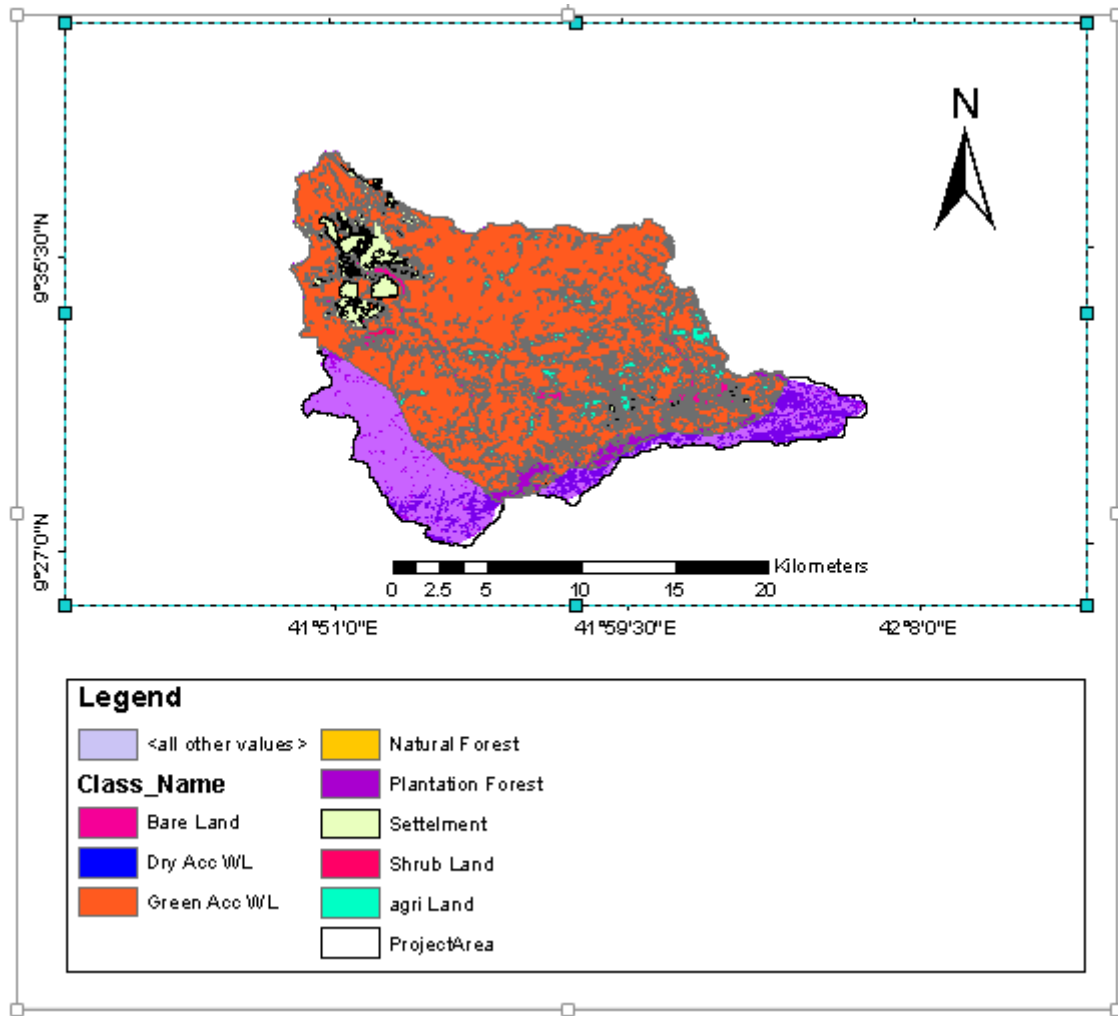


Figure 10 Land use\Land cover March (Landsat TM 2000)

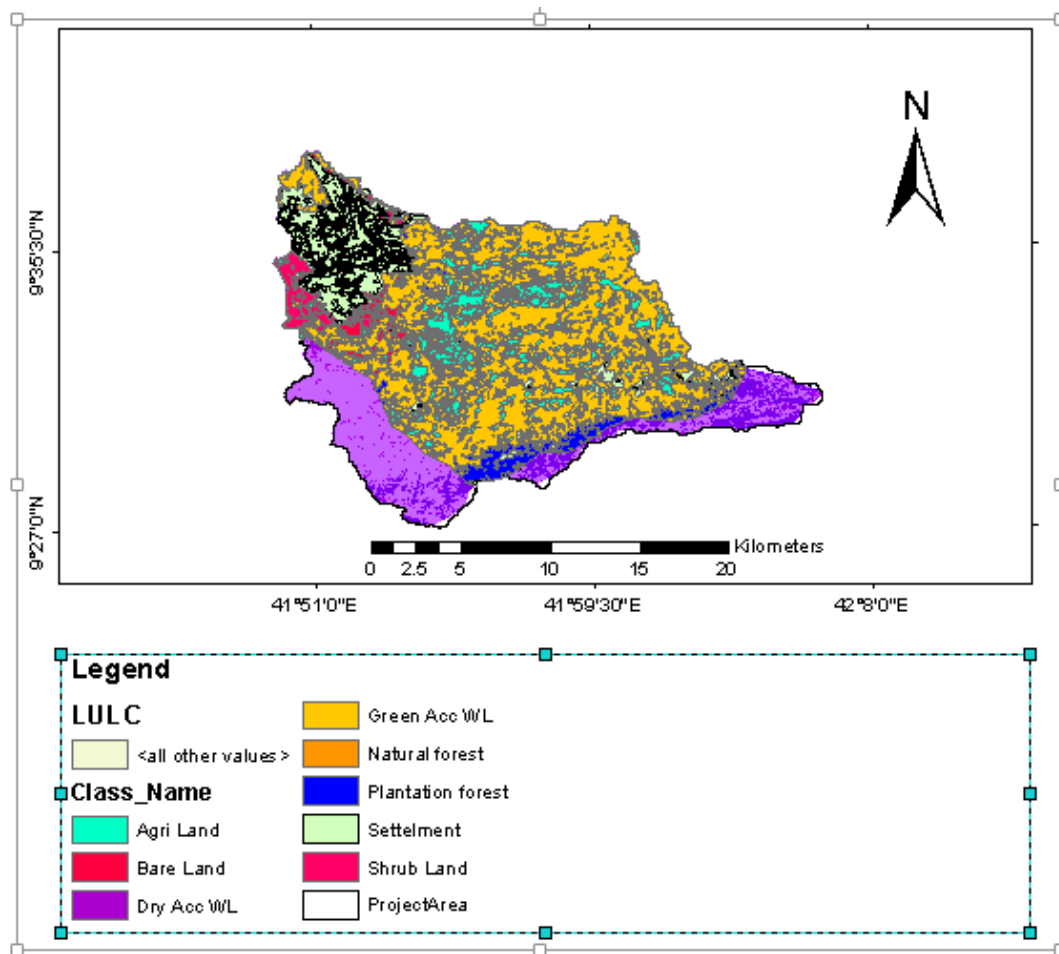


Figure 11 Land use\Land cover (Landsat ETM + 2014)

Table 7. Land use and area coverage

Land use and area coverage (m2)		
Sub-Basin Name	Land use	Area (m2)
300001	Bare land	13614529.814
	Cultivated land	2375623.222
	vegetation	1465426.089
300002	Urban and / or built up area	8289619.470
300003	Bare land	10937772.287
	Cultivated land	15457133.938
	vegetation	8289619.470
	Physiognomic	3618165.897
300004	Physiognomic vegetation	181575.748
	Bare land	15996685.663
	Physiognomic	8289619.470
300005	Cultivated land	181575.748
	Physiognomic vegetation	18197477.950
	Cultivated land	1179814.008

4.10 Rainfall Frequency

Rainfall frequency analysis was used as a key input to the calculation of flood frequency and magnitude. .

The rainfall frequency analysis was carried out using the available 24 hour rainfall data for the rain gauge stations situated in the headwater area. Such data is limited and it was necessary to combine data from different stations in order to arrive at an acceptable representative record. The probability of non-exceedence of a given amount of precipitation in a 24 hour period is presented in Figure 4.

Though rainfalls are registered over 24 hours, rainfall the actual duration of the storm will normally be much less than 24 hours and will include all or nearly all of the recorded 24 hour rainfall amount. For this reason it has been assumed that the maximum rainfall duration of large storms is 6 hours.

4.11 Rainfall Frequency Analysis

4.12 Rainfall Intensity

The highest maximum daily rainfall recorded at any of the above stations was at Kersa where an amount of 166 mm was measured on April 15, 2001. Very little or no rainfall was measured at the other two stations on the same date. 113 mm was recorded at Dire Dawa on December 7, 2003 during the “dry” season and again no or little rainfall is registered at the other two stations at the same date. This clearly indicates that extreme rainfall events of this type will generally have limited aerial coverage and are relatively unrelated to the amount of annual rainfall. In addition, they do not necessarily occur during the main part of the rainy season which clearly complicates the issue of flood preparedness. Lower (in terms of the depth at any particular point) rainfall events can have much larger areal

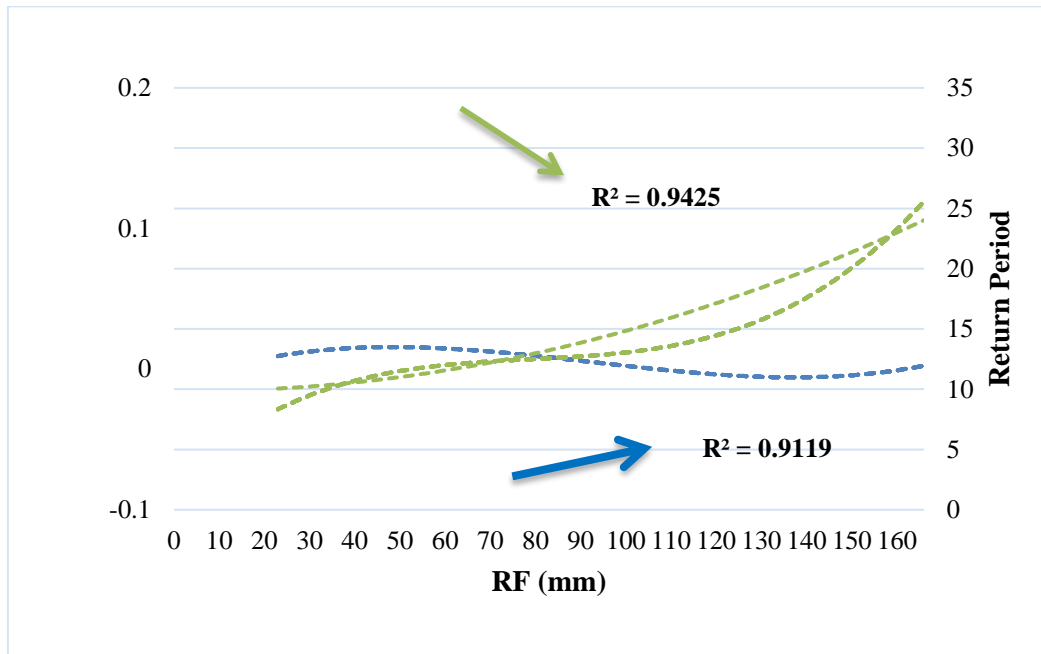


Figure 12 Frequency annual daily maximum RF values using Gumbel (EV1) and Log Pearson III distributions.

4.13 Main rivers and run-off characteristics

There was no flow in the ephemeral rivers and most of the riverbeds were observed that they were completely dry. It was evident from observation of their courses and interviews with the local people that run-off in these streams mostly occurs when there is rainfall in the highlands in the respective catchment. The spate hydrographs characteristically indicate a sharp rise to the peak discharge within a short duration. The duration of run-off is nearly equal to that of rainfall and the run-off hydrograph has very steep rising and falling limbs with a very pronounced peak. In general, run-off occurs vigorously and very quickly and ceases shortly after a while. The catchments of the study area are drained to the Awash River.

The Dechatu River has been gauged at the location of **09034'73"** North and **41052'58"** East with river width of 80 meters with estimated slope of 0.8% close to the proposed dam site for a few years, but only water level data are available from March 2003 to September 2010 and no rating curve has ever been constructed. In order to reconstruct the flood history and to calculate the peak discharge of the main floods occurred in such interval, field measurements of cross section, streambed gradient and bed material grain size were made in the reach with the flow gauge in order to introduce these data into a simple uniform flow equation such as the Chezyequation.

The river bed at the flow gauge site is rather regular as it is straight, has a rectangular cross-sectional geometry and is confined between bedrock slope sides (only on the right banks there is a small alluvial accumulation). Given the reach geomorphology, the variability through time of the monitoring site cross-section width can be considered as negligible. As regards the variation of the streambed elevation, very scarce information is reported in the literature, especially for ephemeral streams with a sand bed and hyper concentrated flow. Billi (2011), in his study on field measurement of bedload transport of the Gereb Oda, a sand bed ephemeral stream in Tigray, Ethiopia, found that in case of hyperconcentrated flow, streambed scouring is limited. This finding is supported also by Powell et al. (2005) in their study using scour chains in Arizona. These latter authors conclude that the streambeds experience little, if any, bed activity during an event. Following these considerations, the streambed elevation at the Dechatu flow gauge site was considered as stable.

The cross-sectional and streambed gradient were measured by a theodolite, whereas the grain size frequency curve of bed material (Fig. 5) was obtained by the transect line frequency by number sampling method (Leopold 1970). Since bed material includes also a non-negligible proportion of sand, the size of the sandy particles was identified by means of a visual comparator with specimens of all the sand fractions, arranged on phi scale, stuck on a wooden tablet. The modal class grain of the sand in a 1 x 1 cm area near the meter dent is considered and visually compared to the reference sieve specimens to assign it to a specific phi class (Billi, unpublished).

Mean flow velocity (v) was calculated by the Chezy uniform flow equation

$$V = C (RS)^{0.5} \quad (1)$$

In which R is the hydraulic radius, S the streambed gradient, and C the roughness Coefficient.

$$C = 8g^{0.5} / f^{0.5} \quad (2)$$

In which g is gravity and $1/f^{0.5}$ is the Darcy–Weisbach friction factor.

To calculate $1/f^{0.5}$, the following equations were used: Leopold and Wolman (1957)

$$1/f^{0.5} = 1.16 + 2 * \log (h/ D84) \quad (3)$$

In which h, is mean depth and D84 is the grain size for which 84 % of the distribution is finer, Limerinos (1970) and Knighton (1998), respectively:

$$1.16 + 2 * \log (R/D^{84}) \quad (4)$$

$$0.28 * \ln (R/D^{84}) \quad (5)$$

Equations (3) and (4) were selected because they are among the most used in the literature and were found to be suitable for sandy gravel rivers. Equation (5) was derived by Knighton (1998) from a very large set of field data measured on fine gravel to sandy rivers and reported in the literature.

In addition, the regime theory equation of Lacey (1946) was used to calculate Velocity as:

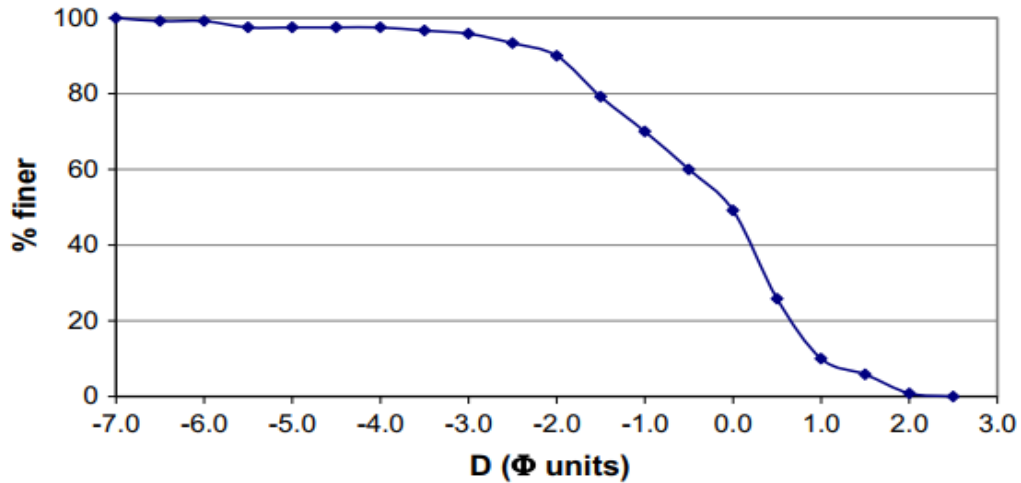


Figure 13. Grain size frequency distribution and material at the flow gauge reach

$$V=10.8 R^{2/3} S^{1/3} \quad (6)$$

And was derived for fine-grained mobile bed rivers. Finally, Grant's equation (1997) was selected as well since it was developed on the base of critical flow condition considerations for mainly sand bed streams as:

$$V= (ghS)^{0.5} \quad 4.8 (h/ D^{50})^{0.11} \quad (7)$$

In which D50 is the grain size for which 50 % of the distribution is finer. No specific equation developed for fine-grained, ephemeral streams is available in the literature; however, Eqs. (3) to (7) that result from different approaches are based on a rather large set of field data and proved to work satisfactorily for gravelly sand rivers; hence, they represent the best alternative to be used on a dry land river such as the Dachau.

The river discharge was calculated for a wide range of flow levels recorded by the flow gauge using all the criteria described above and the results averaged. By these results, a

stage/discharge rating curve was constructed ($R_2 = 0.95$) (Billi, Alemu and Ciampalini, 2015)

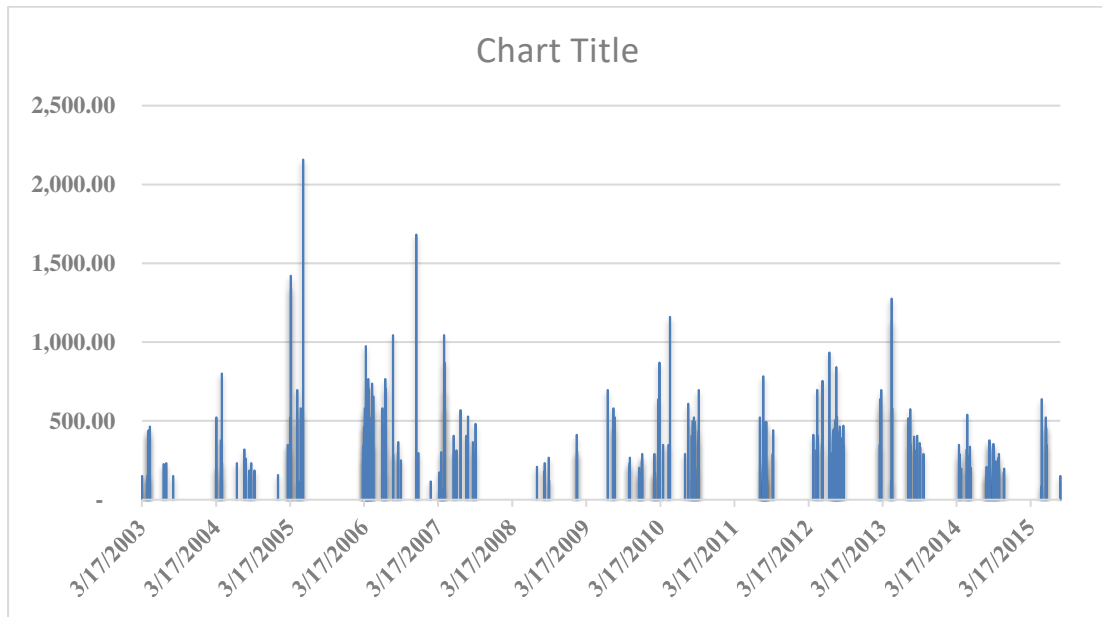


Figure 14 Dechatu River Flow

4.17. Peak Flow Analysis

From outlier value peak flow for Dechatu river is calculated using:-

4.18. Extreme value I distribution

Extreme values are selected maximum or minimum values from a set of data. Extreme value distribution called type I, II and III. The properties of the three limiting forms were further developed by:-

- ❖ Gumbel - For Extreme value Type I distribution
- ❖ Frechet - For Extreme value Type II
- ❖ Weibull - For Extreme value Type III distribution

Extreme value I distribution is one of the distribution among EVI, i.e include Gumbel, exponential, X2, and EVI itself and etc.

Extreme value I distribution
Table 4 EVI distribution using probability of weighted moment (PWM)

YEAR	Discharge Qi (m3/s)	RANK (i)	$F_i = \frac{i-0.35}{N}$	Qi Fi	Qi Fi ²
2003	2,157.60	1.00	0.02	43.83	0.89
2004	1,682.00	2.00	0.05	86.73	4.47
2005	1,276.00	3.00	0.08	105.67	8.75
2006	1,160.00	4.00	0.11	132.31	15.09
2007	1,044.00	5.00	0.15	151.71	22.04
2008	933.80	6.00	0.18	164.87	29.11
2009	800.40	7.00	0.21	166.33	34.57
2010	783.00	8.00	0.24	187.19	44.75
2011	696.00	9.00	0.27	188.14	50.86
2012	638.00	10.00	0.30	192.40	58.02
2013	539.40	11.00	0.33	179.52	59.75
2014	464.00	12.00	0.36	168.93	61.50
2015	266.80	13.00	0.40	105.47	41.69
	957.00			144.08	431.49
	$\sum Qi N = 957$			$\sum Qi Fi N = 144.08$	$\sum Qi Fi^2 N = 431.49$
STD	$\sigma = 519.3457$				

$$\sum Qi | N = M_{100} = 957$$

$$\sum Qi Fi | N = M_{110} = 144.08$$

$$\sum Qi Fi^2 | N = M_{120} = 431.49$$

Where i = the rank and non – negative integer

M = moment of the sample

The peak flow is calculated as:-

$$X = \mu + \alpha \left\{ -\ln \left(-\ln \left(1 - \frac{1}{T} \right) \right) \right\}$$

Where
$$\alpha = \frac{2 \hat{M}_{110} - \hat{M}_{100}}{\ln_2}$$

$$\mu = \hat{M}_{100} - \alpha (0.5772)$$

α and μ are derived from sample estimate and from the theoretical one, i.e.

$$\hat{M}_{100} = \mu + \alpha \varepsilon$$

$$\varepsilon = \text{Euler number} = 0.5772$$

T = Return period and taken as 100 years.

$$\therefore \alpha = \frac{2 * 144.08 - 957}{\ln_2} = \underline{965}$$

$$\mu = 957 - 965 (0.5772) = 400$$

$$\left\{ -\ln \left(-\ln \left(1 - \frac{1}{100} \right) \right) \right\} = 4.6001$$

$$X_{100} = 400 + 295.695 * 4.6001 = \underline{1,760.197 \text{m}^3/\text{s}}$$

Standard Error

$$St = \frac{s}{\sqrt{N}} \sqrt{(1 + 1.14 k + 1.1k^2)}$$

$$St = \frac{24.0124}{\sqrt{13}} = 6.67$$

For 95 % confidence interval and N = 13

$$t_{\alpha/2}, V = 13$$

$$\hat{X} \pm t_{\alpha/2}, V * S_t (\hat{X})$$

$$\hat{X} \pm 2.037 * 6.67$$

$$\hat{X} \pm 13.586$$

V = Degree of freedom

$$X_1 = 1,760.197 + 13.586 = 1,774.4$$

$$X_2 = 1,760.81 - 13.586 = 1,747.224$$

The peak flow 1,760.197 found between x1 and x2 with 95 % probability.

4.19. EVI–Gumbel distribution by the method of moments

Extreme value Type I by the method of moments was introduced by Gumbel. Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. Gumbel equation is f function of recurrence interval “T”.

The peak flow using Gumbel method calculated as:-

$$x = \bar{x} + k_x \sigma$$

$$\text{Where } K = \frac{Y_T - \bar{Y}_n}{S_n} = \text{frequency factor}$$

In which:-

YT = reduced variant , a function of T and given by

$$Y_T = - \left[\ln \left(- \ln \left(1 - \frac{1}{T} \right) \right) \right]$$

\bar{Y}_n = reduced mean, a function of sample size N and is given in table.

S_n = reduced standard deviation, a function of sample size N is given in table.

$$\therefore Y_T = \left\{ - \ln \left(- \ln \left(1 - \frac{1}{T} \right) \right) \right\} = 4.60$$

$$\bar{Y}_{190} = 0.5220$$

$$S_{190} = 1.0565$$

$$K = \frac{4.60 - 0.5220}{1.0565} = 1.875$$

$$\bar{x} = 965$$

$$\sigma_{x-1} = 519.34$$

$$x_{100} = 965 + 1.875 * 519.34$$

$$x_{100} = 1,899.812 \text{ m}^3/\text{s}$$

Standard Error

$$S_e = \frac{S}{\sqrt{N}} \sqrt{(1 + 1.14 k + 1.1 k^2)}$$

$$= \frac{24.03205}{\sqrt{13}} \sqrt{(1 + 1.3 * 1.875 + 1.1 * 1.875^2)} = \mathbf{25.476}$$

For 5 % of level of significant and N = 32

$$V = 32 - 1 = 31$$

$$t_{\alpha/2}, V \pm 2.101$$

$$\hat{x} \pm t_{\alpha/2}, v * S_{\epsilon} (\hat{x})$$

$$\hat{x} \pm 2.037 * 25.476 = 51.89$$

$$X_1 = 1,989.547 + 51.89 = 1,951.702$$

$$X_2 = 1,989.547 - 51.89 = 1,847.922$$

The peak flow **1,899.812** m³/s found between x₁ and x₂ with 95 % of probability.

4.20 Log Pearson type III distribution

This distribution is the standard distribution for frequency analysis of annual maximum floods in the United States. It was developed as a method of fitting a curve to data, and also justified by the fact that it has been found to yield good results in many application, particularly for flood peak data. The mean \bar{y} standard deviation S_y , and coefficient of skew ness C_s are calculated from the logarithms of the data. The frequency factor k_T depends on return period and coefficient of skew ness. When coefficient of skew ness given calculated the standard and error is given in the table

4.21 Log Pearson type III

Peak flow using log person type III calculated with the formula:-

$$Z = \bar{Z} + k_z \sigma_z$$

Where, k_z is a function of skew ness (C_s) and return period and found from table.

$$C_s = \frac{N \sum (Z - \bar{Z})^3}{(N-1)(N-2)\sigma_z^3} = \frac{13 * 0.039831}{(12 * 11 * 0.2^3)} = 0.5178$$

C_s = Coefficient of skew ness

N = Sample size

$$C_s = 0.5178$$

$$K_Z = F(C_s, T), \quad T = 100$$

$$Z_T = \bar{Z} + \delta_Z * C_s$$

$$= 2.92 + 0.2 * 0.5178 = 3.02356$$

$$X_T = \text{Antilog } Z_T = 10^{3.02356} = \rightarrow 2,864$$

The standard error is read from table

Table 5 skew ness

Skewness/Return Period	5	10	25	50	100	200
	1,709.62	1,851.4	2,518.26	3,126.80	3,844.15	4,691.37

Peak flow using log person type III calculated with the formula:-

$$Z = \bar{Z} + k_z \sigma_z \quad 2.686$$

Where, k_z is a function of skew ness (C_s) and return period and found from table.

From the table for coefficient of skew ness = by interpolation the standard error is 2.72.

For 5 % level of significance (α) and $N = 31$

$$t_{\alpha/2} \quad V = 31$$

$$\hat{X} \pm 2.040 * 2.72$$

$$\hat{X} \pm 5.55$$

$$X_1 = 1,125.58 + 5.715 = 1,131.295 \text{ m}^3/\text{s}$$

$$X_2 = 1,125.58 - 5.715 = 1,119.865 \text{ m}^3/\text{s}$$

Peak discharge 1,125.58m³/s found between x_1 and x_2 with 95 % probability.

SUMMARY OF THE DISTRIBUTIONS

Table 6. Summary of the peak flow for T = 100 years with 95 % of probability

Types of Distribution	Peak flow (m³/s)	Standard Error	Maximum flow (m³/s)
EVI	1,896.81	8.65	1,888.16
Gumbel	1,989.547	51.89	2,041.437
Log person	2,864	5.715	2,869.715

Log person type III distribution is selected. It is due to less standard error, it is widely applicable particularly for flood peak data. Therefore, the peak flow is 1,989.547 m³/s with an error of 5.715 and confident interval of 95 %.

5.0 Results and Discussion

Table 7 and Table 8 list the modeling results of the flood volume, peak discharge, their relative errors with respect to the observation data, the difference between the modeled and the observed time of peak appearance, and the Nash efficiency coefficients for the two modeling schemes. Figure 3, Figure 4, Figure 5 and Figure 6 show the modeling and observed variation in the flow

In the modeling, the parameters f_c and N showed a high sensitivity in Scheme I, while the CN showed a high sensitivity in Scheme II. Meanwhile, the Muskingum parameter K showed a high sensitivity in both schemes. These results demonstrate that the soil types, land use, basin topography and the river length play a major role in the flood run-off processes.

5.1. The Runoff-Volume Models

Schemes I and II employ the Initial and Constant-rate model and the SCS-CN model, respectively, to simulate runoff generation. According to the result of the flood volume relative error, RE_v , it can be seen that the error of Scheme I is relatively small for the four flood events, 13 June 1990, 11 July 1990, 16 August 1991, and 3 July 1993, with absolute values less than 10%, but the error increases significantly for the events of 27 July 1982, 14 July 1987, 28 July 1995, and 08 July 1998, with absolute values greater than 15%. However, the error of Scheme II has a small variation and a relatively small average absolute value for most of these events.

This can be explained by the following: due to the semi-arid and sub-humid attributes, the flood runoff is dominated by infiltration-excess under the condition of short but intensive rainfall, or by combined infiltration- and saturation-excess under the condition of long-lasting rainfall of various intensities. In Figure 3, Figure 4, Figure 5 and Figure 6, it can be seen that the floods on 13 June 1990, 11 July 1990 and 3 July 1993 were caused by rainfall of short duration, while the flood on 16 August 1991 was caused by rainfall with a strong intensity. The relative error of the flood volume of these events in Scheme I is relatively small and shows that the Initial and Constant-rate model is effective for modeling the infiltration-excess runoff. However, the increase in the error on 27 July 1982, 14 July 1987, 28 July 1995 and 8 July 1998 indicates that there was additional saturation-excess runoff, a fact that can be seen in Figure 3, Figure 4, Figure 5 and Figure 6, which shows that the

four events had a long, continuous duration. Although the SCS-CN model in Scheme II demonstrated a better performance for runoff volume prediction, it needs to be pointed out that the SCS-CN is an empirical model, which does not consider extreme situations.

Figure 15. Lognormal, Gambel,log Pearson III

The primary objective of frequency analysis is to relate the magnitude of extreme events to their frequency of occurrence through the use of probability distributions (Chow et al., 1988).

The values of the highest rainfall intensity in 24 h ever recorded in the study meteorological stations (Ip) is highly variable and range between 115, 166, and 170 mm/24 h at Dire Dawa Dengego and Kersa, respectively .

The return time interval for a rainfall intensity $I_{24} = 108$ mm/24 h was calculated using the Gumbel method for the meteorological stations with at least 32 years of data record. The results of this analysis show that of the meteorological stations, the probability of a rainfall intensity of 160 mm/24 h is less than one in 15 years. In figure 14.

The system uses SCS-CN method, which is a method of estimating rainfall excess from rainfall. The dominant and influencing form land use type is Acacia and shrubs land. This shows that climatic factors, sensitivity of parameters are influenced by land use in the watershed area thus giving results for analysis

Annual maximum daily rainfall as 6 hours duration storm peak discharges for the 25 years return period result values are close to each other. Ignoring the two extreme values, Run_3

that is using the annual maximum daily rainfall as 6 hours duration storm peak discharges for the 50 years return period result value is chosen for the next step analysis which is flood delineation.

Table 6.3.5 Runoff depth and peak flood value computed at 6th hour rainfall event

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
R40	257.467	2528.7	06Aug2006, 06:00	150.20

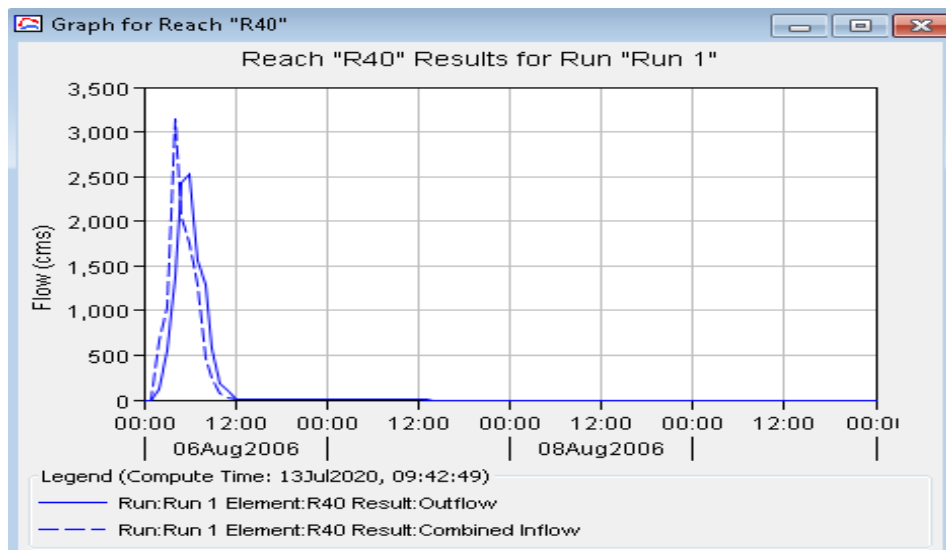


Figure 16 Graph of Dechatu peak flood of 6 hour

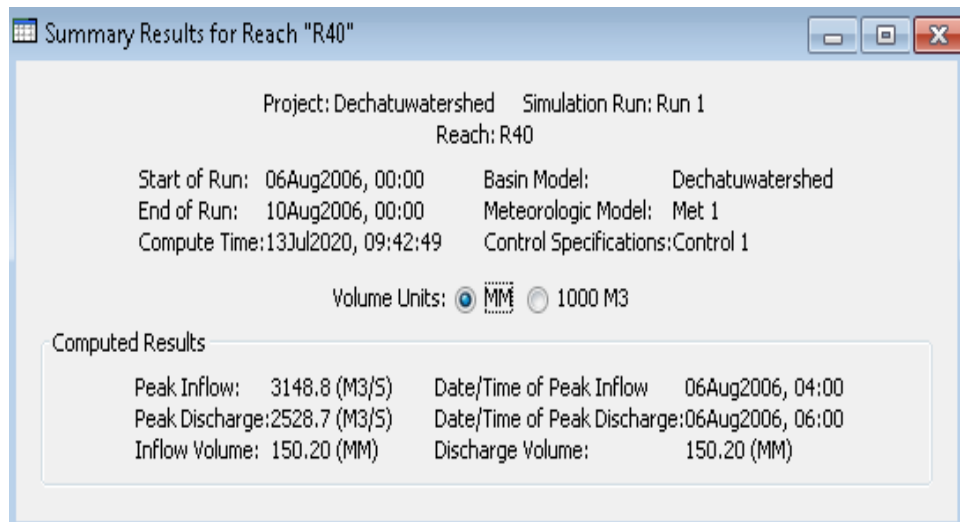


Figure 17 peak inflow & peak discharge

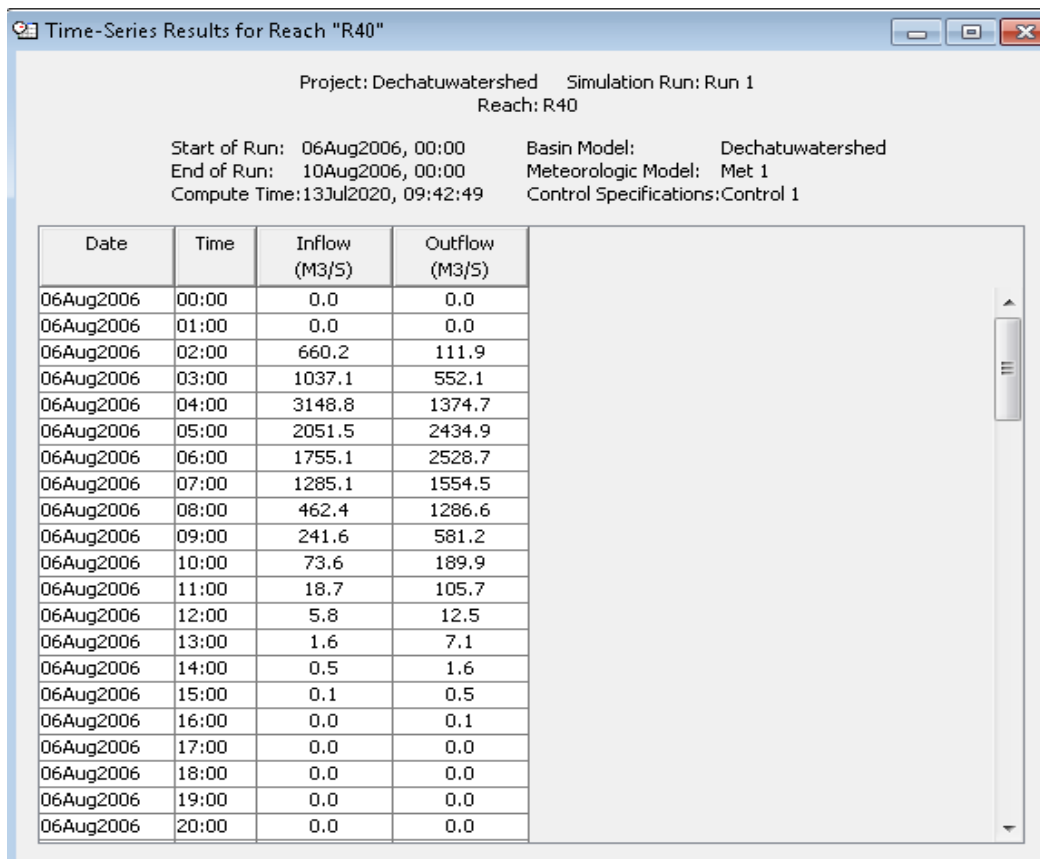
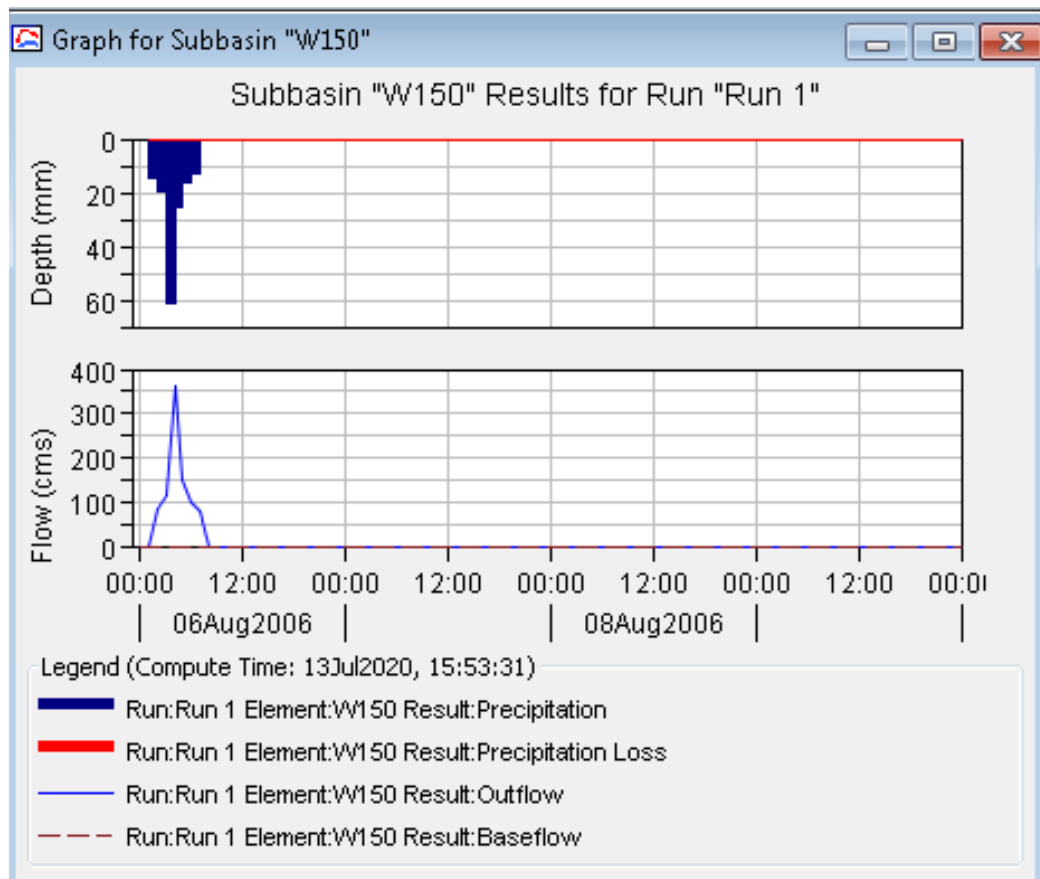
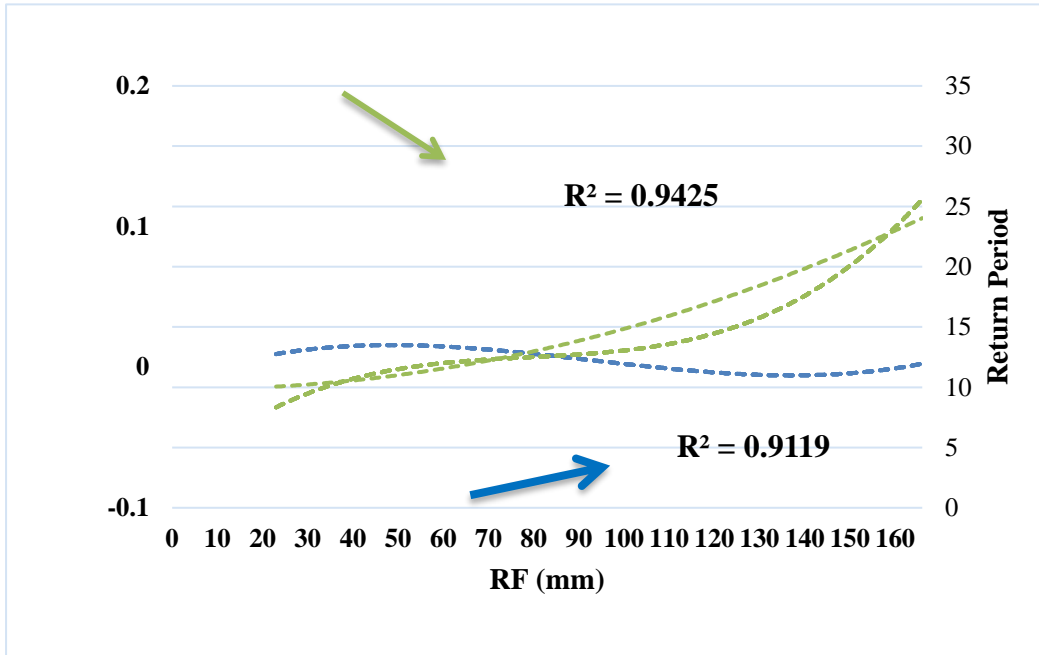


Figure 18. Time series Result





5.2. Flood Flows

The floods larger than 500 m³ s⁻¹, calculated by the methods described in Sect. 4.2.9, are reported in Fig. 12. The flood of August 6, 2006 was the most devastating and killed 256 people. Its peak discharge was calculated to be around 1,508 m³s⁻¹ (2.28 m³ s⁻¹ km⁻²). Alemu (2009), using the Soil Conservation Service Curve Number method (USDA 1986), obtained a peak discharge of 1,400 m³ s⁻¹, i.e., a value very close to that calculated by the simple uniform flow equation. Though the SCS-CN method is empirical and developed for small catchments in the mid-western USA, it was found to be particularly suited for streams with negligible base flow, i.e., rivers for which the ratio of direct runoff to total runoff is close to one, as it is commonly observed in ephemeral streams of arid and semiarid regions (Ponce and Hawkins 1996). This is also the case of the Dechatu that is dry for most of the time and has some water flowing only in response to individual, intense rainstorms. Therefore, it is not surprising that the hydraulic and hydrologic approaches used, though conceptually different, produced a very similar result. In the last decade, the largest flood had a peak discharge of about 2,157.6 m³ s⁻¹ (Total volume 12.6 m³/s) and occurred on May 20, 2005. Other seven large floods, with peak discharge (Q_p) higher than 1,000 m³ s⁻¹ occurred on April 14, 2006 (Q_p = 1,682 m³ s⁻¹), March 20, 2007 (Q_p = 1,044 m³ s⁻¹), March 25, 2010(Q_p = 1,160 m³ s⁻¹), April 6,2006 (Q_p = 1,080 m³ s⁻¹), April 12, 2007 (Q_p = 1,508 m³ s⁻¹), and March 8, 2010 (Q_p = 1,118 m³ s⁻¹). The August 6, 2006 flood was by far the worst in terms of human lives lost because it was a typical, very flashy flood and occurred in the night, before dawn, when most of the people were sleeping. According to eyewitness reports, in fact, the flood wave had a high velocity of propagation and peak discharge followed shortly after the flood onset. The largest flood of May 20, 2005 instead occurred during the day and people had time to move to safe places.

Table 7 skew ness

Skewness/Return Period	5	10	25	50	100	200
	1,709.62	1,851.4	2,518.26	3,126.80	3,844.15	4,691.37

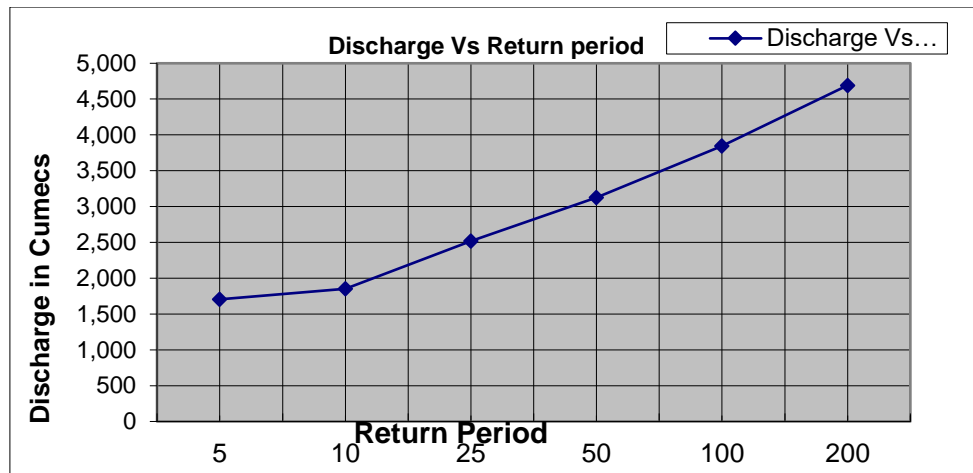


Figure 19. Discharge Vs. Return Period

The river reach within the town of Dire Dawa and the subsequent floods, though a couple of them were of the same order of magnitude as the previous ones, had limited impact. In order to quantify the magnitude of the August 6, 2006 flood and the largest flood of May 20, 2005 (Demessie 2007; Alemu 2009), a flood frequency curve was constructed with the discharge data calculated on the basis of the water level measured by the flow gauge. The discharges with the return times of 5, 10, 20, 50, and 100 years were calculated using the Gumbel EV method and by interpolation (Table 13). The results in Table 13 indicate that the return interval of the largest flood of May 20, 2005 is 20 years, whereas that of August 6, 2006 flood is about 4.5 years. The data used to calculate the flood frequency curve, though from one side may reflect the most recent flood trend, from the other cover a very short time interval (March 2003 to September 2015) that can make the results obtained questionable. Given the limitation of the data available, in an attempt to, at least, indirectly confirm the results obtained, the most renowned empirical equations to calculate the maximum flood (i.e., Q100) reported in the literature were applied to the Dechatu. They are the equations of Pagliaro (1936, in Maione 1977); Rodier and Roche (1984); and Griffiths and McKerchar (2008) which returned the following discharges for Q100, 1,709.62 1,851.4 2,518.26 3,126.80 3,844.15 4,691.37 m³ s⁻¹, respectively. None of these criteria were specifically developed for ephemeral streams of arid and semiarid regions.

5.3. Land use-land cover and changes in Dechatu watershed

Dechatu watershed is not an exception to the global processes of land use/ cover changes though the driving forces and their relative impacts might be different. Understanding changes and the driving forces for such changes are vital for timely, cost effective, socially acceptable and environmentally sound interventions. With these assumptions, satellite images of 1985, 2000 and 2014 were used to evaluate the land use/cover in the stated years and changes happening overtime in the watershed. The 1985 satellite image has shown that Acacia woodland had covered 84.14% of the land mass of the Dechatu watershed followed by Shrub land (11.34%) and plantation forests (0.9117%). The coverage of agricultural land and natural forest were 0.87 and 0.11%, respectively in the specified year. Similarly, though there was extensive decline in coverage, the Acacia woodland (79.25%), shrub land (14.13%) and plantation forests (1.92%) were the largest land covers observed in 2000 satellite image. In 2014 satellite image, the Acacia woodland, shrub land, and bare lands had a coverage of 42.62, 15.02 and 1.29%, respectively, of the total area of the dechatu watershed. Comparison of the vegetation cover for two time intervals (1985-2000 and 2000- 2014) shows that large areas of woodlands have been converted into other land uses during 1985-2000 than 2000-2014. This is primarily because of the massive deforestation took place in 1991 following government change in the country. The annual rate of change was also high for the same time interval. Contrary to woodlands, agricultural land and settlement has shown increment in both time intervals. The coverage of natural forest was small in all satellite images. As mentioned above, the coverage of natural forest was 0.11% of the total area of the dechatu watershed in 1985, which became almost nil in 2014. The small increment in the size of agricultural land in 2000-2014 could be attributed to the absence of suitable land for crop production and inhospitable climatic condition of the area for agricultural activities at least with the currently used technologies. Shrub land, on the other hand, had increased during 1985-2000 with annual decreased of 140.68 ha, which might be credited to the destruction of plantation and natural forests. But in 2000-2014 the size of the shrub land declined with annual change of -3.12%. Acacia woodland have been converted to other land uses such as agricultural land, bare land and settlements during 1985-2014. Out of these 83.72% of the natural forest, 54.31% of plantation forest, and 67.63% Acacia woodland conversions occurred during 1985-2000. Figures 5.1-5.3 show the land use land cover changes of the three time periods considered in this study

6. Discussion

In this study flood hazard forecasting and early warning system is developed. The system uses SCS-CN method, which is a method of estimating rainfall excess from rainfall. Dire Dawa, the second largest city of Ethiopia, has been suffering from disastrous floods in its history. The 2006 flooding was unheard-of disaster that caused severe impacts on human lives and property (Yonas, 2015). It is used to determine flood prone areas using rainfall event, if the amount of rainfall is greater than initial abstraction there will be surface runoff on the area. Potential maximum retention is also related to soil and land use condition of the area. It is potential maximum retention of water by the soil (Bansode and Patil, 2014), initial abstraction is generated from potential maximum retention. CN value is a primary input parameter for the SCS runoff equation (Ponce and Hawkins, 1996). According to Shadeed and Almasri (2010), a high curve number means high runoff and low infiltration, whereas a low curve number means low runoff and high infiltration. CN converter, in the system, is used to convert the value of CN in different antecedent moisture content conditions. Flood analysis application requires rainfall data from the user. Initial abstraction is used to analyze flood prone areas, as described here above if initial abstraction exceeds rainfall there will be flood and vice versa.

The coverage of natural forest was small in all satellite images. As mentioned above, the coverage of natural forest was 0.11% of the total area of the Dechatu watershed in 1985, which became almost nil in 2014. The small increment in the size of agricultural land in 2000-2014 could be attributed to the absence of suitable land for crop production and inhospitable climatic condition of the area for agricultural activities at least with the currently used technologies. Shrub land, on the other hand, had increased during 1985-2000 with annual decrease of 140.68 ha, which might be credited to the destruction of plantation and natural forests. But in 2000-2014 the size of the shrub land declined with annual change of -3.12%. Acacia woodland have been converted to other land uses such as agricultural land, bare land and settlements during 1985-2014

The system also has the capability of disseminating information to community or governmental and non-governmental organizations. To make it secured, messaging application is available to only concerned organizations. The SCS-CN method, adapted for

the analysis, has been widely applied in Ethiopia watersheds in particular and the Ethiopian highlands in general (Setegn et al., 2009; 2010)

7.0 Conclusion

The increase in extreme rains, paired by a marked change in land use/cover and management practices, is considered the main factor responsible for the increased frequency of high flash floods in the town of Dire Dawa during the last decade, though the increase in rainfall intensity is likely playing a more relevant role.

For flash floods with a value above 12.5mm/hour, can cause high peak discharge, capable inflict hazards depending the type of topography, soil property, effect of rainfall over upstream determine the occurrence of flood over flood sensitive areas, the flood hazards in Dire Dawa is favored by its topography, land cover, runoff from highland and intensive rainfall condition.

More intensive and frequent heavy falls with relatively higher rainfall intensity were recorded in 1956, 1977, 1981, 1983, 1988 and 1998, of wet months, slightly frequent but heavy falls were record in April & August 2004 & 2006 (after intensive, frequent hourly rainfalls and wet days).

There exist the likelihood of getting 50.0 mm of daily maximum heavy rainfall in every five years cycle for the month of April and every nine years for the month of August in Dire Dawa. For the maximum hourly rainfall intensity there exist a chance of getting 15.2 and 16.6 mm/hr in every three years of cycle for the months of August and April, respectively.

Lack of optimum areal coverage of representative index hydromet stations defects the work of hydromet at microclimate level.

The prospect of utilization of new technological outputs: from Radar/optical higher resolution satellites enable us fully enhance flood and flush flood early warning systems.

Major investments based on hydromet models are essential in managing rainwater flows and develop rainwater channels along the basin, thus, it will be able minimize flood related hazards.

Develop dikes and flood breaks and environmental rehabilitation at strategic places is the only remedy in alleviating flood risks. Thus the responsible bodies of Dire Dawa Administrative Council should incorporate the flood hazard and flood risk maps in

the currently ongoing activities related to flood disaster, as one of the short term intervention recommendations of the town is identification of critical flood areas

Lack of awareness on the importance of hydro meteorological information made the problem severe during those flood periods.

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