ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT (AASTMT)

College of Engineering and Technology

Construction And Building Engineering Department

FLOOD RISKS AND ITS MITIGATION AT EASTERN YEMEN

(CASE STUDY: WADI HADRMOUT)

A thesis submitted to AASTMT in partial

Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

in

(Environmental Engineering)

By

AYMAN HUSSEIN HUSSEIN TAHER

Supervisors

Prof. Mostafa M.Soliman

Professor of Irrigation and Hydraulics

College of Engineering

Ain Shams University

Prof. Wael M.H. Khadr

Professor of Hydraulics and Water Resources

College of Engineering and Technology

AASTMT

Dr. Abdalhamed El Tahan

Lecturer

Department of Construction and Building Engineering

College of Engineering and Technology AASTMT

الخلاصه

الفيضانات هي اكثر الظواهر الطبيعيه التي تسبب خسائر بالممتلكات والارواح على مستوى العالم و تكون الاضرار والمخاطر شديده في الاماكن الاكثر عرضه للفيضانات المفاجئه. في اكتوبر 2008 ضرب وادي حضرموت في جنوب شرق اليمن فيضان شديد ادى الى خسائر جسيمه في الممتلكات والارواح وقد تعرضت هذه المنطقه سابقا لعده فيضانات لكن يعتبر فيضان اكتوبر 2008 الاسوأ منذ عقود.

تهدف الدراسة الحالية الى حساب كميات مياه الجريان السطحي باستخدام حزمه من البرامج. أيضا اقتراح انشاء هياكل للتخفيف من حده الفيضانات مع اختيار انسب الاماكن لها وفقا لمخرجات الدراسة. لتحقيق أهداف البحث، تم جمع بيانات عن هطول الأمطار وأنوع التربة والتي تتمثل بالخرائط الجيولوجية واستخدام الأراضي وتم استخدام نموذج الارتفاع الرقمي (DEM) للخرائط الطبوغرافية.

باستخدام تقنيات تحليل ترددات اعماق هطول الامطار للسنوات السابقه تم ايجاد احتماليه هطول الامطار ل 50 عام قادمه تساوي 75ملم. تبلغ المساحه الكليه لمستجمع وادي حضرموت 30196.86 كم^2.

استخدم برنامج WMS مع (DEM) في عمل ترسيم لمستجمع وادي حضرموت وتقسيمه الى 8 مستجمعات فرعيه. باستخدام برنامج ARC-GIS تم تجهيز خرائط استخدامات الاراضي وخرائط انواع التربه لمنطقه البحث.

استخدم برنامج HMS - HEC لحساب الهيدروجراف لتدفق الذروه والبيانات الهيدرولوجيه لثمان مستجمعات فرعيه لوادي حضرموت باستخدام المعلمات الاتيه (الأمطار ، والفاقد من الامطار ، واستخدام الأراضي وانواع التربه) وبناء عليه تم حساب اكبر تصرف لمستجمع وادي حضرموت وتم تحديد الاماكن الاكثر عرضه لمخاطر الفيضانات.

بحساب القدره الاستيعابيه لقناه التجميع الرئيسيه لوادي حضرموت وجد ان قدرتها تساوي 5797.33 م^3 / ث وهذه القدره لاتستوعب كميات الجريان السطحي الناتجه عن هطول الامطار ل 75 ملم. وتم اقتراح سدين على المستجمع الفرعي (D) والمستجمع الفرعي (G) حيث اعطيى أعلى تدفق للذروة ينقل من المستجمعات الفرعيه. وقد اصبح تدفق الذروة عند المنفذ الرئيسي للمستجمعات 5525.748 م^3 / ث بدلا من 14241.378 م^3 / ث مع بناء السدود. تعتبر هذه القيمة أقل من القدره الاستيعابيه للقناه.

ووفقا لذالك فان هذا الشرط يلبي خيارات التخفيف وتكون منطقه وادي حضرموت آمنة ضد أي خطر من الفيضانات.

DECLARATION

I certify that all the material in this thesis that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this thesis reflect my own personal views, and are not necessarily endorsed by the University.

(Signature) ....

(Date) 5 / 5 / 2014

We certify that we have read the present work and that In our opinion it is fully adequate in scope and quality as a thesis towards the partial fulfillment of the Master's Degree requirements in

Specialization Environmental Engineering

From

College of Engineering and Technology

Construction and Building Engineering Department
(AASTMT)

Date 5 / 5 / 2014

<u>Supervisor(s):</u>

Name: Prof. Mostafa M.Soliman

Position Professor of Irrigation and Hydraulics, Faculty of Engineering, Ain Shams University

Signature:

Name: Prof. Wael M.H. Khadr

Position Professor of Hydraulics and Water Resources, college of Engineering and Technology, AASTMT

Signature:

Name: Dr. Abdalhamed El Tahan

Position Lecturer Department of Construction and Building Engineering, college of Engineering and Technology, AASTMT

Signature:

<u>Examiners:</u>

Name: Prof. Mohammad Sharif Al mnadely

Position Professor and Head of Irrigation and Hydraulics Department, Faculty of Engineering, Cairo University

Signature:

Name: Prof. Ahmed Ali Hassan

Position Professor of Irrigation and Hydraulics, Faculty of Engineering, Ain Shams University

Signature:

بِسْمِ اللهِ الرَّحْمنِ الرَّحِيمِ

(قَالُوْا سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا إِنَّكَ أَنْتَ الْعَلِيْمُ الْحَكِيْمُ).

سورة البقرة – أية 32

Acknowledgments

I would like to thank the members of my committee Prof. Mostafa Soliman, Prof. Wael Khadr and Dr. Abdelhamid El Tahan for their guidance and Patience during my work towards my master's degree.

I would like to thank all the helpful staff in Arab Academy for Science Technology and Maritime Transport who guided me, including Dr. Akram Sultan.

Lastly, I would like to thank my family and friends for continued support throughout my work on this Master's thesis.

Abstract

Floods are the most natural event that causes damages to property and losses in human life worldwide. The areas that are vulnerable to flash flood have high risk of severe damages. In October 2008, a severe flood hit Wadi Hadramout in southeastern Yemen, led to huge damage in property and human lives. This area was previously subjected to floods but October 2008 flood was the worst.

The current study aims at studying the runoff water quantities using computer model. Also, flood mitigation structure was introduced with the best place according to the study outputs. To achieve the research aims, data about precipitation, geological maps soil type, and land use were collected. A digital elevation model (DEM) was used for topographic.

Using frequency analysis techniques 50 year rainfall probabilities equal 75 mm for Wadi Hadramout were determined. The total catchment area of Wadi Hadramout is 30196.86 km^2.

The WMS software used DEM to delineate Wadi Hadramout catchment. The catchment was divided in to 8 sub-catchments. HEC HMS estimated the flood hydrographs for the 8 sub-catchment using the parameters rainfall (losses, land use and soil characteristics).The SCS method was used to get the lag time for the unit hydrograph. The hydrograph peak flows were also obtained by HEC HMS where representations of the model results were given.

The capacity of the stream at Wadi Hadramout main outlet was calculated and found to be 5797.338 m^3/s .This stream will not be able to convey water at high rainfall events and so flood will be expected A suggestion for constructing dams structure was introduced to mitigate the floods effect at the best locations according to the study results.

The locations of the two dams were determined at sub-catchment (D) and sub-catchment (G) where both give the highest peak flows out of the 8 sub-catchments. The two dams reduced the peak flow at the main outlet of Wadi Hadramout catchment to become 5525.748 m^3/s instead of 14241.378 m^3/s that satisfies the mitigation options of the flood risk in Wadi Hadramout.

TABLE OF CONTENTS Page

CHAPTER3

Hydrologic Analysis

CHAPTER 4

HYDROLOGIC MODELS

CHAPTER 5

RESULTS AND DISCUSSIONS

CHAPTER 6

Conclusions

List of Tables

List of Figures

List of Abbreviations

CN	Curve Numbers
DEM	Digital Elevation Model
EEA	European Environment Agency
EU	European Union
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information System
HEC-HMS	Hydrologic Engineering Center – Hydrologic Modeling System
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
PDS	Partial Duration Series
PMP	Probable Maximum Precipitation
PPF	Plotting Position Formula
SCS	Soil Conservation Service
UH	Unit Hydrograph
UNPD	United Nations Procurment Division
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WMO	World Meteorological Organization
WMS	Watershed Modeling System

CHAPTER 1

INTRODUCTION

1.1 General

The risk always refers to the damage and the presence of different risk results, whether physical, environmental, economic or human.

Floods are considered hydrological event characterized by high discharges and high water levels, which could claim to immersion, causing damage to land, become more tension and especially population growth in flood-prone land.

Wadi Hadramout terrain is rugged mountains, highlands and deserts. The climatic conditions make the Wadi prone to flood disasters.

(Dipl, 2010) A report by (EU, 2007) emphasized that:

i. Floods have the potential to cause fatalities, displacement of people and damage to the environment, to severely compromise economic development and to undermine the economic activities of the community.

ii. Floods are natural phenomena which cannot be prevented. However, some human activities (such as increasing human settlements and economic assets in floodplains and the reduction of the natural water retention by land use) and climate change contribute to an increase in the likelihood and adverse impacts of flood events.

(World Bank, 2009) stated that the Tropical Storm hit Yemen on October 24, 2008. The storm led to severe rain and flooding over the eastern Governorates of Yemen—Hadramout, The total catchment area of the flood affected about 2 million hectare collected some 2 billion cubic meter of water, while the catchment area, which used in this research is equal 30196.86 km^2. Given the topography of the affected area (mountainous terrain, flat valleys and riverbeds), this large quantity of water in the catchment area led to severe flash floods in the valleys, with water surges exceeding 10 meters height in some areas.

This area had experienced major floods in 1989 and 1996 but this flood is considered the most devastating and led to one of the worst natural disasters to hit Yemen in more than 10 years.

Wadi Hadramout was the worst hit region by 67.5% of the total damage and loss in the Hadramout governorate, with 16 of its 19 districts were reported damaged.

Infrastructure was particularly badly hit, with major roads, communications, power, and water supply networks.

This meant that access to the affected areas was very difficult in the early period, and in some cases, it took close to one week to reach some of the affected areas.

As of October 31, 2008, 73 persons were reported to have lost their lives as a result of the floods, 17 people were missing and several have been injured.

The flooding and heavy rain also caused that 2,826 houses and huts to be destroyed and 3,679 houses to be partially damaged. Some 25,000 people were displaced as a result, seeking temporary shelter in mosques and schools or with host families. The impact on agricultural land and people's livelihoods has been particularly devastating. A total of 22,902 (acres) of cultivated agricultural land and 51,455 (acres) of uncultivated land were damaged due to soil erosion.

Infrastructure irrigation public and private also sustained significant damage. In addition, about 550,000 palm trees and 160,000 fruit trees were uprooted. Some 58,500 livestock heads (sheep, goats, camels and cattle) died due to the water surge, and as much as 309,103 honey beehive cells were washed away.

Overall, about 700,000 persons, over 50% of the total population in the affected areas, have had their livelihoods destroyed or significantly affected, where two-thirds of the populations live in Wadi Hadramout.

1.2 Problem Identification And Solution

Several flood disasters account for about a third of all natural disasters (by number and economic losses).In addition they are responsible for over half of the deaths associated with all such disasters (Berz, 1999).

What more there is urgent trend of an increasing number of deaths being due to flood.

Flood risk is considered one of the most important societal challenges all over the world and increased risks are resulting from climate change. Their negative effect can be controlled by studying the frequency and probability of their occurrence. Controlling the excess of water and optimizing water use help us to overcome flood damages.

(Roger, 2004) discussed in detail, floods can take many forms and it is not easy to pin down a precise definition for the term. Broadly-speaking, however, a flood refers to an excess accumulation of water across a land surface: an event whereby water rises or flows over land not normally submerged. Hadramout exposed recently to several floods, specially Wadi Hadramout most vulnerable to flood disaster, where the rise in the population, the rate of unplanned urban development, the different land uses, the absence of any controls, environmental schemes, makes it the most vulnerable to loss of human, animal, agricultural, private property, displacement of many of the population and the loss of public services and infrastructure.

In the current study, Estimate of runoff water quantities using WMS Water Modeling System and HEC – HMS, in addition to flood control solutions and opportunities for the development of the area using rain water are the main research aims. Studying the topography of a catchment, the expected amount of rains, the land use and soil type are very important to estimate the amount of water coming out from a catchment after a rain event. Control structures play an important role on preventing, minimizing flood damage and its management.

1.3 Study Objectives

The objective of this research is to build a runoff prediction model that is capable to analyze the impact of the floods of Wadi Hadramout, find mitigate, and control or protection to the flood risk based on rainfall, land use, soil type and hydrologic modeling.

1.4 Structure Of The Thesis

This thesis is divided into six chapters include the following:

Chapter 1- includes a brief introduction, Problem Identification and Study objectives of the research.

Chapter 2- presents the literature review on the definition of risk, consequence of flood risk and risk assessment. Provides a description of the history of flood in Wadi Hadramout, the reasons for occurrence of floods in Wadi Hadramout and previous relevant studies of the impact of the floods on the Wadi Hadramout.

Chapter 3- This chapter describes the study area, case study methodology, use of geographic information systems (GIS) mapping to describe the nature of the ground cover of land use, soil types and hydrological modeling by WMS.

Chapter 4- This chapter describes the steps of work and a simulation was performed with the dams to storage of rainfall by HEC-HMS.

Chapter 5- discusses the different analysis of the results of the effect of rain on the catchment, sub-catchment, comparing the results with each other and identify areas most influence the risk of flooding in the Wadi.

Chapter 6- Provides a summary of the findings, conclusions of the study and recommendation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Flood risk has an effect and different consequences depending on its size and severity. This chapter discusses the various definitions of risk and history of flooding in the Wadi Hadramout, the reasons for the occurrence of rain and previous studies related to the risks of flooding in the study area.

2.2 Definition of risk

(Pritchard, 2000) gives the following risk-related definitions:

• Hazard: a property or situation that in particular circumstances could lead to harm.

• Risk: a combination of the probability, or frequency, of occurrence of a defined hazard and the magnitude of the consequences of the occurrence.

• Risk assessment: risk estimation and risk evaluation, where risk estimation is concerned with the outcome or consequences of an intention taking account of the probability of occurrence; the risk evaluation is concerned with determining the significance of the estimated risks for those effects.

• Risk management: the process of implementing decisions about accepting or altering risks.

(Pascal, 2002) stated the term “risk” is used to describe potential losses resulting from expected future hazard. "The term risk refers to the expected losses from a particular hazard to a specified element at risk in a particular future time period. Loss may be estimated in terms of human lives, or buildings destroyed or in financial terms".

(Mats, 2005) mentioned that the word risk, there exist several definitions of which activities that are included in the risk management process includes risk analysis, risk evaluation and risk reduction/control (see Figure2.1).

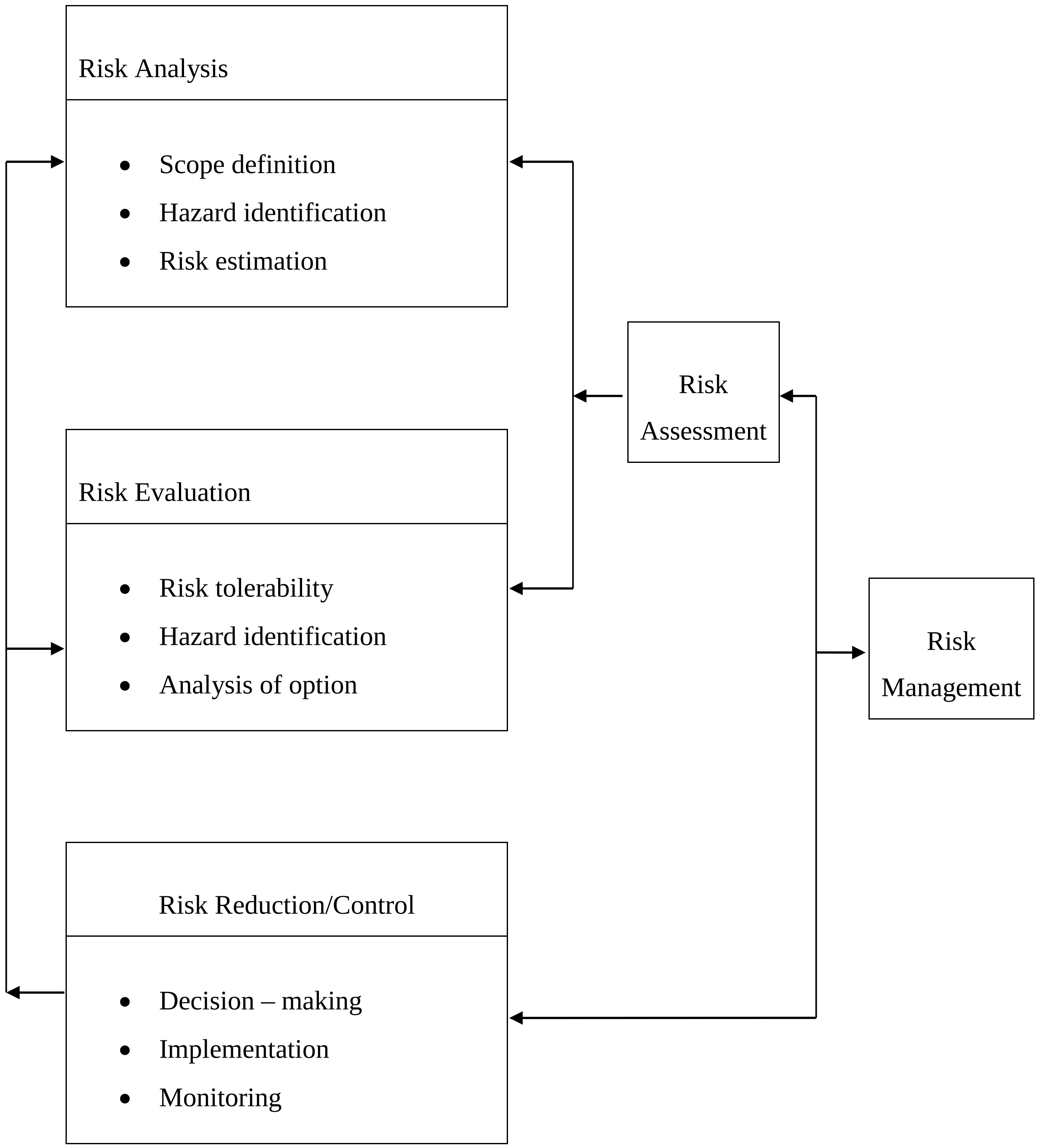

Figure 2.1 a simplified relationship between risk analysis and other risk management activities.

(Reger, 2006) defined risk the contentious issue, but in its most basic sense, it is used to describe an event that brings widespread losses and disruption to a

community. Some definitions include the notion that it exceeds the ability of that community to cope using its own resources.
(Michael, 2012) defined the risk as the “which is expressed as:

Risk (total) = Hazard x Elements at Risk x Vulnerability (Figure.2.2)

By this logic, risk results from the interaction between the flood hazard (i.e., storm), the exposure of the elements (e.g., buildings or dykes) to the event of flood and the vulnerability of the elements that are being impacted (i.e., the stability of the buildings).

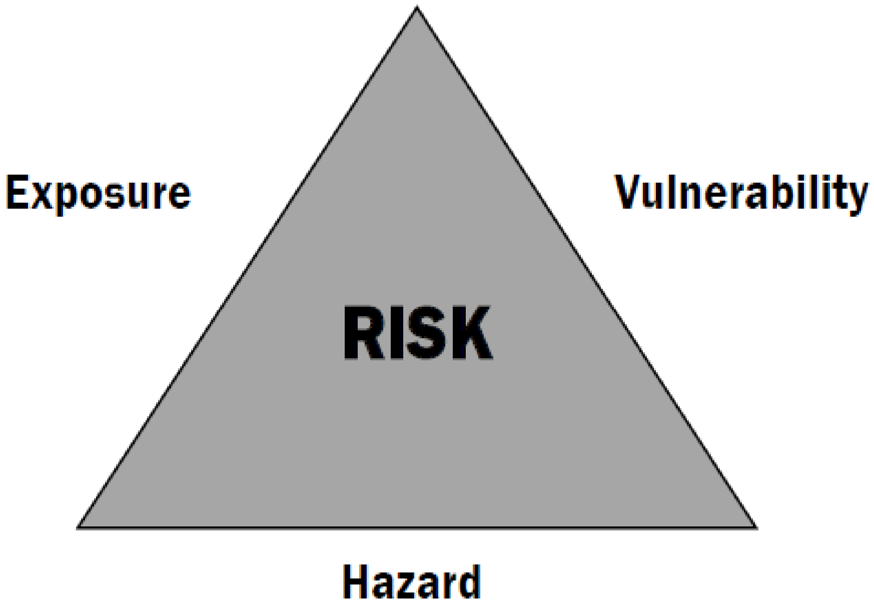

Figure.2.2: Total risk represents the area of the triangle while the sides represent the components of risk. If one of the sides gets larger, so does the total

2.3 Consequences of flood risk

(EEA, 2001) classified them that among all natural disasters that affect humanity, floods are the most common phenomenon that causes severe damage.

(GFDRR, 2009) stated that "floods are the most important and recurring disaster in the YEMEN. Over the last two decades, due to high rates of population growth and urbanization, unplanned and unregulated urban development, and lack of environmental controls, Yemen has become increasingly vulnerable to natural disasters". Increased concentration of physical assets and vulnerable population in high-risk areas are leading to increased exposure to adverse natural events.

(Richard, 2011) defined" risk is measured in terms of likelihoods and consequences". The probability of occurrence of some future event can sometimes be calculated precisely with no uncertainty. Other rare future events, however, are forecasted or predicted with a considerable amount of uncertainty. This level of uncertainty inherent in the forecasting process gives rise to risk.

(Smith, 1998) stated that Flooding has always been a cause of concern for humanity. Severe floods occurring in areas occupied by humans can create natural disasters involving significant loss of human life and property, as well as serious disruption to the ongoing activities of large urban and rural communities.

(Tania, 2012) stated that "this kind of events threats infrastructure, properties and human lives due to an excess of runoff on the surface". In particular, a major problem that is facing nowadays is the management of storm water. The direct consequence of climate changed, precipitation have been changed resulting in increased precipitation and more intense rainfalls.

2.4 Flood risk Assessment

To identify, assess risk must classify the type of damage if tangible and intangible damage in nature. Tangible damages can be evaluated quantitatively in economic terms and intangible losses are important but which cannot converted into a monetary terms (Figure 2.3).

In case of flood damage, both tangible and intangible damages can of two types, direct and indirect damages. Direct losses which are usually occur immediately after the event as a result of physical contact of the floodwaters with humans and with damageable property. Indirect losses are less easily connected to the flood disaster. Direct and indirect damages can be subdivided into primary and secondary categories (Sreyasi, 2007).

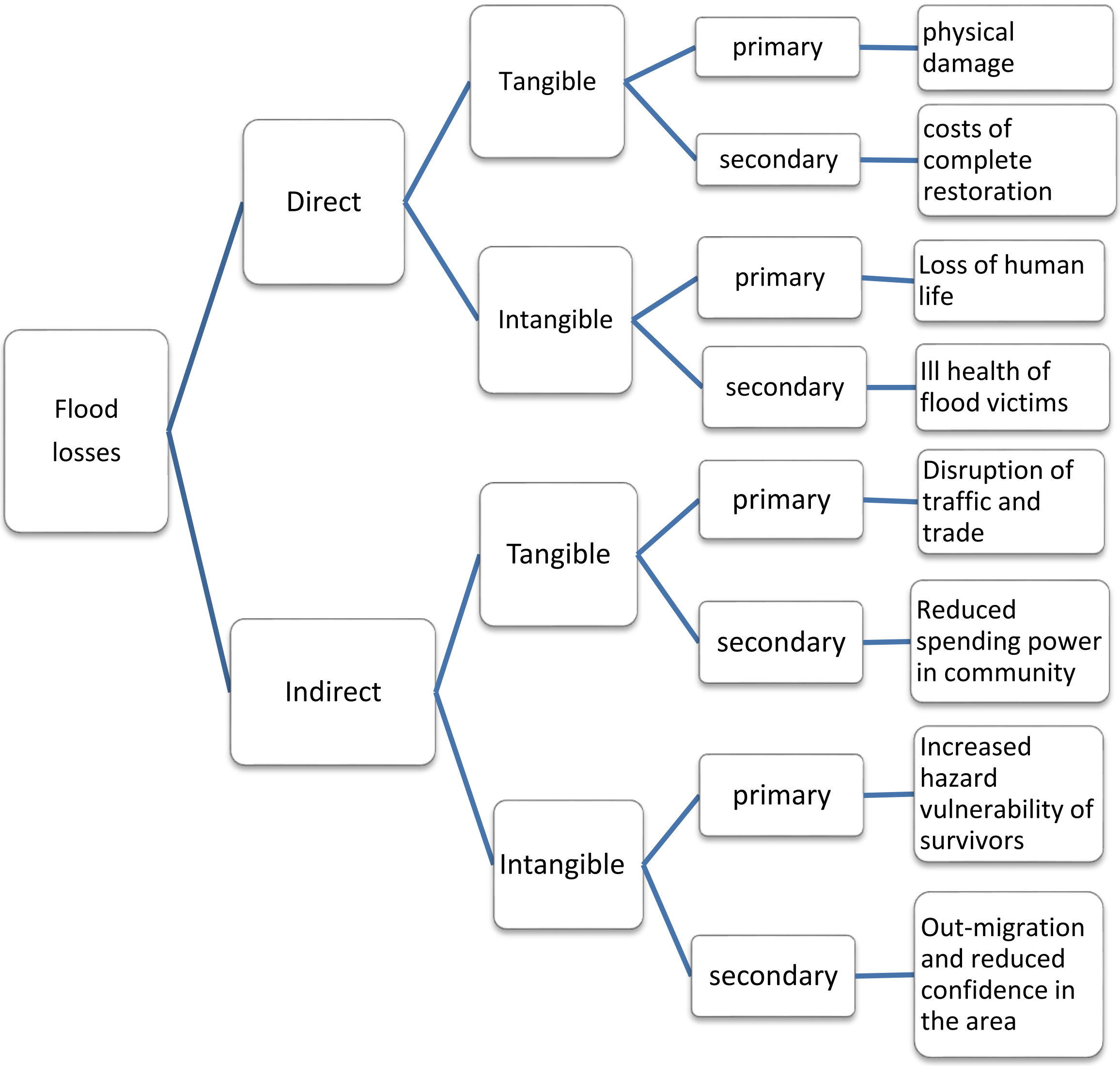

Figure 2.3 The categories of Flood Loss Potential Source: (Sreyasi, 2007)

The framework for risk assessment and risk management is illustrated in Figure 2.4, which shows that the evaluation of the potential occurrence of a hazard and the assessment of potential damages or vulnerability should proceed as parallel activities (WMO, 2006).

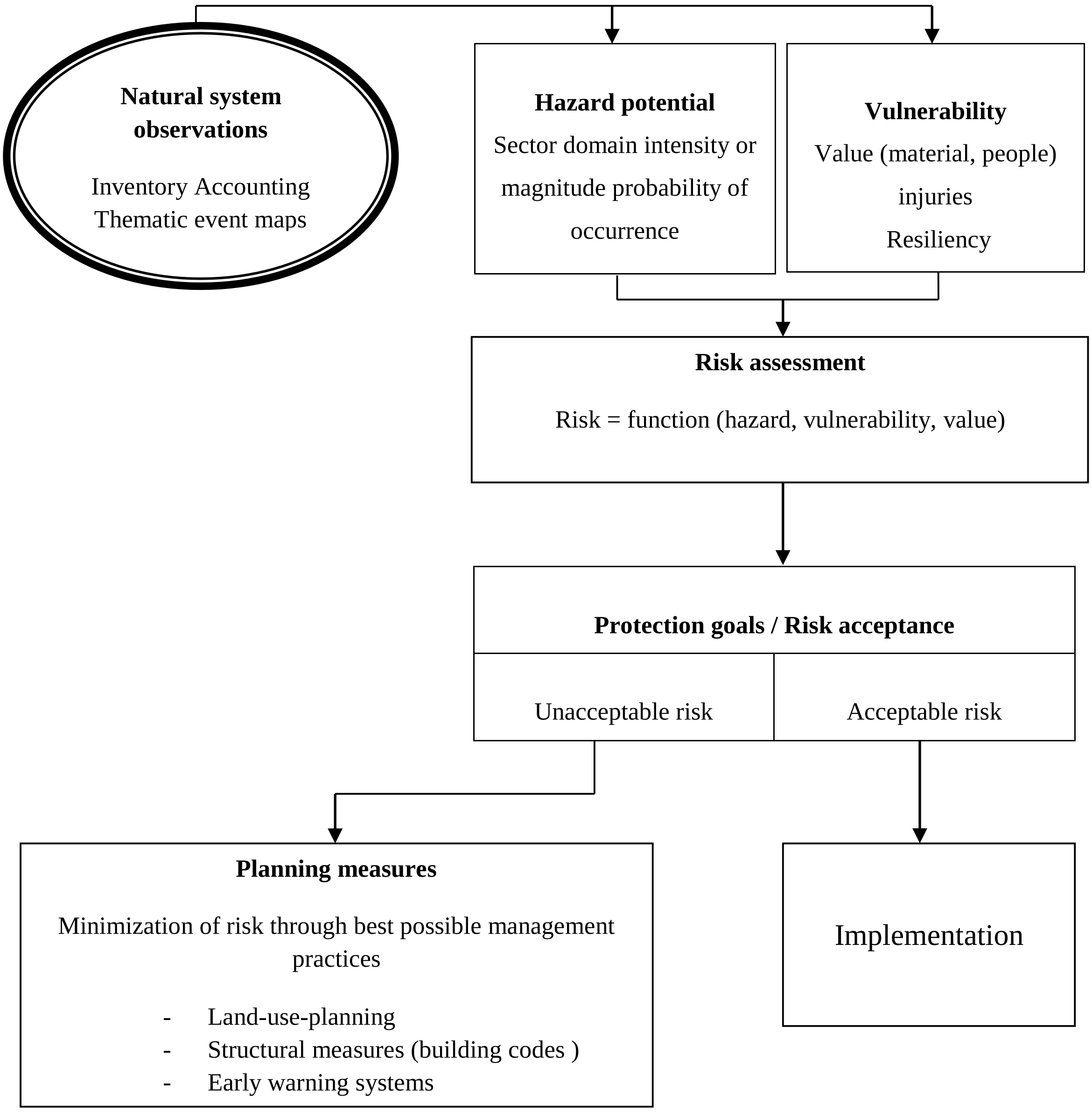

Figure 2.4. Framework for risk assessment and risk management. (WMO, 2006).

2.5 History of Wadi Hadramout Floods

Wadi Hadramout have a history of frequent floods as presented in (Table 2.1-2.2)

Table 2-1 Recent rainfall flow rate and volume for Wadi Hadramout (Kuriyama, 2004).

Year	Month	Day	Maximum flow (m^3/s)	Total flow million m^3
1974	6	2	650	14
1977	4	7	50	1
	10	23	650	35
1981	3	15	139	1
		18	61	2
1986	2	9	112	15
			156	15
			45	14
			202	3
	4	19	45	5
			83	2
1987	4	12	984	8.8
1995	5	15	3082	

Table 2-2 Type of floods and duration at Wadi Hadramout (Breisinge, 2012)

Year	Month	Type	Duration (Day)
1996	June	Flood	12
2002	August	Flood	1
	April	Flood	
2007	March	Flash Flood	3
2008	October	Flash Flood	2

2.6 October 2008 flood

Tropical storm (Deep Depression ARB 2/2008, See Figure 2-5) was first observed on October 19 2008 as an area of low pressure along the south east of Salalah, Oman. It became a deep depression and lost its strength while crossing the Gulf of Aden due to entry of dry air and land interaction as it passed the northeastern coast of Somalia. On 24 October it made its way to the southeastern coast of Yemen. The storm caused severe rain and flooding over the eastern parts of Yemen.

Given the topography of the affected area (mountainous terrain, rivers and flat valleys), this large quantity of water in the catchment area led to severe flash floods in the valleys, with water surges reaching up to 10 meter in some areas. This area had experienced serious floods in 1989 and 1996 but this flood is considered the most devastating. The flash floods and surging water resulted in one of the largest natural disasters to hit Yemen since the last decade (World Bank, 2009).

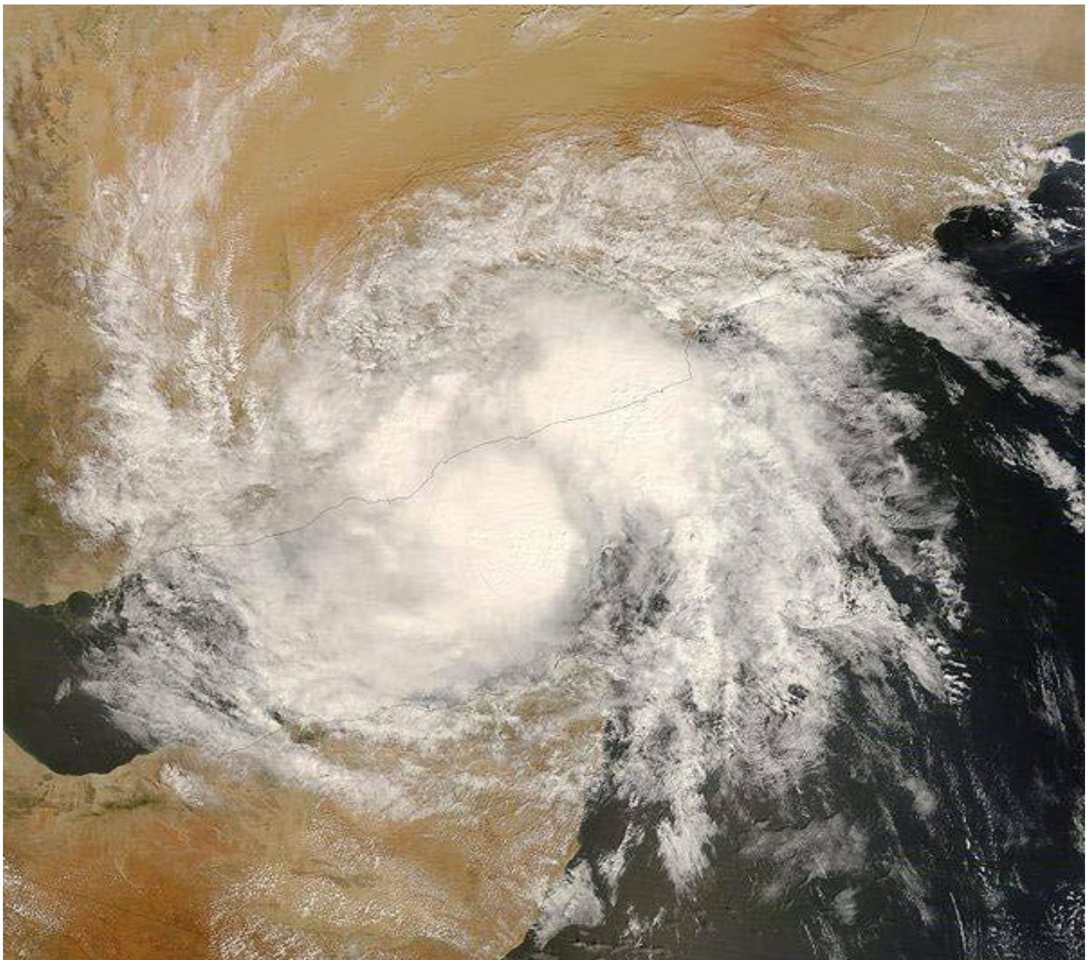

Figure 2.5 Tropical Storm on October 2008 Source: (NASA).

2.6.1 The impact of the disaster flood October 2008

The total value of the disaster effects caused by the October 2008 storm and floods in Yemen is estimated at YR 327,551 million (US$1,638 million —See Table.2.3). This is equivalent to 6% of Yemen's Gross Domestic Product (GDP), which illustrates the sheer magnitude of the disaster; Figures 2.6 and 2.7 illustrate the damage to property and water immersion of the land in the Wadi.

Table 2-3 Summary of Damage and Losses due to the October 2008 Storm and Floods in Yemen (World Bank, 2009).

Sector and Sub-Sector	Disaster Effects			Ownership by Sector	
	Damage (YR,mln)	Losses (YR, mln)	Total (YR, mln)	Public (YR, mln)	Private (YR, mln)
Productive	111.468.3	137,629.7	249,098.0	39,406.5	209.691.5
Agriculture, livestock, fisheries	109.937.0	97,305.0	207.242.0	39.406.5	167,835.5
Industry, Commerce and Tourism	1,531.3	40.324.7	41.856.0		41.856.0
Social Sectors	39,983.4	5.536.0	45.519.4	12.843.9	32,675.5
Housing	32.249.4	3.246.2	35.495.6	2.820.1	32.675.5
Education	3.460.0	34.8	3.494.8	3.494.8	
Health	4.274.0	2.255.0	6.529.0	6.529.0	
Infrastructure	22.532.9	6,520.0	29.052.9	24,581.8	4,471.1
Electricity	4.016.0	1.200.2	5.216.2	5.216.2	
Water and Sanitation	6.033.6	679.0	6,712.6	6.712.6	
Transport	11.999.9	4.326.0	16.325.9	11.942.8	4.383.1
Communications	483.4	314.8	798.2	710.2	88.0
Cross Sectoral	976.9	2,904.0	3,880.9	3.642.2	238.7
Environment	35.0	2.904.0	2.939.0	2.939.0	0.0
Public Buildings	941.9	0.0	941.9	703.2	238.7
Total (YR, million)	174,961.5	152.589.6	327.551.1	80,474.4	247,076.7
Million US Dollar	874.8	762.9	1,637.8	402.4	1.235.4

Figure 2.6 Destruction of property and agricultural land in the Wadi Source: (GFDRR, 2009).

Figure 2.7 Effect of rainfall on agricultural land Source: (GFDRR, 2009).

2.7 Effects of Wadi characteristics

2.7.1 Effects of topography

From using topography data arise at two levels in flood inundation mapping. First, topography affects the hydrologic model (e.g., watershed delineation) that is used to derive the flow estimate. Second, topography plays a significant role in the hydraulic modeling that is used to derive water surface elevations corresponding to the design flow.

Topography is an essential factor in hydrologic models of flooding and runoff. One of the most obvious factors controlling stream flow is the gradient, or slope, of the stream channel (Goldman, 1997).

Topography affects the geometry which defines the flow domain, including river cross-sections and bathymetry mesh in a hydraulic model. (Marks, 2000).
From recent studies, it has been proven that topography is one of the most important parameters in flood modeling (Schumann, 2007).

2.7.2 Effects of soil type

The ability of the soil to retain water influences the rate of runoff during a storm, for example, sandy soils allow for more infiltration of rain water.

Therefore, the soil constituents are important to the accurate modeling of runoff, as well as soil erosion and pollutant transport.
Soil moisture plays an important role in various hydrological processes acting over a range of spatio-temporal scales, like partitioning of rainfall into infiltration and runoff between land surfaces in the form of evapotranspiration is the major link of interaction between hydrological and atmospheric processes. Hence there is a need for accurate spatio-temporal representation soil moisture in the modeling of atmospheric and hydrological processes. The evolution and variability of soil moisture are affected by various factors, such as soil properties, vegetation, atmospheric condition and prevailing topography conditions (Chow, 1988).

Storm runoff from a watershed is influenced by many factors. These include watershed shape, slope, soil type, soil moisture conditions, vegetation and storage.

Of all the loss mechanisms during a rainfall event; soil infiltration is the most significant (Bennington, 2011).

2.7.3 Effects of Land use

The importance of the study, analysis of land use map and the impact of the surface cover to generate runoff resulting from the floods and these effects include the following:

- Interception, surface retention, evapotranspiration.

- Increasing runoff from cropland due mainly of vegetation.

Effect of surface cover directly affect the generation of runoff changes, of the following items:

1. Changes in peak flow characteristics.
2. Changing the stream's flow components.
3. Changes in total runoff.
4. Changes in quality of water.
5. Changes in the hydrological amenities and structures (Yongbo, 2004).

Land use represents the human function of a given area, the land use/land cover change analysis has become a central component in current strategies for managing and monitoring environmental changes (Sekliziotis, 1980)

The Land use refers to the human activity associated with a specific land unit, while land cover refers to all natural features (e.g. vegetation (natural or planted), water, ice, bare rock) and man-made features (e.g. buildings, roads) on the surface of the earth (Thompson, 1996).

Human activities play an important part in virtually all natural systems and are forces for change in the environment at local, regional. The earth's population has been growing rapidly and more stress is put on the land to support the increased population, hydrologic resources are affected both on local and global scale.

The patterns of vegetation on land surface give areas with different runoff generating characteristics, the vegetation cover density and the spatial configuration will both affect the discharge.

As the vegetation density increases, the average infiltration rate will increase, thus leading to a reduction in discharge.

The major changes in land use that affect hydrology are urbanization, by which land is transformed from its natural state or from agricultural use to an economically developed or populating region.

This process can take many forms including irrigation, drainage, deforestation and logging, and urban development, all which result in numerous adverse effects on the quality and quantity of water (Yongbo, 2004).

2.8 The reasons for occurrence of floods in Wadi Hadramout.

(Faisal, 2008) mentioned in his search about the causes, magnitude of floods that occurred on Wadi Hadramout due to several and different reasons as follows:

2.8.1 Natural factors

Natural factors that assist direct impact and increase the destructive forces of the floods are divided into three factors, Topographic, Climatic and Environmental Factors. Those factors are clarified as follows:

2.8.2 Topographic factors

Wadi Hadramout is the most important and largest valley in Hadramout.

Wadi Hadramout is made up of several Wadis, the main Wadi and a number of secondary (reaches). The recent flood was more a mud flow than a water flood, judging by the facts that the disaster had a large impact on both downstream and upstream areas; there were large deposits of mud; and the flow was strong enough to mow down palm trees and destroy concrete walls.

This type of flow generally wields destructive force as it flows linearly toward steep inclines, deposits mud at sudden changes in terrain, and turns into a flood flow in downstream areas. Therefore, it can be said that a mud flow disaster characteristically causes severe damage not only in downstream areas, but in upstream mudslide zones as well.

2.8.3 Climatic factors

The Climate of Wadi Hadramout Desert is very hot. It is dry in summer, very cold in winter with difference in temperatures between summer and winter by14 degrees. The variations of temperature at daytime and nighttime are between 10-14 Celsius degrees.

2.8.4 Environmental factors

The rain source is mostly the isolated cumulative clouds, this phenomena caused the floods in some branches of Wadi Hadramout while the others are dry. If it happened the clouds and then the rain spread over different branches the floods from different branches accumulate and caused severe damage.

Environmental factors help the increase of volume and flood speed. They are related to the characteristics of rainstorms, soil, and vegetation type in the catchment area of Wadi Hadramout. The dry climate and rain storms of strong rainfall that exceeds the capacity of soil absorption, lead to a rapid runoff and influential damage in the Wadi.

2.9 Risk Mitigation for Reducing Exposure to Natural Hazards

(Government Yemen and World Bank., 2009) mentioned in the joint assessment protecting all areas from all natural disasters is neither feasible nor economically viable. Yet, to prevent major economic loss, a risk mitigation strategy can be targeted at areas/sectors that are both populated and vulnerable, and would thus include urban areas, agricultural lands, and key infrastructure.

Strengthening the resilience of regions involves a combination of structural and non-structural measures that are critical, feasible and affordable to mitigate physical damage.

The priorities for intervention should consider risk to lives, property, livelihoods, facilities and services, and the sustainability of actions. The following are the recommended measures:

2.9.1 Non-Structural Measures

A flood protection master plan, based on the outcomes of the detailed hydrological, hydraulic and geological study, is critically needed for Wadi Hadramout.
The master plan would: recommend key flood protection infrastructure for vulnerable areas in the Wadi and identify areas that are flood-prone.

2.9.2 Structural Measures

Long-term structural flood protection interventions would have to be considered in the light of the hydrological study for the affected areas. In particular, there may be ways to reduce the flood risks considerably by widening critical sections of the Wadi that are narrow and are causing a blockage (often due to sedimentation deposits or illegal construction).

2.10 The principle of choosing Wadi Hadramout Catchment

For the following reasons Wadi Hadramout was choose for this study:

1- Frequent floods, obvious impact on the area of the Wadi, especially population growth and agricultural development areas.

2-Fragile infrastructure and lack of construction facilities to protect the Wadi from flooding.

3- The availability of the following criteria for selection:

(A) Availability of images of land cover, land use and vegetation description.

(B) Availability of geological maps to describe the soil through the hydrological data for the soil of Wadi Hadramout catchment.

(C) Availability of coverage for digital elevation model for every 10 meters

(D) Existence depths of rainfall in the Wadi for the past several years.

Chapter 3

Hydrologic Analysis

3.1 Introduction

This chapter describes the study area, presents the methodology that was used in this thesis to provide the scientific application and framework selection for assessing the risk of flooding in the Catchment of Wadi Hadramout. It includes method of studying and analyzing the physical characteristics as well as mapping of flood to control the system of water flow and to find appropriate ways to mitigate flood damage to the Catchment. Especially, the environment of Wadi Hadramout is complex according to Topography and Climate variation. The modeling process is considered as a proper scientific approach to this problem.

3.2 Description of the Study Area

Wadi Hadramout is located in the southeastern part of the Yemen. The study area of Wadi Hadramout lies between latitudes$(14^{\circ}45')$and$(16^{\circ}30')$. The longitudes range between $(47^{\circ}00')$ to$(49^{\circ}30')$.Wadi Hadramout elevation above sea level (Range between 592 to1932 meters) the Wadi length is 900 kilometers and it pours its course to the sea surface.

Figure.3.1 Wadi Hadramout location on the geographical map (OHCA, 2011).

3.2.1. Geology of Wadi Hadramout

According to (UNPD, 2002) report the general geology of the Wadi Hadramout region is a series of thick flat-lying sedimentary units that have been deeply eroded into a complex pattern of Wadi.

This includes the limestone which forms the steep walls of the Wadi.

The Interpretation of geological structures in such flat-lying sedimentary strata is difficult. Many of the faults and fractures are obscured and can only be inferred from an alignment of Wadi drainage patterns.

The generalized geological sequence is outlined in Table 3.1. The valley walls are formed by sub vertical walls of limestones above scree covered steep walls of outcropping sandstone and has not been identified in the outcrops.

In the valley, the layers above the sandstone have been removed by erosion, but the valley is backfilled by a limestone conglomerate, overlain by Quaternary alluvium.

Table 3-1. General Layers section (Wan H. A., 2011).

Age	Formation	Lithology	Location	Thickness	Hydrological significance
Quaternary	Alluvium	Clay, loam, sand and gravel	Valley	Up to 100 m	Aquifer
Neogene	Conglomerate	Calcareous conglomerate - fractured and fissured	Valley	Up to 100 m	Aquifer
Eocene	Jeza	Shale with thin limestones	Plateau	About 40 m	Aquitard
Paleocene	Umm Er Radhuma	Limestone and dolomite	Plateau	About 200 m	Aquifer
Cretaceous	Sharwayn	Mainly marl	Plateau	About 30 m	Aquitard
Upper Cretaceous	Mukalla	Sandstone, fractured and fissured	Valley and plateau	70 m where eroded, up to 400 m	Aquifer
Upper Cretaceous	Fartaq	Dolomite	Valley and plateau	Up to 60 m	Aquitard
Middle Cretaceous	Harshiyat	Shale	Valley and plateau	600 to 700 m	Aquitard
Middle Cretaceous	Qishn	Carbonate	Valley and plateau	Up to 500 m	Aquitard

The Jeza Formation forms the top of the Jol Plateau on both sides of Wadi Hadramout and contains bands of limestone and shale. It is about 40 m thick, but can reach thicknesses of up to 133 m.

The Jeza formation conformably overlies the Umm Er Radhuma Formation.

The Umm Er Radhuma Formation forms the upper part of the Wadi walls in the Wadi Hadramout. It is about 200 m thick and is composed of limestone primarily, with a 2m band of shale near the base of the formation. This stratum conformably overlies the Sharwayn Formation in the Hadramout area.

The Sharwayn Formation is made up of about 30 m of primarily marl with calcareous bands.

Quaternary alluviums is composed of clay, sand, gravel and silt and can be up to 150 m thick in the centre of the valley. In the main valley, this layer overlies the Neogene conglomerates. In the tributaries and along the margins of the main valley, it rests directly on Mukalla sandstone.

The Neogene conglomerate consists of hard limestone clasts in a calcareous matrix which is variably fissured. The conglomerate varies in thickness, reaching 100 m in the centre of the main valley.

The Mukalla formation is made up of 250 to 400 m of mostly friable sandstone, with some interbedded mudstone, ironstone and shale. The Mukalla formation overlays the Fartaq formation unconformably). The underlying formations form the hydraulic base to the shallow aquifer system.

3.3 General Methodology

This section describes the specific tasks that range in the framework of the comprehensive methodology to provide the necessary means for the analysis of the study area, determine the effects of flooding through flood mapping, finding the hydrological parameters for preparing a simulation model and setting the standards for this study.

The general methodology of this research included the following:

1. Frequency analysis.
2. Use Watershed Modeling System (WMS) to delineate the Wadi Hadramout catchment, find the hydrological characteristics of the catchment and divided the catchment to several sub catchments.

3. Use Digital Elevation Model (DEM) to determine topographic details at eastern Yemen (Case Study: Wadi Hadramout).
4. Use geographic information system (GIS) to integrate geographic data for the Wadi Hadramout catchment. These data include land use and soils hydrological group.
5. HEC-HMS (Hydrologic Engineering Center – Hydrologic Modeling System) is used to simulate the storm events to estimate the rainfall-runoff water quantities in Wadi Hadramout catchment.
6. Suggest structure to mitigate flood damage.

3.4 Data collection

Data were collected for the modeling process of Wadi Hadramout Catchment from several and different aspects that include the following:

- Information Obtained about the terrain of Wadi Hadramout, which is in the form of Digital Elevation Model (DEM) and can be downloaded from USGS per Ten-Meter mesh.
- Geological Maps of the Hydrological Groups of soil types and Satellite Imagery to describe the land cover of different land uses.
- Series of rainfall depths for years prior to the long-term in order to shed light on the rainfall system create the probability of rainfalls for years to come and to build a model that simulates Runoff Generation.

3.4.1 Digital Elevation Model (DEM)

DEM. is the basis for digital data and the different characteristics of watersheds. Without DEM. this research would be impossible to finish. It gives the topographic description of the study area in the form of mesh of points with a span 10 m in the horizontal plan. This data can be imported to GIS. software package for data preparation and modeling. Information on terrain of Wadi Hadramout is in the form of digital elevation model (DEM) is available on the internet and can be downloaded from the USGS website. The digital elevation model is shown in figure 3.2.

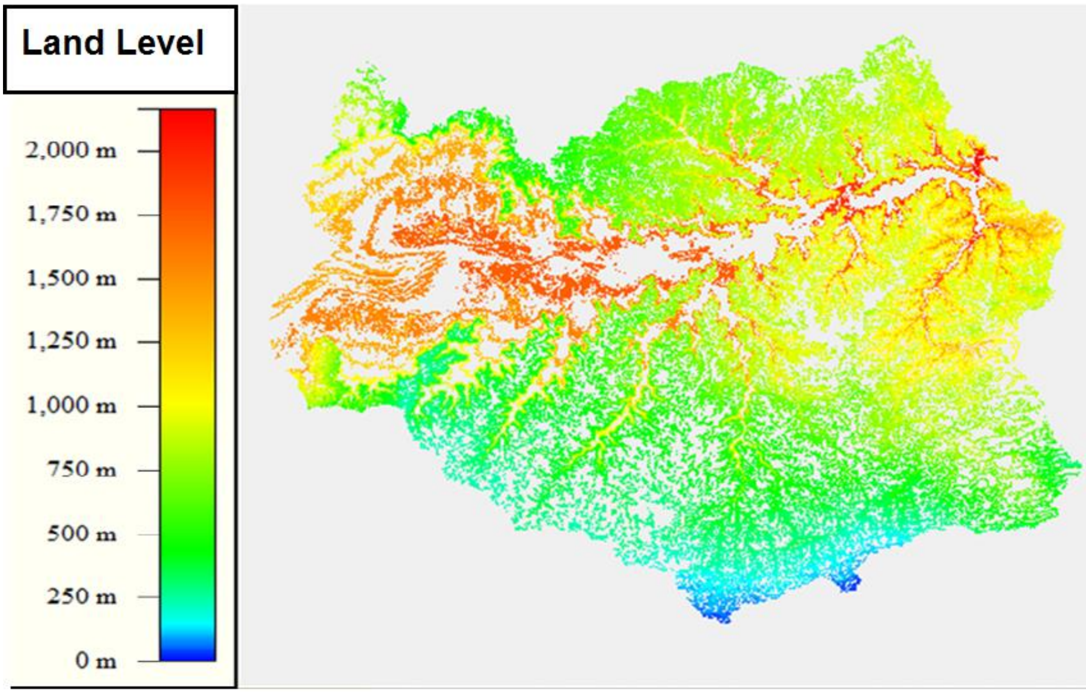

Figure 3.2 DEM of Wadi Hadramout

3.4.2 Digital Geological Maps

The map was obtained in the form of two-dimensional soil types acquired from the Geological Survey and Mineral Resources (Republic of Yemen). The map scale is 1:25000. The study area was described in six maps which were compiled together as one map using geo-referencing as shown in figure 3.3.

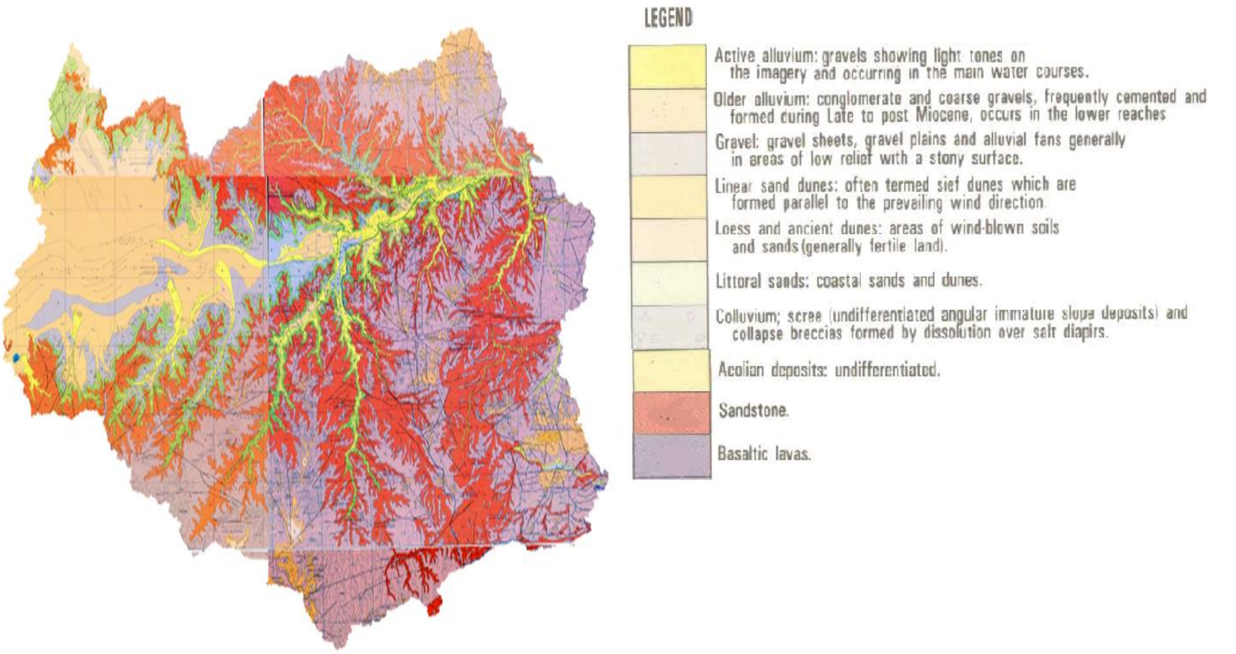

Figure 3.3 Geological maps

3.4.3 Satellite Data

For further analysis the image taken from satellites were collected. This image contains the land use, housing and land cover of the study area. The projection of these maps was UTM, Zone 38N, and WGS1972 Coordinate System.

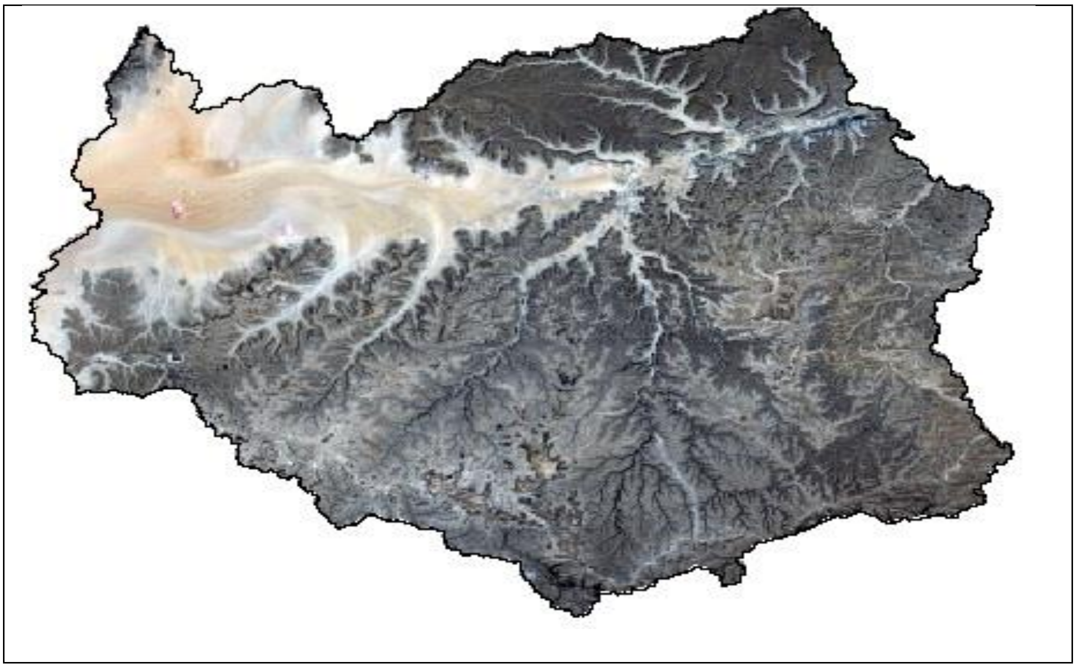

Figure 3.4 Satellite image of the area of study.

3.5 Integration of watershed database

Integrated Database has been built and the calculation of the hydrological parameters required to be used with the hydrological models for Wadi Hadramout. The analyses of Spatial Data, Hydrological Conditions show the impact of the floods on the surface cover. That led to a provision of a plan to manage and mitigate the risk of flooding of the study area. The Geographic Information System (GIS) is used for the preparation of a Natural Geographic Database. WMS was used to find the Hydrological characteristics of the catchment. This data was used for inclusion in HEC-HMS for the construction, preparation of the Hydraulic Model to simulate rainfall and runoff.

3.5.1 Rainfall Analysis

Hydrological events observed in the past can be used to interpret the phenomena and to estimate future events in terms of probabilities of occurrence. This process is called frequency analysis in order to consider the results of the frequency analysis as theoretically valid. Because hydrologic systems are subject to extreme events, including storms and flooding, it is necessary to understand the likelihood of an event happening in any given year. These probabilities are utilized in distributions that are used to relate frequency and magnitude of events. These generally suggest a given return period for an event, which is an estimation of the time interval between storm events. The distributions are developed upon a series of collected data over a period of time ((Bobee, 1991).

The precipitation data are generally ranked from highest to lowest value and depending on which distribution is being used these data are defined by either an Annual Maximum Series or a Partial Duration Series. An Annual Maximum Series is defined roughly by selecting the largest storm event for a given year, where a Partial Duration Series (PDS) includes the largest storms no matter which year they occur. Ranking of these data is necessary if the distribution is to be plotted. Plotting probability data can be useful to interpolate or extrapolate a certain return period.

The main objective of flood frequency analysis is to relate the flood magnitude of extreme events to their frequency of occurrence. The results of flood flow frequency analysis can be used for many engineering purposes: for the design of dams, bridges, culverts, and flood control structures; to determine the economic value of flood control projects; and to delineate flood plains and determine the effect of encroachments on the flood plain (Chow, 1988).

3.5.1.1 Design Storm

In the design storm approach, a historical rainfall record is initially analyzed to obtain the rainfall-return period relations (Morteza, 2011).

3.5.1.2 Rainfall distributions

The intensity of rainfall varies considerably during a storm as well as geographic regions. To represent various regions, Natural Resources Conservation Service (NRCS) developed four synthetic 24-hour rainfall distributions (I, IA, II, and III) from available National Weather Service (NWS) duration-frequency data.

Types I, Type IA is the least intense, IA represent the maritime climate with wet winters and dry summers, type II the most intense short duration rainfall and Type III represents coastal areas where tropical storms bring large 24-hour rainfall amounts (Frederick, 1986).

3.5.1.3 Frequency analysis of Hydro - meteorological data

Rains are the basic conditions and driving the process of runoff and flooding, rainfall data were available from the General Authority for Meteorology Yemen to provide the events of the storm used in the development of the hydrological model.

The events were analyzed to a depth of storms unity of mm rainfall from the previous record from 1996 to 2011, which were monitored by a station of Wadi Hadramout (Seyun) and is located between the latitude $(15^{\circ}45')$ and longitude$(48^{\circ}15')$.

Three different methods were used for rainfall frequency analysis; plotting position formula, Gumbel distribution method and Probable maximum precipitation in order to get probability of rainfall for 25 and 50 years return period. Those methods are:

a. plotting position formula

Weibull equation out of other equations was selected to find the return period. (Makkonen, 2005) this equation is as follows:

$$T=1/P=\left[\frac{N+1}{M}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Eq\ 3.1$$

Where

T is the return period.

P = The probability.

N = Number of years of rainfall depth record.

M = No. descending order of the amount of rainfall recorded.

This formula is applied as given in Table 3-2

Table 3-2 Return period T using Weibull method

Years	Total yearly rainfall (mm)	(N+1/M)	Descending arrangement (pi)	M
1996	58.8	17	89.9	1
1997	37.9	8.5	81.8	2
1998	30.2	5.6	58.8	3
1999	0.1	4.24	58.8	4
2000	11.0	3.4	40.6	5
2001	4.2	2.834	37.9	6
2002	8.0	2.428	30.2	7
2003	1.0	2.125	19.6	8
2004	8.6	1.889	11.0	9
2005	58.8	1.7	10.3	10
2006	81.8	1.545	8.6	11
2007	3.8	1.417	8.0	12
2008	89.9	1.3	4.2	13
2009	19.6	1.214	3.8	14
2010	10.3	1.134	1.0	15
2011	40.6	1.062	0.1	16
			464.3	

The records were plotted as given in Figure.3.5

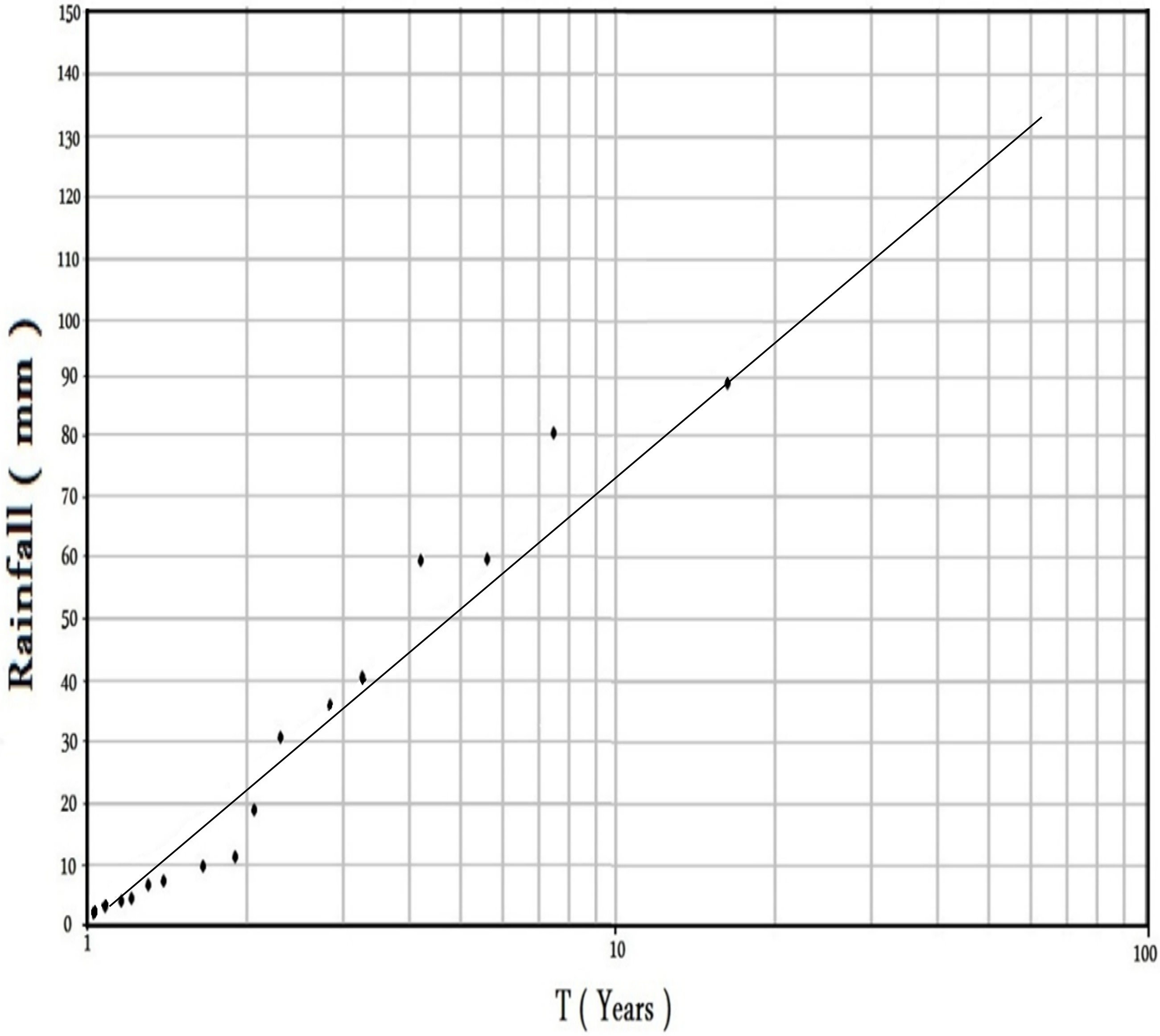

Figure.3.5 relation between rainfall and return period

b. Gumbel distribution method

The Gumbel probability distribution paper is widely used to get the extreme rainfall. (Clarke, 2002) it was used to plot the precipitation against the number of years as given in Figure.3.6.

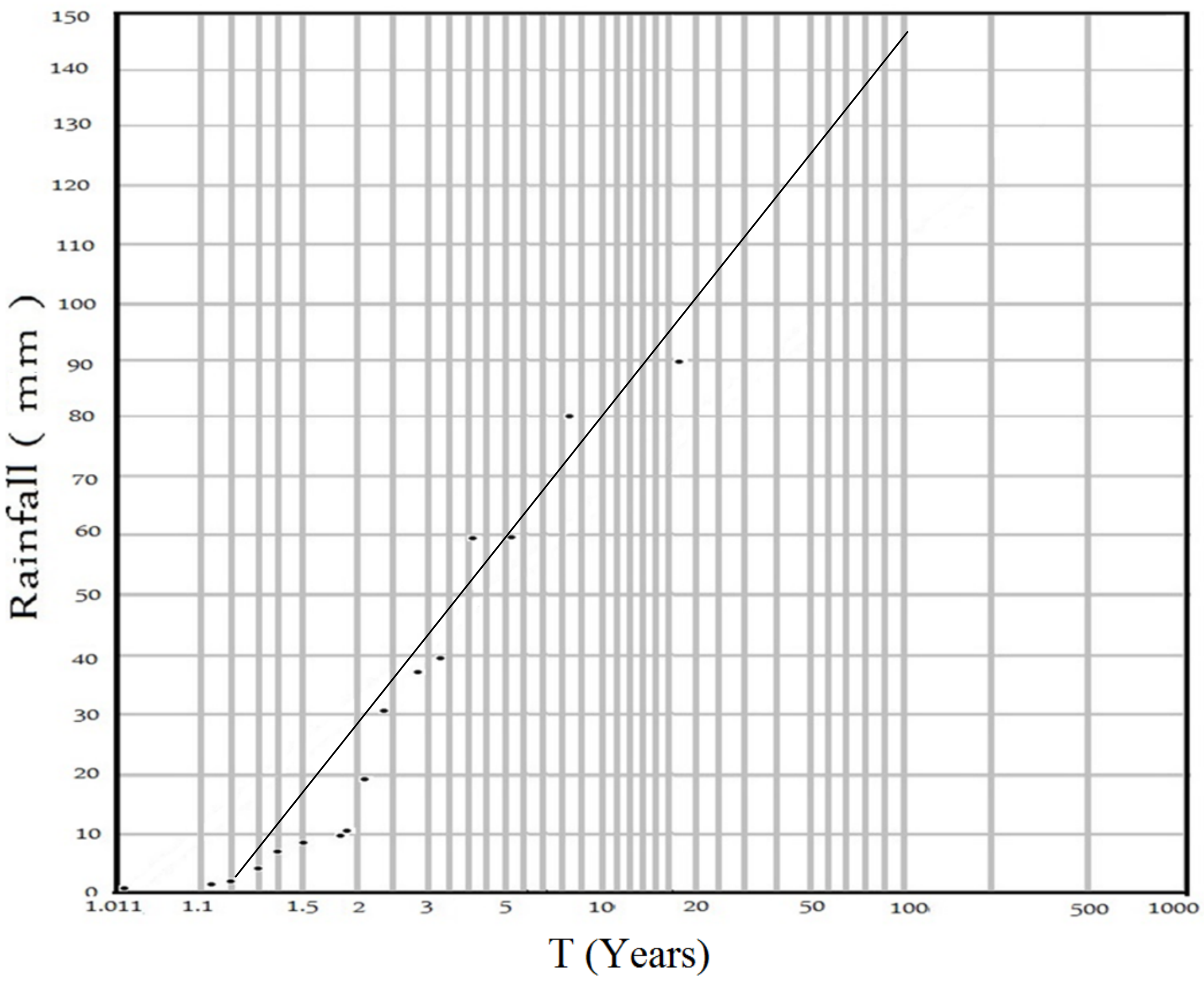

Figure.3.6 relation between rainfall and return period (Gumbel Distribution)

c. Probable maximum precipitation

Chow suggested the following formula for probable maximum precipitation (Dilip G. D., 2008).

$$p_m = [\bar{p} + k\sigma_p] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots..Eq\ 3.2$$

Where

p_m Is the annual rainfall in a given duration.

$\bar{p}$ Is the average annual rainfall.

, σ_p Is the standard deviation of the annual rainfall for given duration.

The standard deviation is calculated using the following formula.

$$S^2 = \left[\frac{\sum(\mathrm{Pi} - \bar{\mathrm{p}})^2}{\mathrm{N} - 1}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \, Eq\ 3.3$$

Where

P_i = amount of rainfall depth recorded (mm)

N = Number of years of rainfall depth recorded.

The value of $\bar{\mathrm{p}}$ for Hadramout Wadi recorded between 1996-2011 and equal 29.01 mm.

σ_p Was also found for the same records as 29.41 mm

K = Is frequency factor, which depends upon the statistical distribution of the series developed by Gumbel, number of years of record, the return period and K values can be found from the following Table:

Table 3-3 Gumbel Extreme Value Frequency Factors (k) (Mostafa, 2010) .

Sample size Of the rainfall record	**Return period**					
	2.33	5	10	20	25	50
15	0.065	0.967	1.703	2.410	2.632	3.321
20	0.052	0.919	1.625	2.302	2.517	3.179