ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT

(AASTMT)

College of Engineering and Technology

Construction and Building Engineering Department

RISK ASSESSMENT OF FLASH FLOOD IN SINAI

By

MOHAMED ASHRAF MOHAMED ELSAYAD

A thesis submitted to AASTMT in partial
Fulfillment of the requirements for the award of the degree of

MASTER of SCIENCE

In

CONSTRUCTION ENGINEERING AND MANAGEMENT

Supervised by

Prof. Dr Gamal Ibrahim Kotb

Deputy Director, Water Resources Research Institute

Prof. Dr. Abd El-Moniem Sanad

Head of Construction and Building Engineering Department, Arab Academy For Science, Technology and Maritime Transport

3102

ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT
College of Engineering and Technology

RISK ASSESSMENT OF FLASH FLOOD IN SINAI

by

MOHAMED ASHRAF MOHAMED ELSAYAD

A Thesis
Submitted in Partial Fulfillment to the Requirements
for the Master's Degree in

CONSTRUCTION ENGINEERING AND MANAGEMENT

Prof. Dr. Gamal Ibrahim Kotb
Supervisor

Dr. Abd El-Moniem Sanad
Supervisor

Prof. Dr. Ahmed Fakhry Khatab
Examiner

Prof. Dr. Anas Mohamed Almolla
Examiner

Acknowledgements

First of all thanks to god for guiding me through this work, for all what I have learnt and for all those people who supported me.

I would like to express my deepest gratitude to Prof. Dr. Gamal Ibrahim Kotb, Professor of Water Resources Management Engineering, Water Resources Research Institute, for his guidance, support and encouragement not only in this research but also through my academic and practical life. His valuable help and professional suggestions in reviewing this thesis added to the value of this research.

I am truly appreciative of the help given to me by Prof. Dr. Abd-Elmoniem Sanad, professor of Structural Engineering, Faculty of Engineering, Arab Academy for Science and Technology in Cairo. He helped me greatly in preparation of the thesis. His professional suggestions and continuous support were so conductive to finish this research.

Thanks for everyone who contributed in this research by any means.

My outmost gratitude goes to my father and my mother for their continuous encouragement, great support, care and love throughout my whole life

I wish to dedicate this work to my father, my mother, my brother, my sisters, my daughter and my dear wife.

RISK ASSESSMENT OF FLASH FLOOD IN SINAI

ABSTRACT

Sinai is identified as a flood prone area where several flash floods were recorded and resulted in significant infrastructural damages, population displacement, and sometimes loss of lives. Most of the flood management strategies in this area have been geared towards preventing flood by an attempt to control the flood water by dams. Very little attention is paid for formulating rational land use planning to reduce flood induced disaster. Flash flood risk is a major issue to governments who ultimately pay the financial costs of losses resulting from flood events, so preparation of flash flood risk map is very important in this area. The preparation of a comprehensive flash flood risk map for this area would be very important to help in developing planning.

In this study the issue of flash flood hazard, vulnerability and risk mapping has been addressed from the perspective of different mapping scale in a GIS environment. Geographical Information System (GIS) is extensively used to assemble information from different maps, remote sensing and digital elevation model. Two different techniques for flash flood hazard mapping are proposed based on hydrological, metrological and hydraulic parameters. Flash flood hazard map using hydrologic and petrologic causative factors obtained by means of weighting a number of causative factors including maximum daily rainfall heights of 50 and 100 years return period, watershed area, slope of the watershed, drainage density and type of soil type and land use. For the second approach, hazard level is estimated as a function of two available parameters from the hydraulic model; flood depth and flow velocity (flood intensity). Then flash flood intensity and flood hazard map using causative factors compiled to the final flash flood hazard map. Finally, risk map for Al-Arish area was developed by the multiplication of the flash flood hazard map for 50 and 100 years return period with the vulnerability map.

This thesis has developed a systematic methodology for estimating flash flood, vulnerability, and risk maps based on a geographic approach using GIS. It concludes from the risk analysis of Al-Arish area that 21% of the houses and built up areas are under very high risk while 38% of it lies in high risk zone. Likewise, 20% of the agricultural land is under high risk while 69% of it lies in the moderate zones. In general, the rest of Al-Arish area is under moderate risk.

Table of Content

List of tables

List of Figures

Acronyms and Abbreviations

G|IS: Geographical Information System

DEM: Digital Elevation Model

RS: Remote Sensing

IDF Intensity-duration-frequency

WMS: watershed modeling system

HEC: Hydrologic Engineering Center

HMS: Hydrologic Modeling System

RAS: River Analysis System

SCS: soil conservation service

GEV: Generalized Extreme Value

WRRI: Water Resources Research Institute

FEMA: Federal Emergency Management Agency

UNDRO: united state disaster relief co-ordination

GWP: Global water partnership

WMO: World meteorological organization

FLAFLOM: Flash Floods in Egypt: Protection and Management

CMDRS: Crisis Management and Disaster Reduction Sector in Egypt

CHAPTER ONE

INTRODUCTION

1) General

1.1) Natural Hazards

During the past decades, natural hazards have caused major loss of human lives and livelihoods, the destruction of economic and social infrastructure, as well as environmental damage. Economic losses have increased almost 10 times during this period. There is an increasing likelihood of human-induced climate change, which, according to the latest projection of the Intergovernmental Panel on Climate Change, will result in more water-related disasters. These changes in temperature and related local rainfall variations affect the environment through accelerated desertification, land degradation, and the availability of water resources, as well as reducing the overall agricultural output. These factors have a compound effect on the occurrence and impact of disasters. On the one hand, they affect the intensity and frequency of extreme hydro-meteorological events, and on the other hand, they increase the vulnerability of societies. Particularly sensitive regions such as mountainous are especially at risk.

Natural hazards are natural phenomena that threaten lives, property, and other assets. Natural hazard refers to all atmospheric, hydrologic, and geologic phenomena that have the potential to affect humans, their structures, or their activities adversely because of their location, severity, and frequency. Natural hazards can be classified by origin to geological Hazards, Climatic Hazards, and Environmental Hazards. Geological Hazards are natural geologic events such as earthquakes, tsunamis, volcanic eruptions, and landslides. Climatic Hazards are extreme weather events causing harm and damage to people such as tropical cyclones, floods, and drought. Environmental Hazards are the hazards that cause the damage for the environment such as environmental pollution or deforestation.

The other distinction of natural hazard types is related to the accumulation of warning signs and vulnerabilities over time to sudden onset hazards and slow onset hazards. Sudden onset hazards have short or no warning and cause immediate damage such as earthquakes, tsunamis, flashfloods, tropical storms, volcanic eruptions, and landslides. Slow onset hazards which act slowly and the damage either immediate or develops over longer time period Such as drought, environmental degradation, desertification, and deforestation.

1.2) Capacity

Capacity can be defined as resources, means and strengths which exist in households and communities and which enable them to cope with, withstand, prepare for, prevent, mitigate or quickly recover from a disaster. People's capacity can also be taken into account. Capacities could be Physical Capacity and Socio-economic Capacity. Physical Capacity is People whose houses have been destroyed by the cyclone or crops have been destroyed by the flood can salvage things from their homes and from their farms. Some family members have skills, which enable them to find employment if they migrate, either temporarily or permanently. Socio-economic Capacity can be described in most of the disasters; people suffer their greatest losses in the physical and material realm. Rich people have the capacity to recover soon because of their wealth. In fact, they are seldom hit by disasters because they live in safe areas and their houses are built with stronger materials. However, even when everything is destroyed they have the capacity to cope up with it.

1.3) Vulnerability

Vulnerability may be defined as the extent to which a community, structure, services or geographic area is likely to be damaged or disrupted by the impact of particular hazard, on account of their nature, construction and proximity to hazardous terrains or a disaster prone area. While natural hazards remain part of our existence, human actions can either increase or reduce the vulnerability of societies to hazards and related disasters. The pattern of development, specifically the persistence of widespread poverty, rapid and uncontrolled urbanization and environmental degradation have led many regions and countries more vulnerable to natural hazards. The factors contributing to increased vulnerability are Rapid growths and increasing poverty in urban areas, Poverty and environmental degradation in rural areas, Poor policy planning, and Last but not least, the emphasis on disaster response.

Vulnerability refers to the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard. Vulnerability has two sides an external side of natural hazard (severity and frequency) and an internal side, which refers to capacity and resilience of the affected community. Externally, the severity and frequency of a hazard event determines the level of vulnerability. Unless the impact of a hazard event is mitigated, the community exposed to it would be vulnerable. Internally, vulnerability refers to the community's capacity to resist and recover from the adverse impact of a disaster. Resilience is, therefore, an integral part of the concept of vulnerability. Vulnerability thus embodies both risk and capacity of households and community to respond to shocks.

Vulnerabilities can be categorized into physical and socio-economic vulnerability. Physical Vulnerability includes notions of what may be damaged or destroyed by natural hazard such as earthquakes or floods. It is based on the physical condition of people and elements at risk, such as buildings, infrastructure etc; and their proximity, location and nature of the hazard. It also relates to the technical capability of building and structures to resist the forces acting upon them during a hazard event. Socio-economic Vulnerability is the degree to which a population is affected by a hazard will not merely lie in the physical components of vulnerability but also on the socioeconomic conditions. The socio-economic condition of the people also determines the intensity of the impact.

1.4) Risk

Risk is a measure of the expected losses (deaths, injuries, property, etc.) that would be caused by hazard event occurring in a given area over a specific time period. Risk is a function of the probability of particular hazardous event and the losses each would cause. The level of risk depends on nature of the hazard, vulnerability of the elements which are affected, and economic value of those elements. Community is said to be at risk when it is exposed to hazards and is likely to be adversely affected by its impact. Exposure is another component of disaster, and refers to that which is affected by natural disasters, such as people and property. So the disaster risk is a function of Hazard, Exposure, and Vulnerability. Growing exposure and delays in reducing vulnerabilities result in an increased number of natural disasters and greater levels of loss. Information from the analysis of an area's hazards and its vulnerability to them is integrated in an analysis of risk, which is an estimate of the probability of expected loss for a given hazardous event.

1.5) Natural Disasters

Natural disasters occur when a natural hazard seriously disrupts the functioning of a community, causing widespread human, material or environmental losses that exceed the community's capability to cope without external relief. It means that the hazard becomes a disaster only when there is greater vulnerability and less of capacity to cope with it. Human actions play a critical role in creating these types of vulnerabilities to natural hazard. Natural disasters have the most severe impact on developing countries, and within those countries, the poor are most seriously affected. Poor communities are often forced to live on more fragile lands, and have little or no resources to recover from disaster impacts. The poor often lose their livelihoods and assets following a disaster. Such losses may take years to recoup and are devastating to poor households and communities.

Natural disasters are unpredictable, destructive and often deadly. A natural phenomenon that occurs in a populated area is a hazardous event. A hazardous event that causes unacceptably large numbers of fatalities and/or overwhelming property damage is a natural disaster. It means that Natural hazard can lead to disaster when humans or human interests appear in the hazard areas.

There are several reasons why groups of people continue to live in hazards zones, despite the existences of measurable and known levels of risk. Some of these areas offer their inhabitants superior economic opportunities, such as those given by fertile volcanic or floodplain soil. But for many groups there is a lack of satisfying alternatives, especially if the resources are not available to allow them to adjust to the hazard or migrate to more promising lands. Some groups instead are dedicated to short term objectives (tourism, agriculture, industry, and others) that locally may be threatened infrequently by natural hazards to strategies for avoiding the destitution likely to occur eventually at particular locations. Groups and individual may remain in hazard zones because they generated high ratios of reserves to potential losses (including the use of insurance as a means of providing for losses that are occasionally extreme).Such people may have become very resilient, being able to bear losses or adapt to risk in whatever manner is necessary.

A hazard may be regarded as the pre-disaster situation, in which some risk of disaster exists, principally because the human population has placed itself in a situation of vulnerability. According to the office of united state disaster relief co-ordination (UNDRO 1982) this can be defined as the degree of loss to a given element or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude. When the risk becomes tangible and impending, there is a distinct threat of disaster. Hence, the sequence of states pertaining to a disaster is as follow:

Hazard → Risk → Threat → Disaster (impact)

1.6) Frequency

Frequency can be defined as the number of events of a given size in a given unit of time and how often a given magnitude of event occurs. The average length of time between events is known as recurrence intervals or return period, and is the reciprocal of their frequency. Studies of the frequency of physical events have generally identified a strong correlation between increases in magnitude and decreases in frequency. Problems occur when the magnitude – frequency curve is projected forward into time periods for which there are few or no data. Thus, it is extremely difficult to predict long return periods and therefore how often very large events will occurs.

Frequencies of hazards appear in floods. Where flooding occurs every year or every few years, the hazard becomes part of the landscape, and projects are sited and designed with this constraint in mind. Conversely, in an area where a tsunami may strike any time in the next 50 or 100 years, it is difficult to stimulate interest in vulnerability reduction measures even though the damage may be catastrophic. With so long a time horizon, investment in capital intensive measures may not be economically viable. Rare or low-probability events of great severity are the most difficult to mitigate, and vulnerability reduction may demand risk-aversion measures beyond those justified by economic analysis.

2) Problems due to natural disasters

2.1) Problems of natural disasters in the world

The increasing frequency and severity of natural disasters is causing substantial loss of life and socio-economic damage and losses. During this century, inadequate planning in rapidly growing cities of the developing world will result in a substantial increase in disaster risks. Disaster risk reduction is a critical element in long-term sustainable development. When a natural disaster strikes, economic losses, as a percentage of gross domestic product GDP, are 20 times greater in developing countries than in developed ones. The 2009 Global Assessment Report on Disaster Risk Reduction concludes that disaster risk is increasing fastest in low- and middle-income countries.

In addition to the economic costs of disasters, there are social and environmental impacts that are many times difficult to quantify. Some examples of social and environmental impacts of disasters include: loss of human life, damage to the environment, losses of natural habitats and destruction of ecosystems, disruption of communities and family life, loss of cultural heritage assets, unemployment, and migration.

Natural disasters have the most severe impact on developing countries, and within those countries, the poor are most seriously affected. Poor communities are often forced to live on more fragile lands, and have little or no resources to recover from disaster impacts. The poor often lose their livelihoods and assets following a disaster. Such losses may take years to recoup and are devastating to poor households and communities.

According to United Nations Development Program (UNDP) Report, Reducing Disaster Risk; A Challenge for Development, more than 180 deaths per day is recorded in different parts of the world as a consequence of natural disasters. On the other hand according to the 2000/2001World Development Report, natural disasters are similar to economic crises, because they can cause sharp increases in poverty and slow the pace of human development.

Global Facility for Disaster Reduction and Recovery (GFDRR) reported that over the past years, both frequency and impact of disasters have been increasing worldwide. In the first decade of the new millennium a string of severe disasters hit countries on all continents. Most notable were the 2004 Indian Ocean earthquake and tsunami which claimed over 250,000 lives, the Haiti Earthquake which killed over 220,000 people and caused an economic impact equivalent to 120% of GDP, floods in Pakistan affecting 20 million people, but also additional earthquakes in Indonesia, floods and droughts throughout Africa, heat waves and fires in Europe, hurricanes in Central America, the Caribbean and the United States, and landslides triggered by typhoons in South East Asia. The social impact of disasters is highest in developing countries, where poor populations are most vulnerable and least resilient. Economic impact of disasters amounted to 63 billion USD in 2009.

In 1975, worldwide economic losses due to severe weather disasters, adjusted for the effects of inflation, were US$4 billion; 30 years later, losses in 2005 were more than US$200 billion, representing a fifty-fold increase (Munich Reinsurance, 2006). Property damage payments by insurance companies also increased fifty-fold during this period, from US$1.6 billion to US$83 billion, again adjusted for the effects of inflation. Data from the Centre for Research on Epidemiology of Disasters indicates that 80% of all natural disasters in the decade from 1996 to 2005 were meteorological or hydrological, and that more than 1.5 billion people worldwide were affected by weather- and water-related disasters between 2000 and 2004 as shown in figure (1.1) (United Nations Educational, Scientific and Cultural Organization, 2006).

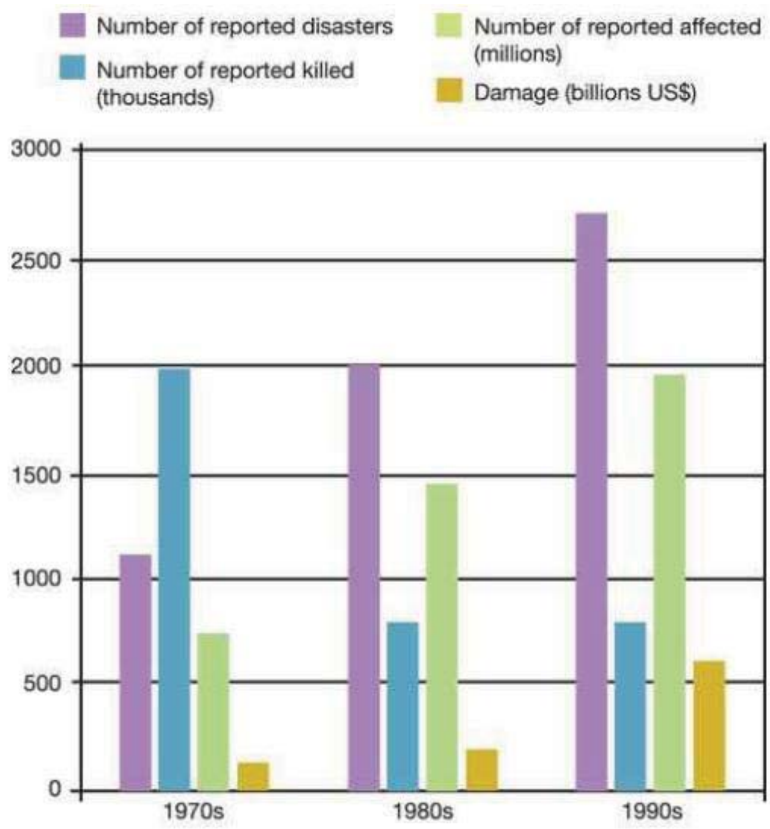


Figure (1.1) Global frequency of natural disaster impacts and associated human and economic losses from the 1970s to 1990s (World Meteorological Organization, 2006)

International Federation of Red Cross and Red Crescent Societies (2004) studied 3000 natural disaster events that occurred around the globe between 1994 and 2003. More than 80% of these were high-impact weather-related events. During this period, 580 000 fatalities and economic losses of US$680 billion were recorded, and an average of 250 million people per year displaced from their homes. More than 95% of the damage to property was recorded in affluent or moderate-income countries. In contrast, more than 90% of the disaster fatalities and 98% of the people displaced by disasters lived in moderate- or low-income nations, primarily in Asia and Africa (International Federation of Red Cross and Red Crescent Societies, 2004). Figure (1.2) shows the World Bank Disaster-related lending, 1980-2003: $ U.S. 40 billion.

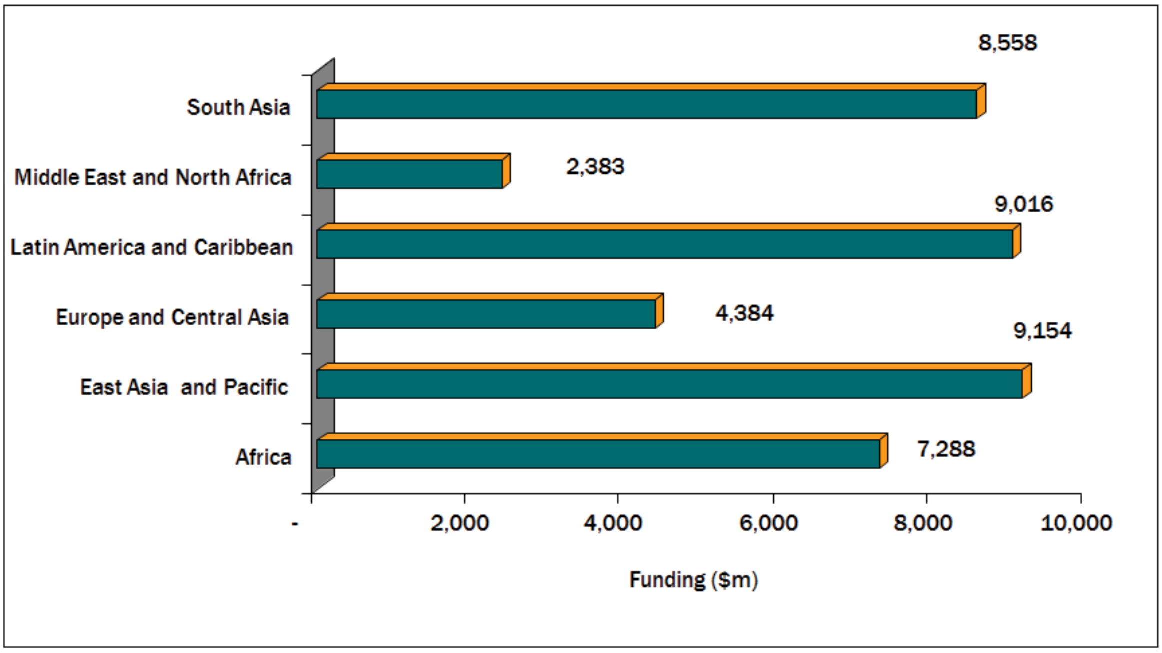


Figure (1.2) World Bank Disaster-related lending (M $) (Reference 1)

2.2) Problems of natural disasters in Egypt

The most common Natural disasters occurred in Egypt are Floods, Earthquakes, Storms, and Desert locust. Country profile of natural disasters effects from 1980 to 2010 reported by Crisis Management and Disaster Reduction Sector in Egypt (CMDRS) (September 2008*)* is summarized in the table (1.1).

Figure (1.3) shows that floods are the most repeated natural disaster in Egypt from 1980 to 2010 as mentioned in Egypt profile. Percentage of reported people affected by Floods is 64.10% as shown in Figure (1.4). Floods happened in 1994 caused the death of people and huge economic damage as shown in table (1.2).

Risk Management is defined as the process of identifying, analyzing and quantifying the probability of losses in order to undertake preventive or corrective actions. The creation of a successful organizational structure of specific management tasks is dependent on an understanding of the tasks associated with disaster risk management. An effective management system is needed for both phases of the risk management cycle Pre-disaster phase and Post-disaster phase. The pre-disaster phase of disaster risk management involves four components. There are Risk identification, risk reduction/mitigation, risk transfer and preparedness. Post disaster phases include three components emergency response, rehabilitation and recovery, and reconstruction.

The pre-disaster phases include analysis of existing vulnerabilities, location, severity, intensity of threat, measures taken to eliminate or reduce the intensity of hazardous event, and develop the mechanisms do not reduce actual vulnerability but reduce financial risk by transfer mechanisms in order to ensure that funds are available when loss occurs. The Pre-disaster's activities include risk assessment, physical mitigation, the creation of economic incentives for mitigation, use of insurance and financial risk transfer instruments, and the creation of early warning and response networks. Figure (1.5) shows the disaster cycle prepared by the World Bank For natural risk reduction. It can help in Pre-disaster activities planning.

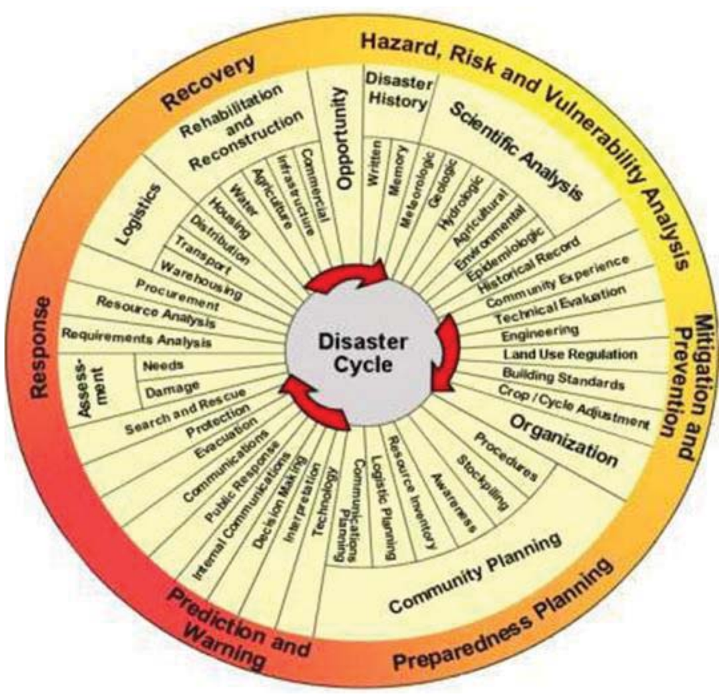


Figure (1.5) disaster cycle (Reference 1)

The post-disaster phases include activities such as search and rescue, evacuation, provision of shelters, first aid, emergency medical care, temporary restoration of transport and communication, Rehabilitation refers to stage when activities aim at restoring conditions in the affected areas and communities, temporary repairs of housing, buildings and infrastructure (transport and public utilities) are done during this period, rebuild critical infrastructure, and allocate appropriate budgetary resources according to newly emerged social priorities. It is important to emphasize that reconstruction should incorporate mitigation measures to reduce vulnerabilities of future disasters.

The aim of disaster risk management Application is the reduction of the disaster risk for people living in the regions that are exposed to natural hazards after identifying hazard and risk exposure, including strategies to avoid hazards, improving the capacity to respond rapidly, warning of an impending hazardous event helping to save lives, and transfer or share the risks that cannot be reduced. Reducing the disaster risk involves, reducing the vulnerability of the population itself to natural events. The concentration in the activities of pre-disaster phase is more important than post disaster as they can save a lot of money. Effective DRM can also save a lot of lives. Without disaster risk management, the destructive force of natural disasters will continue to wreak devastation, often reversing the progress being made in the countries, worsening poverty and thus impeding sustainable development.

4) Problems definition of the Thesis

4.1) Water scarcity

Egypt has total water resources of more than 70 billion cubic meters (BCM) per year. In spite of this huge amount of water, Egypt is water scarce country. Water resources in Egypt dropped during recent years from 1000 m^3/capita/year to 800 m^3/capita/year.Egypt faces numerous challenges due to pressure from population growth, increasing economic development, and global warming. The main water resource in Egypt is The Nile River and it represents around 95% of the total water resources. It is the reason why a very huge percentage of the population is concentrated in the Nile valley and Delta. In other areas as Sinai Peninsula, the water resources are limited. The development of the area is essential. Due to that, the Egyptian government implement El-slam canal to divert water from Nile River to Sinai. However, the canal does not supply the whole Sinai only the North part.

In Sinai, there are many developed areas that entail water demand. It has an international ports and tourism activities. Nuweiba city is one of the most important city in Sinai. The importance of the area will be more and more as The East Delta Electricity Production Company (EDEPC), in cooperation with the Egyptian Electricity Holding company (EEHC), proposes to build and operate a power planet there. That makes the region more attractive for investment.

Bedouins are suffering from water scarcity especially during dry season. It causes agriculture the damage and sheep death. The limited water resources consist of ground water, rainfall, and desalinated sea water. There is tremendous pressure on the water .Also as reported in South Sinai action plan 2003; many wadis have insufficient water to support Bedouins communities and their livelihood activities.

4.2) Flash flood Hazards.

Flash floods are considered to be one of the worst weather-related natural disasters. They are dangerous because they are sudden and are highly unpredictable following brief spells of heavy rain. Flood hazard seems to be increasing as climate change takes effect. It was reported in an Egyptian review in depth Assessment of Progress in Disaster Risk Reduction that floods is the most widely distributed natural risk to life compared to all natural risks. Flash floods are among the most destructive natural disasters and at the same time it is consider an important source of water, especially in arid areas like Sinai. A flash flood can be generated during or shortly following a rainfall event, especially when high-intensity rain falls on steep hill slopes with shallow impermeable soils, and exposed rocks without vegetation. Drainage channels in such areas may be unable to accommodate the runoff that is generated by relatively small, but intense, rainfall events. Figure (1.6) and (1.7) show that Sinai is the most area in Egypt suffers from flash flood just because its huge variation in elevation and high-intensity rain falls. Most of the flood management strategies of this area have been geared towards preventing flood by an attempt to control flood water by dams. Very little attention is paid for formulation rational land use planning to reduce flood induced disaster.

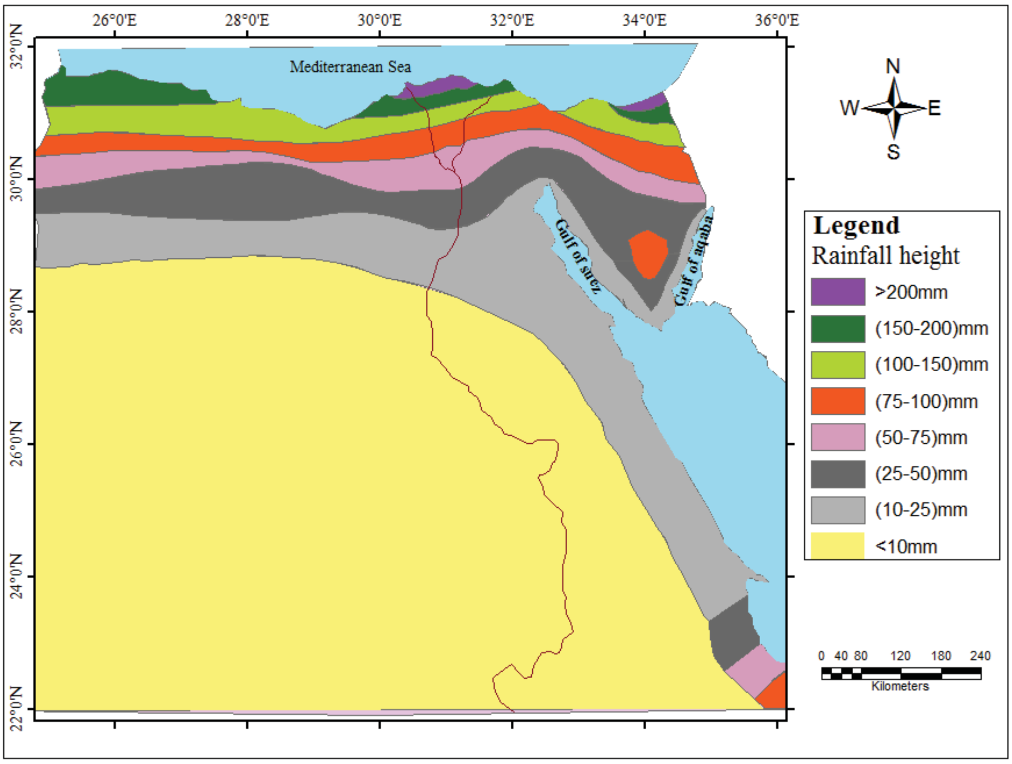


Figure (1.6) Rainfall height in Egypt (Reference 3)

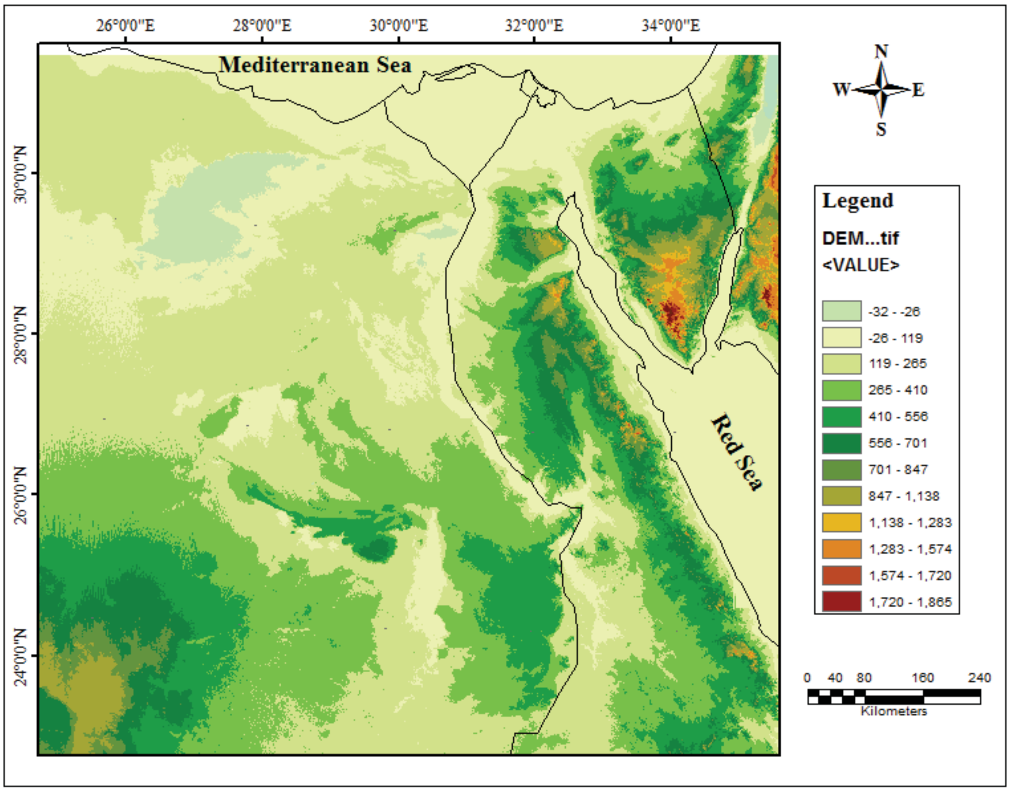


Figure (1.7) Elevation map of Egypt

The limited water resources and flash floods are considered constrains of the area development .This study aim to assess the potential of water harvesting of active Wadis in Sinai .It will help to maximize the full utilization of water resources especially surface water. It will help to achieve sustainable development for the wadis by providing additional water resource and having a role in mitigating the flash flood risk.

5) Research Objectives

The target group is the Bedouins in the area and applying the risk assessment of flash flood techniques will help to reach the goal. The main objectives of the research are :-

- Studying the floods.
- Define the hazard areas in Sinai.
- Define the risk of the floods (frequency and magnitude).
- Probable location and severity of the floods and the likelihood of their occurring within a specific time period in a given area.
- Evaluate the current Vulnerability for buildings at the case study Al-Arish city.
- Produce flood probability map.
- Estimate the potential amount of water that could be harvested and Identify potential sites and techniques for water harvesting throughout the watershed catchment.
- Proposition of technical solution to reduce or mitigate the impact of the hazard.

6) Methodology

To achieve the objectives of this research study, firstly research needs and objectives were defined. Data collection was conducted depending on literature review and field visits. The collected data were analyzed and processed using Arc GIS, Excel, and hydrological model software. The methodology carries out collection and analysis of physical, socioeconomic, environmental and institutional data for active wadis in Sinai. This leads to setup of the GIS-based database "Geodatabase" included hydrology, geology, topographic, and social data. Besides, the analyzed data has been added. The overall methodology followed in the study is illustrated in figure (1.10).The steps for the methodology is as follows:

- Collection of previous studies and conducting literature review related to active wadis in Sinai and the proposed case study.
- Evaluate of available water resources in the study area out of the previous study.
- Collection of Wadi Al-arish and wadi watier data, by meteorological, hydrological, hydro-geological, and soil classification maps.
- Collection of social data by setting up a questionnaire for Bedouins visitation to recognize the flash flood hazard on them and on their activities.
- Developing and geographic model for the study area.
- Analyzing data by using mathematical models and GIS software's.
- Data analysis and processing by using a hydrological model such as watershed modeling system (WMS) to generate the runoff quantity from the historical rainfall height data.
- Mapping of hazards areas and assessing construction vulnerability.
- Risk assessment for very high risk regions.
- Recommendations.

7) Importance of the study

More water availability enhances investments potentials. Water demand will increase and augmenting freshwater resources. From the rain water and flash flood will decrease the gap between supply and demand.

The study focuses on surface water. Applying water harvesting of the generated flash flood will reduce the flood risk at the outlet. Also, it could be used for recharging the ground water aquifers which are the basis for sustainable development in Sinai as it is the perennial water in the study area**.**

Furthermore, Bedouins usually move from place to place searching for fresh grazing for their animals and water for their families. They do not wander aimlessly, but return annually to various specific locations in their territory where the land and water can sustain them for the season. These locations sometimes are hazard areas as flash floods occur there. The study helps to make developed sustainable planning for the Bedouins as hazard areas will be defined. Proved locations to get use of the flooded water and store it will encourage the Bedouins to resettle the area.

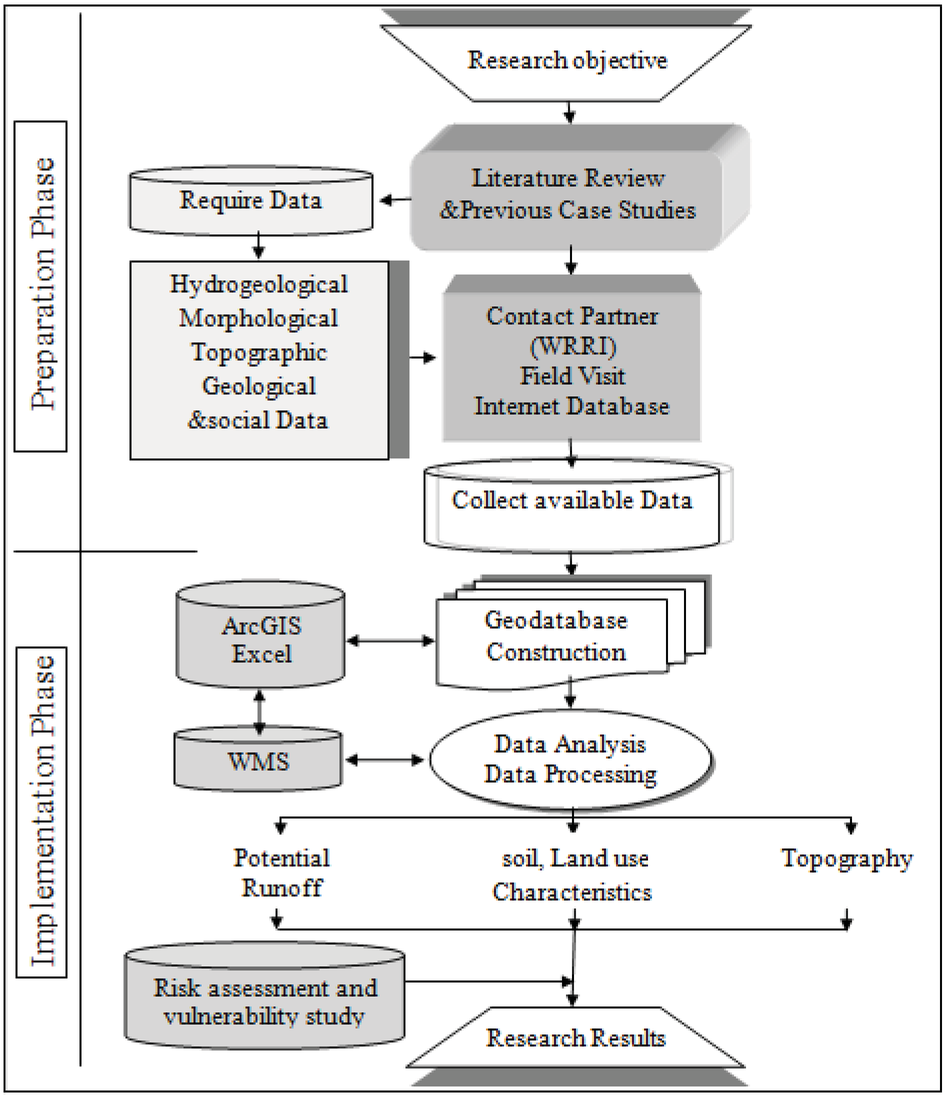


Figure (1.10) Flow Chart depicting the general methodology followed

Assessment of the flood risk is a complex problem that can only be solved through interdisciplinary research. A two-step approach has been adopted. First it was needed to characterize the flood hazard using a selected set of indicator maps, like the spatial distribution of flow velocity, water height, speed of propagation, duration, etc. The second step was to estimate how the flood hazard indicators interfere with human activities in the flooded area. Agricultural activities will suffer damage in different ways than for instance an industrial zone or an urban area. Also aspects of civil protection need to be considered, like when people need to be evacuated and which transportation lines are still available in the inundated area. Vulnerability assessment carries exercise further by showing how civic infrastructure and population are likely to be affected by a hazard event. It is necessary to first identify physical vulnerabilities such as geographical remoteness of the community and its fragile location. An analysis of socio-economic vulnerability of the community shows the impact on people's livelihood, income and consumption of the people. It explains the differential impact of a hazard on various groups such as the poor and low-income groups. It also analyzes how schools, hospitals, roads and transport, electric and communication lines would be affected by a hazard event in a particular area.

The aim of any risk study is to minimize the harm caused by flooding. This involves reducing the likelihood of flooding and reducing the impacts when flooding occurs. At the same time there are underlying pressures that are increasing risk, such as climate change, housing development or changes in land use. Flood risk assessment and flood mapping will help to show which places are most at risk and in what circumstances. After that the governments can take the correct strategy for flood risk reduction or mitigation. Also, they can select the suitable locations of weirs and dams for two reasons the first, is to prevent the risk and the second is to collect water in this arid area for Bedouins.

The local knowledge on flash floods of Bedouins is needed for the development of the early warning system. Because of the rapidity of flash flood occurrence and its power, flash flood experts recommend the use of early warning systems for reducing vulnerability. Flood risk assessment helps to create flood vulnerable map and from the rainfall historical data we can make early warning system. Early warning system is very important to protect the city by reducing the losses and victims in the region.

Moreover, Except for the danger for the life of the population, the floods cause also considerable material and financial losses. The measures for reducing the losses are undertaken depending on the capital value of the threatened objects and the expected consequences from their damage or destruction. Disasters have a negative impact on economic activity and the associated economic uncertainties hamper investment in long-term commercial relationships. Conversely, particular types of economic activity and a truncated policy focus can increase a country's economic vulnerability to natural disasters. The damage and reconstruction needs assessment methodology is designed to assess the losses and damages from catastrophic events in terms of assets, infrastructure and to estimate the overall impact of disaster on economic performance of the country. Flood risk assessments can mean that you avoid tens of thousands of pounds worth of damage if a flood does occur as well as taking measures to help prevent one form happening in the first place. Therefore flood risk assessments can help save damage and safeguard peoples' welfare.

8) Thesis outline

The thesis consists of seven chapters in addition to the abstract, references, appendixes, and Arabic summery.

- Chapter 1: The main objective of this chapter is to have a basic understanding of various concepts used in disaster management, identification of the problem, the study objectives, and the outline of this thesis.
- Chapter 2: it contains the previous works and researches in the study area. In additional to the review of the previous works in risk assessment.
- Chapter 3: it contains the important characteristics for the study area to help in the estimation of the flash flood.
- Chapter 4: it contains the hydrological studies concerned with different methods for estimating runoff hydrographs.
- Chapter 5: it contains the watershed modeling application of the Study area like geomorphological parameters of the watersheds response.
- Chapter 6: it contains flash flood hazard, vulnerability, and risk mapping for the study area. After that prepared the maps of the flood plain areas due to damage estimation curves for the study area.
- Chapter7: it contains the summery, the main finding, and recommendation for this study.

CHAPTER TWO

Literature Review

2.1) Introduction

A risk assessment can identify the probability of harm, assess the impact of it, and pose intervention strategies which may diminish the risk or reduce the harm. Assessments cannot prevent risk but it helps to define the strategies that will be followed in the risk management as risk assessment is the first step in risk management. Different methodologies and techniques of the risk assessment have been produced to reduce or mitigate the losses to lives and property damages. Literature reviews and previous studies of the risk assessment will produce the effective methodologies that help reaching the study objectives.

2.2) Flood Hazard and Flood Risk Assessment

Mapping flood risk and hazard is not a new endeavor in the developed countries of the world. Different methodologies and techniques of flood risk have been reviewed in order to reduce large-scale losses to lives and property (Askew, 1999; Smith, 1999). There are lots of attempts but those studies have both advantages and disadvantages (Kannami, 2008).

Flood risk maps have been prepared from satellite data for more than a decade by hydrologists and geographers all over the world. These are considered static techniques because they characterize the area at a particular point in time. While a dynamic long term flood history is desirable, such static techniques are capable of yielding useful information for flood hazard assessment, especially in the diagnostic and preliminary stages of an integrated development planning study. In the absence of information from dynamic techniques, it is possible to estimate the probability of a flood event occurrence when information from static techniques is combined with historical flood observations, disaster reports, and basic natural resource information, particularly hydrologic data.

Extreme events often exert a disproportionately large effect on the environment, much larger than those associated with the more commonplace typical events, and they are mostly associated with risks affecting humans. The extremes of rainfall result in a variety of hazardous phenomena ranging from intense drought through to mega- and super flooding events (HERSCHY, 2002) and associated consequential problems.

Risk assessment is the first step in risk management (Kates and Kasprson,1983) comprises of three distinct steps for Risk assessment:

a) An identification of hazards likely to result in disasters.
b) An estimation of the risks (possibility of such event) of such event.
c) An evaluation of the social consequences (loss created by each event) of the derived risk. When risk analysis is undertaken, risk (R) is taken as some product of probability (P) and loss (L).

R = P x L

Flood risk involves both the statistical probability of an event occurring and the scale of the potential consequences (Smith, 1996). All development of land within the floodplain of a watercourse is at some risk of flooding, however, small. The degree of flood risk is calculated from historical data and expressed in terms of the expected frequency 50 year or 100 year flood.

The National Authority for Remote Sensing and Space Science (1997) has carried out a study which deals with the hydrograph characteristics of drainage basins that threaten the Red Sea towns in Egypt including Ras Gharib, Hurghada, Safaga,Mars Alam,Quseir,Abu Ramad, Halaib, and shalatin. In this study the flash flood potentials of the basins was defines according the morphometric parameters. The parameters of each drainage basin are assessed by using two hydrogeomorphic graphical relations: the first is bifurcation ratio (R_B) versus drainage Frequency (F) which is the number of streams per unit area, and the second is bifurcation ratio (R_B) versus drainage density (D) which is the ratio of the total length of streams within a watershed to the total area of the watershed.

The basins which are present in field A are characterized low flood opportunity. Field B indicates basins of high flooding opportunity and low ground water potentialities. Field C points to basins of moderate flooding probabilities and ground water potentialities. This approach was proposed by (El Shamy,1992) for basins assessment in regard to flash flood and ground water possibilities (El Shamy, 1992)

(Mobarek,1981) prepared vulnerability maps depends on the following parameters.1) Water depth during the peak flow; 2) flow velocity in main stream; 3) maximum grain size for sediment; 4) volume of sediment transport. Table (2.1) shows the risk classification according to (Mobarek,et.al. 1981).

Risk degree	water depth (cm)	water velocity (m/s)	Max.grain diameter, (cm)	sediment volume (1000 m^3)
high	> 50	> 2	> 12	>100
medium	25 - 50	1.2 - 2	5-12	50 - 100
low	<25	<1.2	< 5	< 50

Table (2.1) Risk classification according to (Mobarek,et.al. 1981)

Mobarek's approach depends mainly on hydraulic parameters, while El-shamy approach depends on few selected morphometric parameters to define the risk degree. There is a need to establish a risk analysis that takes into consideration the most effective morphological parameters for more accurate assessment. Also, to compare the resulting risk degree with the outputs of the hydrologic analysis for better matching.

2.2.1) Risk Assessment Techniques

Ologunorisa and Abawua(2005), reviewed some of techniques of flood risk assessment using case studies from different countries in the world. These techniques are meteorological, hydrological, hydro-meteorological, Socio-Economic, and those based on Geographic Information System (GIS).

a) Meteorological Parameters

Various definitions have been used in definition of flooding (that is large rainfall that is caused surface runoff) over a certain region depending on the purpose in view. This simple parameter, rainfall, which can reflect many aspects of flood, is used in partially all definitions of flood. Meteorological flood can be defined as an event over a region where that rainfall is mostly higher than the climatological mean value because the natural vegetation and economic activities of the region have been adjusted to the long-term average rainfall of that region (Parthasarathy, et al 1987). Therefore, the conditions which lead to flood occur when the rainfall amount over a particular region is more than a certain amount, normal for that region (Friedman, 1957). When the seasonal rainfall is in an excess of 26-50 percent of normal over a meteorological subdivision is regarded as a moderate flood, and an excess of more than 50 percent of the normal as a severe flood; while the rainfall between 0-26 percent of normal is regarded as a less severe flood. This is the definition that has been adopted by the Indian Meteorological Department in 1971(Parthasarathy et al, 1987)

(Laughlin and Kalma ,1990) developed a methodology for frost risk mapping based on regional weather data and local terrain analysis. Minimum air temperatures were measured during three winters with a network of stations in open, undulating terrain. It was observed that the change in minimum air temperature with elevation could be predicted from mean night time wind speed, total nighttime net radiation loss and a hill-top reference minimum temperature. It was also found that the deviation of temperatures at individual sites could be predicted from a local terrain parameter which reflects the extent of cold air accumulations. Finally, the study describes the model and illustrates the regional weather and terrain effect with three-dimensional block diagrams.

b) Hydrological Parameters

Trinic (1997) did hydrological analysis of high flows and floods of the River. Particular attention was paid to the causes of flood wave volumes from direct inflows above reference discharged and of constant duration were analyzed. The results of hydrological analysis of the flood wave hydrographic can be used to improve manipulation with waters using weirs, flood diversion canals and retentions.

(Nobilis and Lorenz,1997) made a study deals with the analysis of previous floods, the assessment of damage, and the evaluation of possible changes in the flood behavior due to natural or artificial influences. The results of the analysis show areas with predominantly linear trend and areas with predominant positive significant linear trend. The authors observed that based on such investigations, realistic design values may be calculated taking into account the end of stationary due to climate change.

c) hydro-meteorological parameter

Kuchment (1997) estimated the risk of rainfall disastrous floods using physically-based model of river runoff generation. Disastrous floods can be caused by unusual combinations of hydrometeorological factors and river basin conditions that have not been observed during a long observation period. Physically-based models of runoff generation enable one to find dangerous possible combinations of hydrometeorological factors and to estimate the risk of extreme floods. Analysis of runoff generation on a number of the Russian rivers have shown that although the probable maximum precipitation rate is usually larger than the probable maximum snowmelt rate, the maximum floods of the medium and large rivers of Russia are of snowmelt origin. A comparison of the calculated maximum rainfall discharge has been carried out. It has been revealed that in the same region, the probable maximum discharge may be of rainfall origin depending on the river basin area and runoff generation mechanism.

d) Socio-Economic parameter

Oriola (1994) observed that various socio-cultural activities have promoted flooding in many urban environments. These activities are characterized by stream or river channel encroachment and abuse, increased paved surface and poor solid waste disposal techniques, due to a high level of illiteracy, a low degree of community awareness, poor environmental education, ineffective town planning laws and poor environmental management. He argued that government, at various levels needs to address these issues. He concluded that flood risk in the urban environment was a function of the following factors: Land-use pattern, refuse disposal habits, the nature of the surrounding buildings, distance of building from the course of the streams, rainfall amount and duration, the relief or the terrain, slope, gradient, and other stream basin parameters.

e) Combination of Hydrometeorological and Socio-Economic Factors.

Hogue et al (1997) undertook an assessment of the risks involved with cyclones and storm surges. The study finds the extent of storm surge flooding and the related risk in the metropolitan area. To identify the risk, the depth and extent of storm surge flooding for different probability of occurrence have been predicted and were expressed as a hazard index. The city area was divided into five categories of land-use: industrial area, commercial areas, planned housing areas, unplanned housing areas and mixed areas. For each, population density and economic importance of the areas have been considered and were expressed as an importance index. Using the hazard index and importance index, the risk for each area was calculated. On the analysis, the whole city area was classified into four categories: the low risk area, the risk area, the high risk area, and the severe risk area.

Ologunorisa **(2004)** undertook an assessment of flood risk using a combination of an hydrological techniques based on some measurable physical characteristics of flooding, and social-economic techniques based on vulnerability factors. Some of the physical characteristics of flooding selected include depth of flooding (meters), duration of flood (hours/weeks), perceived frequency of flood occurrence, and relief or elevation (m) while the vulnerability factors selected include proximity to hazard source, land use or dominant economic activity and adequacy of flood alleviation schemes and perceived extent of flood damage. He derived rating scale for the nine parameters selected, and 18 settlements randomly selected across the three ecological zones in the region were rated on the basis of the parameters. Three flood risk zones emerged from the analysis. These are the severe flood risk zones, moderate flood risk zones and low flood risk zones. Some strategies for mitigating the hazard of flooding in the region were identified.

f) Geographical Information System (GIS)

Okoduwa (1999) applied Geographic Information System (GIS) in the prediction of urban flooding. This was achieved by creating a digital database of selected variables such as land use, land cover and soil strength. The software used was Arc-view and the overlay techniques in GIS were used for analysis. The result of the analysis showed high flood prone areas, medium flood prone areas and low flood prone areas.

In carrying out the overlay operation, Okoduwa (1999) first carried out the land use and the reclassified Digital Elevation Model (DEM). The land use map and the relief map were overlaid using the union function with the geo-processing hazard contained in the Arc view. The union function was used to create new theme by overlaying two polygons of the input theme. That is, the land use them and relief theme, were split at their intersection. The dissolved function contained in the geo-processing wizard was used to enhance the merging of the feature of the two themes which generated a theme called land Relief The land relief map was then overlaid on the soil strength, and high intensity of land use as well as areas with low relief, are areas that are prone to high flooding, while areas with high soils strength, low intensity of land use, as well as with high relief are prone to low flooding. Also areas with medium soil strength, medium intensity of land use as well as areas with medium relief are prone to medium flooding. Having overlaid the land Relief map on the soil strength map, the overlay gave a map (of Benin City), showing areas that are prone to high flooding areas prone to medium flooding, and areas that are prone to low flooding respectively.

Okoduwa (1999) reported that in flood forecasts were prepared for the Watershed, , using a hydraulic model and a GIS. The objective was to test what extent the integration of a hydraulic model and a GIS can contribute to the quantitative assessment of effects of the upstream land use changes on downstream flood pattern. The Hec-1 hydraulic model and (GIS) were used. The result of the simulation was able to show the effect of the land use changes on flood levels down steam. The result of the study further showed that a hydraulic model like HEC-1 makes it possible to predict the effects of upstream land use changes on downstream level. GIS appeared to be an efficient tool for the preparation of part of the input data required by such a model but it was not possible to link the GIS and the HEC-1 directly. It could not be confirmed whether the use of a GIS would be an advantage when other hydraulic model are used.

Ologunorisa (2005), Geographic Information System (GIS) techniques is the most recent and holds a lot of promises as it is capable of combining all the known techniques and parameters **of** predicting flood risk. The study concludes that the use of GIS technique should be encouraged in risk assessment of flooding as it is capable of integrating the geomorphological, hydrological, meteorological and socio-economic variables.

2.2.2) Risk, Hazard, and Vulnerability Relationship

Flood risk is a function and a product of hazard and vulnerability (Ologunorisa, 2005) as shown in equation (2.2). A real flood risk level requires a certain level of hazard, and for the same location, a certain level of vulnerability. A situation of risk is due to the incompatibility between hazard and vulnerability levels on the same land plot.

Risk = Hazard x Vulnerability

Ologunorisa and Abwua defined the three terms, according to the United Nations Commission for Human Settlement (UNCHS-HABITAT) (1981), in the following way:

1) **Hazard**: is the probability that in a given period in a given area, an extreme potentially damaging natural phenomenon occurs that induce air, earth movements, which affect a given zone. The magnitude of the phenomenon, the probability of its occurrence and the extent of its impact can vary and, in some cases, be determined.

2) **Vulnerability**: of any physical, structural or socio-economic element to a natural hazard is its probability of being damaged, destroyed or lost. Vulnerability is not static but must be considered as a dynamic process, integrating changes and developments that alter and affect the probability of loss and damage of all exposed elements.

3) **Risk**: can be related directly to the concept of disaster, given that it includes the total losses and damages that can be suffered after a natural hazard: death and injured people, damage to property and interruption of activities. Risk implies a future potential condition, a function of the magnitude of the natural hazard and of the vulnerability of all the exposed elements in a determined moment.

(Pramojanee, 2001) discussed the procedures that were applied for mapping flood Hazard and risk areas. In his procedure remote sensing interpretation and GIS were applied. By means of weighting, a number of causative factors including annual rainfall, size of watershed, size of watershed, side slopes of watershed, gradient of river and stream, drainage density type of soil and land use, communication line and infrastructures, and population density were considered for rating the degree of hazard and risk.

2.2.3) Damages and Losses in Flood Risk Assessment

The risk assessment process aims to support rational decision-making for the risks. An important part of the evaluation of risk is the valuation of the consequences after the flood disaster, such as the loss and damages. In the context of risk assessment consequences are generally quantified in terms of economic damage and / or loss of life (Jonkman *et al*., 2003). Jonkman talked about the advantages of using loss of life and economic damage as Indicators in the risk assessment is that those types of consequences are: quantifiable in an objective way (fatalities or monetary valuation) and considered to be the most relevant and important losses in the public perception of disasters.

Fokkema (2007), defied damaged and losses. He defined damage as the total or partial destruction of physical assets existing in the affected area. Damage occurs during and immediately after the disaster and is measured in physical units (square meters of housing, kilometers of roads, and etcetera). He defined Losses as changes in economic flows arising from the disaster. They occur until full economic recovery and reconstruction is achieved, in some cases lasting for several years. Typical losses include the decline in output in productive sectors (agriculture, livestock, industry and commerce) and the lower revenues and higher operational costs in the provision of services (education, health, water and sanitation, electricity, transport and communications).

The World Bank (2005), defined the dames and losses as the costs of disasters. The focus of the cost on two types the direct and indirect costs. Direct costs of natural disasters include physical damage to infrastructure, raw materials, buildings, etc. while indirect costs include the loss of earnings, unemployment, loss of productivity due to death, illness and injuries, public finance expenditure. In addition to these disaster costs, there are social and environmental impacts that are many times difficult to quantify. Some examples of social and environmental impacts of disasters include: loss of human life, damage to the environment, losses of natural habitats, disruption of communities and family life, loss of cultural heritage assets, unemployment, and migration.

2.3) Flood Risk Management

Flood risk is a function of probability of flooding and damage resulting from flooding. Flood risk management aims to lower the probability of flooding events and their effect is measured by the damage they cause. However, it should be considered that flood risk management does not only involve minimizing the actual risk, but also deals with the perceived risk as well. The goal of flood risk management is the minimizations of flood risk through the implementation of measures that can most efficiently reduce risk. This can be done by reducing the probability of flooding, minimizing potential damage or a combination of both (Hooijer et al, 2002).

2.3.1) Flood Risk Management approaches

(Blackwell and E. Maltby, 2006) talked about five basic approaches that can be taken to flood risk management: i) Runoff reduction measures, ii) Preventive flood risk reduction measures, iii) Preparatory measures, iv) Incident measures, v) Post-flooding measures. **i)**Runoff reduction measures are focused at land use management in the run-off generation areas. Land **use** management measures are aimed at reducing the effects of land drainage, deforestation and urbanization on peak flows. These types of measures are most effective in small catchments and when implemented over a large proportion of it**.** **ii)**Preventive flood risk reduction measures flood risk reduction measures include flood control, spatial planning and raising awareness. This actually involves a wide range of categories including technical measures (flood storage, dams, embankments, walls). **iii)**Preparatory measures include flood forecasting, warning and emergency plans. Components of these measures are identification of the likelihood of flooding events, forecasting future river stage/flow conditions, the issuing of warnings to the appropriate authorities and the public about the extent, severity and timing of floods, dissemination of warnings and the responses by the public**. iii) Incident measures** These measures include crisis management, evacuation of the population in areas threatened by flooding and local emergency protection in these areas. Post-flooding measures include aftercare, compensation and Payment of insurance money. They bring relief to those affected by disasters. Other post flooding measures include the reconstruction of damaged buildings, infrastructure and flood defences, post-flood recovery and regeneration of the environment and economic activities in the flooded area, reviewing of flood management activities to improve the process and planning for future events.

2.3.2) Flood Risk Assessment and Management

The e risk assessment encompasses the identification, quantification and evaluation of risks associated with a given system. It is carried out because involved parties (designers, managers, decision makers) want to identify and evaluate the risks and decide on their acceptability. Outcomes of risk assessment can be used in the design process to decide on the required safety levels of new systems (e.g. a new tunnel) or to support decisions on the acceptability of safety levels and the need for measures in existing systems (a flood defence system). A quantitative measure of some form is needed to transfer decisions on acceptable safety into a technical domain (Voortman, 2004). After risk assessment the design of civil structures, such as the height of a flood defence or the strength of a building can be estimated. Overall, the risk assessment aims to support rational decision-making regarding risk bearing activities (Apostolakis, 2004).

Based on (Faber and Stewart, 2003; Jongejan, 2006), Risk Assessment can be summarized in the following steps:

- **System definition:** Definition and description of the system, its elements and the scope and objectives of the analysis.
- **Qualitative analysis:** Hazards, failure mechanisms and scenarios are identified and described.
- **Quantitative analysis:** The probabilities and consequences of the defined events are determined. The risk is quantified in a risk number or graph as a function of probabilities and consequences.
- **Risk evaluation:** With the results of the former analyses the risk is evaluated. In this phase the decision is made whether the risk is acceptable or not.

After Flood risk assessment we can know we will need flood risk management or not and to what level as shown in figure (2.2). Flood risk management includes the element of risk reduction and control. Risk reduction and control Depends on the outcome of the risk evaluation measures can be taken to reduce the risk. It should also be determined how the risks can be controlled, for example by monitoring, inspection or maintenance for the dams or barriers. Based on the outcomes of the risk evaluation phase, different decisions can be made:

• Avoid the risk by not proceeding with the system.

• Reduce the risk: either by reducing the probabilities, physical effects or consequences;

• Accept the risk. One can also choose to transfer the risk through insurance or other financial mechanisms.

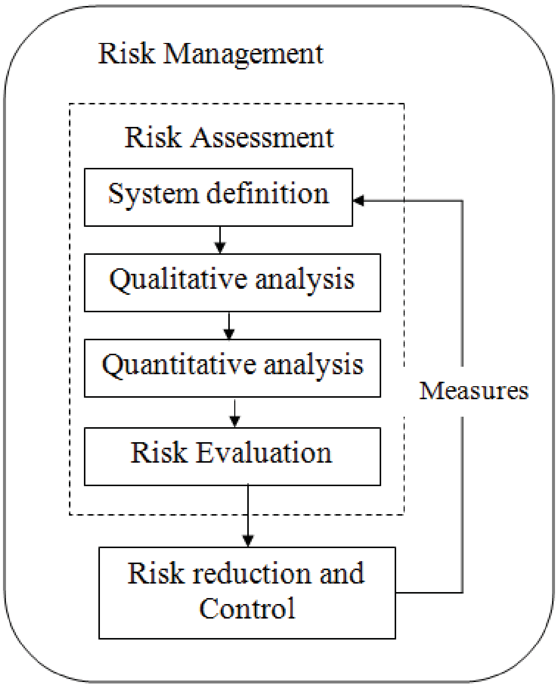


Figure (2.1) Schematic view of steps in risk assessment and risk management, Fokkema(2007)

2.3.3) Flash Flood Mitigation

Flash floods are extreme hydrological events that occur in response to very high rainfall or a cloudburst of short duration. Their characteristics feature is the overtopping of defined courses of rivers (Narain, et al.,2005). The phenomenon is considered one of the natural disasters in the world. Flash floods are responsible for the loss of lives, a severe blow to regional development, the main source of soil erosion and accidental pollution.

A lot of measures are being used to control or mitigate flood effects some of which are not properly designed or implemented often caused by intensive and severe floods. The construction of unsuitable and unwell-designed structures such as bridges, flood walls, groins and dikes as well as human interferences may have significant effects on flooding or flood exaggeration. The effects may be imposed through changing of cross sections, flow velocity, storage area, flow level and extension. Mostly of focused are mitigation measures in the upstream side of the catchment areas, which are physically distant from the monuments.

There are two types of measures that can be used for flood mitigation in flood management: structural and non-structural measurements. The former includes different types of works and interventions aimed at either controlling flood or reducing flood peak. The later offers a variety of possibilities ranging from land use planning to constructions and structure management codes to contribute towards the mitigation of flood-related problems (Colombo et al., 2002).

Structural measures mainly consider the hydrological and hydraulic implications of flooding, which generally are solved by choosing the alternative that maximizes the expected net benefits. Colombo et al., (2002) mentioned catchment-wide interventions as a way of structural measurements that leads to mitigate flash floods. Catchment-wide interventions can be effective to decrease surface runoff and soil erosion and therefore to reduce flood peak. However, they suggested some water control works structural as solutions contribute to flood reduction and protection. Some of these structures are used mainly as floodwater harvesting. Following are briefly for the suggested structure:

1- Check Dams

   The main function of the check dam is to impede the soil and water removed from watershed. This structure lasts to about 2-5 years. The cost of the structure depends on the material used, the size of gully and the height of the obstruction. A permanent check dam can be constructed using stones, bricks and cement (FAO.1997). According to Colombo, et. al., (2002), check dams reduce the water velocity during flood events by increasing the concentration time of the hydrographic basins and reducing flood peak and solid transport capacity of water flow. FOA,(1997) mentioned this type as water conservation structure for groundwater recharge.

2- Drainage Ditches

Coating and canalization works are used especially in case of watercourses running in sloping and easily erodible substratum (Colombo, et al.,2002). Deep percolation ditches has been practiced mostly at the local scale for agricultural production (Abu-Zreig et al., 2000).

3- Bench-terraces

They consists of horizontal benches with a slight counter slope, filled with earth, branchwood and willow-tree cuttings in a special arrangement. Terraces are covered with the back-filling coming from the upper terrace. These works can strengthen slopes where numerous landslides occur and in soils prone to water stagnation (Colombo, et al., 2002).

(Al-weshah et al.,1999) developed a flood analysis model and calibrated for the Petra catchment in Jordon. They analyzed different four possible watershed management scenarios to estimate their effectiveness in reducing floods in critical sites. The four scenarios are:

I- Afforestation of selected parts of the watershed.

II- Construction of storage / detention dams.

III- Combination of storage / detention dams and afforestation.

IV- Contour terracing and construction of check dams with afforestation.

The flood simulation model predicts that the measures can reduce flood peak-flows and volume by up to 70%, which could be too high amounts of water to generate flash flood.

2.4) Previous Studies In the study area (Sinai)

Many researches were conducted at the study area. The studies are summeriezrd below:
WRRI (1995) mentioned that, the geomorphology, geology, and water potentialities studies in the area extending from Taba-Nukhel in the north and Nuweiba-Geble Catherine in the south are presented. Also in this research geophysical, geoelectric and geomagnetic

surveys study are conducted in order to prospect ground water within the area of Wadi Watier and its tributaries. These geomagnetic surveys included measurements of 29 Vertical Electric Sounding (VES), these measurements aimed to locate areas having high potentialities of the groundwater.

(WRRI, 1996) mentioned that Wadi Watier receives large amount of rainfall which can support some activities to enhance the sustainable development in the area. It was reported that protection and utilization structures are essential to prevent possible destruction due to floods. WRRI, recommended to maximum use of available runoff water which is estimated based on the maximum daily 25-years return period with rainfall duration of 2-hours to be 45 million m^3/season.

JICA (1999), carried out geological analysis, using LANDSAT images, aerial-photos and the field survey in order to clarify the regional geological conditions of the area, and by using geophysical methods in this research to determine the hydrological conditions of each formation, therefore, Transient Electro Magnetic (TEM) survey method was applied to the Quaternary deposits.

Fahmi, et. al. (2002), proposed number of seventeen detention dams and five storage dams in the study area. These dams are proposed to develop the area in Sinai and to prevent possible disasters from flash floods. The storage water could be used for direct use and ground water recharge. Locations of the dams were selected according to the peak discharge as well as the total available water volume. The total capacity of the dams is about 20 millionm^3.

WRRI (2004), proposed some of protection dams to protect the area from the flash flood hazards. The result was number of 11 detention dams. The three 1^{st}priority proposed dams were conducted during the project period and finished in 2006.

Ibrahim (2004) studied watershed management for Watier area. He estimated an average runoff volume of surface water at 14 million m^3 and the total groundwater production which could be available from the existing unused wells in Watier area is 1700 m^3/ day and 2400 m^3/ day for drinking and irrigating purposes.

Youssef Shawky (2008), Studied the flash floods and their effects on the development in El-Qaa plain area in south Sinai. He did this study in applied geomorphology using GIS and Remote Sensing. He pointed out the morphometric analysis of the main basins and their drainage network in the study area. In this study all rainfall characteristics are regarded here such as rainfall types, distribution, rainfall intensity, duration, frequency, and the relationship between rainfall and runoff. Then he concerned with assessment of flood hazard and estimated the runoff. Finally, he proposed Control aspects of flash flood mitigation in the study area.

E. El-Sayed and Emad Habib (2008), studied advanced Technique for Rainfall-Runoff Simulation in Wadi Sudr south-west Sinai. The model is based on the Gridded Surface and Subsurface Hydrologic Analysis (GSSHA) modeling system. The results also indicated significant sensitivity to the selection of model parameters and the representation of rainfall spatial variability due to the limited number of rainfall gauges in the catchments. the results of this study highlight the complexity of rainfall-runoff processes in arid regions especially under the constraints of limited information on rainfall variability and the significant heterogeneity in watershed properties and model parameters.

Samuel Fockedey (2010), predicted early warning systems (EWS) forecast flash floods. This thesis reported about an early warning system called FlaFloM (Flash Flood Manager). An early warning system called FlaFloM (Flash Flood Manager) has been created for Wadi Watier – Sinai by Antea Group (Belgium), the Vrije Universiteit Brussel (Belgium) and the Water Resources Research Institute (Egypt). The FlaFloM System consists of models for rainfall forecasting, rainfall-runoff modeling, hydraulic modeling and a warning system, each one sending his output to the next model. To counteract lack of data, Remote Sensing and rainfall forecasting are used. In the framework of this thesis, rainfall and rainfall forecasting data of the January 2010 event are gathered, parsed through the FlaFloM System and compared with the scarce available field observations. Secondly a water balance of the hydrological model is made.

Eman Ahmed (2010), predicted the flood hazard and risk areas in wadi Al-Arish north Sinai . This research has developed a systematic methodology for estimating flood hazard, vulnerability, and risk map based on a geographic approach using GIS and Remote Sensing. It concluded that GIS techniques appear to be most promising as it is capable of integrating all the other techniques of flood risk assessment. The flood hazard and risk map obtained from this study can be used as basic data for designing flood prevention assist flood mitigation and land use planning.

Ahmed M. Youssef**,** Biswajeet Pradhan, and Abdallah Mohamed (2010), estimated Flash flood risk along the St. Katherine road (Wadi Feiran), southern Sinai, using GIS based morphometry and satellite imagery. They determined the risk degree of the different sub-basins using morphometric parameters. They reported that determining the impact of the lithological units distribution on the most influenced sub-basins, it was found that the most hazardous basins are located on basement complex which represent an area of 1,467 km2 (80% of the total area) of the Feiran Basin. Risk analysis was performed for the study area. These results can be used as basic data to assist flood mitigation and landuse planning. The results shown in this paper can help the developers, planners and engineers for forestation and land-use planning. However, one must be careful while using the models for specific site development.

Eman Ahmed Hassan El-Sayed 2011, constructed the rainfall intensity-duration-frequency (IDF) relationship. She did it by using the length of the available records and number of analyzed events of daily rainfall recording rain stations since 1988 and by using empirical equation to represent Intensity- Duration-Frequency relationship for Sinai Peninsula. A Matlab model is prepared to compute the rainfall depths for durations; 5, 15, 30, 60, 120 and 1440 minutes for all available rainfall events of 12 stations. According to the maximum rainfall depths for considered durations at different return periods are extracted from the best fit distribution. The parameters of rainfall intensity-duration-frequency equation are generated to create parameters contour maps. The parameter contour maps are used to estimate these parameters at ungauged sites. Accordingly the IDF curves are constructed for ungauged sites to estimate rainfall intensity for various return periods and rainfall durations.

CHAPTER THREE

Characteristics of the study area

A variety of soils can be found in Sinai. The major causes of this variety are the extreme conditions which from these soils: climate, arid in the south and wet in the mountainous ridge and the Mediterranean Seaside, variable geology as shown in figure (3.2) (sedimentary rocks, volcanic rocks, Granite rocks, sand dunes, alluvium, Limestone, Sabkha, etc.), different topographic circumstances: topography varying from 5 m above the Mediterranean sea level in the north Sinai to 2640 m in south-east Sinai. Also, physical weathering from both water and wind modifies the soils.

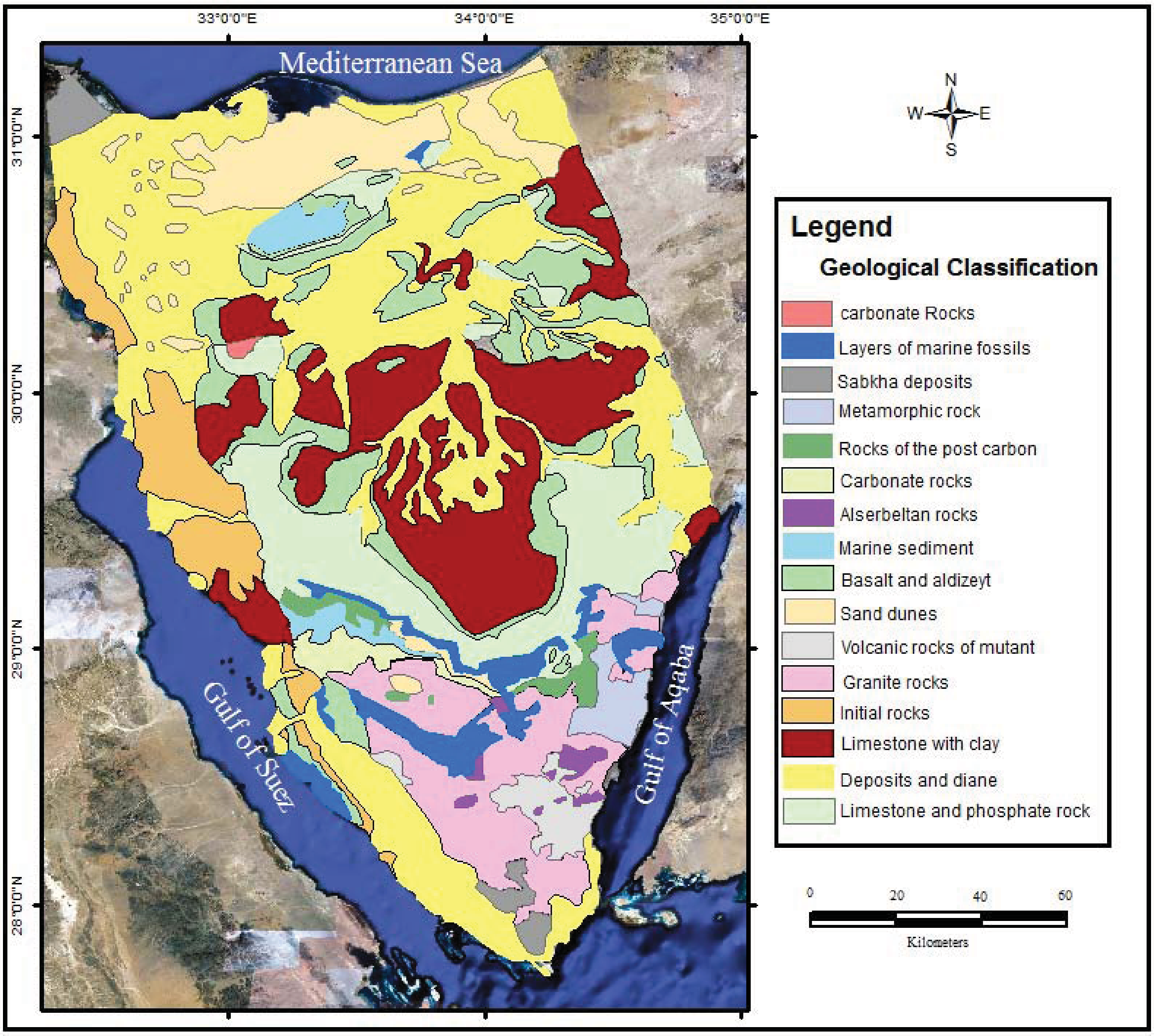


Figure (3.2) Geological setting for Sinai (Reference 4)

3.2.2) Geological setting

The geology of the Sinai Peninsula can be divided into three main areas: the northern part, the central part and the southern part. The northern part runs parallel with the

Mediterranean coast and consists of dried up river beds, or wadis, leading to sand dunes, Lime stone, Marine sediments and deposits formed by the changing levels of the Mediterranean Sea during the glacial periods that some geologists claim occurred and the flash flood occurred in the study area. The central part runs between Gulf of Suez and Gulf of Aqaba and consists of Carbonate rocks, Limestone, clay, Basalt and Aldizeyt. In the central part, a high area of limestone formed during the Tertiary Period. The highlands extend towards the south until it goes over into the third area consisting of granite and volcanic rocks, deposits, and layers of Marine fossils. Limestone and sandstone sediments are replaced by granite and basalt escarpments that slope into the Red Sea and the Gulf of Aqaba. Both rocks are produced by volcanic activity on the bottom of the ocean from the Precambrian Age.

The geology of the Sinai Peninsula consists of kinds of rocks, Sand dunes and deposits. The kinds of rocks are such as igneous rocks, metamorphic rocks, and sedimentary rocks. The deposits are such as old, recent and sabkha deposits.

3.2.2.1) The igneous rocks

This kind of rocks is distributed in the southern and eastern part of the study area, covered 13237 km² for about 21.7% of total area. It can be divided into:

3.2.2.1.1) Granite rocks

These are comprising from coarse to medium grained alkaline granite and covered of about 5490 km² nearly 9% of the study area. The distribution and areal extent of granite rocks in the study area is shown in figure (3.2).

3.2.2.1.2) Volcanic rocks

These rocks cover about 1037 km² for about 1.7% of the total area, allocated in St. Catherine area in Wadi Firan basin, Qabeliat Mountain, El-Banat Mountain and Wadi Emlaha basin. These rocks contain a metamorphosed pyroclastic.

3.2.2.1.3) Basalt rocks

These rocks cover about 6710 km² for about 11 % of the total area, allocated in wadi Al-Arish and few in middle Sinai.

3.2.2.2) Metamorphic rocks

The metamorphic rocks in the plain area consist of Gneiss rocks, coarse to medium grained banded hornblende. These rocks cover about 610 km² for about 1% and are surrounding the middle part of Wadi Firan and near wadi watier.

3.2.2.3) Sedimentary rocks

The most prominent sedimentary rocks in the study area comprise limestone, limestone with clay, and siltstone. Limestone in the study area contains fragments of fossils including gastropods, echinoderms and foraminifers; these were probably deposited in a low energy environment with normal marine salinities (NOWEIR and EL-SHISHTAWY, 1996). It covers nearly 20740 km² for about 34% of the study area. ***Siltstone*** (Matulla formation) is composed mainly of brown to reddish siltstone, shale, sandy shale, sandstone and less abundantly limestone and dolomite. This suite of rocks was deposited during a time of fluctuating sea-level (NOWEIR and EL-SHISHTAWY, 1996). These rocks cover approximately 2013 km² for about 3.3 % of the total area.

3.2.2.4) Sand dunes

As Sinai considered arid or semi arid area it contains sand dunes in some areas at north Sinai as shown in the figure (3.2).These cover approximately 3660 km² for about 6 % of the total area.

The Wadi bottom is covered mostly by sandy and silty sediments. Stratified and sorted poor sand deposits at the surface are supposed being formed when windblown materials were transported among patchy rocks. Such sand sheets could be categorized to high, moderately high, moderately, moderately low and low velocity.

3.2.2.5) Deposits

Deposits are considered to be one of the largest deposits in North and south Sinai, extending in nearly 20130 km² for about 33% of the study area. Sediments are mostly composed of coarse material such as boulders and gravels which become significantly smaller in size. *Deposits are* distributed in Wadi floors so they may be related to the watershed areas in sedimentary rocks.

3.2.2.6) Sabkha deposits

Sabkhat is the correct plural, despite the prevalent use of sabkhas (NEAL, 1975). Originally the term was applied to both coastal and inland saline depressions. Sabkha sediments are dominated usually by carbonates, evaporates, fluviatile, aeolian and marine debris and are sometimes cemented with carbonate or gypsum (COOKE et. al 1993). They cover nearly 610 km² for about 1 % of the study area.

3.2) Topography of Sinai Peninsula

ASTER-GDEM was developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). Its resolution is 1 arc-second (30 m) (ERSDAC,2009). From this data set, a Digital Elevation Model (DEM) was downloaded for the study area, as shown in figure (3.3). In addition, topographic maps with scale 1:500,000 covered the study area are available in (*http://free-gis-data.blogspot.com*). The maps were created by the Egyptian Military survey Department in 1987. Aerial photographs were used with scale 1:25,000 for that purpose. The maps were reversed from the field until May 1988. The GDEM is converted to Raster layer and compared with topographic maps using ArcGIS software. As a result, it is accepted and used for the data analysis.

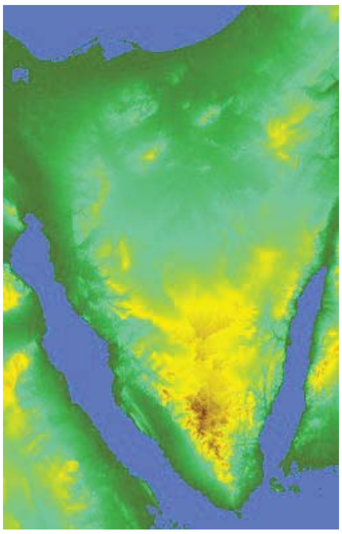


Figure (3.3) Digital Elevation Model (DEM) for Sinai *(*Reference 5)

The topography of Sinai Peninsula has an elevation difference of 2640 m between its highest point and lowest point above the sea level. Sinai Peninsula can be divided into two parts: the northern part and the southern part. The northern part runs parallel with the Mediterranean coast and has a slope of about 1:25 towards the north as shown in figure (3.3). The elevation attains it's highest altitude of 1400 m above the sea level at jabal Umm Mafrud at the south edge of northern part of Sinai and drops to range between 230 m at jabal El Thamila and 500 m at jabal Ash Shaira in the eastern edge of the northern part where Wadi El Jeria joins Wadi Al Arish. Figure (3.4) represents the simulation of Digital Elevation Model of Sinai Peninsula.

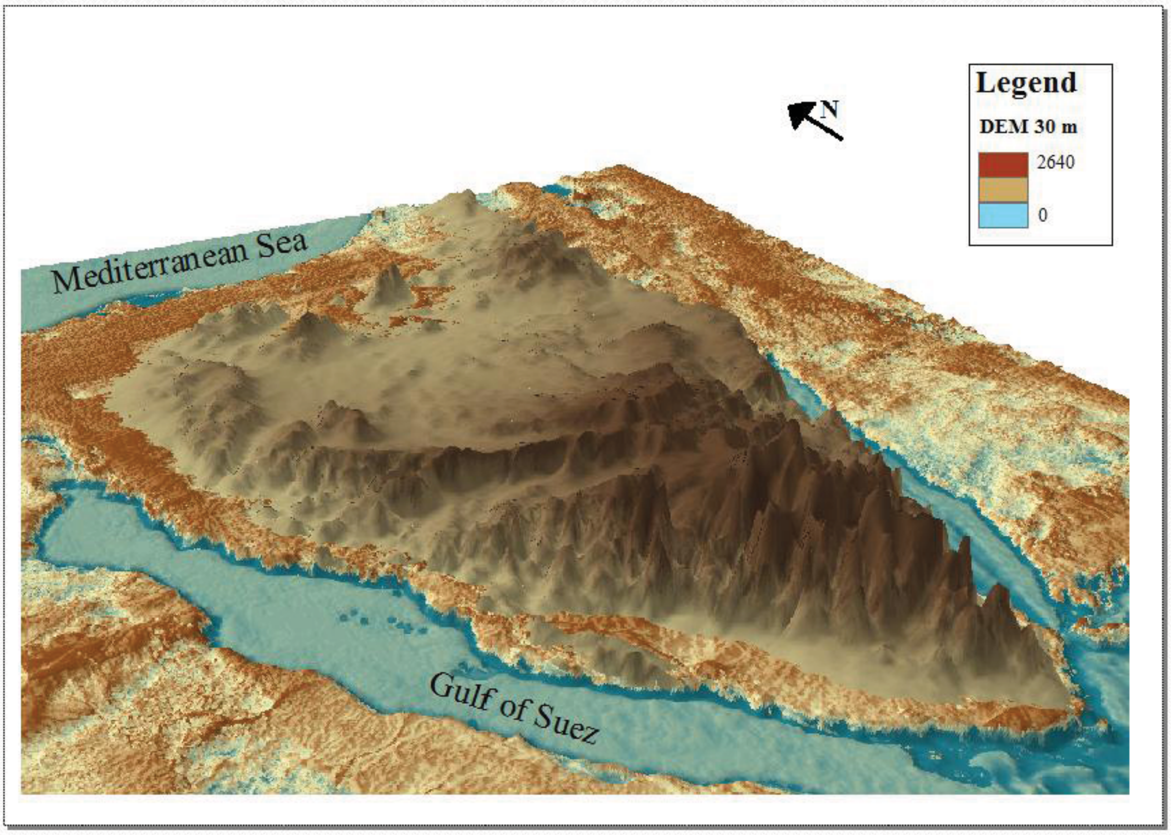


Figure (3.4) Digital Elevation Model representing Sinai topography

The Southern section is an extremely tough terrain. It is composed of high rise Granite Mountains. Jabal Katherine rises about 2640 meters above sea level. Jabal Katherine has a slope of about 1: 0.05 towards the east, 1: 0.18 towards the west, 1: 0.02 towards the north and 1: 0.19 towards the south in the southern part of Sinai.

Contour map is generated by using the Digital Elevation model (DEM) with resolution 30 m which is presented in figure (3.5) from which we can detect the highest zone is concentrated at the southern zone of Sinai Peninsula. In the south, the towering red mountains are surrounded by deep valleys.

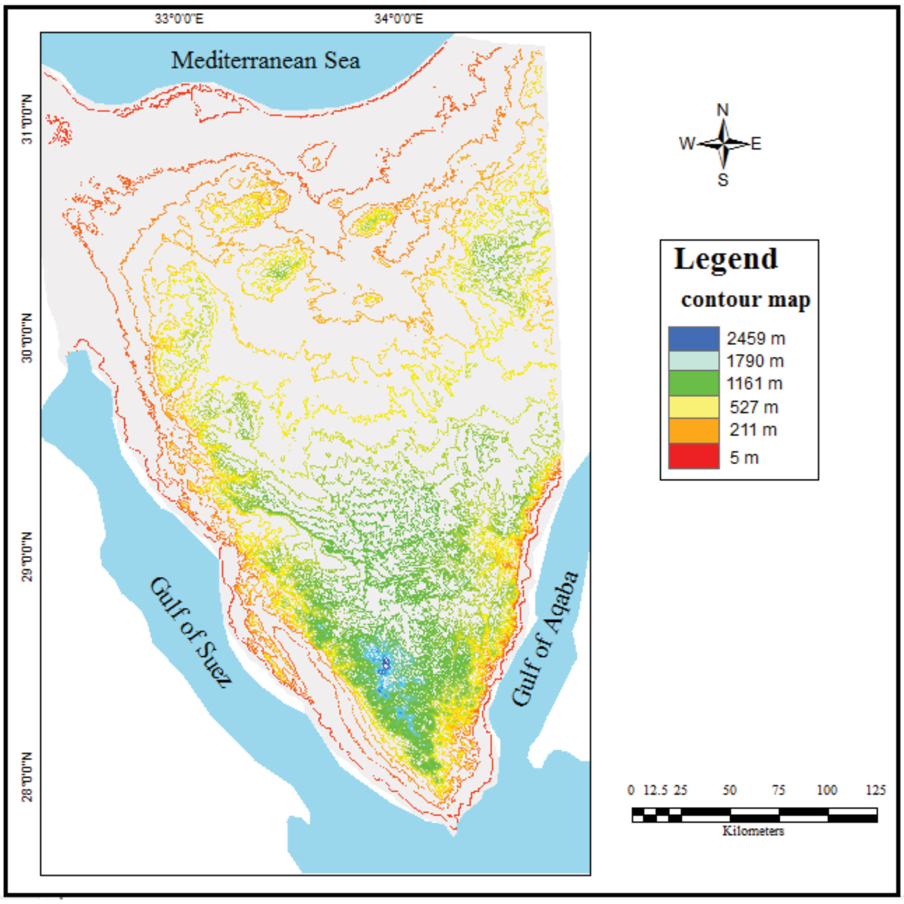


Figure (3.5) Contour Map of Sinai Peninsula

3.3) Climatic conditions

3.3.1) Introduction

Usually the rain in deserts, as elsewhere, is variable in frequency, intensity, duration and spottiness, so that generalizations are difficult. Nevertheless, certain features of desert precipitation are important in the context of fluvial processes. The spatial and temporal variability is not unique to deserts, but it is exceptionally important because it means that commonly only parts of drainage systems are affected by rainfall and activated by runoff at any time. Equally important, the location of runoff often varies from event to event. It can be noticed that the location of precipitation and runoff may be predictable where the cause is fixed.

The climatic conditions of the Sinai Peninsula are similar to those, which characterize desert areas in other parts of the world. They include extreme aridity, long hot and rainless summer months and a mild winter. During the winter months some areas of

Sinai experience brief but intensity of rainfall that makes Wadi beds overflow and sometimes cause severe flash floods which damage the roadways and, sometimes, human lives (JICA,1999) .

The climate of any particular place is influenced by several interacting factors. These include latitude, elevation, nearby water, topography, and prevailing winds. Rainfall is strongly influenced by variation of climate changing from arid desert environment to a cool and moderately humid mountainous area.

In the present study, the climatic conditions of Sinai are discussed in the light of available records. There are eighteen meteorological stations in Sinai. The locations of meteorological stations in Sinai are presented in Figure (3.6) and table (3.1) Present the latitude, longitude and elevation of the meteorological stations.

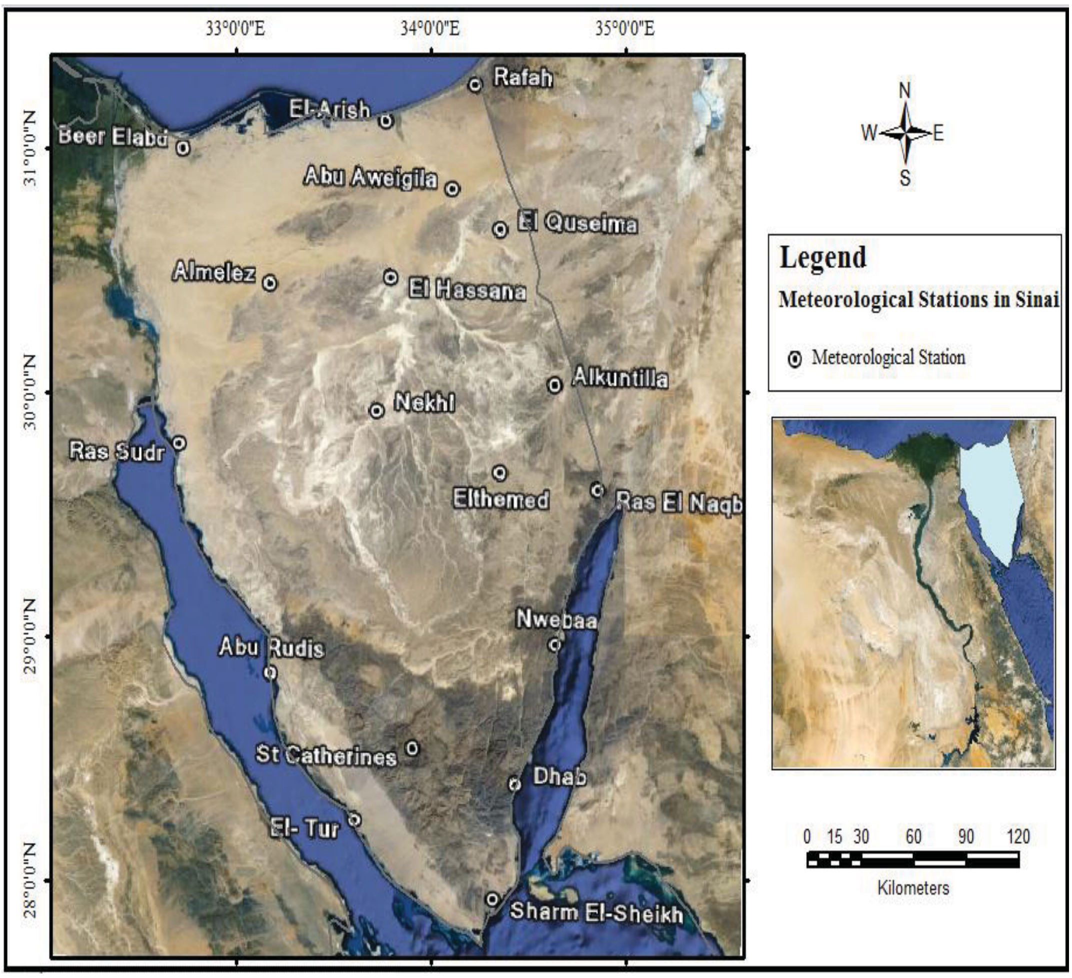


Figure (3.6) The locations of meteorological stations in Sinai (*Reference 3*)

Location	Station name	Lat.	Long.	Elevation (m)
Northern stations	Rafah	31° 16'	34° 14'	67
	El Arish	31° 07'	33° 46'	15
	Beer Elabd	30° 59'	32° 41'	18
	Abu Aweiqila	30° 50'	34° 07'	140
	El Quseima	30° 40'	34° 22'	330
	El Hassana	30° 28'	33° 48'	250
	Al Melez	30° 26'	33° 10'	486
	Al Kuntilla	30° 00'	34° 41'	530
	Nekhl	33° 44'	29° 85'	402
	Ras El Naqb	29° 36'	34° 52'	760
	Elthemd	29° 40'	34° 22'	625
Southern stations	Ras Sudr	29° 45'	32° 42'	290
	Nwebaa	28° 57'	34° 38'	50
	Abu Rudis	28° 50'	33° 11'	55
	St Catherines	28° 32'	33° 55'	1,652
	Dhab	28° 23'	34° 26'	12
	El Tur	28° 14'	33° 37'	47
	Sharm El-Sheikh	27° 55'	34° 19'	114

Table (3.1) The latitude, longitude and elevation of the meteorological stations

3.3.2) Temperature and Rainfall

The climate is characterized in general by volatile rainy winter and hot, strong wind, high evaporation, low rain, and low relative humidity in summer (May to September). During the period May/June to September/October the mean daily maximum temperature is 28^{o}C to 37^{o}C in the North, 31^{o}C to 42^{o}C near the south coast and 35^{o}C to 41^{o}C inland. Minimum temperatures average between 20^{o}C and 25^{o}C in the summer. But in autumn and spring, the climate is less volatile than winter with some times heavy rain. In winter (November to March), the temperature falls to around 6^{o}C - 10^{o}C, and may drop below 0^{o}C. These variations are expected because of the differences in position, elevation, and distance from the coast and environment around the stations.

In winter season, rainfall on the northern region, close to the Mediterranean Sea, reaches its maximum quantity during December and January. According to Water Resources Research Institute (WRRI) and Meteorological Authority rainfall measurement stations, the total quantity of rainfall varies from area to another. The average amount of rainfall varies from 60 to 100 mm per year near the coast and decreases towards the West to about 60 millimeters in Portsaid. These values increase about 100 mm in Al Arish, and up to 120 mm in Rafah. On the other hand, these amounts of rain are decreasing to about 50 mm at latitude 30° 30´ and to about 30 mm in Nekhl , 20 mm in Suez and the same in Al Tur. The range of average annual rainfall in the southern heights is between 30 and 60 mm. Finally, Rainfall occurs mainly, in the north of the peninsula and to a lesser extent in the southern mountain region. The precipitation comes almost exclusively in winter and may sometimes occur as snow on the high peaks. Figure (3.7) Shows average yearly rainfall heights of all stations for Sinai.

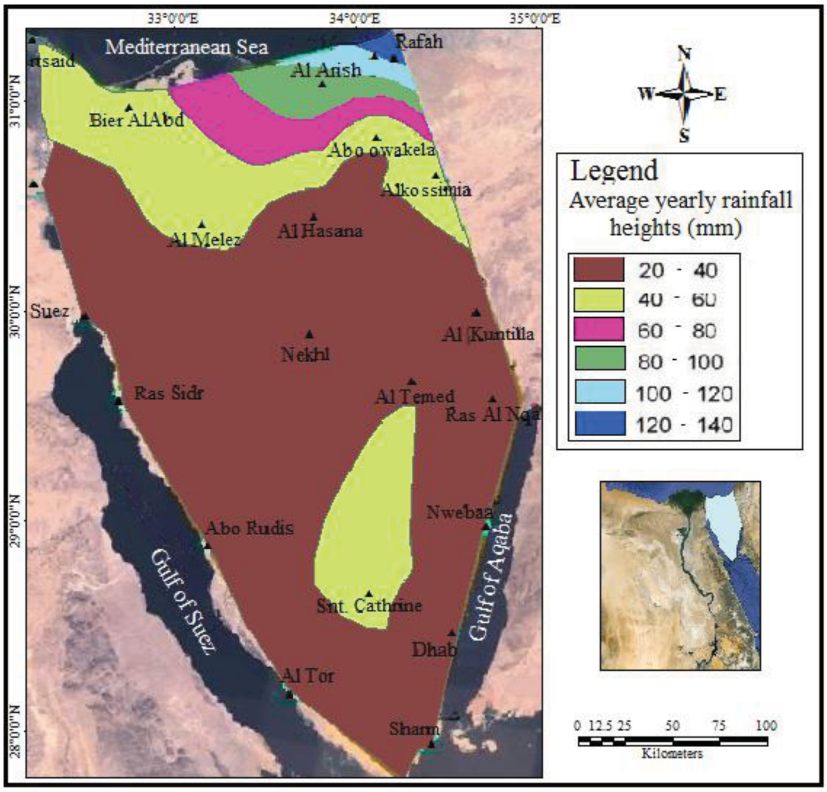


Figure (3.7) Average yearly rainfall heights for Sinai (WRRI)

Eman Ahmed Hassan 2011, represented daily rainfall recording rain stations since 1988. The length of the available records and number of analyzed events are listed in table (3.2).The errors in the data are removed through quality control and verification analysis. Also, these rainfall measurements are checked with the General Metrological Authority (GMA) measurements.

Station Name	Elevation	Observation Period	No. of years	No. of Events	Max. Event (mm)	Aver. Duration (hr)
El Maghara	3	1990-2010	17	44	27.5	3.3
El Timed	625	1990-2010	8	25	38.6	3.7
El Godirat	390	1990-2010	18	53	20	5.6
El Kontila	530	1990-2010	11	25	9.6	4.4
Ghrandal	69	1992-2010	17	48	19.3	3.3
El Rwafaa	136	1990-2010	20	61	25	6.6
El Hassana	250	1991-2010	15	26	17.4	5.1
Ber Albd	18	1990-2010	16	53	26.8	6.1
Nekhl	402	1990-2010	6	22	23.6	1.7
St. Cathrine	1652	1990-2010	17	38	25.02	4.7
Ras Sudr	290	1990-2010	20	51	27.4	4.6
Nuweiebaa	50	1988-2010	9	20	16.7	3.3

Table (3.2) Number of recorded year and events (*Reference 5*)

Flooding, resulting from convective rains has been observed during all seasons (DAMN,1983). According to SALEM (1993) the mean annual rainfall ranges between 10.4 mm / year at El-Tur. 15.4 mm / year at Ras Sudr, 21.5 mm / year at Abu Rudeis, and 63 mm / year at St. Catherine, and these amounts indicate that the rain increases toward the east of Sinai. The hydrographical basins of the study area have high surface water potentialities. This is due to the fact that the eastern branches of their steep sloping channels drain the highlands of south and central Sinai where high rates of rainfall prevail (SAAD et. al.,1980). However, chances for infiltration are limited due to the steep rocky slopes of their Wadis.

3.3.3) Evaporation

Evaporation in the arid zones is the most affecting factor in the hydrological cycle. The evaporation data for the north Sinai are presented in table (3.1) as recorded from different meteorological stations. From the mean evaporation values from the meteorological stations, it can be concluded that the monthly evaporation ranges from 1.5 to 10.3 mm/d. The monthly evaporation decreases during winter to 1.5 mm/d especially in December and increases to10.3 mm/d in July. Generally, the evaporation rates decrease eastward.

3.3.4) Wind

Surface wind plays an important role for horizontal and vertical thermal exchange and dominates the most of climate elements such as evaporation, humidity and precipitation. On the other hand, wind speed is different from one area to another and from season to season depending on pressure distributions, topographic and local relief (SALEM, 1993). The prevailing winds in the area, generally, are from the North or North-West and the winds from South-West cause the orographic rainfall (WRRI, March.2009).

In spite of the Mediterranean depressions which affect in winter Northern Egypt directly, causing variable surface winds, both in speed and direction, the study area is practically unaffected by these depressions and remains for most of the time, under the eastern flank of the sub-tropical high pressure gradient. Orographic effects in the southern Sinai may transform these winds into strong ones.

It has been noticed that the frequency of strong and gale winds decreases considerably in southern Sinai. Northeasterly winds become more frequent in the spring and autumn months along the Mediterranean coast line. This fact reveals that the eastern Mediterranean is becoming an area of relatively high pressure. In southern Sinai northerly winds prevail during this period; they are interrupted only temporarily by the passage of depressions. Autumn, especially October, is the time of lowest wind speed (SOLIMAN, 1972).

The northern part of the Sinai is mainly affected by northwestern winds coming from the Mediterranean Sea. However, during El-Khamasin storms (which are warm storms carry out the fine sand and dust from location to another depend on direction of the wind with generally high temperature in atmosphere) the direction of the wind changes from south to southwest. Wind direction is predominantly from NW at Abu rudeis 50.9%, Sh. El-Sheikh 42.2% and El-Tur 37.1%, whereas the predominant direction at St. Catherine is SW with percent 32%, with regard to relief and topographic factors of this area; especially in winter December is considered being the month of highest wind activity 41% at St. Catherine area.The lowest percent of wind direction has been computed to 2.6% E, at El-Tur, to2.6% N at St. Catherine, to 5% NE at Abu Rudeis and to 5% S at Sh. El-sheikh.The calm periods decrease in the area along Gulf of Suez reaching to 0.1% at El-Tur,3.1% at Abu rudeis. The calm period is typical for December, while it is measured at Sharm El-Sheikh to 5.5%, and at St. Catherine to 6.1% due local relief and altitude which is over 2600m.

It is observed from the Egyptian meteorological authority from 1934 to 1994 that the average wind speed is about 9-37 km/h. Maximum speed has been recorded at El-Tor to 37 km/h in June, 35 km/h in August and September, but, at St. Catherine maximum speed has recorded in October and November to 33 km/h. Relative high speed is reported in summer during June and July along Gulf of Suez at El-Tur and Abu Rudeis stations, while the minima speed has measured to 7 km/h in February at Ras Sudr and St. Catherine stations.

3.4) Drainage paths of Sinai

There are three drainage paths of Sinai Mediterranean Sea, Gulf of Suez and Gulf of Aqaba as shown in figure (3.8) .These three drainage paths defined according to the boundary that appears from topography map of the site by using Digital Elevation Model in Arc GIS program. The outputs of this program are the area drain in Mediterranean Sea is 23749m^2, the area drain in Gulf of Suez is 18542 m^2 , in Gulf in Aqaba is 11360 m^2 and outside eastern boundary is 2610 m^2.

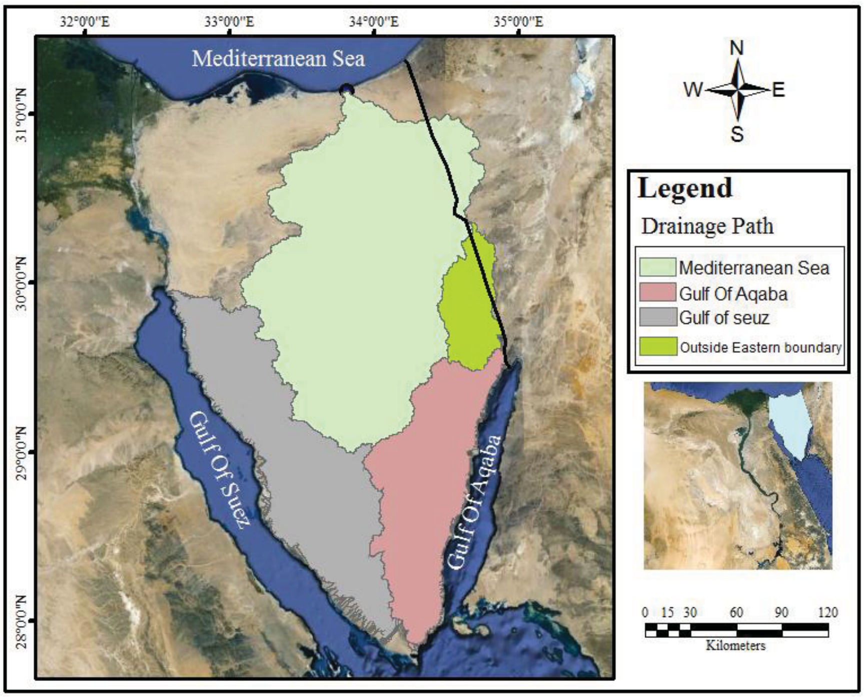


Figure (3.8) Drainage paths of Sinai

Chapter 4

Hydrological Study

4.1) Introduction

Studying flash floods in watersheds is determined by gathering and analyzing meteorological, topographical, and morphological data. However, in many arid and semi arid regions data is usually limited and incomplete and watersheds are mostly ungauaged. It is a challenge to select the proper runoff model which suits the available data. This problem has been tackled by a number of researchers who have studied and analyzed watersheds in arid zones in an attempt to develop appropriate rainfall-runoff models. In studying wadi systems, the area bounded by water divides where any drop of rain will be retained, may be termed watershed, catchment area, or basin according to different authors. A smaller area within a watershed is termed sub-catchment.

4.2) Surface Water Runoff

When rainfall reaches the Earth's surface, water evaporates, infiltrates into the soil, or runs over the surface. The kinds of ground cover greatly influence the proportions of each of these actions. In various types of communities, and within communities, there are different cover types. If the rainfall intensity exceeds the evaporation rate and infiltration capacity of the soil, surface runoff occurs as shown in figure (4.1). It also occurs when rainfall falls on impervious surfaces, such as roadways and other paved areas. Water flows across the surface as either confined or unconfined flow. Unconfined flow moves in broad sheets of water often causing sheet erosion. It can also pick up and adsorb or carry contaminants from the surface. Water that flows along the surface may become trapped in depressions. Here water may either evaporate back into the air, infiltrate into the ground, or spill out of the depression as it fills. If local drainage conditions are inadequate to accommodate rainfall through a combination of evaporation, infiltration into the ground, and surface runoff, accumulation of water in certain areas may cause localized flooding problems (FEMA, chapter 2).

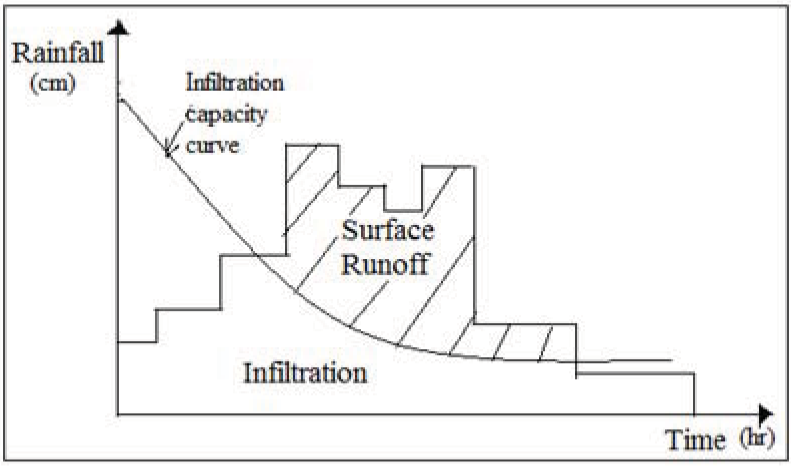


Figure (4,1) Rainfall – time curve showing Surface runoff

4.3) Factors Affecting rainfall-Runoff Relationship

Chow, et al., (1988) divided the parameters to generate runoff into two categories or characteristics. The first order attributes the climatic elements as rainfall. The other factor refers to those related to the watershed characteristics as basin size, shape and slope. Table (4.1) summarizes these factors.

Factor 1	Factor 2		
Rainfall (storm) Factors	Watershed characteristics		
	Topographic features	Land cover	Soil and geology characteristics
Rainfall intensity	Slope	Vegetation density	Soil texture
Rainfall duration	Catchement size	Vegetation characteristics	Soil crust
Rainfall spatial distribution	Catchement Shape	Land use	Soil moisture

Table (4.1) Factors affecting rainfall-Runoff relationship

The storm factors influencing the shape of the flood hydrograph, peak flow and the volume of runoff include:

- Rainfall intensity, which affects the amount of runoff and the peak flow rate. As for a given rainfall duration, an increase in intensity will increase the peak discharge and the runoff volume, provided the infiltration capacity of the soil is exceeded.

- Rainfall duration affects the amount of runoff, the peak flow rate and the duration of surface runoff. The duration of a rainfall with a given intensity determines, in part, the amount and timing of the peak flow.
- The spatial distribution of rainfall can cause variations in hydrograph shape. If the center of the storm is close to the basin outlet, a rapid rise, sharp peak and rapid recession of the hydrograph is observed. But if a larger amount of rainfall occurs in the upper reaches of a basin, the hydrograph exhibits a lower and delayed peak.
- The direction of storm movement with respect to orientation of the basin can affect both the magnitude of the peak flow and the duration of surface runoff. Storm direction has the greatest effect on elongated basins. On these basins, storms that move upstream tend to produce lower peaks of a larger duration than storms that move downstream.
- Finally, the type of storm is important in that thunderstorms produce peak flows on small basins, whereas large cyclonic or frontal-type storms are generally dominant in producing major floods in larger basins.

Precipitation in arid and semi-arid zones results largely from convective cloud mechanisms producing storms typically of short duration, relatively high intensity and limited areal extent which called sporadic storms. It is usually in the winter season (Al-Weshah, 2002).

The topography, area, land use, vegetative cover and geologic factors in the catchment affect the rainfall-runoff processes. The dominant factors related to the watershed characteristics are:

- Catchment area, which has a major effect on the flood hydrograph. Although the peak flow will be higher for a bigger catchment, the peak flow per unit area is relatively lower for a bigger catchment size for a given rainfall depth. This is partly related to the areal properties of the storm event, to transmission losses and to the larger time required for the total catchment to contribute to the peak runoff.
- Catchment shape affects the peak flow. By considering the hydrograph of discharge from differently shaped catchment with the same surface area and subject to rainfall of the same intensity, it can be noted that the elongated watersheds will have less peak flow than equivalent circular watersheds.

- Drainage pattern along with the arrangement of the natural stream system determine the efficiency of the drainage system. With other factors being constant, the time required for water to flow a given distance is directly proportional to flow path. A well-defined drainage system reduces the flow distance, thus reducing the travel time, and the resulting outflow hydrograph will usually have a shorter time to peak.
- Slope of the catchment: the steeper the slope of the catchment, the more rapidly surface runoff will travel. Therefore the time to peak will be shorter and the peak will be higher. Infiltration capacity tends to be lower as slope get steeper.
- Storage in the catchment: Antecedent conditions will affect soil moisture and ground water storage, and in general, the wetter the catchment, the greater will be the volume of storm runoff. In additional, artificial storage, such as reservoirs or detention ponds, must first be filled before any runoff occurs, which usually delayed the time to peak and attenuates the peak flow.
- Soil and geology of the catchment: soils and geology of the catchment primarily influence the groundwater component and the subsurface losses. Hydrologic soil groups are classified based on the soil drainage potential. High infiltration rates reduce the surface runoff; high permeability combined with high transmissivites substantially enhances the base flow component.
- Time of concentration: This is a time parameter that is related to other watershed characteristics such as slope, length, and area. The time of concentration is defined as the time needed for a drop of water to travel from the most distant point in the watershed to the design point downstream. It includes both time of overland flow and time for channel flow.

4.4) Runoff Estimation

There are a number of approaches to compute runoff from rainfall. One of the first approaches is the Rational Method which relates peak runoff to rainfall intensity through proportionality factor. The second approach is the hydrograph approach which starts with rainfall hyetograph, accounts for rainfall losses and temporary storage effects in transit.

4.4.1) Rational Method

Mathematically, the rational method relates the peak discharge (q, m^3/sec). The rational formula is :

$$Q_r = K\,C\,i_r\,A$$

Where:

Q_r = the peak flow rate in m^3/s for return interval T years.

C = the runoff coefficient depends on land use.

i_r= the design rainfall intensity in cm per hour for return period of T years over time of concentration.

K= 0.028 constant for SI units.

A= the catchment drainage area in KM^2.

This equation depends on assumptions:

1. The peak flow occurs when the entire catchment is contributing to the flow.
2. The rainfall intensity is the same over the entire catchment area.
3. The rainfall intensity is uniform over time duration equal to or greater than the time of concentration. The time concentration is the time it takes for runoff to travel to a point of interest from the hydraulically most distant point of the area to the outlet once the soil has become saturated and minor depressions filled. It is assumed that when the duration of the storm equals the time of concentration, all parts of the watershed are contributing simultaneously to the discharge at the outlet.

The Rational Method can provide satisfactory estimates of peak discharge on small urban catchments (catchment drainage area less than two KM^2) (Pilgrim and Cordery1993).

4.4.2) Flow Hydrographs Method

A flood hydrograph is a continuous graph that represents the instantaneous rate of discharge of a stream with respect to time. It is normally obtained by plotting a continuous stage recorder which indicates stage versus time, and then transforming it into a discharge hydrograph by the application of the rating curve. The hydrograph includes four component elements, which are direct surface runoff, interflow, ground water or base flow, and channel precipitation. In most hydrograph analyses, interflow and channel precipitation are grouped with surface runoff rather than treated separately. During large storms, surface runoff is the most significant hydrograph component.

4.4.3) Soil Conservation service Hydrograph Method

The soil conservation service (SCS) method was originally based on the observed runoff from agricultural Watershed (SCS 1983).In addition; the SCS developed guidance for using this method on urban areas.

The SCS method uses a curve number to define some of the characteristics of the watershed. The curve number reflects a combination of the soil hydrological group, the land use and the treatment class. This combination of items used in determination of the curve number is referred to as the hydrological soil-curve complex. The curve number then selected, based on the hydrological soil-curve complex, and is used to determine runoff volume. One item which most affects the soil cover complex is the hydrological characteristic of the soil itself.

4.4.3.1) Soil Classification (SCS 1985)

The SCS classified the soils into four different hydrographical groups; A, B, C, and D. These hydrographical groups are based on the infiltration capacity of each soil and are defined as follows:

Group A: (Low runoff potential). Soils having a high infiltration rate even when thoroughly wetted and consisting chiefly of deep, well-drained to excessively drained sands or gravels. These can be deep sand, deep loess and aggregated silts.

Group B: Soils having moderate infiltration rate when thoroughly wetted and consisting chiefly of moderately deep to deep, a moderately well to well drained soils with moderately fine to moderately coarse texture. These can be shallow loam and sandy loam.

Group C: Soils having a slow infiltration rate when thoroughly wetted and consisting chiefly of soils with layer that impedes downward movement of water, or soil with moderately fine to fine texture. Common examples are clay loams, shallow sandy loam, soils low in organic content and soils usually high in clay.

Group D: (High runoff potential). Soils having a very slow infiltration rate when thoroughly wetted and consisting chiefly of clay soils with high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material. Examples are soils that swell significantly when wet, heavy plastic clays and certain saline soil.

4.4.3.2) Curve Number (SCS 1985)

The curve number is used for numerical definition of the soil-cover complex for a watershed area. The selection of a curve number is based on the soil hydrographical group, the percentage of impervious cover, the condition of vegetative cover and the antecedent moisture condition.

The impervious cover in the watershed includes roofs, sidewalks, paved driveways, paved streets, paved alleys and paved parking areas. Impervious surfaces in a large watershed are usually included in a composite curve number which defines the entire watershed or subarea. However, a small drainage area such as a mall shopping area may have such an insignificant area of unpaved surfaces and landscaping that it may be more practical it as 100% impervious.

The condition of the vegetative cover in unpaved areas has an effect on the volume and rate of runoff from a watershed. The SCS has qualitatively defined vegetative cover as poor, fair or good condition relative to the percentage of ground cover. These qualitative terms are defined below.

Poor: Less than 50% ground cover; heavily grazed with no plant litter.

Fair: 50 to 75% ground cover; not heavily grazed, some plant litter.

Good: Greater than 75% ground cover; only lightly or occasionally grazed.

Precipitation loss is calculated based on supplied values of CN an I_a (where I_a is an initial surface moisture storage capacity in units of depth). CN and I_a are related to a total runoff depth for a storm by the following relationship:

$$P_e = \frac{(P-I_a)^2}{(P-I_a)+S}$$

Where:

P_e is the accumulated excess, P is the accumulated rainfall depth, and S is the currently available soil moisture storage deficit.

Initial abstraction I_a includes all losses before runoff begins; water retained in surface depression, water intercepted by vegetation evaporation, and infiltration. Through many studies of small agricultural watershed, I_a is found to be approximated by the following empirical equation:

$$I_a = 0.2 \text{ x } S$$

By removing I_a as an independent parameter, this approximate allows use of a combination of S and P to produce runoff amount.

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

S is related to the soil and cover conditions of the watershed through the CN. S (inch) is related to the CN by:

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

4.4.3.3) Synthetic Unit Hydrograph

The SCS developed a method for constructing a synthetic unit hydrograph. This method requires only the determination of the time to peak and the peak discharge, t_p and q_p respectively (soil conservation services 1971) and (Mccuen 1989). The time to peak t_p expressed in hours is defined as:

$$t_p = \frac{D}{2} + 0.6\, t_c$$

Where D is the duration of rainfall (hr), and t_c is the concentration time (hr). In turn the concentration time is estimated by:

$$t_c = 0.000877\, L_f^{0.8}\, (1000/CN - 9)^{0.7}\, S^{-0.5}$$

Where L_f is the flow length (the longest path from the outlet to the divide as shown in figure (2.2)) in ft, CN is the curve number defined by the SCS, and S is the average watershed slope (in percentage).

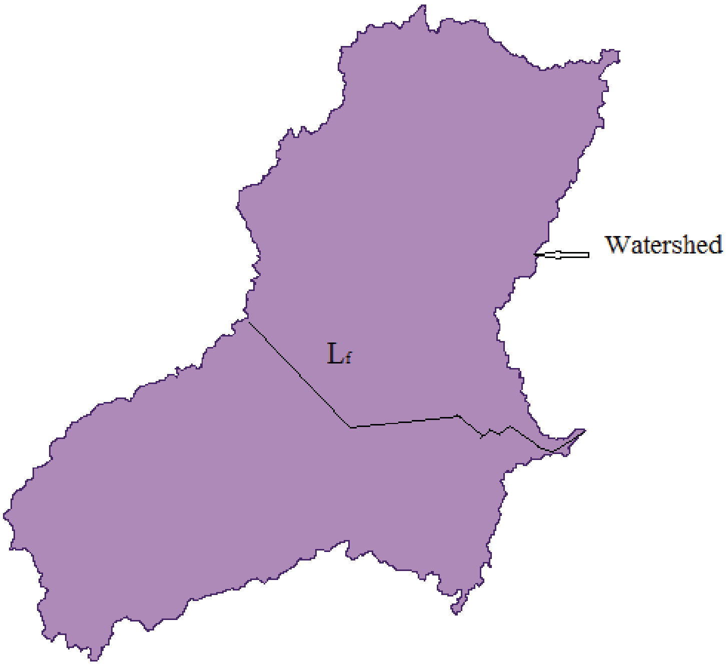


Figure (4.2) Sketch for flow length (Lf)

The peak discharge q_p in cfs is given by:

$$q_p = \frac{484\ Ai}{t_p}$$

Where A is the drainage area in mi^2, and I is the runoff depth in inches: for a unit excess precipitation (that part of a rain available for runoff), i=1 inch.

The base time of the unit hydrograph is defined as:

$$t_b = \frac{8}{3} t_p$$

Where t_b is in hrs. Figure (4.3) shows the SCS runoff hydrograph elements.

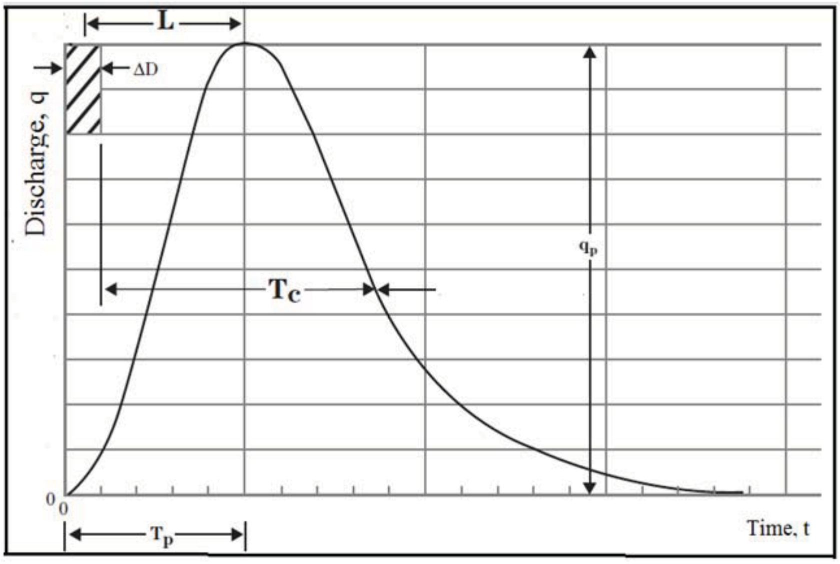


Figure (4.3) Runoff hydrograph elements

4.4.4) The Snyder's Unit hydrograph Method

The Snyder's UH, (1938) method is quite similar to SCS method. The peak discharge to lag time relationship is expressed indicated:

$$q_p = \frac{640\ A\ C_p}{t_L}$$

Where:

q_p= Peak discharge (CSF)

A = Area (mi^2)

C_p= Storage coefficient (is a coefficient derived from gauged watersheds in the area, and represents the effects of retention and storage).

t_L= Lag time between the middle of the rainfall and the hydrograph peak discharge as shown in figure (2.4) and is assumed equal to 0.6 t_c (hr)

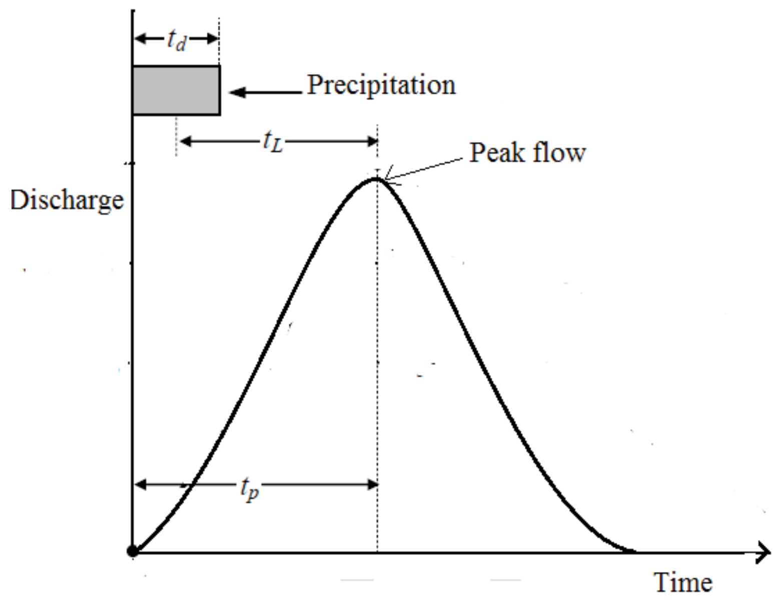


Figure (4.4) Watershed lag time definition

4.4.5) Geomorphologic Instantaneous Unit Hydrograph Method

As the duration of uniform rainfall becomes shorter, the resulting unit hydrograph approaches an instantaneous unit hydrograph. The Instantaneous Unit Hydrograph (IUH) is the hydrograph of runoff that would result if an inch water is spread Instantaneously and uniformly over an area and then allow to runoff.

Rodriguez-Iturbe and valdes(1979) introduced an approach which consists of linking the traditional IUH concept to some geographic parameters of a basin. These researchers expressed the IUH as a function of Horton's ratio (bifurcation ratioR_B, area ratio R_A, length ratio R_L), a scale variable L_Ω , length of highest order stream, and a dynamic parameter v (which can be represented by the peak flow velocity). Rodriguez-Iturbe (1982) used Manning's equations to express the IUH as a function of Manning's roughness coefficient, mean width, and mean slope of the highest order stream instead of the dynamic parameter v. They established a link between climate, the geomorphologic structure, and the hydrologic response of a basin to developed the geomorphoclimatic IUH. Using this approach , Hebson and wood(1982) developed flood frequency distributions from rainfall distributions and geomorphologically derived unit hydrographs for two Appalachian Mountain watersheds of 105 Km^2 and 992 Km^2 area.

Rodriguez (1979) , Gupta, and Waymire(1980) introduced an effective technique utilizing easily accessible geomorphologic and geometric basin parameters to obtain an analytical expression for basin response. The technique assumes that the individual channels behave as linear reservoirs and uses concepts of probability theory and geomorphology to estimate the Geomorphologic Instantaneous Unit Hydrograph (GIUH). The concept of GIUH hydrograph is utilized in calculating the influence of the channel network on the delay and the shape of the hydrograph. A detailed derivation of the GIUH-method has been given by Rodriguez-Iturbe and Valdes(1979). Rodriguez (1979) derived the peak discharge q_p and time to peak t_p of GIUH as:

$$q_p = \frac{1.31}{L} R_L^{0.43} \text{ v}$$

$$t_p = \frac{0.44\, L}{v} \left(\frac{R_B}{R_A}\right) R_L^{0.38}$$

Where L is the length in kilometers of the highest order stream, and v is the peak velocity of the response in meters per second. Parameters t_p and q_p are given in hours and in per hour, respectively. R_B , R_A , and R_L are stream's bifurcation ratio, and length ratio, respectively which apply for strahler ordering, as explained by Horton (1945) applying Strahler ordering. These ratios are illustrated in figure (4.5) and can be obtained as

$$R_B = \frac{N_{\omega-1}}{N_\omega}$$

$$R_A = \frac{A_\omega}{N_{\omega-1}}$$

$$R_L = \frac{L_\omega}{L_{\omega-1}}$$

Where:

N_ω = Number of streams of order ω in a network.

A_ω= mean area drained by a stream of order ω.

L_ω = mean length of streams of order ω.

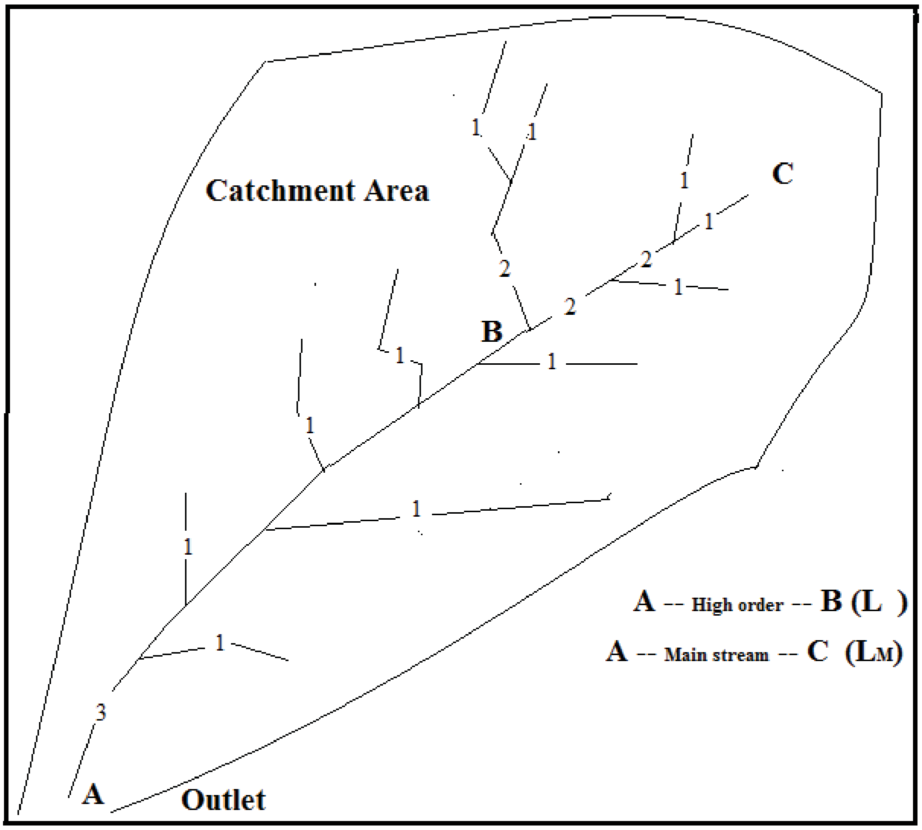


Figure (4.5) Sketch for the stream network of a watershed, (Horton,1945)

As a result from the difficulties in estimating the peak velocity v in equations (4.7) and (4.8), and the relation that v must be a function of the effective intensity and duration, they developed equations called the Geomorphoclimatic Instantaneous Unit Hydrograph (G-GIUH) where the peak discharge and time to peak as follow:

$$q_p = \frac{0.871}{\pi_i^{0.4}} \qquad (\frac{1}{\text{hours}})$$

$$t_p = 0.585\ \pi_i^{0.4} \qquad \text{(hours)}$$

Where π_i is defined as

$$\pi_i = \frac{S^{2.5}}{i_r\ A \quad R_L\ \alpha^{1.5}}$$

Where i_r is the intensity of effective rainfall in centimeters per hour is, A is the area of the watershed in Km^2, and α is the kinematic wave parameter for the stream of highest order. The parameter α is defined as :

$$\alpha = \frac{S^{0.5}}{n \; b^{2/3}}$$

Where S is the average slope of the highest order stream, n is the average Manning roughness coefficient of the highest order stream, and b is the average width of the highest order stream , in meters.

4.4.6) Time-Area Method

Time- area methods utilize a convolution of the rainfall excess hyetograph with a time area diagram representing the progressive area contributions within a catchment in set time in set time increments.

The peak discharge, Q_P is the sum of flow contributions from subdivision of the catchment defined by time contours (called isochrones), which are lines of equal flow time as shown in figure (2.6) to the point where Q_P is required.

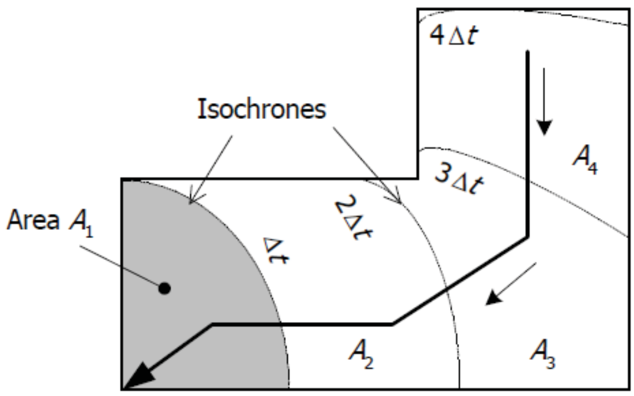


Figure (4.6) Catchment Isochrones in time- area method

The flow from each contribution area bounded by two isochrones (T-ΔT) is obtained from the product of the mean intensity of rainfall (i) from time T-ΔT to the area (ΔA). The whole catchment is taken to be contributing to the flow after T equals to T_c. Accordingly, the peak discharge can be estimated using the following equation:

$$Q_P = \sum_{k=1}^{n} i_{(n-k)} \cdot \Delta A_k$$

Where

n = the number of incremental areas between successive isochrones given by $(T_c/\Delta T)$

k = a contour from one to n.

This method employs two components 1) a translation hydrograph to reflect the travel (lag) time required for one unit of rainfall excess to reach the basin outlet from isochrones-delineated basin segments, and 2) a linear reservoir to represent natural storage effects. The translation hydrograph is routed through the linear reservoir; the resultant outflow is an instantaneous unit hydrograph.

4.5) GIS and WMS for Hydrologic and Hydraulic Modeling

Over the past few years, GIS has gained considerable importance in the engineering applications particularly in Hydrology and Hydraulics. Early applications started at the 1980s, and GIS began to be used to represent the flow of water on the land surface. Then WMS was initially developed by the Engineering Computer Graphics Laboratory in the early 1990s. WMS is Hydrologic Extension for GIS.

4.5.1) Digital terrain data for Hydrologic Modeling

DeVantier and Feldman (1993) reviewed the connection between GIS and hydrologic modeling. This review summarized past efforts and current trends in using digital terrain models, and GIS to perform hydrologic analysis. the link between GIS and hydrologic modeling becomes more natural as the concern about spatially distributed terrain parameters and the use of computers for hydrologic analysis turns more popular. Digital terrain models (DTM) are the means used by GIS to describe the spatially distributed attributes of the terrain, which are classified as topologic and topographic data. Digital elevation models (DEM) refer to the topographic data, while all large amount of information required to describe the terrain, GIS provides a powerful storage system and a computationally intensive system.

Terrain data could be dealt with in different ways, depending on the type of models to be used. The grid approach divides the terrain into identical square cells arranged in rows and columns; triangular irregular networks (TIN) select a set of representative irregularly distributed points and connecting them by straight lines producing triangles; and digital line graphs is digitally representing the elevation contour lines as a set of point-to-point paths. Hence, grid data, because of its geometric structure, leads to finite difference methods of runoff computation. There is interface designed to import GIS data into WMS. When the data is imported into WMS, it is automatically linked to each of the hydrologic models supported in WMS.

4.5.2) Stream-Watershed Delineation Based on Digital Terrain Data

Hutchinson (1989) presented an interpolation algorithm to determine the DEM from elevation data points and stream lines. This algorithm produces DEM's that are consistent with the stream lines and has proven to produce more accurate DEM's than the ones obtained with previous methodologies. Jensen and domingue (1988) and Jensen (1991) presented a grid scheme to delineate watershed boundaries and stream networks to defined outfalls(pour points). The scheme uses digital elevation data to determine the hypothetical direction of flow from each cell in a grid to one of its eight neighboring cells. The cells contributing flow to the pour point can be counted, representing area, and the cells having no contributing flow define drainage boundaries . cells having a flow accumulation in excess of a threshold establish stream network cells. Tarboton et al. (1991) computed stream slopes and stream lengths using a similar grid system. In addition, the authors proposed criteria for proper selection of the threshold based on statistical properties of the terrain. Jones et al. (1990) employed a triangulation scheme on digital elevation data to determine watershed boundaries and flow paths. Procedures for delineating streams and watersheds from DEM's, as well as for correcting DEM's depressions produced by data noise, can be found in maidment (1994), ESRI (1992), Garbrecht and Martz (1995 a, 1995 b) and Martz and Garbrecht (1992).

4.5.3) Runoff modeling using GIS and WMS

Grid-based GIS proved to be a suitable tool for hydrologic modeling, mainly because" raster systems have been used for digital image processing for decades and armature understanding and technology has been created for that task" (maidment 1992 a). the ESRI arc /INFO-GRID system and the united states army corps of engineers GRASS system use a grid data structure. Grid systems have proven to be ideal for modeling topographically driven flow, because a characteristic of this type of flow-directions do not depend on any time dependent variable. This characteristic is what makes topographically driven flow easily modeled in a grid environment and, consequently , grid systems include hydrologic functions as part of their capabilities. At present, hydrologic functions, available in GRID and GRASS, allow one to determine flow direction and drainage area at any location, stream networks, watershed delineation, etc. (maindment 1992).

WMS is a graphically based, comprehensive hydrologic modeling environment that is designed to take advantage of watershed data developed or stored in GIS. Although it is neither a complete GIS itself nor an extension created with GIS programming languages, it is capable of creating, reading, and writing GIS data layers using the shape file format.
The rainfall runoff mode in WMS is one of the most frequently used events in hydrology. It determines the runoff signal which leaves the watershed from the rainfall signal received by the basin. The catchment area has been divided into the numbers of divisions equal to the numbers of rain gauge station. A lump model is also developed using average rainfall of the catchment. In case of lump model, average rainfall is calculated. In order to estimate runoff from rainfall events, loss rate or infiltration parameters for the basin have to be calculated, which is a basic input for further rainfall runoff modeling. The infiltration capacity of the basin depends on the land use and soil property. Therefore the estimation of infiltration parameters or curve number of the basin must be made initially. An inverse model is formulated and solved for estimating the curve numbers for the lump and distributed models.

Maidment's (1993) talked about the importance of velocity time-invariance for existence of a unit hydrograph with a constant time base and relative shape. In Maidment's articles, from a constant velocity grid, a flow time grid is obtained and subsequently the time area diagram and the isochrone curves are determined. The watershed response is calculated as the sum of the responses of each individual grid-cell, which is determined as a combined process of channel flow (translation process) followed by a linear reservoir routing . Although an approximate method, the the model shows a good fit for unit hydrograph of the severn watershed at plynlimon in wales.

Olivera et al.(1995) and Olivera and Maidment(1996) present a grid-based unsteady flow , linear approach that uses the diffusion wave method to model storm runoff and constituent transport. The routing from a certain location to the outlet is calculated be convolving the responses of the grid-cells of the drainage path. Sensitivity of the model results to the spatial resolution of the data has been addressed by Vieux (1993), who discusses how the grid-cell size affects the terrain slope and flow path length, and accordingly the surface runoff. Vieux and Needham(1993) conclude that increasing the cell size shortens the streams length and increases the sediment.

4.5.4) Floodplain Modeling

In the area of floodplain management, GIS offer the ideal environment for automating the water surface elevations in order to delineate floodplain. In 1993, the US corps of engineers has developed integration between HEC-2, a widely used floodplain determination package, and GRASS, software developed to work with raster. The integration package accesses HEC-2 output in tabular form, and converts it into GRASS format. Beavers (1994) performed a methodology connecting hydraulic modeling of river channels. A GIS based tools, named ARC/HEC2 developed to assist hydrologists in floodplain analysis. ARC/HEC2 consists of a compilation of ARC/info macro language scripts and C-programs used to pre- and post-process terrain and floodplain data used for the HEC-2 hydraulic model.

For floodplain determination, Tate et al. (1999) developed a straightforward approach for processing output of the HEC-RAS hydraulic model. HEC-RAS differs from HEC-2 model in that the capability to import and export GIS data was included in the program. They aimed to enable two and three-dimensional floodplain mapping and analysis in the Arc view geographic information system. A planimetric floodplain view is developed using digital orthophotography as a based map. A digital terrain model was synthesized from HEC-RAS cross sectional coordinate data and a digital elevation model.

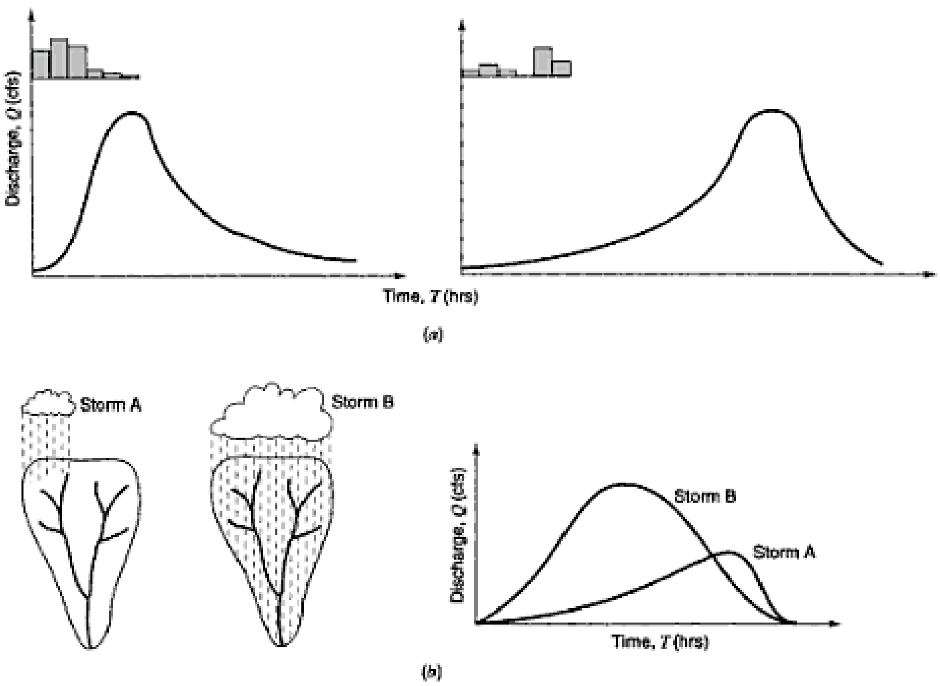
4.6) Factors affecting the watershed response

Many factors affect the watershed response. Watershed response is mostly depending upon the rainfall pattern, characteristics, and the geomorphologic features of the Wadi. In order to classify the watersheds according to its flood risk, the most important morphological features will be discussed.

4.6.1) Climatic factors

Climate is the average state of the atmosphere during a period of time. The climatic conditions are one of the master factors in hydrological response since they affect most components of the hydrologic cycle and supply energy and water to the watershed. Solar radiation is the primary external energy source driving the climate system. There are some other factors which can affect the earth's climate such as volcanic eruptions and human-induced changes. Climatic conditions affect the type of vegetation and land use in the watershed. These in turn have great effects on evaporation and evapotranspiration.

Climatic data such as temperature, humidity, solar radiation, and precipitation are also necessary for estimating water losses. The yield of watersheds is directly related to temperature. High temperatures increase water losses from the lakes which modify the amount and timing of runoff. Rainfall is the primary source of water supply. Its characteristics such as intensity, duration and frequency are important in determining the hydrologic response of watershed. Figure (4.7) illustrates the effects of storm shape, size and movement on runoff. Figure (4.8) illustrate the effect of rainfall intensity on the overland flow.



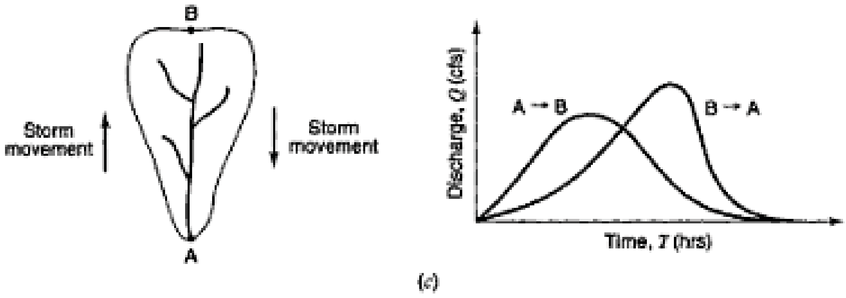


Figure (4.7) Effects of storm shape, and movement on surface runoff.(a) Effect of time variation of rainfall intensity on the surface runoff; (b) Effect of storm size on surface runoff; (c) Effect of storm movement on surface runoff (*Masch1984*)

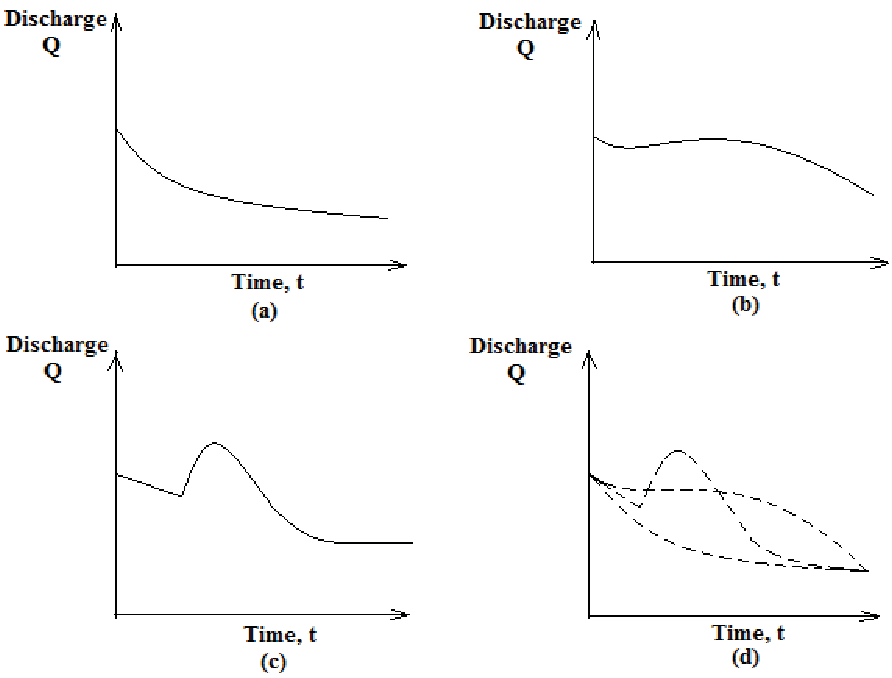


Figure (4.7) Hydrograph resulting from storms of different intensities. (a) Low intensity storms that result in no overland flow. (b) Low to medium intensity conditions. (c) High intensity conditions that results a pure overland flow. (d) Combination of all hydrographs component. (Viessman et. al. 1977)

4.6.2) Geometric and Geomorphological Factors

4.6.2.1) Area (A)

Drainage area is a very important watershed characteristic because it reflects the volume of water that can be generated by rainfall. Commonly in hydrologic design, a constant depth of rainfall is assumed. Accordingly, under this assumption the volume of runoff water would be the product of excess rainfall depth and the drainage area. The longer the time base of surface-runoff hydrograph result of the larger the drainage area. Thus, for the same rainfall excess, the peak discharge, expressed in units of volume per time per watershed area, will decrease with watershed size.

In general, a large watershed is one in which the storage effects, dominate the response. This storage makes the response of the catchment to the rainfall occur on a prolonged period. Consequently large watersheds are less sensitive to variation of rainfall duration and land use. On the other hand, small watersheds are controlled by overland flow, land use, slope, etc. They have a strong influence on the magnitude of the peak discharge. Thus the effects of storage are small and catchment is very sensitive to rainfall. However, the watershed area alone is not the only deciding factor. Two watersheds of the same size may behave quite differently. Also two watersheds could be similar in terms of hydrograph shape independent of the size of the watersheds.

4.6.2.2) Length (L)

The length of watershed is the second watershed characteristic of interest. The length of the watershed is important in hydrologic computations. The valley length is usually defined as the distance measured along the main channel from the watershed outlet to the basin divide. The watershed length is the maximum distance from the outlet point to the watershed divide. While the drainage area and length are both measure the watershed size, they may reflect different aspects of size. The drainage area is used to indicate the potential for rainfall to provide a volume of water. The length is usually used in computing a time parameters, which is a measure of the travel time of water through a watershed.

4.6.2.3) Shape

Watersheds have an infinite variety of shapes. Watershed shape is important for hydrologic similarity because it affects the magnitude and the time distribution of runoff reaching the outlet. A circular watershed whose drainage tributaries are compactly organized so that water from all parties of the watershed has a comparatively short distance to travel will discharge its runoff more quickly and reach greater flood peak than an elliptical watershed in which the larger part of the watershed is remote from the outlet (Langbein 1947). This means that an elliptical watershed will produce a smaller peak flood level than a circular one with the same area when all other conditions are similar. Figure (4.8) shows the effect of basin shape on surface runoff hydrograph shape.

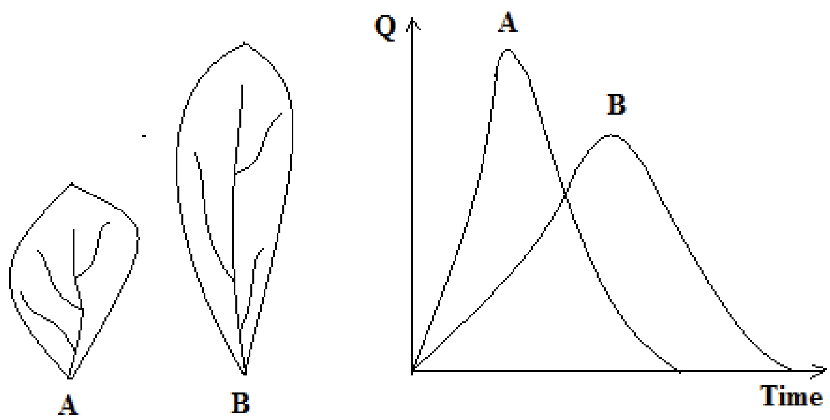


Figure (4.8) Effects of basin shape on surface runoff

A number of watershed parameters have been developed to reflect watershed shapes such as (McCuen 1989) :

1. Length to the center to of area, defined as the distance in mile measured along the main channel from the watershed outlet to the point on the main channel opposite the centroid of area.

2. Shape index I_{sh}

   $$I_{sh} = 1.27 \frac{A}{P^2}$$

   Where A is the watershed area and P is the watershed parameter.

3. Compactness coefficient F_c

   $$F_c = \frac{P}{(4\pi A)^{0.5}}$$

   Where P and A are the parameter and area of the watershed, respectively.

4. The circularity ratio R_c

   $$R_c = \frac{A}{A_0}$$

Where A_0 is the area of a circle having a parameter equal to the parameter of the watershed.(R_c) is always less than 1.

5. Elongation ratio R_e

The elongation ratio is defined as the diameter of a circle has the same area as the watershed area divided by the basin length which is the straight-line distance from the outlet point on the watershed divide, (Morisawa,1985). It can be given by equation (4.4)

$$R_e = \frac{2}{L_b}\left(\frac{A}{\pi}\right)^{0.5}$$

Where L_b is the maximum distance from the outlet point to the watershed in Km.

4.6.2.4) Stream order

Horton (1945) developed a method for classifying channels by order. Later Strahler (1952) proposed an ordering system. The classification methodology is as follows:

i. Channels that originate at a source are defined to be first order stream.

ii. When two streams of order i join, a stream of order i+1 is created.

iii. When two streams of different order join, the channel segment immediately downstream will have the higher order of the two combination streams.

Figure (4.9) shows an example of a Strahler ordering system for a fourth order watershed. The order of a channel network or drainage basin is that of its highest order stream. The order of a drainage basin provides a crude description of the topologic of a channel network. However the channel network is highly dependent on terrain resolution.

4.6.2.5) Drainage density and stream Frequency

One of the geomorphological characteristics of interest is a drainage density. Drainage density D is the ratio of the total length of streams within a watershed to the total area of the watershed (Horton 1945). Drainage density has units of inverse length, and it depends on the level of resolution of the stream network. Drainage density can be considered as a basic length scale, and it can be used to characterize the degree of drainage development within a watershed.

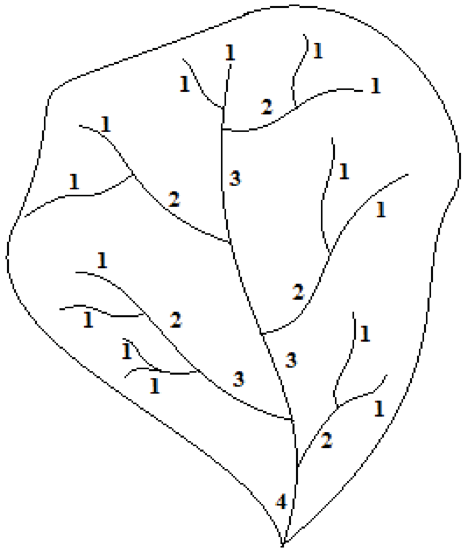


Figure (4.9) Example of Strahler ordering system

A high value of D indicates high density of streams and rapid storm response (Bras 1990). Drainage density is expressed by:

$$D = \frac{Slu}{A}$$

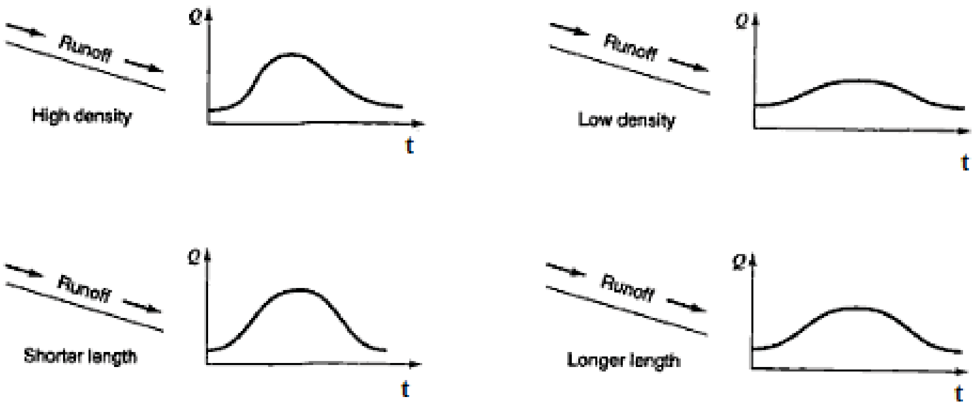
Where A is the area of the watershed, and Slu is the sum of stream length.

On the other hand, stream frequency F is defined as the number of streams per unit area (Horton 1932), and is expressed by :

$$F = \frac{SNu}{A}$$

Where A is the area of the watershed, and SNu is the sum of stream number.

Stream frequency is a scale, or resolution dependant quantity. Note that the drainage density and stream frequency are independent on drainage size,, thus they can be used as a comparison between two stream networks. Watersheds which have similar values of drainage density and stream frequency are more likely to have similar response. Figure (4.10) shows the effect of drainage density on surface runoff.



Figure(4.10) Effect of drainage density and channel length on surface runoff (Masch 1984)

4.6.2.6) Length of overland flow (L_o)

Length of overland flow (L_o) is the distance that water should cover on the land before it can reach a stream of the studied watershed. The average length of overland flow is given approximately by:

$$L_o = \frac{1}{2D}$$

Where D is the drainage density.

4.6.2.7) Stream Morphology Ratio

Horton (1945) developed some quantitative expressions of channel network which are the bifurcation ratio R_B , and length ratio R_L. Latter, schuumm (1956) developed the area ratio R_A . These streams ration are defined before in Runoff Estimation Methods and repeated here for convenient refrence by the following equations:

$R_B = \frac{N_{\omega-1}}{N_\omega}$ Where: N_ω = Number of streams of order ω in a network

$R_A = \frac{A_\omega}{N_{\omega-1}}$ Where: A_ω= mean area drained by a stream of order ω.

$R_L = \frac{L_\omega}{L_{\omega-1}}$ Where: L_ω = mean length of streams of order ω.

Weighted mean of bifurcation Ratio (WMBR) which is more accurate in representing the bifurcation ratio is given by multiplying the bifurcation ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values.

4.6.2.8) Relief

The relief is the elevation difference between reference points. Maximum watershed relief is the elevation difference between watershed outlet and the highest point on the watershed perimeter. Watershed relief is indicative of the potential energy of a drainage system present by virtue of elevation above a given datum. The internal relief, E is given by the difference between elevation of 10% of the watershed length from the source and 15% of watershed length from the outlet. Several parameters have been developed to reflect the watershed relief. For instance the relief ratio (R_r) is given by:

$$R_r = \frac{R}{L_B}$$

Where L_B is the watershed length which is the maximum distance from the outlet point to the watershed divide in Km.

Slope is also an important factor in the momentum. Both watershed and channel slope may be of interest. Watershed slope reflects the rate of change of elevation with respect to distance along the principal flow path. For instance the Watershed slope (S_l) is given by:

$$S_l = \frac{E}{0.75\ VL}$$

Where VL is the valley length which is the length of the main stream from the edge of the watershed to the outlet of the watershed in Km.

4.6.2.9) Sinuosity (S_i)

Sinuosity is a measure of channel curvature, usually quantified as the ratio of the length of the channel compared to the length of a straight line along the valley axis. A decrease in sinuosity as a result of channel straightening increases channel slope, leads to changes in water and sediment discharge, and triggers morphological channel adjustments are difficult to evaluate a priori. However, it is known that sinuosity is directly related to channel stability, therefore, a reduction in sinuosity is likely to decrease channel stability (Blench, 1986). Sinuosity is given by:

$$S_i = \frac{VL}{L_B}$$

Where VL is the length of the channel and L_B is the length of a straight line along the valley axis.

4.6.2.10) Ruggedness (R_a)

Ruggedness number is a combined measure of relief and stream density. As topography becomes more convoluted, the ruggedness number increases. The Ruggedness number (R_a) could be given by:

$$R_a = R.D$$

Where R is the watershed relief and D is the drainage density.

4.6.2.11) Texture ratio (R_t)

Texture ratio is an expression of the relative channel spacing in fluvial dissected terrain. As fine drainage texture to well drained basin and coarse drainage texture leads to poorly drained basin. Texture ratio is given approximately by the following equation:

$$R_t = \frac{\sum_{\omega=1}^{\omega=n} N_\omega}{P}$$

Where N_ω is the number of streams order ω, and P is the watershed perimeter.

Chapter 5

Modeling application of the Study area