

**Sudan University of Science and Technology**  
**College of Graduate Studies**



A Thesis Submitted To the Admission of the Degree Of  
Master of Science in Engineering Surveying  
(Geographic Information Systems and Remote Sensing)

**MINIMIZATION OF FLASH FLOODS WATER  
USING GIS BASED WATER HARVESTING**

تقليل أثر السيول باستخدام حصاد المياه المبني  
على نظم المعلومات الجغرافية

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## **ABSTRACT**

In the last few years devastating flash floods descending downstream through valleys have occurred in East Nile Locality-Sudan. A flash flood can be caused by intense rain, particularly when it takes place in a saturated area where rain has previously fallen. Under these conditions the additional rain runs off over the surface and accumulates in streams and channels at a much accelerated pace. Runoff is the one of the components consists of water cycle and useful water resources to stand human life. The aim of this research is to estimate analysis and predict the runoff to make stable water use and flood control by water harvesting projects. Soba Valley (East Nile Locality-Sudan) has been selected as study area. To achieve this aim the various raster and feature class data had been used for computing Hydrologic parameters. For estimating runoff, Soil Conservation Service method had been adopted to calculating water Transformation and losses and Muskingum method has been chosen to calculate flood routing. The runoff model had been created and the annual runoff for streams has been calculated. The simulated runoff values can be used for flood control and flood damage estimation studies in the future. Then dam's location had been selected to minimization flash flood risk according to runoff volume, soil type and topography. A model builder had been designed to repeat the steps of the processes and analysis automatically in a quick manner to save time for the study of any other similar areas. General impact for selected dam on residential and agricultural areas had been identified to compare the proposed dams' alternatives.

## المستخلص

في السنوات القليلة الماضية هنالك سيول مدمرة قدمت من مصب الوديان الواقعه في محلية شرق النيل، ولاية الخرطوم - السودان. سبب هذه السيول هو الامطار الغزيرة وانحدار الارض من الشرق الى الغرب في اتجاه النيل الازرق ، عندما تهطل الامطار بصورة متكرره تتشبع الارض فيؤدي هذا الى حدوث الجريان السطحي للمياه، ويتراكم في الوديان الطبيعيه بوتيرة متسارعة ، الجريان السطحي هو أحد مكونات دورة المياه ، ويعتبر مصدر مهم لموارد المياه. الهدف من هذه الدراسة هو التقدير والتحليل والتنبؤ بكمية المياه الجارية لجعل استخدامها مستمرا ، والسيطرة على الفيضانات بمشاريع حصاد المياه. لقد تم اختيار وادي سوبا (محلية شرق النيل-ولاية الخرطوم) كمنطقة دراسة . للوصول الى الهدف من هذه الدراسة استخدم نموذج الارتفاعات الرقمي والبيانات الخطية لحساب الثوابت الهيدرولوجية. ولحساب الجريان السطحي استخدمت طريقة خدمة حفظ التربة (SCS) لحساب تنقل وفواقد المياه ، وتم اختيار طريقة التدفق (Muskingum) لحساب تتبع الفيضان من نقطه الى اخرى. وقد تم إنشاء نموذج للجريان السطحي وتم حساب الجريان السطحي السنوي للوديان. قيم الجريان الناتجة من المحاكاة يمكن أن تستخدم للسيطرة على الفيضانات ودراسة تقييم الأضرار الناجمة عن الفيضانات في المستقبل. ثم تم اختيار مواقع السدود بناء على حجم الجريان ، الميلان واستخدامات الاراضي. . وقد تم تصميم وبناء نموذج لتكرار خطوات العمليات وتحليلها تلقائيا بطريقة سريعة لتوفير الوقت لدراسة أي مجال من المجالات الأخرى المماثلة. الاثار العامه الناتجه من اختيار موقع السد تم توضيحها على المناطق السكنيه والزراعيه للمفاضلة بين السدود المقترحه.

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## **LIST OF ABBREVIATIONS**

|                   |  |
|-------------------|--|
| <b>DEM</b>        | Digital Elevation Model  |
| <b>GIS</b>        | Geographic Information Systems   |
| <b>HEC-GEOHMS</b> | Hydrologic Engineering Center's - Geospatial Hydrologic<br>Modeling System |
| <b>HMS</b>        | Hydrologic Modeling System   |
| <b>SRTM</b>       | Shuttle Radar Topography Mission   |
| <b>SCS</b>        | Soil Conservation Service  |
| <b>USGS</b>       | United States Geological Survey  |
| <b>WGS</b>        | World Geodetic System  |



# CHAPTER ONE

## INTRODUCTION

### 1.1 General Overview:

Water is one of the main requirements for healthy plant growth. Most arid and semi-arid regions, however, suffer from insufficient and unreliable rainfall. In these areas a high rate of evaporation in the growing season is also common. When it rains in (semi-) arid areas, the rain- storms are usually heavy. The prevailing soils generally cannot absorb the amount of the water which falls in such a short time. As a result, rain- fall in (semi-)arid areas is often accompanied by a large amount of surface runoff.

Most techniques for water collection make use of large water sources such as rivers and ground water (e.g. wells and irrigation systems), and require large-scale investments. But in many countries in the world small-scale, simple methods have been developed to collect surface runoff for productive purposes. Instead of runoff being left to cause hazards, it is harvested and utilized. Many types of water harvesting techniques with many different applications are available.

Water harvesting can be defined as the collection of runoff for its productive use. Runoff may be collected from ground surfaces as well as from seasonal streams. Water harvesting systems which harvest runoff from ground surfaces fall under the term of rainwater harvesting, while all systems which collect runoff from seasonal streams are grouped under the term of flood water harvesting. (Anschütz et al. 1997)

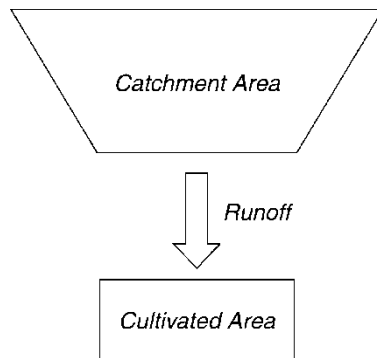


Figure 1.1 Principle of water harvesting for plant production (Critchley 1991)

## 1.2 Problem Statements:

### 1.2.1 Flash floods negative impacts

In the few last year's devastating flash floods descending downstream through valleys have occurred in the study area. Flash flood is, in short, a sudden local flood of great volume and short duration which follows within a few (usually less than six) hours of heavy or excessive rainfall. A flash flood can be caused by intense rain, particularly when it takes place in a saturated area where rain has previously fallen. Under these conditions the additional rain runs off over the surface and accumulates in streams and channels at a much accelerated pace. Heavy rains, most frequently connected with convection clouds, cover small regions and are short-lived (from a few minutes to a few hours), but very intense such as 100 mm (or 100 Liters per square meter) in the span of an hour or more. Violent rainfall causing flash floods can be accompanied by strong winds. They can also appear locally in a large area covered by rainfall. In summary there are various factors contributing to flash flood risk, some being influenced by human intervention and others entirely rather independent from human action. The phenomenon of the flash flood is one of the most difficult natural hazards to predict in terms of time and place of occurrence. As a result, it is challenging for the concerned authorities and communities to respond appropriately and response plans are essential tools. Records of loss of life and damage caused by flash floods worldwide show that these have continued to rise steadily during recent years. Clearly, the response has been to call for increased efforts to protect life and property.( Eltaib et al. 2011)



## Negative impacts on:-

- **residential areas :-**

Housing, schools, hospitals and public facilities etc. are affected by the flash floods, causing loss of properties, lives and the displacement of the population that impacts negatively social, health, economic and psychological aspects among residents of the area.

- PRE-FLOOD Khartoum June 7<sup>th</sup> 2013 - Source: Digital Globe Satellite Imagery



Figure 1.2 Pre-Flood Khartoum June 7th 2013

- FLASH FLOODING Khartoum August 11th 2013- Source: Digital Globe Satellite Imagery



Figure 1.3 Flash Flooding Khartoum August 11th 2013

- **Highways and roads:-**

Severe effects are caused to the road layers that lead to collapse of surface layer (asphalt layer) and washing away several meters of the road, disabling the transportation system (i.e. residents and commercial transportation).



Figure 1.4 Washed away Highways

- **Environmental:-**

Stagnant waters left after the floods form shallow ponds within and around the residential areas, mixed with pit latrines waste water and garbage dumps infusion; flood water becomes a good environment for breeding of mosquitoes, flies and microbes that cause diseases and like malaria, typhoid, schistosomiasis, cholera etc. (Figure 1.5)



Figure 1.5 Water mixed with garbage dumps infusion

- **Agricultural areas:-**

The infrastructure of Irrigation schemes and farms such as canals, hydraulic structures, pumping stations and cultivable fields are damaged.

- **Grazing land and soil:-**

Grazing routes are interrupted as well as lead to animal deaths.

Soil degradation may also be caused within steep streams.

Therefore to reduce the above mentioned consequences reviewing the technical side of the problems makes it an absolute necessity to conduct water harvesting multipurpose environment friendly projects study for the natural drainage system that causes the catastrophe.

## **1.3 Previous Studies:**

### **1.3.1 Flash Flood and Runoff:**

- A research was conducted in Umdawanban area which is within the study area and the following was resulted (Eltaib et al. 2011):-
  1. Flash Flood hazard is destructive and frequently occurring phenomenon in the study area. Due to lack of proper warning information about the flash flood hazard to the people living in the flash flood prone area is not communicated effectively. Due to which affecters receive more damages. Due to severe lack of land use planning in the study area.

2. The potential benefits of GIS expert systems for natural disaster mitigation are three fold: First, it allows for an optimized, cost-effective mitigation strategy. Second, it allows for the identification of very rare but potentially extremely disastrous hazards, by providing an avenue for specialized research to enter the decision process. Third, if implemented in a standardized way in many regions, it allows investors to compare risks, and to minimize their own exposure. This is an important economical factor, since a safer country attracts investments and decreases the interest rate which in turn stimulates more mitigation, in a positive feedback loop.
  3. Satellite data, utilized in the study, were visually and digitally processed and interpreted. The geomorphological hazards with reference to floods have been assessed. The study showed that an area extends as a belt along Umdawanban Villages is subject to flash floods risk. Water in rainy season's flows from the north east towards the Blue Nile incorporating flood at Umdawanban Villages. Major Landuse such as settlements, cultivation, and other buildings were constructed at the flood prone areas, which are classified as environmentally risk areas.
  4. It were also conclude that intensive utilization of GIS and RS augmented with other environmental data will help in producing and update risk maps. Those maps could help in producing a sound rescue map for the area that definitely at risk. Some of the areas classified as high-risk areas could be treated according to priority. Monitoring of environmental hazards in the area is essential, as the severe destruction could be expected during every rainy season.
  5. Either the existing system of bridges duties needs to be made to work more effectively or it needs to be replaced. The Government should explore the practicality, costs and benefits of pursuing both courses of action. Work should begin as soon as possible.
- Another research was conducted by Remote Sensing Authority - NCR Khartoum- Sudan and the following maps were produced (Hamid et al. 2013):

- Lengths of some valleys exceed 70 km, therefore, such valleys are expected to carry huge amount of water in a destructive manner.

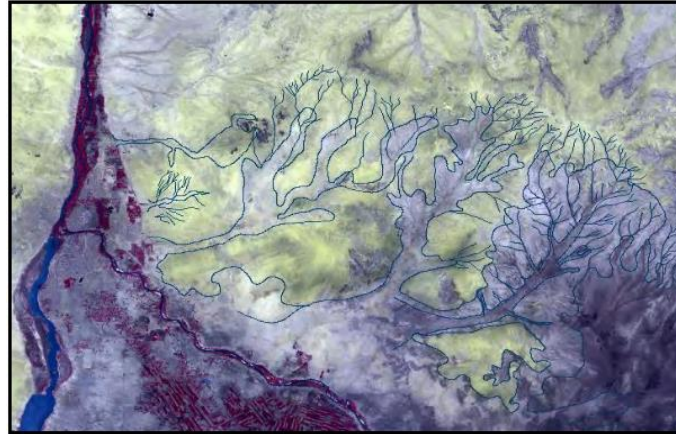


Figure 1.6 Areas and lengths of the Valleys

- Most of the Valleys end up in Deltas. No distinct water courses reach the Nile.



Figure 1.7 1972 Landsat image of the region



- construction of houses and Roads on the drainage lines

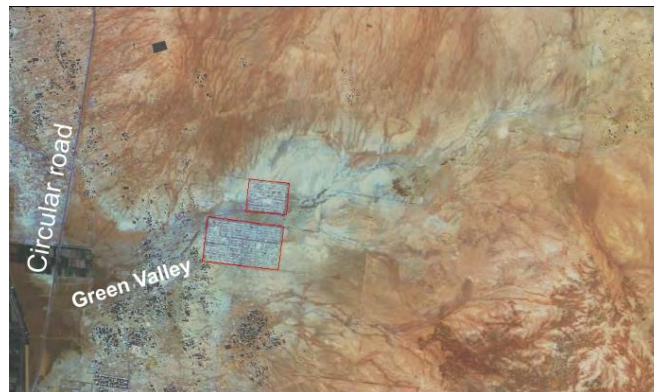


Figure 1.8 Fomosat 8 August 2013-Green Valley

### 1.3.2 DAM Site Selection:

- (Sanyal & Lu 2004)) On the application of Remote Sensing in flood management noted that DEM model is the main part of flood hazard mapping. In particular, slopes data from DEM are useful for many hydrological studies and can be employed for dam location selection. Furthermore, a limited effort has been devoted in recent years to determine the capability of these techniques in assisting engineering dam design by allowing efficient, quick and economic data collection. However, the application of remote sensing in ephemeral streams is limited compared with permanent rivers.
- (Kumar 2009) used remote sensing and GIS techniques to assign the location of small water harvesting structures across streams/watersheds. Various thematic layers such as Landuse/Landcover, geomorphology and lineaments were used. These layers along with geology and drainage were integrated using GIS techniques to derive suitable water harvesting sites. In addition to the suitable site selection of the dams, they calculated the storage and transmittance of groundwater in the study area.
- (Youssef et al. 2014) furthermore, proposed three dam site locations for Jeddah City in Saudi Arabia based on topographical analysis using different

data sets such as topographic maps, remote sensing images, a digital elevation model with 90-m resolution (STRM 2000) and geological map. In addition, these selected locations were in the outlet areas where large tracts of land could be temporarily inundated by water as a result of water being held back by the proposed dam.

## **1.4 Thesis Objectives:**

This thesis aim to:

➤ General Objectives:-

- Deriving options for Minimizing the damage and utilizing flood waters by allocating water harvesting projects.

➤ Specific Objectives:-

- Identification of The Catchment Areas.
- Development Runoff Model.
- Estimation of Annual Runoff for Streams In The Study Area.
- Suitable Site for Water Harvesting Projects (Locations Map).
- General Impacts for Water Harvesting Projects.

## **1.5 Thesis layout:**

This thesis consists of six chapters, Chapter one contains an introduction. Chapter two explains floods (definition, principal types, causes, effects and benefits) and Water harvesting. Chapter three GIS Applications in Hydrology, HEC-geo HMS, HMS and Water harvesting Chapter four illustrate the Methodology, steps of runoff model and proposed water harvesting projects (location map). Chapter five present results and analysis finally, conclusion and recommendations statein Chapter six.

## CHAPTER TWO

### FLOODS AND WATER HARVESTING

This chapter explains floods (definition, principal types, causes, effects and benefits) and Water harvesting.

#### 2.1 Flood

The following explains floods (definition, principal types, causes, effects and benefits)

##### 2.1.1 Overview:

A flood is an overflow of water that submerges land which is usually dry. The European Union (EU) Floods Directive defines a flood as a covering by water of land not normally covered by water.(James M. Wright 2007) In the sense of "flowing water", the word may also be applied to the inflow of the tide.

Flooding may occur as an overflow of water from water bodies, such as a river or lake, in which the water overtops or breaks levees, resulting in some of that water escaping its usual boundaries, or it may occur due to an accumulation of rainwater on saturated ground in an areal flood. While the size of a lake or other body of water will vary with seasonal changes in precipitation and snow melt, these changes in size are unlikely to be plains of rivers. While riverine flood damage can be eliminated by moving away from rivers and other bodies of water, people have traditionally lived and worked by rivers because the land is usually flat and fertile and because rivers provide easy travel and access to commerce and industry.

Some floods develop slowly, while others such as flash floods, can develop in just a few minutes and without visible signs of rain. Additionally, floods can be local, impacting a neighbourhood or community, or very large, affecting entire river basins.



## 2.1.2 Principal types:

There are several different types of floods. Most communities experience only a few of them. Floods are generally grouped into the following types as shown in (figure 2.1);

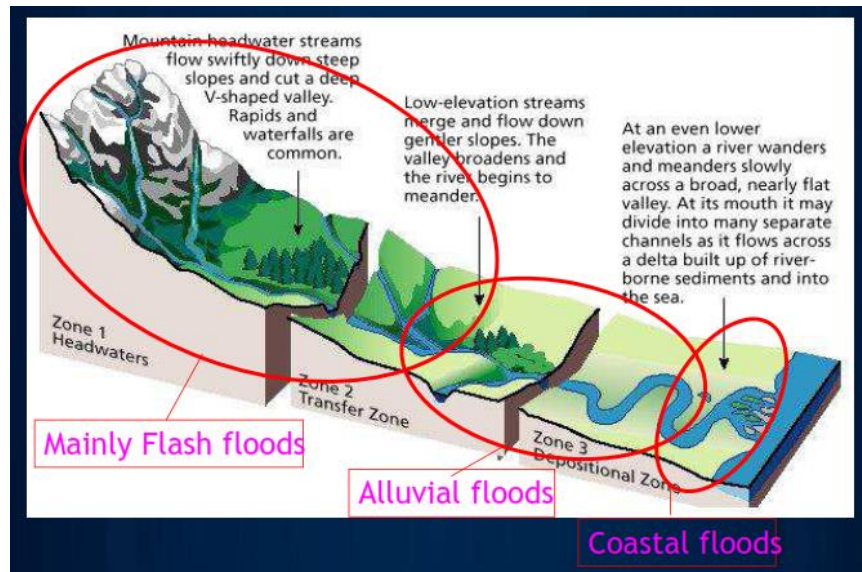


Figure 2.1 Flood Types (Y Paithankar 2013)

### 2.1.2.1 Areal

Floods can happen on flat or low-lying areas when water is supplied by rainfall or snowmelt more rapidly than it can either infiltrate or run off. The excess accumulates in place, sometimes to hazardous depths. Surface soil can become saturated, which effectively stops infiltration, where the water table is shallow, such as a floodplain, or from intense rain from one or a series of storms. Infiltration also is slow to negligible through frozen ground, rock, concrete, paving, or roofs. Areal flooding begins in flat areas like floodplains and in local depressions not connected to a stream channel, because the velocity of overland flow depends on the surface slope. basins may experience areal flooding during periods when precipitation exceeds evaporation.(James M. Wright 2007)

### 2.1.2.2 Riverine (Channel)

Floods occur in all types of river and stream channels, from the smallest ephemeral streams in humid zones to normally-dry channels in arid climates to the world's

largest rivers. When overland flow occurs on tilled fields, it can result in a muddy flood where sediments are picked and carried as suspended matter or bed load. Localized flooding may be caused or exacerbated by drainage obstructions such as landslides, ice, debris, or beaver dams.

Slow-rising floods most commonly occur in large rivers with large catchment areas. The increase in flow may be the result of sustained rainfall, rapid snow melt, monsoons, or tropical cyclones. However, large rivers may have rapid flooding events in areas with dry climate, since they may have large basins but small river channels and rainfall can be very intense in smaller areas of those basins.

Rapid flooding events, including flash floods, more often occur on smaller rivers, rivers with steep valleys, rivers that flow for much of their length over impermeable terrain, or normally-dry channels. The cause may be localized convective precipitation (intense thunderstorms) or sudden release from an upstream impoundment created behind a dam, landslide, or glacier. In one instance, a flash flood killed 8 people enjoying the water on a Sunday afternoon at a popular waterfall in a narrow canyon. Without any observed rainfall, the flow rate increased from about 50 to 1,500 cubic feet per second (1.4 to 42 m<sup>3</sup>/s) in just one minute. (James M. Wright 2007) Two larger floods occurred at the same site within a week, but no one was at the waterfall on those days. The deadly flood resulted from a thunderstorm over part of the drainage basin, where steep, bare rock slopes are common and the thin soil was already saturated.

Flash floods are the most common flood type in normally-dry channels in arid zones, known as arroyos in the southwest United States and many other names elsewhere. In that setting, the first flood water to arrive is depleted as it wets the sandy stream bed. The leading edge of the flood thus advances more slowly than later and higher flows. As a result, the rising limb of the hydrograph becomes ever quicker as the flood moves downstream, until the flow rate is so great that the depletion by wetting soil becomes insignificant.

### **2.1.2.3 Flash Flood**

These are related to rivers in inland areas and can occur within a short period of excessive rainfall or a dam or levee failure or dam spills or a sudden release of water.

Flash floods are normally identified by their sudden rise in water levels followed by rapid decrease causing high flow velocities that can be very destructive especially in densely populated areas. Flash floods are very unpredictable and move with an unusual strong current carrying high volume of rubbles, sediments and dust and causing destruction/devastation to communities and infrastructures that stand along its path.

#### **2.1.2.4 Estuarine and coastal**

Flooding in estuaries is commonly caused by a combination of sea tidal surges caused by winds and low barometric pressure, and they may be exacerbated by high upstream river flow.

Coastal areas may be flooded by storm events at sea, resulting in waves over-topping defences or in severe cases by tsunami or tropical cyclones. A storm surge, from either a tropical cyclone or an extra tropical cyclone, falls within this category. Research from the NHC (National Hurricane Center) explains: "Storm surge is an abnormal rise of water generated by a storm, over and above the predicted astronomical tides. Storm surge should not be confused with storm tide, which is defined as the water level rise due to the combination of storm surge and the astronomical tide. This rise in water level can cause extreme flooding in coastal areas particularly when storm surge coincides with normal high tide, resulting in storm tides reaching up to 20 feet or more in some cases."(James M. Wright 2007)

#### **2.1.2.5 Urban flooding**

Urban flooding is the inundation of land or property in a built environment, particularly in more densely populated areas, caused by rainfall overwhelming the capacity of drainage systems, such as storm sewers. Although sometimes triggered by events such as flash flooding or snowmelt, urban flooding is a condition, characterized by its repetitive and systemic impacts on communities, that can happen regardless of whether or not affected communities are located within designated floodplains or near any body of water.(James M. Wright 2007) Aside from potential overflow of rivers and lakes, snowmelt, storm water or water released from damaged water mains may accumulate on property and in public rights-of-way, seep

through building walls and floors, or backup into buildings through sewer pipes, toilets and sinks.

In urban areas, flood effects can be exacerbated by existing paved streets and roads, which increase the speed of flowing water.

The flood flow in urbanized areas constitutes a hazard to both the population and infrastructure

#### **2.1.2.6 Catastrophic**

Catastrophic flooding is usually associated with major infrastructure failures such as the collapse of a dam, but they may also be caused by drainage channel modification from a landslide, earthquake or volcanic eruption. Examples include outburst floods and lahars.

### **2.1.3 CAUSES:**

#### **2.1.3.1 Upslope factors**

The amount, location, and timing of water reaching a drainage channel from natural precipitation and controlled or uncontrolled reservoir releases determines the flow at downstream locations. Some precipitation evaporates, some slowly percolates through soil, some may be temporarily sequestered as snow or ice, and some may produce rapid runoff from surfaces including rock, pavement, roofs, and saturated or frozen ground. The fraction of incident precipitation promptly reaching a drainage channel has been observed from nil for light rain on dry, level ground to as high as 170 percent for warm rain on accumulated snow.(James M. Wright 2007)

Most precipitation records are based on a measured depth of water received within a fixed time interval. Frequency of a precipitation threshold of interest may be determined from the number of measurements exceeding that threshold value within the total time period for which observations are available. Individual data points are converted to intensity by dividing each measured depth by the period of time between observations. This intensity will be less than the actual peak intensity if the duration of the rainfall event was less than the fixed time interval for which measurements are reported. Convective precipitation events (thunderstorms) tend to

produce shorter duration storm events than orographic precipitation. Duration, intensity, and frequency of rainfall events are important to flood prediction. Short duration precipitation is more significant to flooding within small drainage basins.(James M. Wright 2007)

The most important upslope factor in determining flood magnitude is the land area of the watershed upstream of the area of interest. Rainfall intensity is the second most important factor for watersheds of less than approximately 30 square miles or 80 square kilometers. The main channel slope is the second most important factor for larger watersheds. Channel slope and rainfall intensity become the third most important factors for small and large watersheds, respectively.(Territory & Flood 2005)

Time of Concentration is the time required for runoff from the most distant point of the upstream drainage area to reach the point of the drainage channel controlling flooding of the area of interest. The time of concentration defines the critical duration of peak rainfall for the area of interest. The critical duration of intense rainfall might be only a few minutes for roof and parking lot drainage structures, while cumulative rainfall over several days would be critical for river basins.

### **2.1.3.2 Downslope factors**

Water flowing downhill ultimately encounters downstream conditions slowing movement. The final limitation is often the ocean or a natural or artificial lake. Elevation changes such as tidal fluctuations are significant determinants of coastal and estuarine flooding. Less predictable events like tsunamis and storm surges may also cause elevation changes in large bodies of water. Elevation of flowing water is controlled by the geometry of the flow channel.(James M. Wright 2007) Flow channel restrictions like bridges and canyons tend to control water elevation above the restriction. The actual control point for any given reach of the drainage may change with changing water elevation, so a closer point may control for lower water levels until a more distant point controls at higher water levels.

Effective flood channel geometry may be changed by growth of vegetation, accumulation of ice or debris, or construction of bridges, buildings, or levees within the flood channel (Maidment, David R 2002).

### **2.1.3.3 Coincidence**

Extreme flood events often result from coincidence such as unusually intense, warm rainfall melting heavy snow pack, producing channel obstructions from floating ice, and releasing small impoundments like beaver dams. Coincident events may cause extensive flooding to be more frequent than anticipated from simplistic statistical prediction models considering only precipitation runoff flowing within unobstructed drainage channels. Debris modification of channel geometry is common when heavy flows move uprooted woody vegetation and flood-damaged structures and vehicles, including boats and railway equipment.

Some researchers have mentioned the storage effect in urban areas with transportation corridors created by cut and fill. Culvert fills may be converted to impoundments if the culverts become blocked by debris, and flow may be diverted along streets. Several studies have looked into the flow patterns and redistribution in streets during storm events and the implication on flood modelling.(James M. Wright 2007)

## **2.1.4 EFFECTS:**

### **2.1.4.1 Primary effects**

The primary effects of flooding include loss of life, damage to buildings and other structures, including bridges, sewerage systems, roadways, and canals.

Floods also frequently damage power transmission and sometimes power generation, which then has knock-on effects caused by the loss of power. This includes loss of drinking water and water supply, which may result in loss of drinking water or severe water contamination. It may also cause the loss of sewage disposal facilities. Lack of clean water combined with human sewage in the flood waters raises the risk of diseases, which can include typhoid, giardia, cryptosporidium, cholera and many other diseases depending upon the location of the flood.

Damage to roads and transport infrastructure may make it difficult to mobilize aid to those affected or to provide emergency health treatment.

Flood waters typically inundate farm land, making the land unworkable and preventing crops from being planted or harvested, which can lead to shortages of food

both for humans and farm animals. Entire harvests for a country can be lost in extreme flood circumstances. Some tree species may not survive prolonged flooding of their root systems (James M. Wright 2007)

#### **2.1.4.2 Secondary and long-term effects**

Economic hardship due to a temporary decline in tourism, rebuilding costs, or food shortages leading to price increases is a common after-effect of severe flooding. The impact on those affected may cause psychological damage to those affected, in particular where deaths, serious injuries and loss of property occur.

Urban flooding can lead to chronically wet houses, which are linked to an increase in respiratory problems and other illnesses. Urban flooding also has significant economic implications for affected neighbourhoods. In the United States, industry experts estimate that wet basements can lower property values by 10-25 percent and are cited among the top reasons for not purchasing a home. According to the U.S. Federal Emergency Management Agency (FEMA), almost 40 percent of small businesses never reopen their doors following a flooding disaster. In the United States, insurance is available against flood damage to both homes and businesses.(James M. Wright 2007)

#### **2.1.5 BENEFITS:**

Floods (in particular more frequent or smaller floods) can also bring many benefits, such as recharging ground water, making soil more fertile and increasing nutrients in some soils. Flood waters provide much needed water resources in arid and semi-arid regions where precipitation can be very unevenly distributed throughout the year and kills pests in the farming land. Freshwater floods particularly play an important role in maintaining ecosystems in river corridors and are a key factor in maintaining floodplain biodiversity. Flooding can spread nutrients to lakes and rivers, which can lead to increased biomass and improved fisheries for a few years.

For some fish species, an inundated floodplain may form a highly suitable location for spawning with few predators and enhanced levels of nutrients or food. Fish, such

as the weather, make use of floods in order to reach new habitats. Bird populations may also profit from the boost in food production caused by flooding.(James M. Wright 2007)

## **2.2 Water harvesting:**

Water harvesting has been defined and classified in a number of ways by various authors over the years. The large majority of definitions are closely related. The following discuss the definition, aim, Conditions, techniques of water harvesting and transect of water harvesting through history.

### **2.2.1 Definition of water harvesting:**

Water harvesting is defined as “The collection and management of floodwater or rainwater runoff to increase water availability for domestic and agricultural use as well as ecosystem sustenance”. (Rima & Hanspeter 2013)

### **2.2.2 Aim of water harvesting:**

The aim of water harvesting is to collect runoff from areas of surplus or where it is not used, in addition it can be used as an efficient tool to suppress the flash floods impacts; storing water and making it available, where and when there is shortage. This results in an increase in water availability by either (a) impeding and trapping surface runoff, and (b) maximizing water runoff storage. Water harvesting makes more water available for domestic, livestock and agricultural use by buffering and bridging drought spells and dry seasons through storage. (Rima & Hanspeter 2013)

### **2.2.3 A transect of water harvesting through history:**

Water harvesting has been used in India, the Middle East, the Americas and Africa throughout history, and was the backbone of agriculture especially in arid and semi-arid areas worldwide. Some of the very earliest agriculture, in the Middle East, was based on techniques such as diversion of wadi flow onto agricultural fields. In India, water harvesting is an ancient technique dating back some 4,000 to 5,000 years. In North America the agriculture of many indigenous peoples in what are now the



southern states was historically dependent on simple methods of flood water harvesting.

In the early 20th century, the primary focus of conservation agencies was soil erosion control aimed at reducing soil losses; this progressed to soil and water conservation, based particularly on structural measures (terraces; gabion weirs etc.).

The harvesting of runoff that went with some soil conservation measures was more or less a side-effect whose potential was unappreciated. Furthermore, the success of the green revolution, based on hybrid seeds, inorganic fertilizers and pesticides, resulted in a rapid expansion of irrigated areas – and this was seen as the "modern" way forward to improving agricultural water management. However, this expansion soon reached its limits due to over-abstraction, declining water resources and salinization, which led to further impoverishment and in some situations to conflicts.

Furthermore the ecological problems associated with dam building became barriers to new construction. Water scarcity and the widespread droughts in Africa led to a growing awareness of the potential of water harvesting for improved crop production in the 1970s. After a quieter period in the late 1980s, water harvesting Again became the subject of study and project implementation at the turn of the century, and indigenous practices regained credence. In China today, Water harvesting is seen as a major component in reducing the rural exodus and controlling severe soil erosion and is subject of dedicated projects, aimed at helping millions of people. (Hudson, N.W. 1987)

#### **2.2.4 Conditions for water harvesting:**

- **Climates**

Water harvesting is particularly suitable for semi-arid regions (300-700 mm average annual rainfall). It is also practiced in some arid areas (100-300 mm average annual rainfall). These are mainly subtropical winter rainfall areas, such as parts of North Africa. In most tropical regions the main rainfall period occurs in the 'summer' period, when evaporation rates are high. In more arid tropical regions the risk of crop failure is considerably higher. The costs of the water harvesting structures here are also higher because these have to be made larger.(Anschütz et al. 1997)

- **Slopes**

Water harvesting is not recommended on slopes exceeding 5% because of the uneven distribution of runoff, soil erosion and high costs of the structure required.

- **Soils and soil fertility management**

Soils in the cultivated area should be deep enough to allow sufficient moisture storage capacity and be fertile. Soils in the catchment area should have a low infiltration rate. For most water harvesting systems soil fertility must be improved, or at least maintained, in order to be productive and sustainable. The improved water availability and higher yields derived from water harvesting lead to a greater exploitation of soil nutrients. Sandy soils do not benefit from extra water unless measures to improve soil fertility are applied at the same time. (Anschütz et al. 1997)

- **Crops**

One of the main criteria for the selection of a water harvesting technique is its suitability for the type of plant one wants to grow. However, the crop can also be adapted to the structure. The basic difference between perennial (e.g. trees) and annual crops is that trees require the concentration of water at points, whereas annual crops usually benefit most from an equal distribution of water over the cultivated area. (Anschütz et al. 1997)

- **Technical criteria**

When selecting a suitable water harvesting technique, two sets of criteria, of equal importance, should be taken into account (Anschütz et al. 1997):

- 1- A water harvesting technique should function well from a technical point of view.
- 2- It should 'fit' within the production system of the users. If the risk of production failure of the new technique is too high compared with proven techniques, or the labor requirements of the new technique are too high, your proposed water harvesting system, although designed well, will not be adopted because the priorities of the future users are different.

### **2.2.5 Selecting a water harvesting techniques:**

Figure 2.2 provides an overview of preliminary selection of a water harvesting technique. The list of water harvesting techniques in Figure 2.2 is far from complete. You will probably come across different traditional and/or non-traditional techniques. Water harvesting systems can be grouped into two categories: Systems in which the bunds follow the contour line are called contour systems. Systems in which bunds do not follow the contour line, but enclose a part of the slope are called freestanding systems. Water harvesting systems for trees usually have an infiltration pit because the harvested water has to be concentrated near the tree. On long slopes systems with an infiltration pit are not advisable, because these systems harvest a large quantity of runoff water, too much to be collected in an infiltration pit. On long slopes the water is collected in a larger, cultivated area and used for either fodder/rangelands or crops. All kinds of variation are possible within water harvesting systems. The bunds can be constructed using a variety of materials: earth, stones and living and/or dead vegetable material (living barriers or trash lines). The bunds may or may not have a provision for draining the excess harvested water. For the free-standing systems variations are also possible in the layout of the bunds. They can be semi-circular, V-shaped or rectangular.

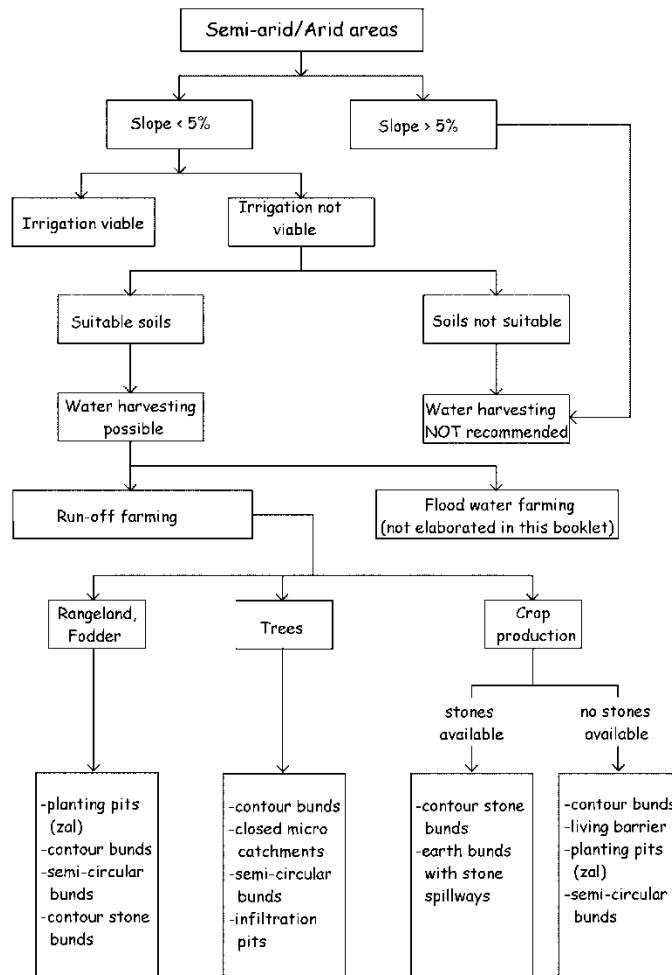


Figure 2.2 Selection of a water harvesting system (Critchley 1991)

## 2.2.6 Small Earth Dams

Small earth dams are water harvesting storage structures, constructed across narrow sections of valleys, to impound runoff generated from upstream catchment areas. Construction of the dam wall begins with excavation of a core trench along the length of the dam wall which is filled with clay and compacted to form a ‘central core’ that anchors the wall and prevents or minimizes seepage. The upstream and downstream embankments are also built using soil with 20-30% clay content. During construction either by human labor, animal draught or machine (bulldozer, compacter, grader etc.) – it is critical to ensure good compaction for stability of the wall. The dam is fenced with barbed wire to prevent livestock from eroding the wall. Typical length of the embankment is 50-100 m with water depth ranging 4-8 m. An emergency spillway (vegetated or a concrete Shute) is provided on either, or both sides, of the wall for safe

disposal of excess water above the full supply level. The dam water has a maximum throwback of 500 m, with a capacity ranging from 50,000 – 100,000 m. The dams are mainly used for domestic consumption, irrigation or for watering livestock. If the dams are located on communal lands, their establishment requires full consultation and involvement of the local community. The government provides technical and financial assistance for design, construction and management of these infrastructures. Community contribution includes land, labor and local resources. The community carries out periodic maintenance of the infrastructure – including vegetation management on embankment, desilting etc. – and of the catchment areas (through soil and water conservation practices). (Rima & Hanspeter 2013)

# **CHAPTER THREE**

## **GIS IN HYDROLOGY, RUNOFF, HEC-GEOHMS AND HEC-HMS**

This chapter explain the application of GIS in hydrology, runoff, the tool that had been used in this thesis (HEC-GEOHMS) and the software (HEC-HMS).

### **3.1 GIS in hydrology:**

Geographic information systems (GIS) have become a useful and important tool in hydrology and to hydrologists in the scientific study and management of water resources. Climate change and greater demands on water resources require a more knowledgeable disposition of arguably one of our most vital resources. As every hydrologist knows, water is constantly in motion. Because water in its occurrence varies spatially and temporally throughout the hydrologic cycle, its study using GIS is especially practical. GIS systems previously were mostly static in their geospatial representation of hydrologic features. Today, GIS platforms have become increasingly dynamic, narrowing the gap between historical data and current hydrologic reality.

The elementary water cycle has inputs equal to outputs plus or minus change in storage. Hydrologists make use of a hydrologic budget when they study a watershed. A watershed is a spatial area, and the occurrence of water throughout its space varies by time. In the hydrologic budget are inputs such as precipitation, surface flows in, and groundwater flows in. Outputs are evapotranspiration, infiltration, surface runoff, and surface/groundwater flows out. All of these quantities, including storage, can be measured or estimated, and their characteristics can be graphically displayed in GIS and studied.

As a subset of hydrology, hydrogeology is concerned with the occurrence, distribution, and movement of groundwater. Moreover, hydrogeology is concerned with the manner in which groundwater is stored and its availability for use. The characteristics of groundwater can readily be input into GIS for further study and

management of water resources. Because 98% of the world's available freshwater is groundwater, the need to keep a closer eye on its disposition is readily apparent (Wine, Michael L. 2012).

### **3.2 GIS in surface water:**

It is possible to access historical and real time stream flow data via the Internet. Embedded within a GIS are layers with stream locations and gage or measuring/monitoring sites. It's also possible to link radio transmitted and remotely sensed (Remote Sensing) data in GIS. Historical and real time data are available from the United States Geological Survey (USGS) in the form of gage height and stream flow or discharge in cubic feet per second. Within a GIS, it's possible to direct link via the Internet to real time data. Other sources of data for flood information and water quality come from the National Weather Service (NWS) and United States Environmental Protection Agency (EPA). All these data are available for analysis within GIS, providing a spatial representation of what would otherwise be data in a table type format.

GIS is much more capable of displaying data spatially than temporally. Within one GIS, ESRI's ArcGIS for example, is it possible to delineate a watershed. Digital elevation model (DEM) data are layered with hydrographic data so that the boundaries of a watershed may be determined. Watershed delineation aids the hydrologist or water resource manager in understanding where runoff from precipitation or snowmelt will eventually drain. In the case of snowmelt, snowpack coverage may be determined from ground stations or remotely sensed observers and input into GIS to determine or predict how much water can be counted on to be available for use by cities, agriculture, and environmental habitat.

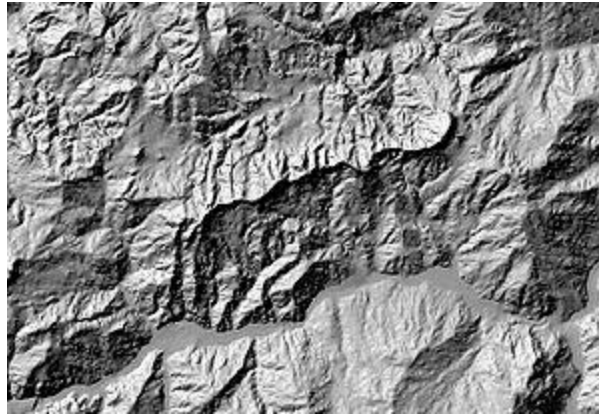


Figure 3.1 Digital Elevation Model

A digital elevation model (DEM) from which a watershed may be delineated within a GIS

Another useful application for GIS regards precipitation, but other hydrologic data (evapotranspiration, infiltration, and groundwater) may be treated similarly. Precipitation is an area event measured using data from point locations. The difficulty in using point data lies in extrapolating these point measurements to areas. One useful method to extrapolate data is to construct Thiessen polygons which assess the distance and geometry of points in a plane and determines representative areas for which to assign precipitation values. GIS applications like ArcGIS are capable of constructing Thiessen polygons, and other methods of determining area precipitation are viable with GIS as well.

A step up in complexity from manual analysis of select spatially depicted hydrologic data is to display a representative version of hydrologic reality and perhaps merge it with a numerical or other model which might predict what might happen say x amount of rainfall occurs or to forecast, for example, runoff following the passage of an approaching weather system. One such method to do this would be to connect a GIS data model with a simulation model. The GIS data model has all the relevant surface water features with attributes that describe historical or current hydrologic data. The data model structures all the pertinent data to arrive at a representative depiction of hydrologic reality for display and analysis. One data model which does this is Arc Hydro, created cooperatively by ESRI and the Center for Research in Water Resources (CRWR) at the University of Texas at Austin to work within ESRI's ArcGIS. It is important to understand the data model does not predict as this is the



function of the simulation model that Arc Hydro might feed. The simulation model is very complex and beyond the scope of this article.

By synthesizing GIS technology with hydrologic data, it has become possible to elucidate the effects of watershed-scale land-use and land-cover changes. For example, with growing pressures on water resources there is a strong interest in how forestation affects water yields. GIS and remote sensing facilitate quantifying long-term changes in forest cover since aerial photography records are available across much of the United States since as early as the 1930s. Even earlier than the 1930s the USGS started systematically gauging many watersheds throughout the country. Once long-term land-cover trends have been quantified in a gauged watershed, it becomes possible to statistically compare the long-term land-cover changes with the land-use changes to determine, for example, if forestation is actually reducing stream flow as is widely perceived. Thus using GIS data together with hydrology data can allow for knowledge based water resources decision making at far lower costs than traditional methods (Wine, Michael L. 2012).

### **3.3 GIS in groundwater:**

As mentioned earlier, 98% of the available freshwater (negating polar and glacial ice) for human and environmental uses is in groundwater. In the United States, about ¼ of the water used for personal, commercial/industrial, and irrigation uses comes from groundwater. With increasing demands placed on surface water resources, it is likely the demand for groundwater will increase. In some places, this resource has already been severely tapped, and even mismanaged. An example here is the surface water decline in the Republican River watershed of Nebraska and Kansas where over-pumping of groundwater for irrigation in Nebraska has depleted surface water available for downstream flow and use in Kansas resulting in a lawsuit by that state against the state of Nebraska. Although not as apparent as surface water flow, groundwater can also be characterized spatially in a GIS and analyzed by scientists and natural resource managers.

It can be argued that the depiction of groundwater is an even more complex task than that of surface water. The two resources are by no means disjoint, as knowing where

surface water recharges groundwater and where groundwater flows supply surface water is an important aspect of the hydrologic cycle. Hydrogeology is especially well suited to GIS. Groundwater moves much more slowly than surface water, on the order of less than a meter per day up to perhaps a hundred meters per day, and is 3-dimensional in flow. In contrast, surface water flows much faster and is more two-dimensional. Groundwater flow is a function of geology and “head,” the total potential energy at a location. Groundwater flows from higher head to lower head at a travel rate and flow path dictated by geology. Head values, geology, groundwater flow direction, even water table height and location of aquifers are among the quantities which may be presented spatially in GIS and used for analysis, management of water availability and water quality, and land use practices.

A very large amount of data from wells is available such as location, depth to water, stratigraphy, water quality and chemistry, aquifer characteristics, and the list goes on. The volume of data can be managed in a GIS and manipulated to display spatial characteristics for analysis and water resource planning. For example, in a simple application of GIS, the effect of a new well can be studied on the existing groundwater and surface water. The results of such a study can be used by decision makers to determine whether or not to proceed with drilling.

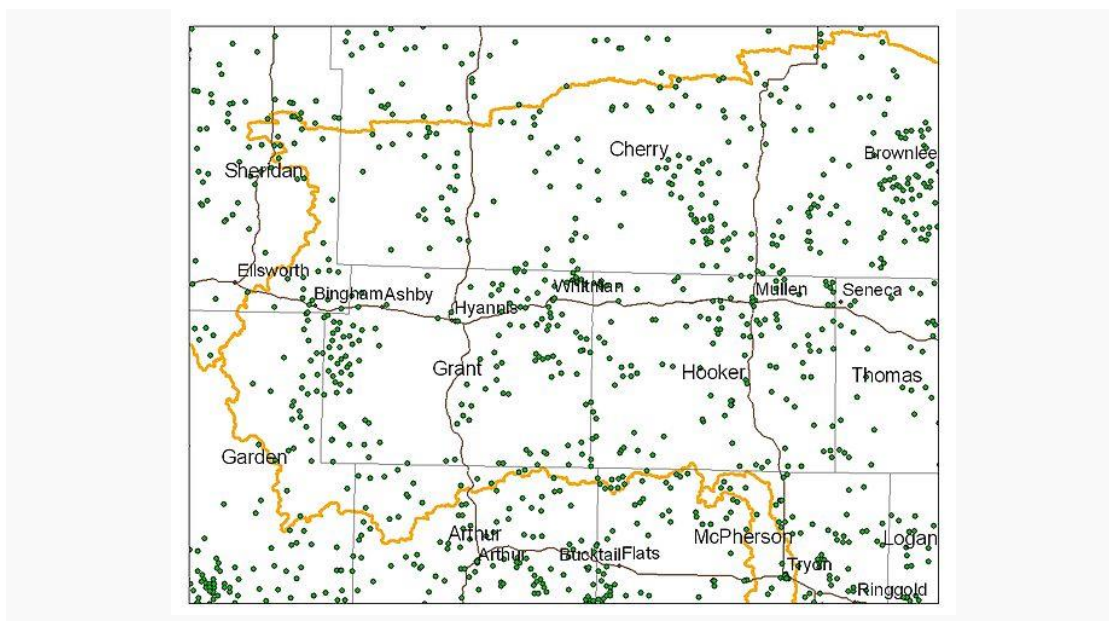


Figure 3.2 Nebraska Sand hills: registered well locations in the Upper Loup basin

An especially useful application of GIS concerns water quality in groundwater. For construction/situating of industrial plants, landfills, agricultural activities, and other potential groundwater contamination sources, it is useful to know how existing groundwater supplies could be affected or would be at risk of impact. Further, in the case of groundwater contamination and the need for subsequent containment and cleanup of the contaminant, an existing framework of the groundwater system would be valuable in planning remediation measures. This GIS could be the front end to a groundwater modeling simulation devised to fully capture the contaminant. An additional example concerning the use of GIS addresses a common problem associated with groundwater pumping and land subsidence or intrusion in coastal areas. Areas that have been over pumped of groundwater can subside, and when near the sea, this may invite flooding. Also, over pumping of groundwater in coastal regions may bring a different problem, such as the case in California where salt-water intrusion has compromised the aquifer. Generally, a salt water interface inland of the coast extends below the land surface dependent on the distance from the coast. Over pumping can bring the salt water interface to a higher position and contaminate an aquifer. A careful study and management of groundwater within GIS or with modeled GIS data can forestall or alleviate these problems (Wine, Michael L. 2012).

### **3.4 Runoff Basics**

Runoff is that portion of precipitation that flows over land surfaces toward larger bodies of water. Before runoff can occur, rainfall must satisfy the immediate demands of infiltration, evaporation, interception, surface storage, surface detention and/or channel detention. Some are very minor losses, *e.g.*, interception by a corn crop is only about 0.02 inches. However, in a forested area interception may not be minor, accounting for up to 25 percent of the rainfall. For short time periods (storms) on agricultural lands:

$$\text{Rainfall} - \text{runoff} = \text{infiltration}$$

This can be illustrated by a hydrograph with a steady rainfall input:

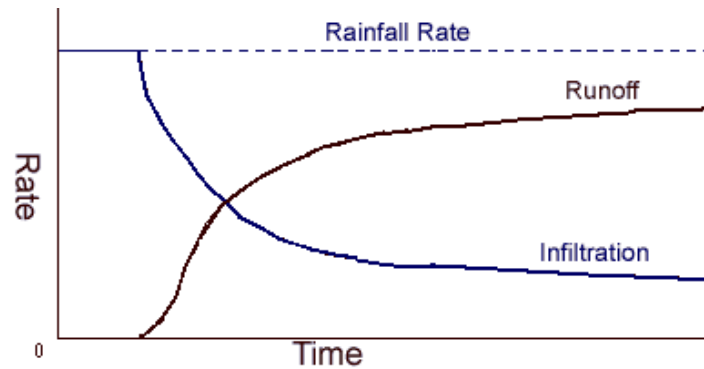


Figure 3.3 Runoff vs. Infiltration

### 3.4.1 FACTORS AFFECTING RUNOFF:

There are two broad categories of factors that control runoff: rainfall (storm) characteristics and watershed physical conditions. Important rainfall characteristics include duration, amount, intensity and distribution. Key watershed factors are:

#### 3.4.1.1 Size

For a fixed return interval, as watershed size increases, the runoff per unit area decreases. This occurs primarily because **average** rainfall amount decreases with increasing area; secondarily, increased travel time for runoff allows more infiltration and other losses.

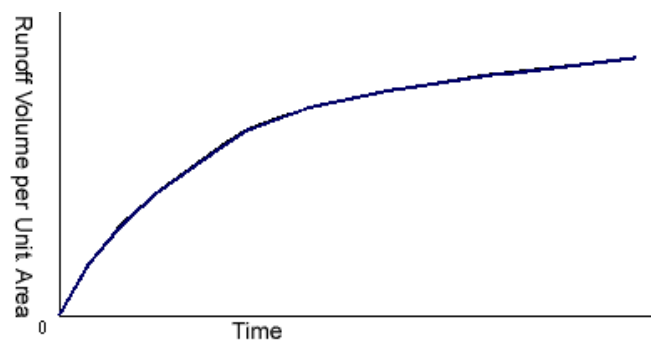


Figure 3.4 Runoff Volume vs. Time

### **3.4.1.2 Shape**

For equal sized watersheds, runoff decreases as overland flow length increases. This results from the increased time of concentration. Longer duration storms, needed to produce runoff from all points in watershed, have lower average intensities.

### **3.4.1.3 Topography**

Surface slopes and roughness greatly influence runoff. Steep slopes reduce time of concentration and detention volume. Roughness increases surface storage and promotes greater infiltration, both of which decrease runoff.

### **3.4.1.4 Soils**

Watershed soils influence infiltration and deep seepage rates. Infiltration must be satisfied before runoff begins.

### **3.4.1.5 Surface culture**

Modern agricultural practices promote infiltration, slow runoff and reduce the antecedent water content of soils prior to a storm event.

### **3.4.2 Runoff hydrograph:**

A graph of runoff rate vs. time is called a runoff hydrograph. The shape of a hydrograph depends on the time distribution of rainfall and upon watershed flow characteristics. However, most hydrographs bear some resemblance to the "typical shape" shown below:

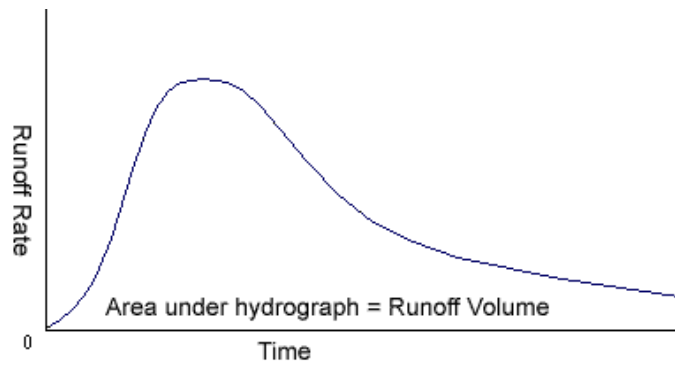


Figure 3.5 Hydrograph Shape

The receding limb of a hydrograph usually extends over a longer period of time than the rising limb. The area under the curve gives the volume runoff (volume/time x time = volume). In this course, we will primarily use the peak runoff rate in our problems. Since hydrographs of previous storm events are seldom available for small watersheds, estimates of peak rates and/or volume must be made using computational models rather than from statistical analyses of past records.

## 3.5 HEC-GeoHMS:

### 3.5.1 Overview:

The Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) is a software package for use with the ArcMap Geographic Information System. GeoHMS uses ArcMap and Spatial Analyst to develop a number of hydrologic modeling inputs. Analyzing digital terrain information, HEC-GeoHMS transforms the drainage paths and watershed boundaries into a hydrologic data structure that represents the watershed response to precipitation. In addition to the hydrologic data structure, capabilities include the development of: grid-based data for linear quasi-distributed runoff transformation (Mod Clark), the HEC-HMS basin model, physical watershed and stream characteristics, and background map file.

HEC-GeoHMS provides an integrated work environment with data management and customized toolkit capabilities, which includes a graphical user interface with menus, tools, and buttons. The program features terrain-preprocessing capabilities in both interactive and batch modes. Additional interactive capabilities allow users to construct a hydrologic schematic of the watershed at stream gages, hydraulic

structures, and other control points. The hydrologic results from HEC-GeoHMS are then imported by the Hydrologic Modeling System, HEC-HMS, where simulation is performed.

### **3.5.2 Program Features:**

#### **3.5.2.1 Data Management:**

HEC-GeoHMS performs a number of administrative tasks that help the user manage GIS data derived from the program. The data management feature tracks GIS data layers and their names. Prior to performing a particular operation, the data manager will offer the appropriate data inputs for operation, and prompt the user for confirmation. Other times, the data management feature manages the locations of various projects and also performs error checking and detection.

#### **3.5.2.2 Terrain Preprocessing:**

HEC-GeoHMS allows users to perform terrain preprocessing in either a step-by-step fashion or batch mode. In The step-by-step process, the user often has the opportunity to examine the outputs and make corrections to the dataset, as appropriate. Batch Processing will allow terrain preprocessing to be performed unattended.

#### **3.5.2.3 Basin Processing:**

The emphasis of the subbasin delineation, processing, and manipulation capability is on flexibility, ease of use, and user interactivity. As the user subdivides a basin or merges many smaller subbasins together, the results of the operation are displayed immediately for the user's confirmation. The ability to perform subbasin processing interactively is powerful, because the results are presented quickly for the user to make a modeling decision instead of having to reprocess the data. For example, the user can obtain a stream profile and look for significant grade breaks. If a subbasin subdivision at a grade break is desired, the user, using the delineation tool, just clicks on the stream at the grade break. Other tools allow the user to delineate subbasins in a batch mode by supplying a dataset containing point locations of desired outlets.

### **3.5.2.4 Hydrologic Parameter Estimation:**

Users can now compute the Curve Number (CN) and other loss rate parameters based on various soil and land use databases. The curve number can represent an average value for a subbasin or an individual cell for a grid-based subbasin. In addition, watershed and channel characteristics together with a spreadsheet template are linked to HEC-GeoHMS to assist the user with estimation of initial values of time of concentration. Also, basin and channel characteristics can be used to calculate CN Lag and simple prismatic Muskingum-Cunge routing parameters.

### **3.5.2.5 HMS Model Support:**

HEC-GeoHMS produces a number of hydrologic inputs that are used directly in HEC-HMS. In addition, the program supports the estimation of hydrologic parameters by providing tables of physical characteristics for streams and subbasins. While working with HEC-GeoHMS, the user can use other ArcGIS extension programs to perform spatial operations and develop additional parameters for populating the hydrologic model.

## **3.5.3 Intended Application of HEC-GeoHMS:**

HEC-GeoHMS is intended to process watershed data after the initial compilation and preparation of terrain data is completed. The assembly of GIS data can be performed using standard GIS software packages that support ARC Grid format. Even though this user's manual provides some guidance and discussions on the proper approach for assembling data, HEC-GeoHMS is not intended as a tool for data assembly. When assembling data, it is important to understand how to use GIS software to put data of different types and formats into a common coordinate system. A few examples of required data include digital elevation models (DEM), digital stream alignments, and stream gage locations.

When the data assembly is complete, HEC-GeoHMS processes the terrain and spatial information to generate a number of input files for an HEC-HMS model. It is intended that these input files provide the user with an initial HEC-HMS model. The



user can estimate hydrologic parameters from stream and subbasin characteristics, gaged precipitation, and stream flow data. In addition, the user has full control in HEC-HMS to modify the hydrologic elements and their connectivity to more accurately represent field conditions.

### 3.6 HEC-HMS:

#### 3.6.1 BACKGROUND:

HEC-Hydrologic Modeling System (HEC-HMS) is a program designed by the US Corps of Engineers to simulate surface water hydrology. It includes several hydrologic components that represent rainfall, evaporation, and snowmelt. There are subroutines for the calculation of infiltration, losses, base flow, and run-off and different methods for the calculation of each one. Additionally, HEC-HMS offers different analysis tools to better visualize and understand the results obtained.

Because of its numerous choices in the methods used for the calculation of run-off and other hydrologic elements, the challenge for the modeler is to use the most appropriate methods for the estimation or calculation of required parameters.

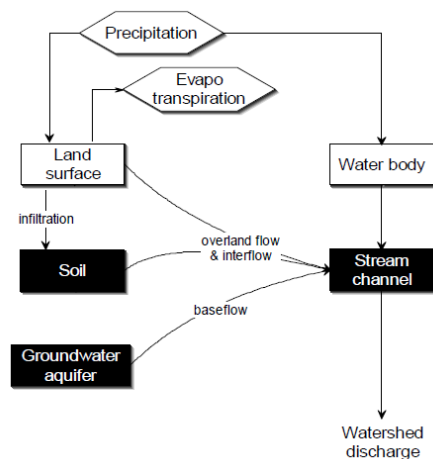


Figure 3.6 HEC-HMS representation of Watershed Runoff

HEC-HMS model can be adapted to fit almost any watershed. It includes all the components of the hydrologic cycle like precipitation, evaporation, infiltration, surface runoff, and base flow. Basin models, meteorological models, and control specifications are the main components of HEC-HMS model for simulations.

### **3.6.2 HEC-HMS RAINFALL-RUNOFF MODEL:**

The parameters and structure of traditional hydrological models are not adaptable for the data derived from remote sensing. Therefore, a hydrological model based on geographical information system and remote sensing must be deployed to develop the basin model, and hence the HEC-HMS was chosen for simulating the rainfall runoff response. HEC-HMS model can be adapted to fit almost any watershed. It includes all the components of the hydrologic cycle like precipitation, evaporation, infiltration, surface runoff, and base flow. Basin models, meteorological models, and control specifications are the main components of HEC-HMS model for simulations.

### **3.6.3 Muskingum Routing:**

Need:

- Muskingum K (Travel Time): hr.
- Muskingum X (Storage Routing)
- Time Steps (or sub reaches)

Muskingum K is the travel time for the reach, and is determined by dividing the mean velocity by the reach length. Velocity can be determined from a hydraulic model, such as HEC-HMS or HEC-RAS, or performing a simple open-channel flow calculation using Manning's equation. Channel velocities can also be assumed, using the rule-of-thumb presented in the previous section.

Muskingum X is the only means represent storage for the routing step using this routing procedure. Muskingum X ranges from 0 to 0.5, where 0.5 is used for smooth uniform channels with a pure translation of the flood wave. A value of 0.2 is generally used for natural streams and a value of 0.45 is used for most improved urban channels.

The number of time steps is the time it takes a drop of water to travel the entire length of the routing reach divided by the computation time of the hydrologic model. To estimate the time it take a drop of water to travel the length of the reach, a hydraulic model should be used. As a rule of thumb, water in a stream can travel 2 mi/hr.,

although in channelized streams, the rate can increase to 10 mi/hr., or even greater, depending on overland slope and channel roughness.

Figure 3.7 shows the effect of Muskingum K and X coefficients on the routed hydrographs.

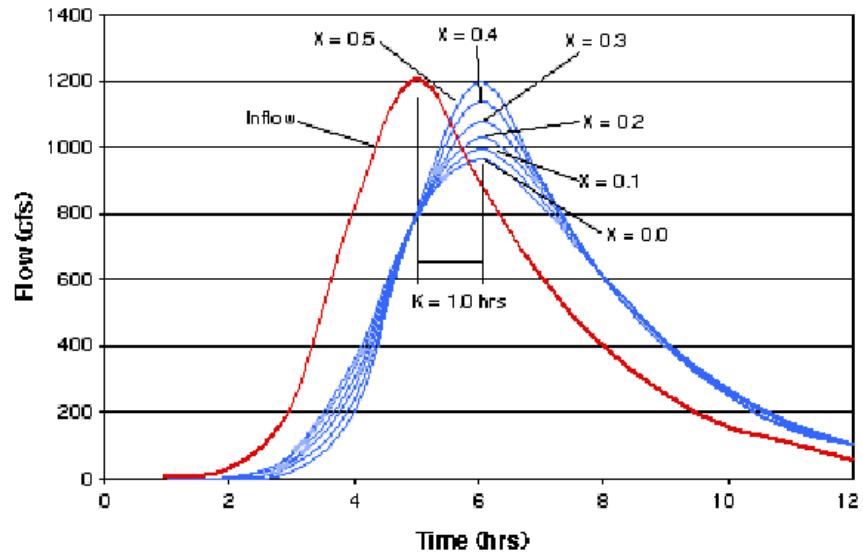


Figure 3.7 Muskingum Routing

# CHAPTER FOUR

## METHODOLOGY

This chapter illustrates the Methodology, steps of runoff model and proposed water harvesting projects (location map).

### 4.1 Study area:-

The study area consists of East-Nile and Bahri localities in Khartoum state. The catchments of the natural streams in the study area lay between latitudes ( $16^{\circ}40'59''\text{N}$ - $14^{\circ}50'26''\text{N}$ ) and Longitudes ( $34^{\circ}38'52''\text{E}$ -  $32^{\circ}05'23''\text{E}$ ) (Figure 4.1)

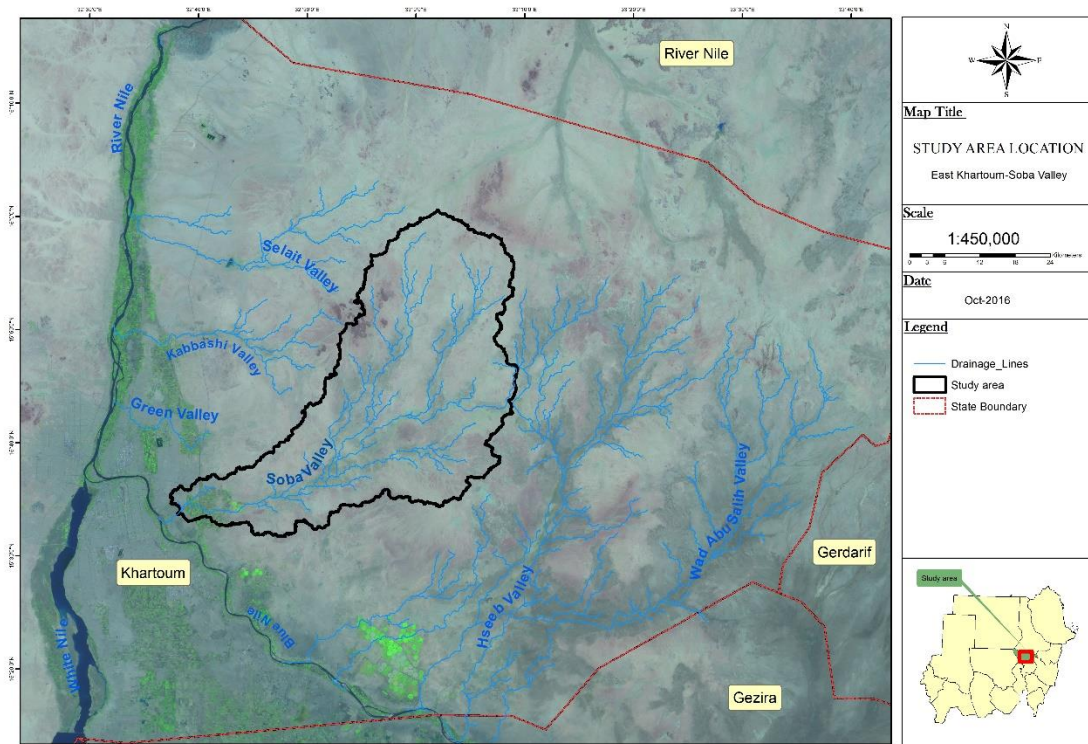


Figure 4.1 Study area

Several valleys dominate the area. Territory of the national capital is classified under the climatic category of the southern Sahara. Khartoum region is categorized within the zone of semi- arid, which is characterized by the high temperature degree during the day all over the year. The rainfalls fluctuate from year to year and the annual average ranges from 200 mm in the north to 250 mm in the south. Temperatures are highest at the end of the dry season due to cloudless skies. The warmest months are

May and June, when the average temperature is 41°C and max temperatures can reach up to 48°C. (Eltaib et al. 2011)

## 4.2 Work plan:-

The research had been carried out in two main steps; namely hydrological analysis and selection of dam sites.

### 1- hydrological analysis

In the first component, Arc-Hydro tool was used to determine the drainage network (drainage lines and catchment boundary). The result was then processed in Hec-GeoHMS tool to produce HMS model after that Hec-HMS was used to run the model (discharge and hydrograph).

### 2- selection of dam sites

In the second component, topographic analysis was conducted to compute area and volume for selected location of dam.

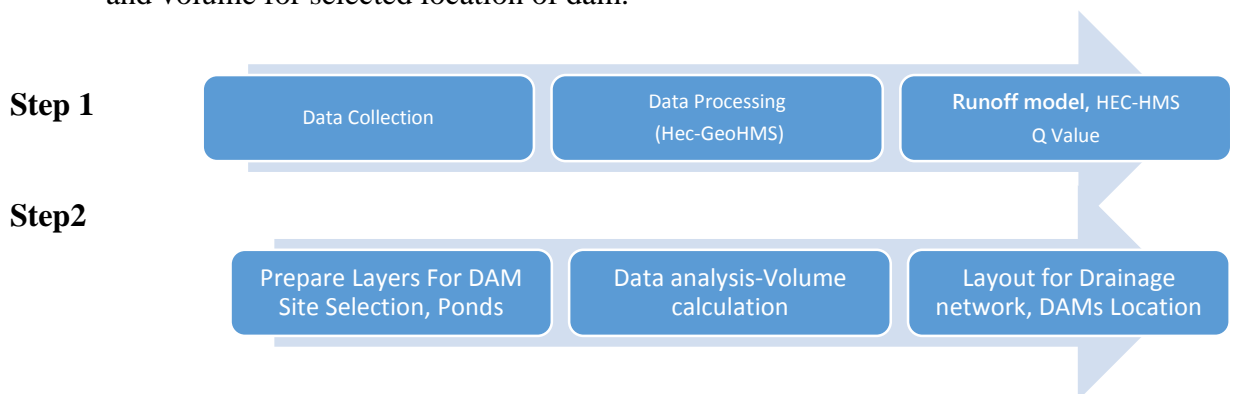


Figure 4.2 Methodology Flow diagram

## 4.3 DATA Collection:-

### 1- Digital Elevation Model:-

- Date of data: Aug. 2008
- Data Coverage (7490Km<sup>2</sup> – 84\*92Km) (East-Nile and part of Bahri localities in Khartoum state and north east Gezira state. The catchments of the natural streams that flow through them lay between latitudes (15°07'38.6"N- 16°01'3.6"N) and Longitudes (33°8'48.8"E- 33°03'8.8"E)
- Produced by SRTM-USGS
- Resolution: 30\*30 m

- Datum: WGS84
  - Projection: UTM, Zone 36N.
  - [www.opentopography.com](http://www.opentopography.com)
- 2- Satellite Image (Landsat 8 -173/49):-
- Date of data: May. 2015 and Feb. 2016
  - Resolution: 30\*30 m
  - Datum: WGS84
  - Projection: UTM, Zone 36N.
  - [www.earthexplorer.com](http://www.earthexplorer.com)
- 3- Shape file of Soil data:-
- Date of Collected data: 2010 By Ministry of Water Resources and Electricity.
  - Data Coverage (7490Km<sup>2</sup> – 84\*92Km) (East-Nile locality in Khartoum state latitudes (15°07'38.6"N-16°01'3.6"N) and Longitudes (33°8'48.8"E-33°03'8.8"E)
  - Datum: WGS84
  - Projection: UTM, Zone 36N.
- 4- Shape file of landuse and Land cover data:-
- Date of Collected and prepared of data: 2010 By Ministry of Water Resources and Electricity.
  - Data Coverage: Khartoum state
  - Datum: WGS84
  - Projection: UTM, Zone 36N.
- 5- Data from Google earth:-
- Villages in the study area.
  - All Agriculture projects in the study area.
  - Roads and their pipe culverts.

6- Rainfall Data:-

- The rainfall data (listed in table 4.1) has been collected from Sudan Meteorological authority (1971-2010) and form TRMM.com (2001-2015) (Appendix A) due to leak information in study area and there is no gauge for rainfall measuring, TRMM daily rainfall has been used.

Table 4.1 Rainfall data (1971-2010)

| Year | JAN | FEB | MAR | APR | MAY  | JUN  | JUL  | AUG   | SEP   | OCT  | NOV  | DEC |
|------|-----|-----|-----|-----|------|------|------|-------|-------|------|------|-----|
| 1971 | 0   | 0   | 0   | 0   | 0    | 0    | 53.8 | 33.2  | 31.9  | 1.6  | 0    | 0   |
| 1972 | 0   | 0   | 0   | 0   | 0    | 6.5  | 6    | 110.5 | 10    | 0.6  | 0    | 0   |
| 1973 | 0   | 0   | 0   | 0   | 14.2 | 0    | 74.6 | 0     | 34.3  | 51.6 | 0    | 0   |
| 1974 | 0   | 0   | 0   | 0   | 0    | 13.9 | 55.4 | 12    | 4.7   | 0    | 0    | 0   |
| 1975 | 0   | 0   | 0   | 0   | 4.2  | 0    | 0.9  | 50.1  | 47.8  | 0    | 22.2 | 0   |
| 1976 | 0   | 0   | 0   | 0   | 0    | 0    | 43   | 80.1  | 25.7  | 7.8  | 0    | 0   |
| 1977 | 0   | 0   | 0   | 0   | 0    | 0    | 37.4 | 125.6 | 2.9   | 0.8  | 0    | 0   |
| 1978 | 0   | 0   | 0   | 0   | 0    | 4    | 60.3 | 46.3  | 14.5  | 8.5  | 0    | 0   |
| 1979 | 0   | 0   | 0   | 0   | 3.2  | 12.1 | 2.7  | 62.3  | 19.8  | 0    | 0    | 0   |
| 1980 | 0   | 0   | 0   | 0   | 0.7  | 4.2  | 60   | 19.2  | 11    | 1.2  | 0    | 0   |
| 1981 | 0   | 0   | 1.4 | 0   | 1.2  | 1.7  | 86.9 | 30.7  | 12.9  | 6.3  | 0    | 0   |
| 1982 | 0   | 0   | 1.6 | 0   | 5    | 0    | 9.4  | 46.9  | 39.8  | 0    | 0    | 0   |
| 1983 | 0.6 | 0   | 0   | 0   | 1.1  | 46.5 | 23.2 | 6.8   | 5.8   | 0    | 0    | 0   |
| 1984 | 0   | 0   | 0   | 0   | 1.4  | 0    | 0    | 0     | 3.3   | 0    | 0    | 0   |
| 1985 | 0   | 0   | 0   | 0   | 9.1  | 3.1  | 16.4 | 0.3   | 9.9   | 0    | 0    | 0   |
| 1986 | 0   | 0   | 0   | 0   | 0    | 0    | 9.1  | 21.9  | 16.3  | 10.4 | 0    | 0   |
| 1987 | 0   | 0   | 0   | 0   | 21.1 | 23   | 22   | 48.9  | 0     | 0.6  | 0    | 0   |
| 1988 | 0   | 0   | 0   | 0   | 0    | 0    | 65.9 | 200.5 | 46.3  | 1.9  | 0    | 0   |
| 1989 | 0   | 0   | 0   | 0   | 5.8  | 1.3  | 0    | 24.7  | 48    | 0    | 0    | 0   |
| 1990 | 0   | 0   | 0   | 0   | 0    | 0    | 2    | 0     | 2.4   | 0    | 0    | 0   |
| 1991 | 0   | 0   | 0   | 0   | 2.3  | 0    | 4.3  | 37.7  | 0     | 0.6  | 0    | 0   |
| 1992 | 0   | 0   | 0.6 | 0   | 10.8 | 4    | 6.9  | 89    | 38.6  | 0    | 0    | 0   |
| 1993 | 0   | 0   | 0   | 0   | 3.8  | 0    | 1    | 33.4  | 0     | 1.6  | 0    | 0   |
| 1994 | 0   | 0   | 0   | 0   | 12.7 | 0    | 51.3 | 48    | 101.2 | 19.4 | 0    | 0   |
| 1995 | 0   | 0   | 0   | 0   | 0    | 0.3  | 83.9 | 52.9  | 46.5  | 11.4 | 0    | 0   |

|      |   |   |   |    |      |      |      |       |      |      |     |   |
|------|---|---|---|----|------|------|------|-------|------|------|-----|---|
| 1996 | 0 | 0 | 0 | 0  | 19.5 | 0.4  | 32   | 55    | 91.9 | 0.5  | 0   | 0 |
| 1997 | 0 | 0 | 0 | 0  | 0    | 3.1  | 50.9 | 35    | 9.2  | 42.8 | 0   | 0 |
| 1998 | 0 | 0 | 0 | 0  | 0    | 0    | 0    | 21.3  | 85.4 | 4    | 0   | 0 |
| 1999 | 0 | 0 | 0 | 0  | 0    | 1.9  | 26.9 | 47.3  | 25.5 | 29   | 0   | 0 |
| 2000 | 0 | 0 | 0 | 0  | 0    | 0    | 1.4  | 8.5   | 15.3 | 34.8 | 0   | 0 |
| 2001 | 0 | 0 | 0 | 0  | 0    | 0    | 37.4 | 73.7  | 13.5 | 3.2  | 0   | 0 |
| 2002 | 0 | 0 | 0 | 0  | 0    | 0    | 7.7  | 82.6  | 13.7 | 3.5  | 0   | 0 |
| 2003 | 0 | 0 | 0 | 0  | 23.5 | 44.3 | 27.2 | 39.4  | 11   | 8.4  | 7.6 | 0 |
| 2004 | 0 | 0 | 0 | 0  | 0    | 0.3  | 6    | 88.8  | 9.6  | 5    | 0   | 0 |
| 2005 | 0 | 0 | 0 | 0  | 32.8 | 0    | 77.6 | 30.3  | 0    | 0    | 0   | 0 |
| 2006 | 0 | 0 | 0 | 0  | 8    | 1.8  | 1.5  | 37.2  | 85.2 | 0    | 0   | 0 |
| 2007 | 0 | 0 | 0 | 0  | 0    | 0    | 25.8 | 145.9 | 0.5  | 5.8  | 0   | 0 |
| 2008 | 0 | 0 | 0 | 13 | 0    | 8.1  | 8.4  | 42.3  | 7.4  | 3    | 0   | 0 |
| 2009 | 0 | 0 | 0 | 0  | 0    | 0    | 29.2 | 101.2 | 4.8  | 0.5  | 0   | 0 |
| 2010 | 0 | 0 | 0 | 0  | 0.2  | 1.4  | 13.9 | 43    | 18   | 0    | 0   | 0 |

- Khartoum Maximum Rainfall in One Day (1941-2014)- Source: Nile Basin Initiative (NBI) - Eastern Nile Technical Regional Office (ENTRO)‘Assessment of 2013 Flash Floods in Khartoum and Mitigation Measures Case Study: Wadi Soba – Khartoum, Nile East Locality’ (August 2013)

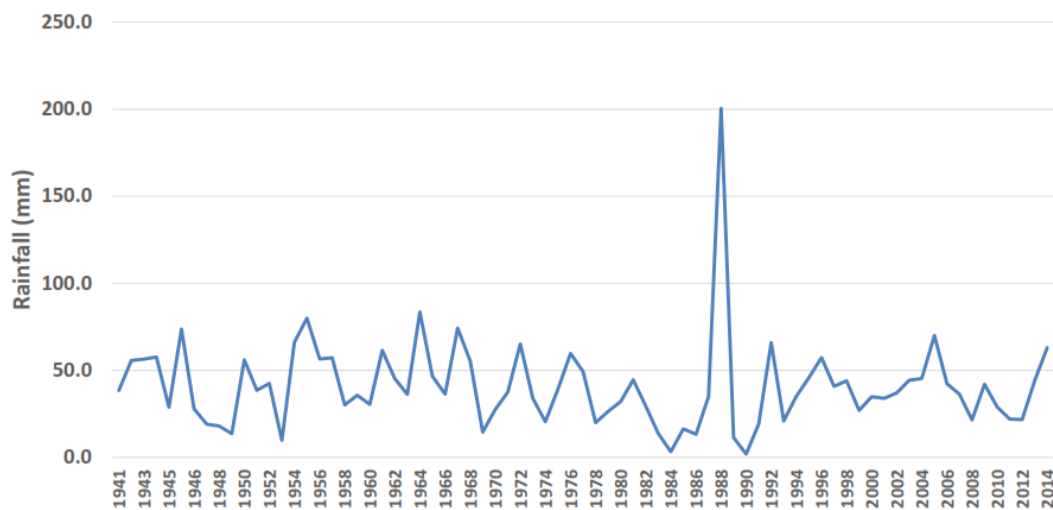


Figure 4.3 Khartoum Maximum rainfall in one day



- **Highest Recorded Maximum - 200.5 mm in August, 1988**
- **Lowest Recorded Maximum – 2.0 mm in July, 1990**
- **2013 Maximum – 44.0 mm**
- **2014 Maximum – 63.0 mm**
- Intensity Duration Frequency curve (IDFC) had been collected from UNOPS

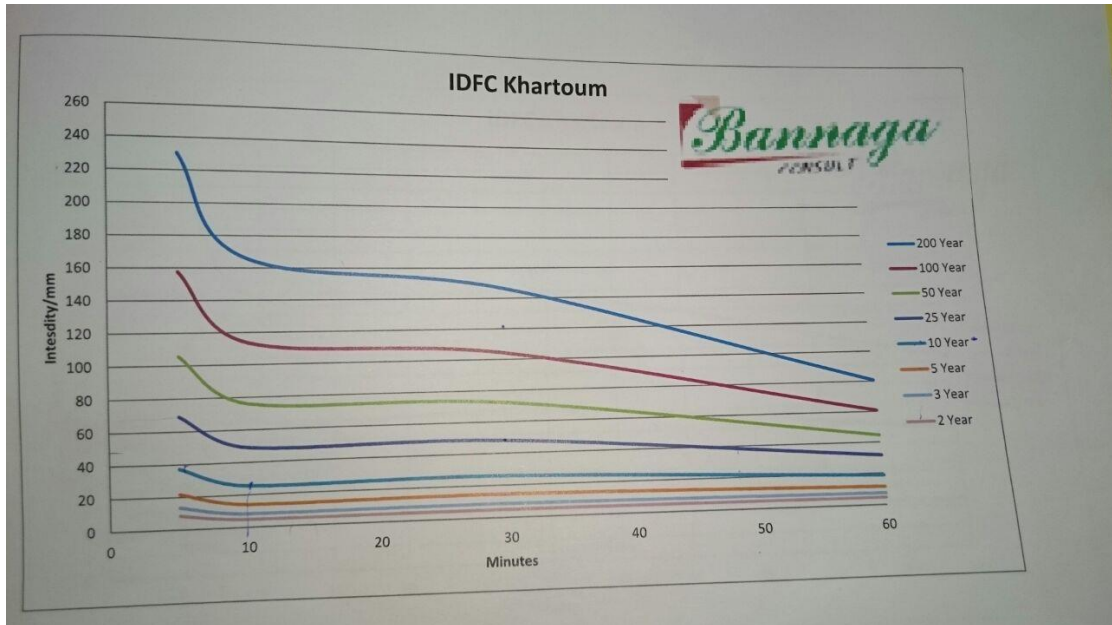


Figure 4.4 IDFC Khartoum

#### 7- Field Trips:-

Field trips were made in order to investigate fully the hydrological and hydraulic characteristics of, Haseeb and Soba valleys (Figure 4.5). By traveling up and downstream of the catchment it was possible to obtain information about vegetation, land use, type of soil and similar information needed in estimating the discharge.

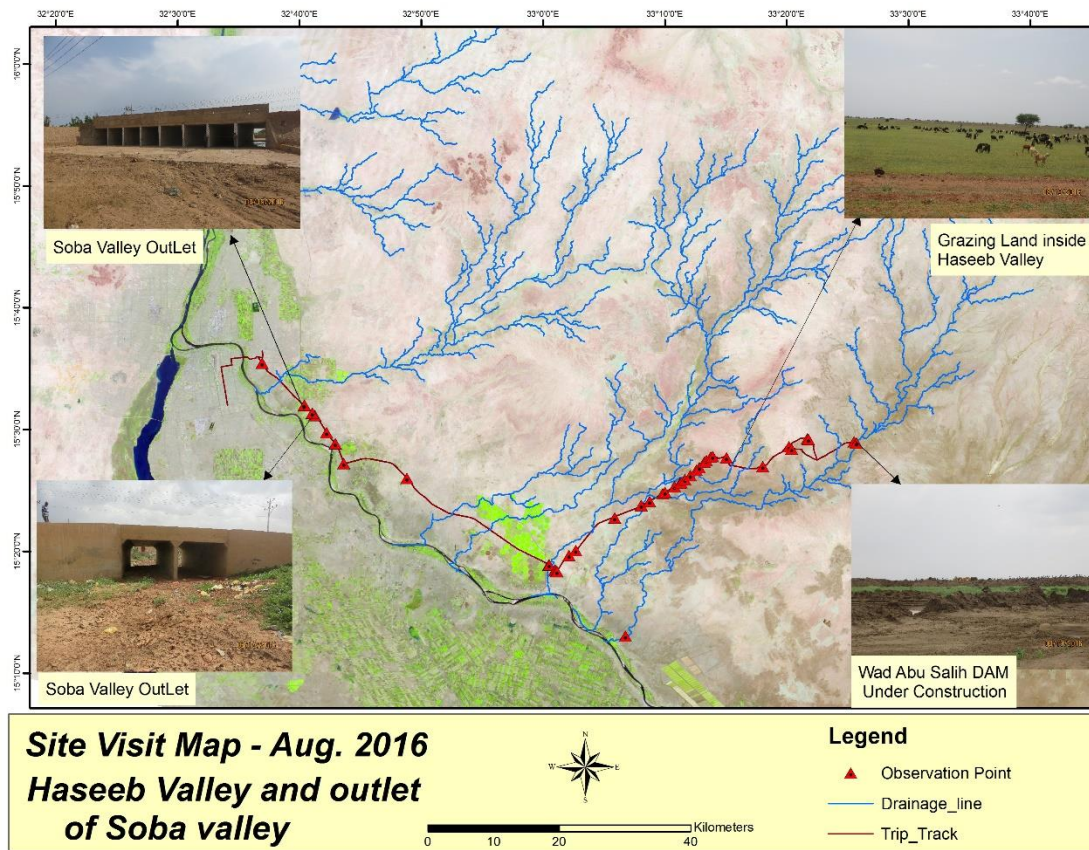


Figure 4.5 Site Visit (Aug. 2016) Map

#### 4.4 Data processing:

The first step in doing any kind of hydrologic modeling involves delineating streams and watersheds, and getting some basic watershed properties such as area, slope, flow length, stream network density, etc. Traditionally this was (and still is!) being done manually by using topographic/contour maps. With the availability of digital elevation models (DEM) and GIS tools, watershed properties can be extracted by using automated procedures. The processing of DEM to delineate watersheds is referred to as terrain pre-processing. There are several tools available online for terrain pre-processing. In this research, we will use Arc Hydro tools to process a DEM to delineate watershed, sub-watersheds, stream network and some other watershed characteristics that collectively describe the drainage patterns of a basin. The results from this process can be used to create input files for many hydrologic models such as (Scharffenberg 2013).

#### **4.4.1 Terrain Preprocessing:**

The Terrain Preprocessing functions were the next steps had been taken to prepare the data. With terrain preprocessing, a terrain model had been used as an input to derive eight additional datasets that collectively describe the drainage pattern of the watershed and allow for stream and subbasin delineation.

The first function had been used Fill Sinks which is a tool to remove sinks or depressions created by the reconditioning process.

The next step is Flow Direction had been used in order to define a flow direction for each cell in the DEM. The numbers in the legend represent the following directions: 1= east, 2 = southeast, 4 = south, 8 = southwest, 16 = west, 32 = northwest, 64= north, 128 = northeast.

The next step uses the Flow Accumulation operation which determines the contributing area to each cell in the map.

The Stream Definition editor had been used in order to classify all cells belonging to the stream network. This tool uses the information from the flow accumulation data to determine what cells belong to a stream network. The flow accumulation for a particular cell must exceed a user- defined threshold to be considered in the stream.

The next had been used the Stream Segmentation operator which divides the stream produced by stream definition into separate sections. The stream segments are the sections of a stream that connect two successive junctions, a junction and an outlet, or a junction and a drainage divide.

The next step had been used Catchment Grid Delineation which delineates a subbasin for every stream segment created in Stream Segmentation. An illustration of all the subbasins that were created from the Catchment Grid Delineation.

Catchment Polygon Processing had been taken as the next step, which created a vector layer of subbasins with the subbasins created in Catchment Grid Delineation.

Drainage Line Processing had been the next step which created a vector stream coverage. The light blue lines illustrated below in (Figure 4.6) represent the vector stream coverage.

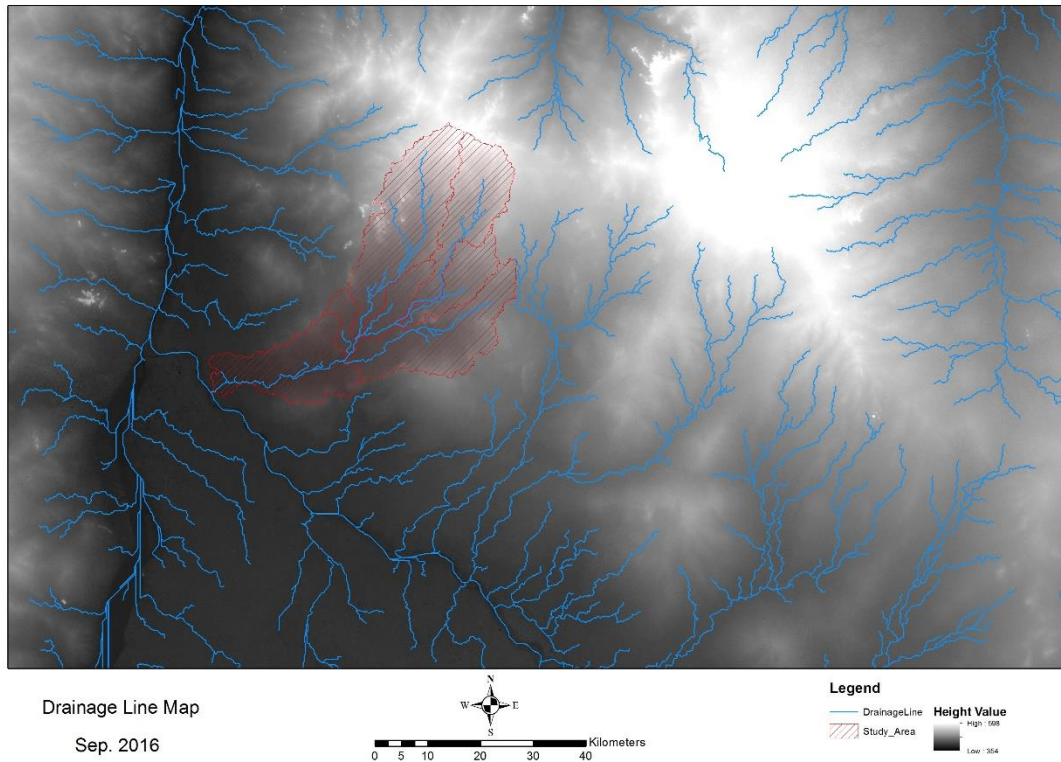


Figure 4.6 Drainage line Processing


Adjoint Catchment Processing had been the next step taken to generate the aggregated upstream catchments from the Catchment feature class. For each catchment that is not a head catchment, a polygon representing the whole upstream area draining to its inlet point is constructed and stored in a feature class that has an Adjoint. Catchment tag. This feature class had been used to speed up the point delineation process.

The final step in the Terrain Preprocessing had been Watershed Aggregation which aggregates the upstream subbasins at every stream confluence. This is a required step and is performed to improve computational performance for interactively delineating subbasins and to enhance data extraction. (Matthew J. Fleming 2013)

#### 4.4.2 Hec-GeoHMS Process:

With all of the Terrain Reconditioning and Terrain Preprocessing finished the HMS Project Setup began. The Terrain Reconditioning and Terrain Preprocessing prepared the terrain data in a way that the HEC- GeoHMS tools could use. The HMS Project Setup menu is responsible for extracting data that will be used to develop the necessary information to create a HEC- HMS project. ((Matthew J. Fleming



2013)The first step had been to start the new project and select the outlet point for the project. Using Add project point  the outlet point of the valley watershed had been set in ArcMap. This created the project point, as well as the project area shown below in (Figure 4.7) and (Figure 4.8)

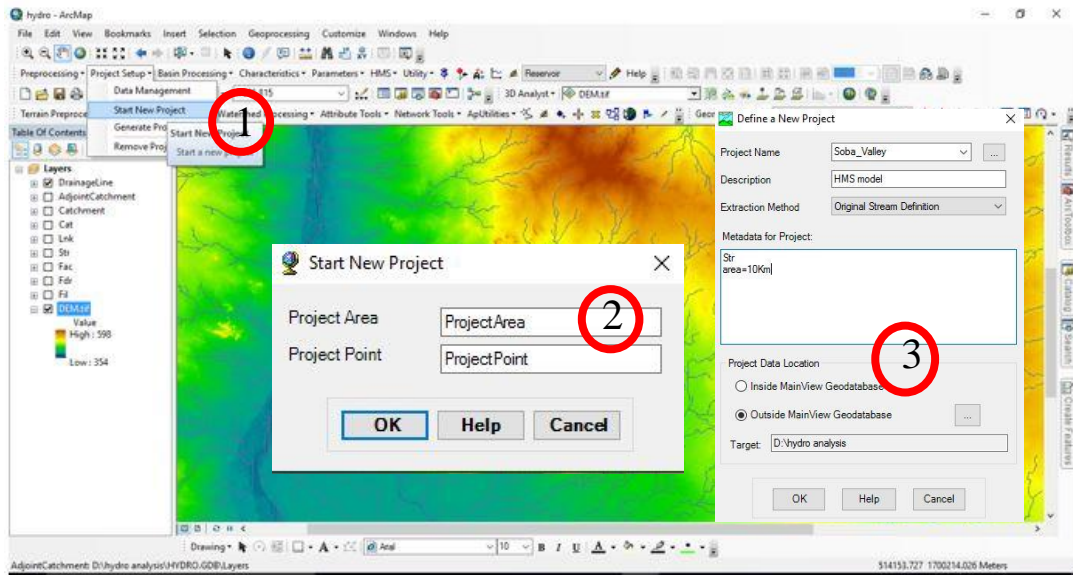


Figure 4.7 Define New Project

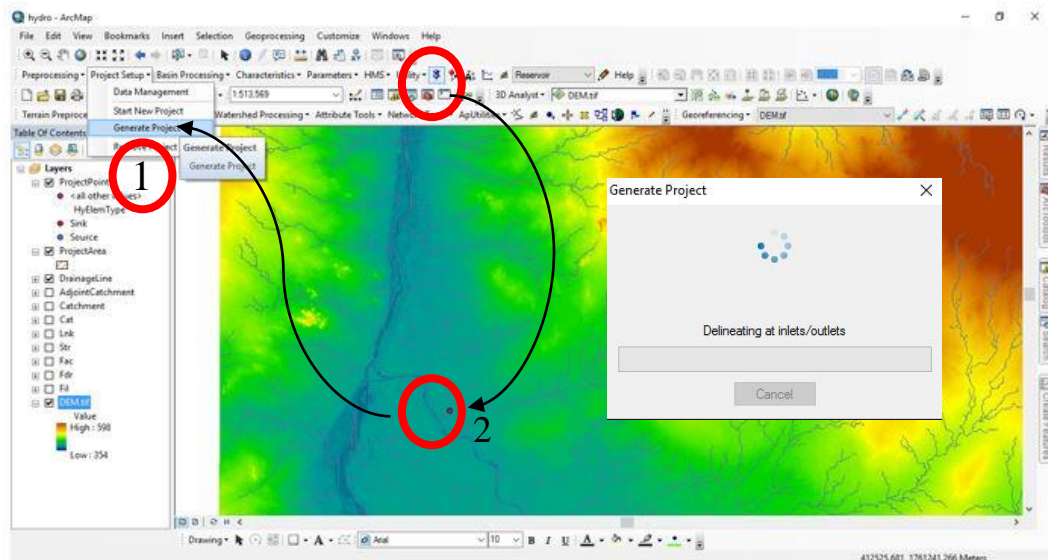


Figure 4.8 Steps for Creating New Project

Basin is divided on the basis of stream flow gage station. To make single subbasin the catchments in the same subbasin had been merged. After merge and split of basin river reach had been divided. The next step was to create a river profile, .The river profile tool had been found under the Basin Processing menu. The purpose of the river profile is to illustrate the elevation changes and breaks in the river (Figure 4.9).

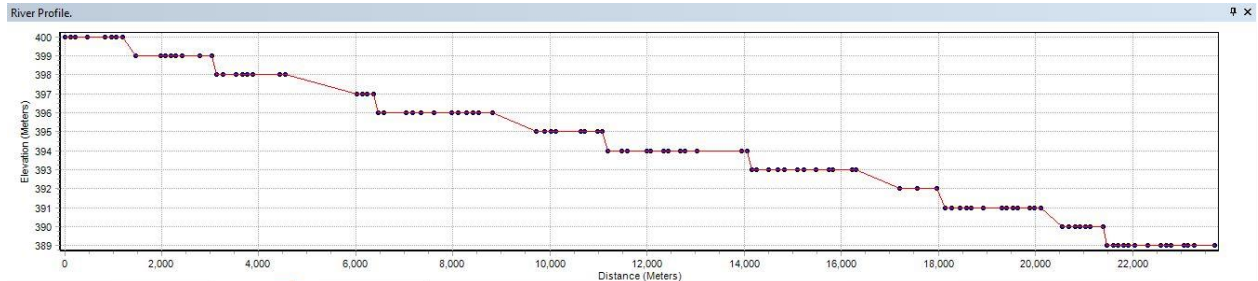


Figure 4.9 Stream Profile

The next steps had been used to obtain stream and subbasin characteristics using HEC- GeoHMS. These tools extract the topographic characteristics of streams and subbasins and are available from the Basin Characteristics menu on the HEC-GeoHMS Project View toolbar.

The first step in this process had been used the function River Length which adds a field named “RivLen” with the length of the river within the basin in the attribute table of the river. The River Slope function had been used to calculate the river slope of the river within the project area. It added the values for “ElevUP”, “ElevDS” and “Slp” in the attribute table of the river shown in Table 4.2 below.

Table 4.2 River attribute table

|  | OBJECTID* | Shape*   | arcid | grid_code | from_node | to_node | Shape_Length | HydroID | NextDownID | DrainID | Slp      | ElevUP | ElevDS | RivLen       |
|--|-----------|----------|-------|-----------|-----------|---------|--------------|---------|------------|---------|----------|--------|--------|--------------|
|  | 1         | Polyline | 1     | 3         | 1         | 2       | 11105.510604 | 1       | 5          | 18      | 0.00063  | 448    | 441    | 11105.510604 |
|  | 2         | Polyline | 2     | 1         | 3         | 2       | 24058.204636 | 2       | 5          | 16      | 0.001455 | 476    | 441    | 24058.204636 |
|  | 3         | Polyline | 3     | 2         | 4         | 5       | 26384.49942  | 3       | 6          | 17      | 0.001554 | 483    | 442    | 26384.49942  |
|  | 4         | Polyline | 4     | 4         | 6         | 5       | 16090.969737 | 4       | 6          | 19      | 0.001429 | 465    | 442    | 16090.969737 |
|  | 5         | Polyline | 5     | 6         | 2         | 7       | 9251.858468  | 5       | 14         | 21      | 0.000649 | 441    | 435    | 9251.858468  |
|  | 6         | Polyline | 6     | 8         | 5         | 7       | 7813.737736  | 6       | 14         | 23      | 0.000896 | 442    | 435    | 7813.737736  |
|  | 7         | Polyline | 7     | 7         | 8         | 9       | 14985.718827 | 7       | 9          | 22      | 0.001602 | 492    | 468    | 14985.718827 |
|  | 8         | Polyline | 8     | 9         | 10        | 9       | 9366.311174  | 8       | 9          | 24      | 0.001388 | 481    | 468    | 9366.311174  |
|  | 9         | Polyline | 9     | 11        | 9         | 11      | 14459.753799 | 9       | 12         | 26      | 0.001245 | 468    | 450    | 14459.753799 |
|  | 10        | Polyline | 10    | 5         | 12        | 11      | 35288.42651  | 10      | 12         | 20      | 0.001502 | 503    | 450    | 35288.42651  |
|  | 11        | Polyline | 11    | 14        | 13        | 14      | 905.686879   | 11      | 13         | 29      | 0.003312 | 421    | 418    | 905.686879   |
|  | 12        | Polyline | 12    | 12        | 11        | 14      | 43112.651769 | 12      | 13         | 29      | 0.000742 | 450    | 418    | 43112.651769 |
|  | 13        | Polyline | 13    | 13        | 14        | 15      | 30546.149626 | 13      | 15         | 28      | 0.000786 | 418    | 394    | 30546.149626 |
|  | 14        | Polyline | 14    | 10        | 7         | 15      | 54848.092342 | 14      | 15         | 25      | 0.000748 | 435    | 394    | 54848.092342 |
|  | 15        | Polyline | 15    | 15        | 15        | 16      | 6531.56361   | 15      | -1         | 30      | 0        | 394    | 394    | 6531.56361   |

Next the Basin Slope function had been used to determine the average basin slope in the watershed. It adds a field in the subbasins attribute table called “Basin Slope”,

which is the average slope of the subbasin. The basin slope is illustrated below in Table 4.3.

Table 4.3 Subbasin attribute table

| OBJECTID * | Shape * | grid_code | Shape_Length | Shape_Area       | HydroID | DrainID | Name | Description | PrecipGage     | TotStormP  | BasinSlope | LossMet |
|------------|---------|-----------|--------------|------------------|---------|---------|------|-------------|----------------|------------|------------|---------|
| 1          | Polygon | 1         | 128164.7632  | 186752582.585657 | 16      | 16      | W160 | <Null>      | Precip Gage 1  | 161.6026   | 0.968034   | SCS     |
| 2          | Polygon | 2         | 146187.9342  | 392007250.757869 | 17      | 17      | W170 | <Null>      | Precip Gage 2  | 167.980316 | 1.090196   | SCS     |
| 3          | Polygon | 3         | 130895.5468  | 155407579.419569 | 18      | 18      | W180 | <Null>      | Precip Gage 3  | 162.007477 | 0.910912   | SCS     |
| 4          | Polygon | 4         | 114510.8476  | 234983949.160756 | 19      | 19      | W190 | <Null>      | Precip Gage 4  | 181.201141 | 1.169171   | SCS     |
| 5          | Polygon | 5         | 162208.5292  | 383348639.266289 | 20      | 20      | W200 | <Null>      | Precip Gage 5  | 194.609573 | 1.119534   | SCS     |
| 6          | Polygon | 6         | 104133.87    | 135190342.64529  | 21      | 21      | W210 | <Null>      | Precip Gage 6  | 171.904907 | 0.921972   | SCS     |
| 7          | Polygon | 7         | 115785.2126  | 199645213.933377 | 22      | 22      | W220 | <Null>      | Precip Gage 7  | 181.676178 | 1.186999   | SCS     |
| 8          | Polygon | 8         | 32223.2436   | 11600053.928065  | 23      | 23      | W230 | <Null>      | Precip Gage 8  | 177.31102  | 0.815087   | SCS     |
| 9          | Polygon | 9         | 102677.4516  | 117301402.196323 | 24      | 24      | W240 | <Null>      | Precip Gage 9  | 184.379501 | 1.143431   | SCS     |
| 10         | Polygon | 10        | 250321.8048  | 452443531.675928 | 25      | 25      | W250 | <Null>      | Precip Gage 10 | 185.888809 | 0.998692   | SCS     |
| 11         | Polygon | 11        | 55161.8232   | 63253437.028001  | 26      | 26      | W260 | <Null>      | Precip Gage 11 | 198.975296 | 1.129232   | SCS     |
| 13         | Polygon | 13        | 96487.6774   | 72359479.258125  | 28      | 28      | W280 | <Null>      | Precip Gage 12 | 195.528259 | 0.932338   | SCS     |
| 14         | Polygon | 14        | 181324.0124  | 575296388.382672 | 29      | 29      | W290 | <Null>      | Precip Gage 13 | 203.45694  | 1.148566   | SCS     |
| 15         | Polygon | 15        | 80467.0818   | 67272026.878984  | 30      | 30      | W300 | <Null>      | Precip Gage 14 | 200.045959 | 1.082852   | SCS     |

Next, the Longest Flow Path tool had been used to compute the longest path a drop of water can take to contribute to the outlet in the watershed. The Longest Flow Path tool created the longest flow length, upstream elevation, downstream elevation, and slope between the endpoints. The attribute table for the Longest Flow Path layer can be seen below in Table 4.4.

Table 4.4 Longest Flow path attribute table

| OBJECTID * | Shape *  | Shape_Length | DrainID | Slp      | ElevUP | ElevDS | Slp1085  | Elev10 | Elev85 |
|------------|----------|--------------|---------|----------|--------|--------|----------|--------|--------|
| 1          | Polyline | 36490.617417 | 114     | 0.003124 | 552    | 438    | 0.002887 | 443    | 522    |
| 2          | Polyline | 47773.050846 | 105     | 0.002658 | 551    | 424    | 0.002121 | 431    | 507    |
| 3          | Polyline | 36490.617417 | 114     | 0.003097 | 551    | 438    | 0.002887 | 443    | 522    |
| 4          | Polyline | 47773.050746 | 105     | 0.0027   | 553    | 424    | 0.002121 | 431    | 507    |
| 5          | Polyline | 29119.072212 | 103     | 0.002885 | 514    | 430    | 0.002564 | 432    | 488    |
| 6          | Polyline | 19088.917711 | 126     | 0.004191 | 500    | 420    | 0.002794 | 423    | 463    |
| 7          | Polyline | 20294.343375 | 121     | 0.003696 | 492    | 417    | 0.002628 | 421    | 461    |
| 8          | Polyline | 8515.285667  | 122     | 0.002701 | 453    | 430    | 0.002662 | 430    | 447    |
| 9          | Polyline | 20260.428934 | 130     | 0.001826 | 451    | 414    | 0.001711 | 415    | 441    |
| 10         | Polyline | 13246.518997 | 129     | 0.002491 | 452    | 419    | 0.001912 | 419    | 438    |
| 11         | Polyline | 41249.85072  | 149     | 0.001406 | 468    | 410    | 0.001099 | 413    | 447    |
| 12         | Polyline | 13927.87505  | 143     | 0.001939 | 440    | 413    | 0.001723 | 414    | 432    |
| 13         | Polyline | 13927.87505  | 143     | 0.001939 | 440    | 413    | 0.001723 | 414    | 432    |
| 14         | Polyline | 7043.250528  | 138     | 0.003691 | 440    | 414    | 0.00284  | 416    | 431    |

The next step had been used the Basin Centroid tool to find the centroid of the subbasins. The center of gravity method had been used to find the centroid because this would represent an adequate centroid location for the subbasins. The center of gravity method computes the centroid as the center of gravity of the subbasin.

The Centroid Elevation tool had been used to compute the elevation of each centroid point (Figure 4.10).

After that the Centroidal Flow Path tool had been used to compute the flow path of the centroid by projecting it onto the longest flow path. The centroidal flow path is then measured from the projected point into the longest flow path to the subbasin outlet.

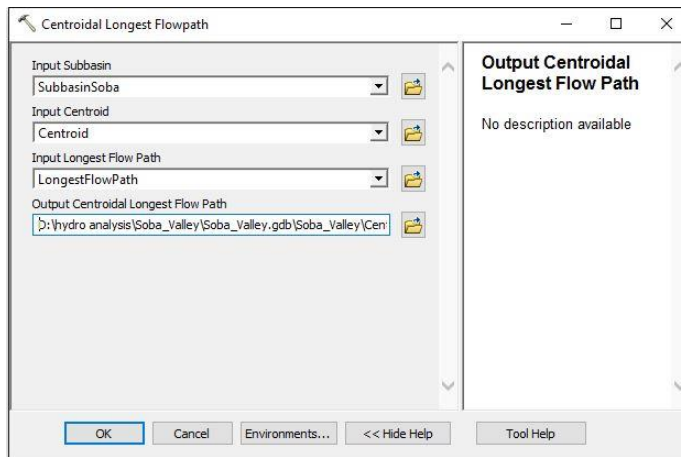


Figure 4.10 Centroid Longest Flow path

**- Unit Hydrograph Method**

The Purpose of unit hydrograph is to generate the hydrographs for the storm in the hydrologic events periods. SCS unit hydrograph, Snyder synthetic unit hydrograph and Clark Synthetic hydrograph methods are commonly used (Wurbs and James, 2002). This study had been adopted the SCS unit hydrograph method. The SCS unit hydrograph is used because it requires two parameters, which are watershed area and lag time as the study area is un-gauged and lacks information.

**- SCS Unit Hydrograph**

SCS Unit Hydrograph was developed by NRCS in the 1950's based on analyses of many unit hydrographs for gaged watersheds in various conditions. Due to simplicity and easy to use SCS hydrograph have been used and applied throughout the United States and the world. The SCS Unit hydrograph only has two parameters, which are watershed area  $A$  and lag time  $t_L$ . The time to peak  $T_P$  is estimated as a function of rainfall duration  $D$  and the peak of the unit hydrograph  $Q_P$  is estimated as flow. Equation (1 and 2) (Wurbs and James, 2002).

$$T_P = \frac{D}{2} + t_L \dots \dots \dots (4.1)$$

$$Q_P = \frac{484A}{T_P} \dots \dots \dots (4.2)$$

The HMS Process tool had been used (Figure 4.11) to select the methods to be used by HEC- HMS to analyze the watershed. The SCS method had been chosen for both the Loss and the Transform Method, and Muskingum method had been chosen for the Route Method.



Then the River Auto Name and Basin Auto Name tools had been used to assign names to the river reaches and subbasins.

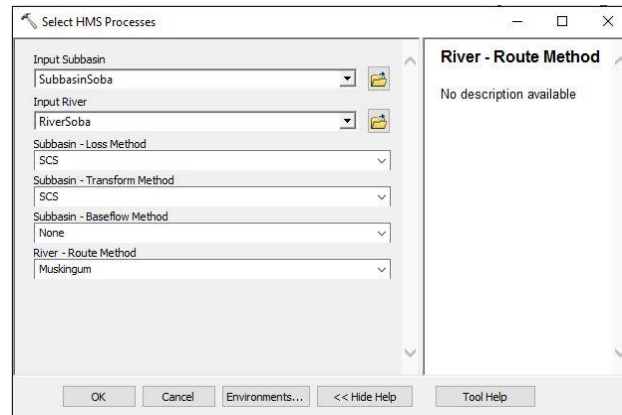


Figure 4.11 Select HMS Process

- CN Lag time

CN Lag time is calculated to be used in SCS transform method in HMS. Using CN Lag time of concentration is computed. After computing CN grid and other hydrologic parameters HMS setting is executed. HMS setting assign the loss method, transform method and routing method will be used in HMS and generate the HMS schematic, such as river reach, junction and subbasin.

### 4.4.3 Computing SCS Curve Number in GIS:-

The runoff curve number (also called a curve number or simply CN) is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess

(1) Land use Reclassification and delineation

Land use raster data has attribute categorized in accordance with land cover. Origin land use data has many land cover category to facilitate the process it is needed to simplify the category. To reduce the category raster reclassify had been used (Figure 4.12). To extract the land use data which fit in the extent of study area raster calculator or extract by mask had been used. Extracted land use raster had been converted to polygon.

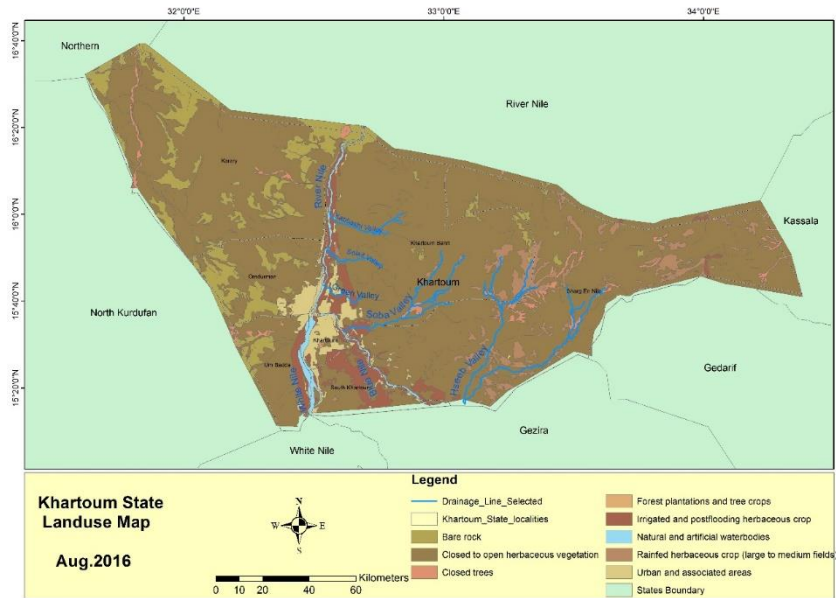


Figure 4.12 Reclassify Map

(2) Soil data modification

To compute CN soil data (Figure 4.13) has to include information of hydrologic soil group. However, soil geodatabase files that had been collected have hydrologic soil group (Table 4.5).

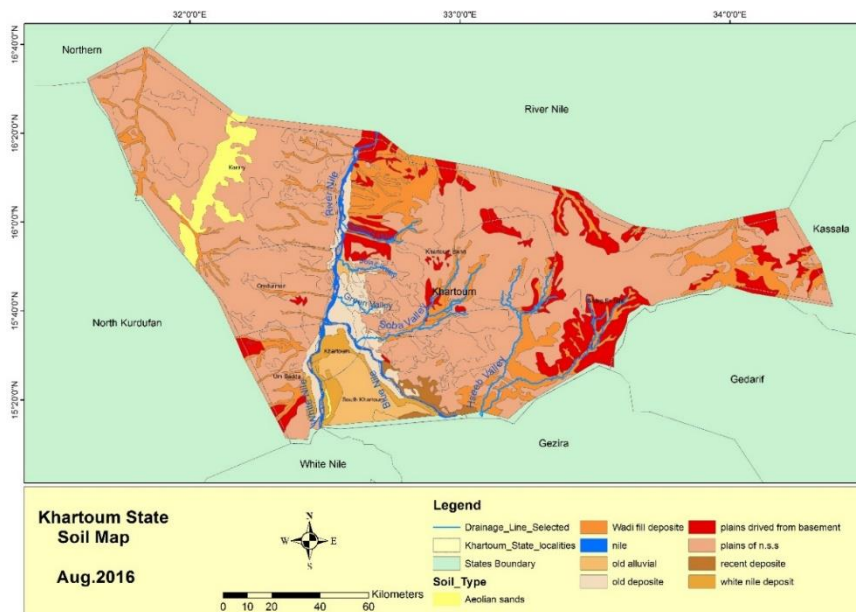


Figure 4.13 Soil Map

Table 4.5 hydrologic soil group

|   | H1DLIM | HYDROGROUP | PctA | PctB | PctC | PctD |
|---|--------|------------|------|------|------|------|
|   | 0.14   | C          | 0    | 0    | 100  | 0    |
|   | 0.17   | D          | 0    | 0    | 0    | 100  |
|   | 0.14   | C          | 0    | 0    | 100  | 0    |
|   | 0.07   | C          | 0    | 0    | 100  | 0    |
| ▶ | 0.16   | D          | 0    | 0    | 0    | 100  |

(3) Union soil and land use data

Treated soil and land use data have union processing. Through union processing attributes of soil and land use data combined to one shape file (Table 4.6). These union file and CNLookup tables are used computing CN grid process in HEC-GeoHMS.

Table 4.6 Landuse and Soil attribute table

|     | HYDROGROUP | PctA | PctB | PctC | PctD | FID_landus | LCID | LCNAME   |
|-----|------------|------|------|------|------|------------|------|--|
| C   | 0          | 0    | 100  | 0    |      | 1          | FR-1 | Closed trees                                     |
| C   | 0          | 0    | 100  | 0    |      | 3          | RL-1 | Closed to open herbaceous vegetation             |
| C   | 0          | 0    | 100  | 0    |      | 4          | BA-1 | Bare rock  |
| C   | 0          | 0    | 100  | 0    |      | 5          | AG-1 | Rainfed herbaceous crop (large to medium fields) |
| C   | 0          | 0    | 100  | 0    |      | 6          | AG-3 | Irrigated and postflooding herbaceous crop       |
| D   | 0          | 0    | 0    | 100  |      | 3          | RL-1 | Closed to open herbaceous vegetation             |
| D   | 0          | 0    | 0    | 100  |      | 6          | AG-3 | Irrigated and postflooding herbaceous crop       |
| C   | 0          | 0    | 100  | 0    |      | 3          | RL-1 | Closed to open herbaceous vegetation             |
| C   | 0          | 0    | 100  | 0    |      | 4          | BA-1 | Bare rock  |
| C   | 0          | 0    | 100  | 0    |      | 3          | RL-1 | Closed to open herbaceous vegetation             |
| D   | 0          | 0    | 0    | 100  |      | 3          | RL-1 | Closed to open herbaceous vegetation             |
| D   | 0          | 0    | 0    | 100  |      | 6          | AG-3 | Irrigated and postflooding herbaceous crop       |
| D   | 0          | 0    | 0    | 100  |      | 0          | UR   | Urban and associated areas                       |
| D   | 0          | 0    | 0    | 100  |      | 2          | UR   | Urban and associated areas                       |
| D   | 0          | 0    | 0    | 100  |      | 0          | UR   | Urban and associated areas                       |
| ▶ D | 0          | 0    | 0    | 100  |      | 2          | UR   | Urban and associated areas                       |

- CNLookup table is like index can related the land use and soil group attribute with CN (Table 4.7).

Table 4.7 CNLookup table

| OID | Field1 | Value | Descript     | A   | B   | C   | D   | LUValue |
|-----|--------|-------|--------------|-----|-----|-----|-----|---------|
| 0   | 0      | 1     | Water        | 100 | 100 | 100 | 100 | 1       |
| 1   | 0      | 4     | Forest       | 43  | 85  | 76  | 82  | 4       |
| 2   | 0      | 5     | Agricultural | 64  | 75  | 82  | 85  | 5       |
| 3   | 0      | 2     | Urban        | 77  | 85  | 90  | 92  | 2       |
| 4   | 0      | 3     | Barron       | 77  | 86  | 91  | 94  | 3       |

HEC-GeoHMS had been used to generate the curve number grid. The Hydrologic Parameter Estimation tools had been used next to estimate some of the hydrologic parameters. The first tool had been used Subbasin Parameters from Raster. This tool operates on a raster layer and computes the average hydrologic parameters for each subbasin. Using the land use data and impervious surfaces data, the Curve Number and Percent Impervious for each subbasin were determined respectively. An image of landuse data within the subbasin is shown in (Figure 4.14).

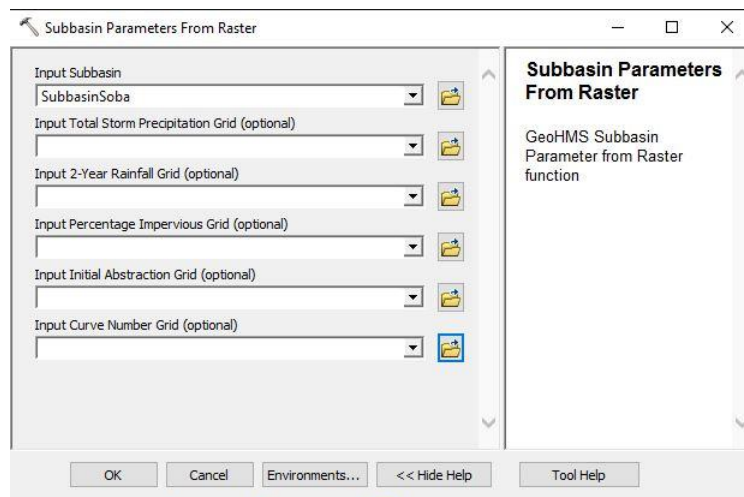


Figure 4.14 Subbasin Parameters from Raster

After that, the hydrologic inputs for HEC- HMS were developed. The first tool had been used Map to HMS Units. This converts the physical characteristics of reaches and subbasins into English units.

The HMS Data Check tool had been used to check the datasets for inconsistencies. This tool checks the datasets for consistency in describing the hydrologic structure of the model. No errors were found. (Figure 4.15)

```
CHECKING SUMMARY
*****

Unique names          - no problems.
River containment     - no problems.
Center containment    - no problems.
River connectivity    - no problems.
VIP relevance         - no problems.
```

Figure 4.15 Checking Summary

HEC- HMS Basin Schematic had been used to create the GIS representation of the HEC- HMS model. This tool builds a simple hydrologic network that contains HEC- HMS model elements and shows their connectivity. After creating the HEC- HMS Schematic, the HMS Legend tool had been used to input HEC- HMS icons to represent point and line features.

Add Coordinates tool had been used which added coordinates to the HMS Nodes and HMS Link layers. Then the Prepare Data for Model Export tool had been used. This tool gathers parameter data stored in the attribute tables for the subbasin and river layers and prepares it for export to the HEC- HMS basin model file. The Background Map tool had been used to create the background map layers.

#### **4.4.4 Hydrologic Modeling System Process:**

##### **4.4.4.1 Muskingum Routing Method:**

The Muskingum method is a simple, approximate method to calculate the outflow hydrograph at the downstream end of the channel reach given the inflow hydrograph at the upstream end. No lateral inflow into the channel reach is considered. Among many models used for flood routing in rivers, it is a straight forward hydrological flood routing technique used in natural channels, and it has been extensively applied in river engineering practice since its introduction in 1930s. It was applied to both gauged and ungauged watersheds.

The routing method deals with the movement of the water in the reach. The Muskingum routing method is popular and relatively simple to use for stream flow, hence it had been selected (Wurbs and James, 2002).

Muskingum routing method is represented as follow:-

$$S = K(xI + (1 - x)O) \dots\dots\dots (4.3)$$

$$O_2 = C_1I_2 + C_2I_1 + C_3I_0 \dots\dots\dots (4.4)$$

Where, S is storage, I is inflow, O is outflow, t is travel time.

$$C_1 = \frac{0.5\Delta t - kx}{k - kx + 0.5\Delta t} \dots\dots\dots (4.5)$$

$$C_2 = \frac{0.5\Delta t + kx}{k - kx + 0.5\Delta t} \dots\dots\dots (4.6)$$

$$C_3 = \frac{k - kx - 0.5\Delta t}{k - kx + 0.5\Delta t} \dots\dots\dots (4.7)$$

$$C_1 + C_2 + C_3 = 1 \dots\dots\dots (4.8)$$

Where k travel time and x is storage routing.

#### **4.4.4.2 Control Specifications:**

HEC-HMS control specifications had been used to define the simulation start and stop time and the time step interval. It should match with the time windows of the time-series precipitation data.

#### **4.4.4.3 HEC-HMS Simulation:**

The HEC-HMS model components such as basin models, meteorological models, and control specifications had been created and populated with data, and simulations had been executed with various inputs. HEC-HMS allows many combinations of different model parts to run for various scenarios.

#### **4.4.5 Select Suitable Site For Water Harvesting Projects:**

After the boundary of the watershed derived from the DEM by software ARC hydro, the software ArcGIS used to derive the layers of different orders of valleys from the DEM According to the results of Slope and hydrology analysis, seven locations had been selected as suggested water reservoir. The path profiles were done by Global Mapper in the seven selected locations; also the watersheds of the selected reservoirs were derived by Hec-GeoHMS. The major landuse, landcover, stream order and location of water body were projected on the watershed area of the valley to see the impact of suggested locations on area.

#### **4.4.6 Calculating the volume and surface of a reservoir:**

The surface areas, volume of reservoirs, determined for every suggested location. Using ArcGIS by converting contour into a Triangulated Irregular Network (TIN), then the contour that marks the reservoir maximum level had been selected and converted into a Polygon after that to calculate the total volume of the reservoir the volume model had been prepared and run to achieve the area and volume of reservoir.

#### **4.4.7 Model Builder**

Model Builder is very useful for constructing and executing simple workflows, it also provides advanced methods for extending ArcGIS functionality by allowing you to create and share your models as tool.

Model had been built to assemble all the previous procedures (Terrain preprocessing) in one tool called Hydro model (Figure 4.16), another models had been built to dam sites locations and calculate the area and volume of reservoir the models called dam location selection model (Figure 4.17) and Volume model (Figure 4.18) and (Figure 4.19) shows the flowchart of hydro model.

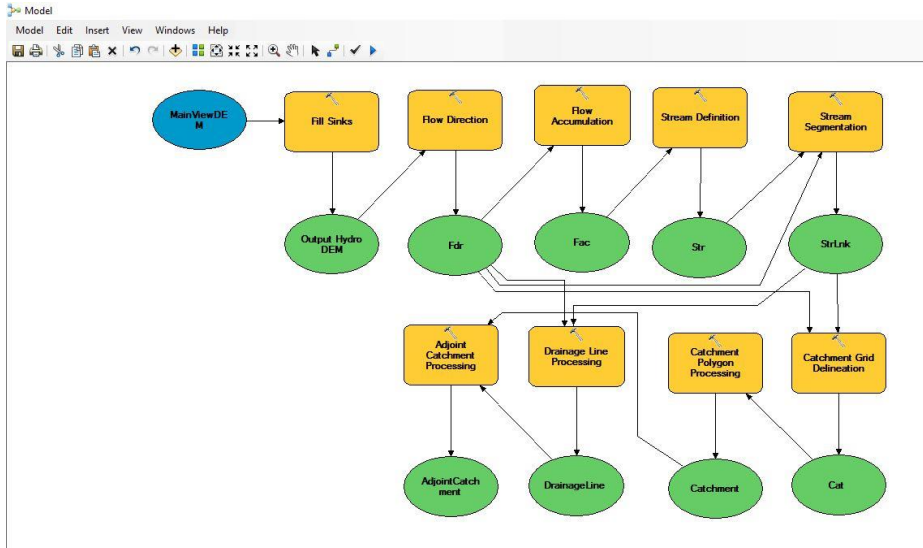


Figure 4.16 Hydro model

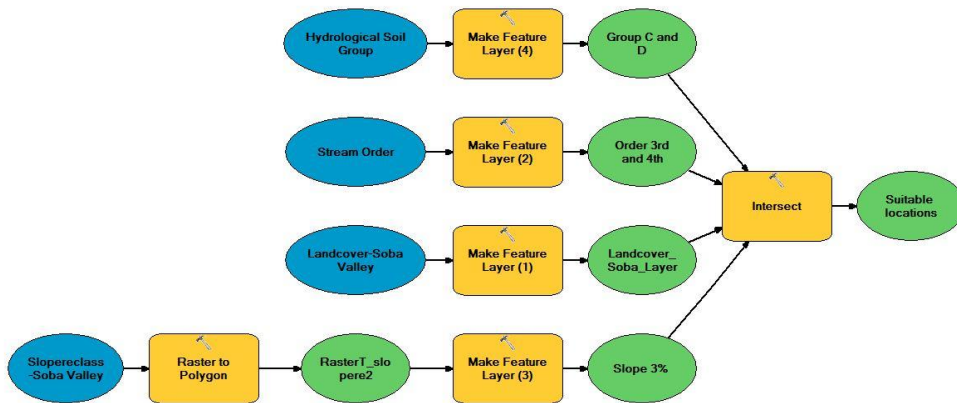


Figure 4.17 dam location selection model



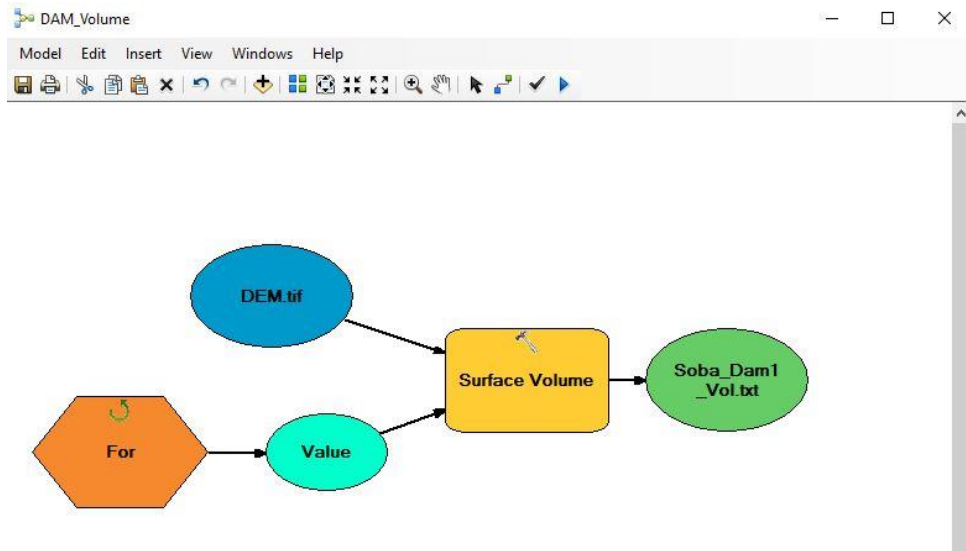


Figure 4.18 Volume Model

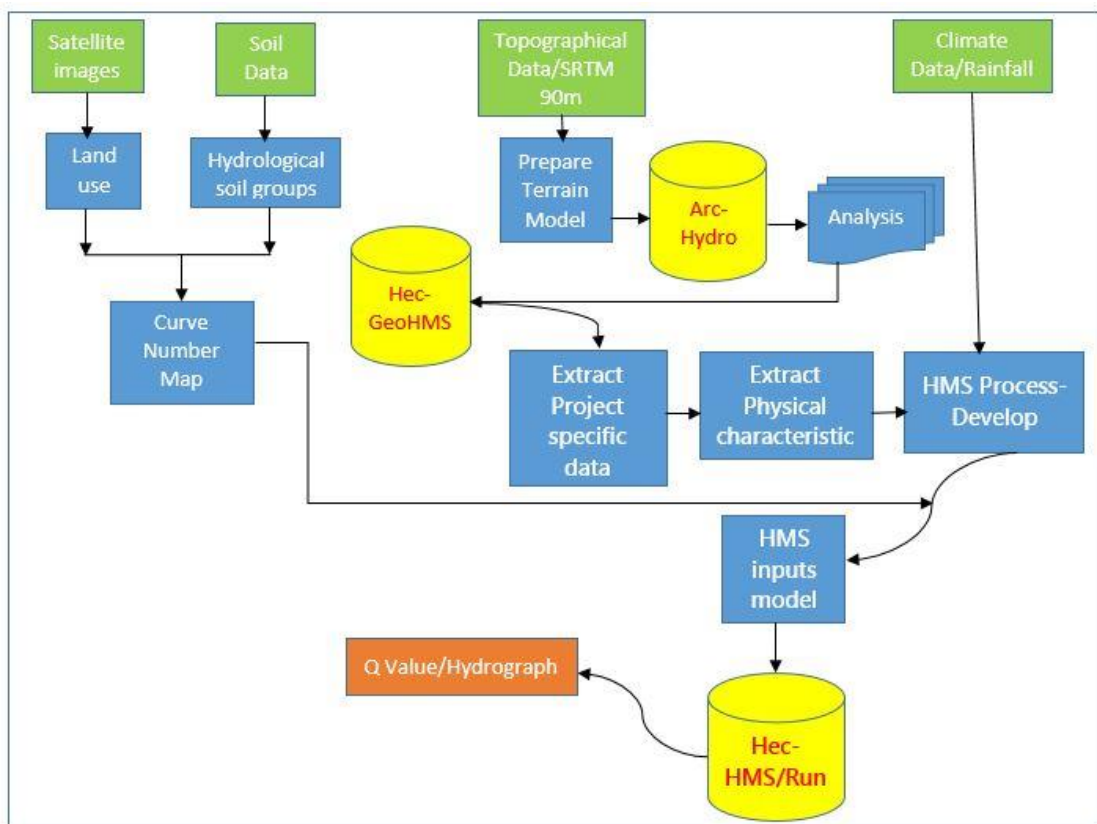


Figure 4.19 Flowchart of the Hydro model

# CHAPTER FIVE

## RESULTS AND ANALYSIS

This chapter presents results of data processing and analysis of the previous chapter and explanations of these results obtained.

The analysis steps as shown in the Flowchart (figure 4.19) had been applied and the following results had been obtained:

- Runoff model had been built using HEC-GeoHMS and drainage network had been resulted as shown on (Figure 5.1) and soba valley subbasin shown on (Figure 5.2)

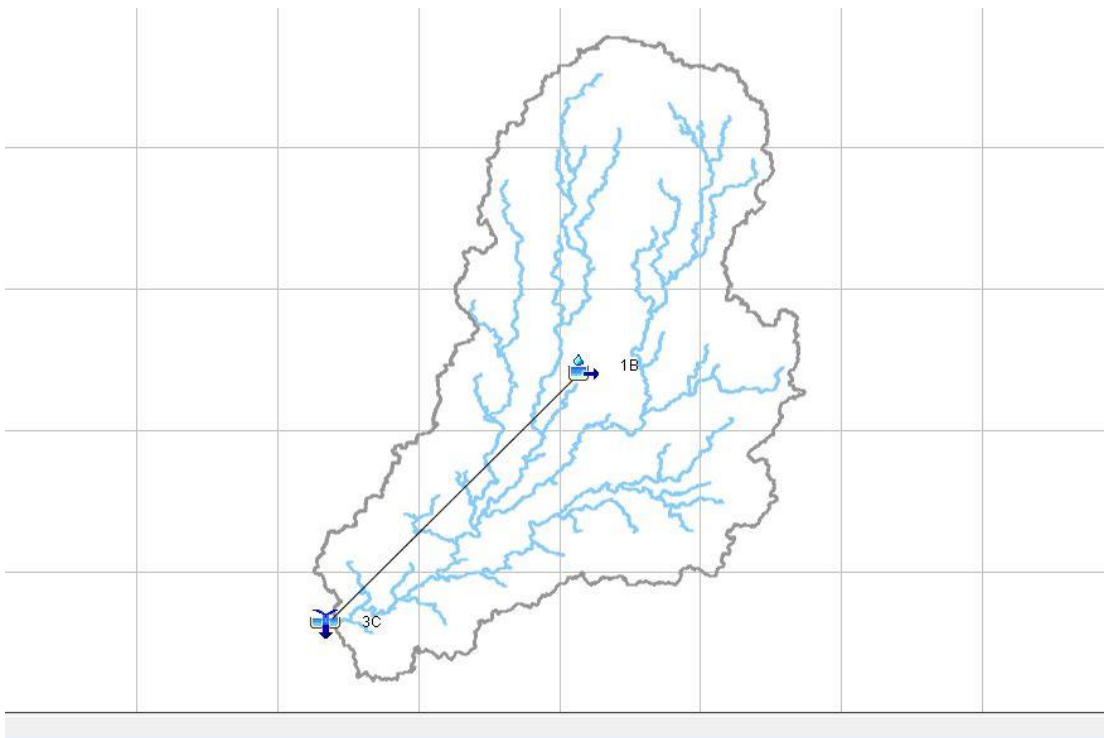


Figure 5.1 Runoff Model

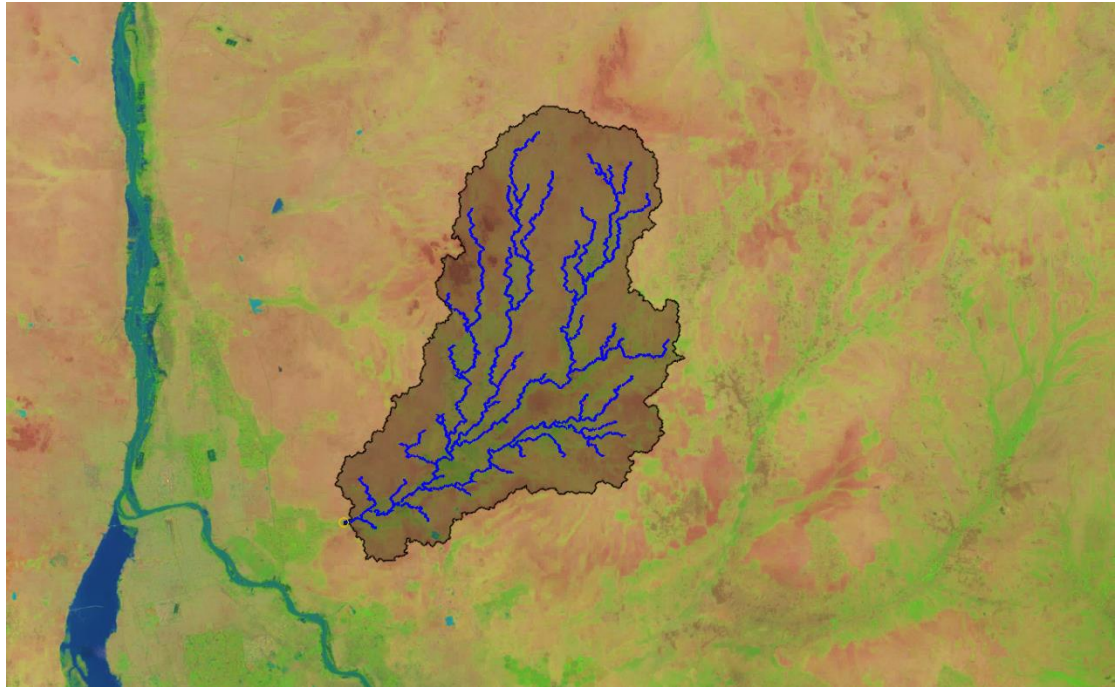


Figure 5.2 Soba Valley Subbasin

- Runoff through the Valley was finally estimated using HEC-HMS. All parameters needed for the HMS were computed through, ArcGIS and HEC-GeoHMS. The hydrograph of subbasin and routed hydrograph at each junction were created. This results show the hydrograph of basin located in the downstream of Soba Valley in the periods from Jan.01.2013 to Dec.31.213. (Figure 5.3 &5.4) represents the runoff of SCS transform method and (Figure 5.5 & 5.6) represents the Flow volume from 2001 to 2015.

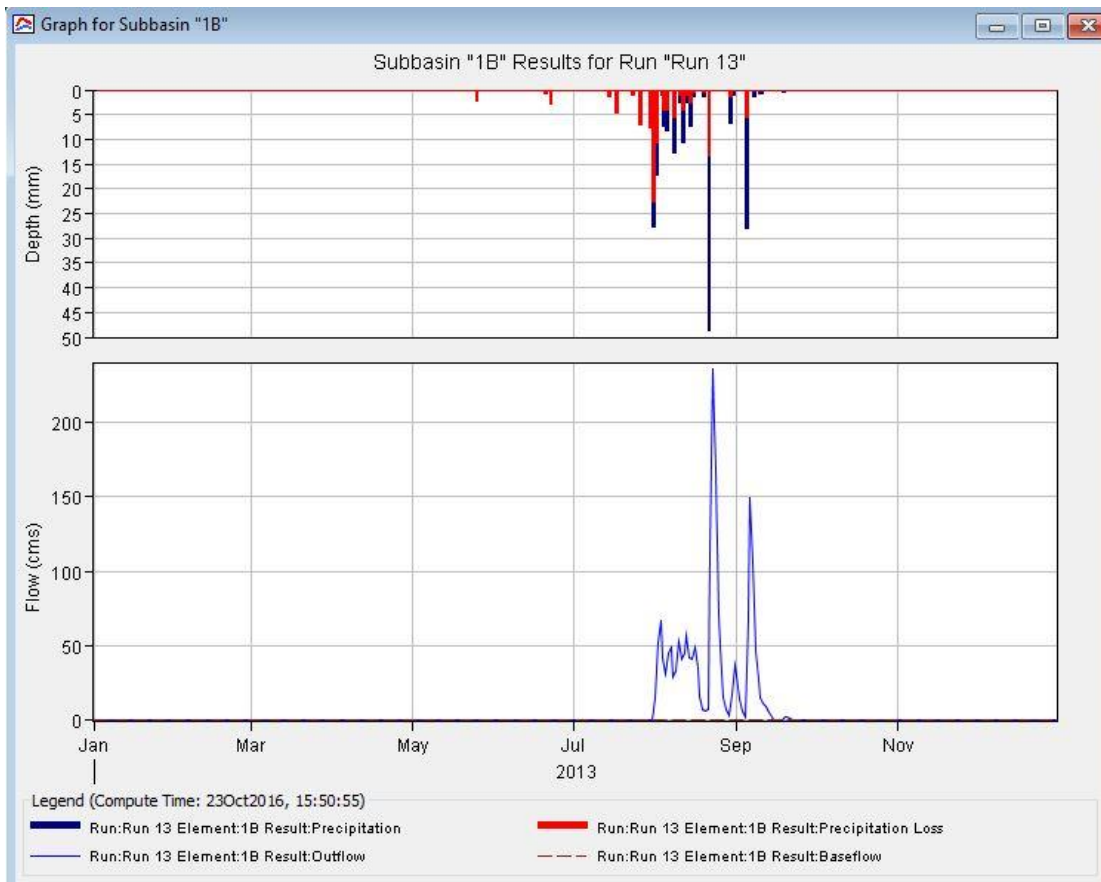


Figure 5.3 Runoff of SCS Transform method

Show Elements: All Elements Volume Units:  MM  1000 M3 Sorting: Hydrologic

| Hydrologic Element | Drainage Area (KM2) | Peak Discharge (M3/S) | Time of Peak     | Volume (1000 M3) |
|--------------------|---------------------|-----------------------|------------------|------------------|
| 1B                 | 1552.3562           | 235.7                 | 23Aug2013, 00:00 | 170216.7         |
| 3C                 | 1552.3562           | 235.7                 | 23Aug2013, 00:00 | 170216.7         |

Figure 5.4 Summary Results

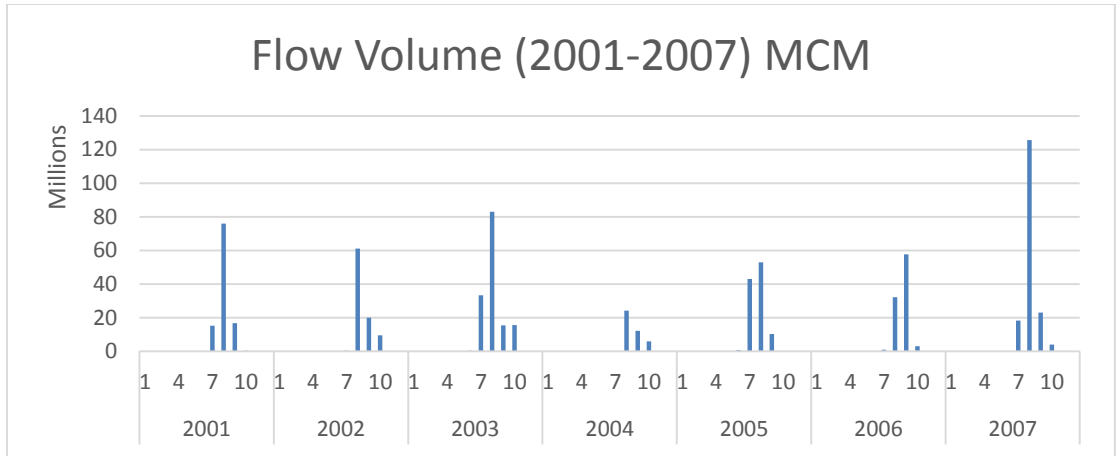


Figure 5.5 Flow Volume from (2001-2007)

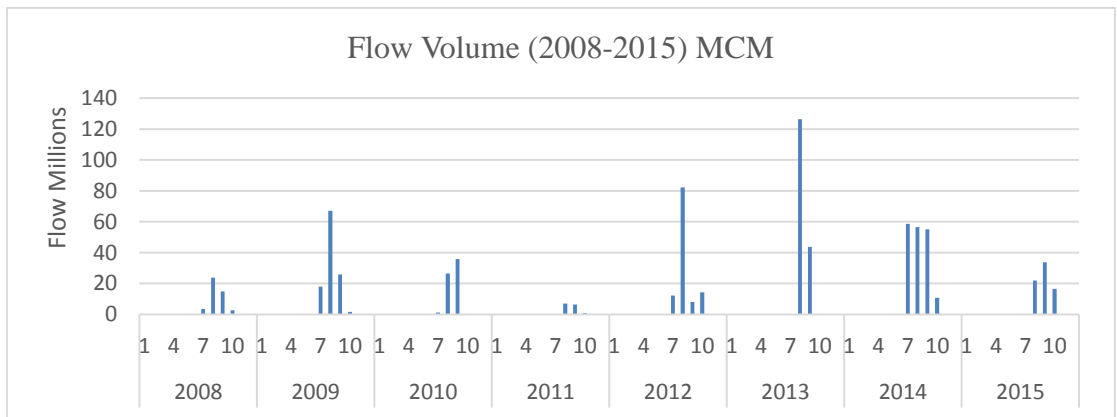


Figure 5.6 Flow Volume from (2008-2015)

- Volume model had been built and using to calculate reservoir volume for selected sites the following had been resulted:

Table 5.1 Reservoir Surface Area and Volume

| <b>Elevation (m)</b> | <b>Reservoir Surface Area(Km2)</b> | <b>Reservoir Volume (10<sup>6</sup> m3)</b> |
|----------------------|------------------------------------|---|
| 391                  | 4.467                              | 4.76  |
| 392                  | 7.375                              | 10.39                                       |
| 393                  | 11.071                             | 19.25                                       |
| 394                  | 15.339                             | 32.15                                       |
| 395                  | 20.302                             | 49.58                                       |
| 396                  | 26.408                             | 72.41                                       |
| 397                  | 33.994                             | 101.97                                      |
| 398                  | 43.666                             | 139.88                                      |
| 399                  | 55.287                             | 188.40                                      |
| 400                  | 68.791                             | 249.34                                      |
| 401                  | 83.967                             | 324.67                                      |
| 402                  | 99.694                             | 415.56                                      |
| 403                  | 114.612                            | 522.17                                      |
| 404                  | 127.828                            | 643.08                                      |
| 405                  | 140.585                            | 776.82                                      |
| 406                  | 153.434                            | 923.28                                      |
| 407                  | 167.390                            | 1082.83                                     |
| 408                  | 183.062                            | 1257.00                                     |
| 409                  | 200.925                            | 1447.70                                     |
| 410                  | 219.975                            | 1656.95                                     |
| 411                  | 239.212                            | 1885.49                                     |
| 412                  | 257.766                            | 2133.20                                     |
| 413                  | 275.236                            | 2399.06                                     |
| 414                  | 291.542                            | 2681.91                                     |
| 415                  | 306.498                            | 2980.50                                     |
| 416                  | 320.568                            | 3293.58                                     |
| 417                  | 334.862                            | 3620.66                                     |
| 418                  | 350.828                            | 3962.51                                     |
| 419                  | 368.115                            | 4320.90                                     |
| 420                  | 384.397                            | 4696.53                                     |

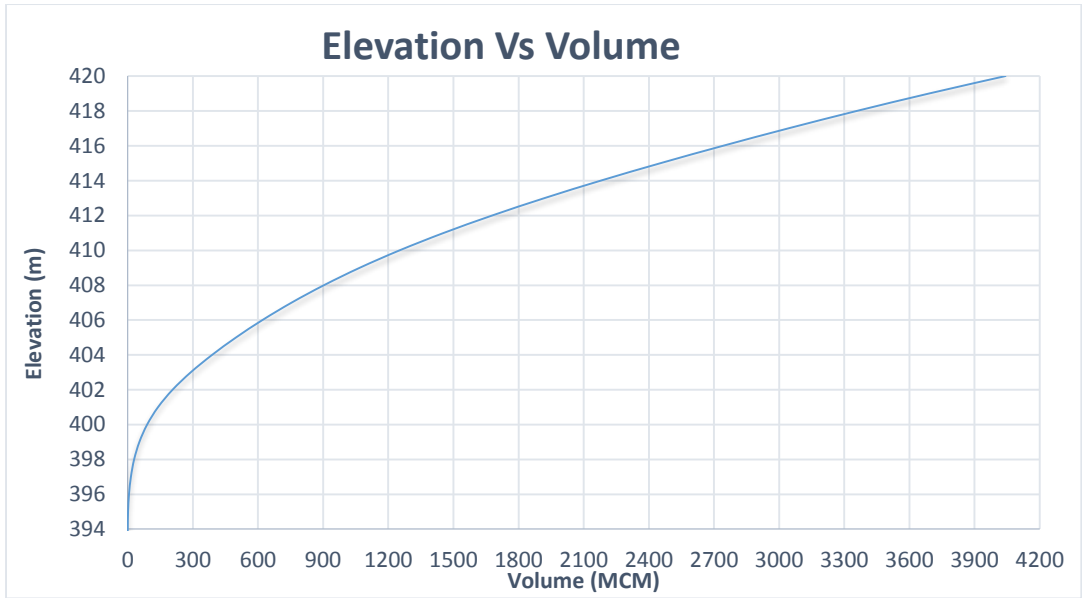


Figure 5.7 Elevation vs. Volume

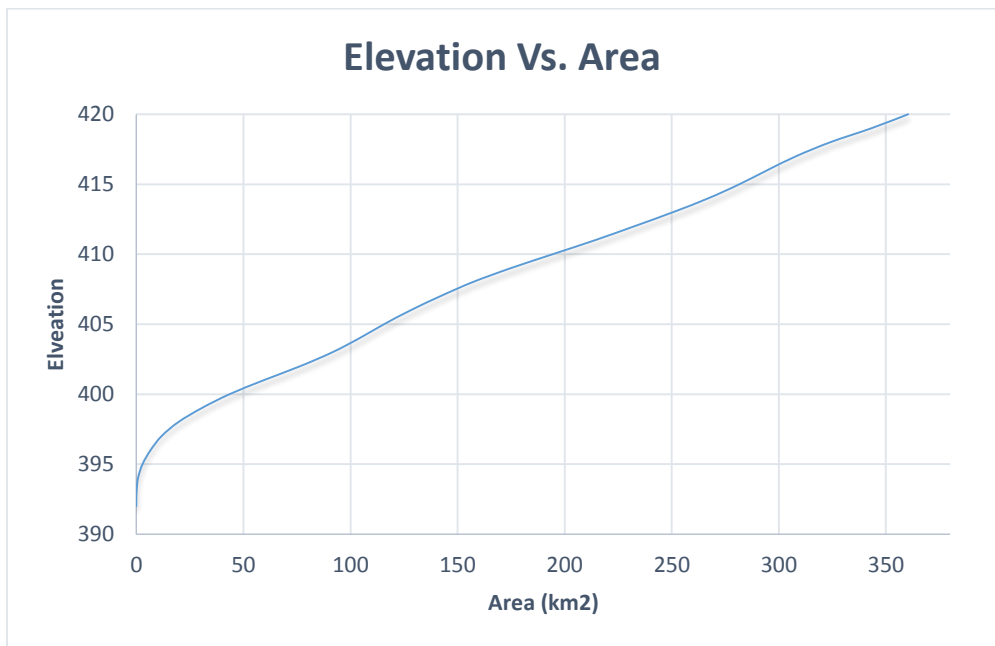


Figure 5.8 Elevation vs. Area

- Applying conditions of dam site selection in 2.2.4 the following results had been achieved:

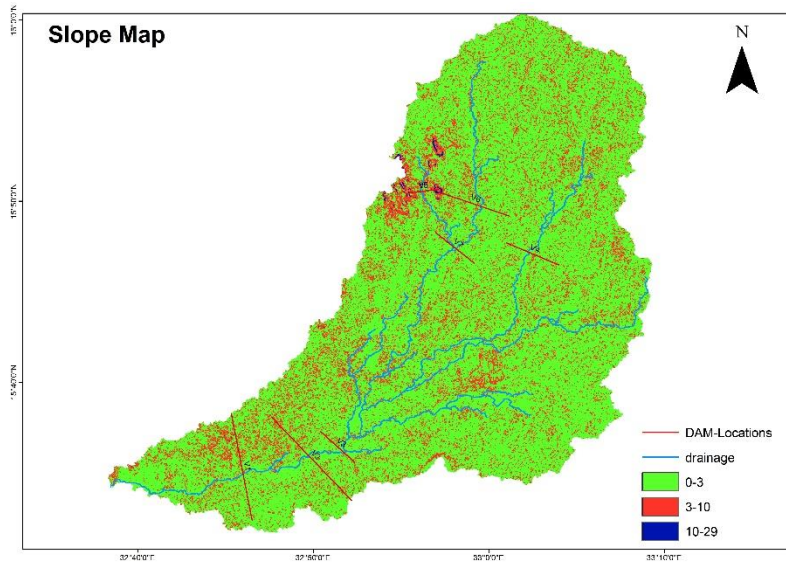


Figure 5.9 Slop Map

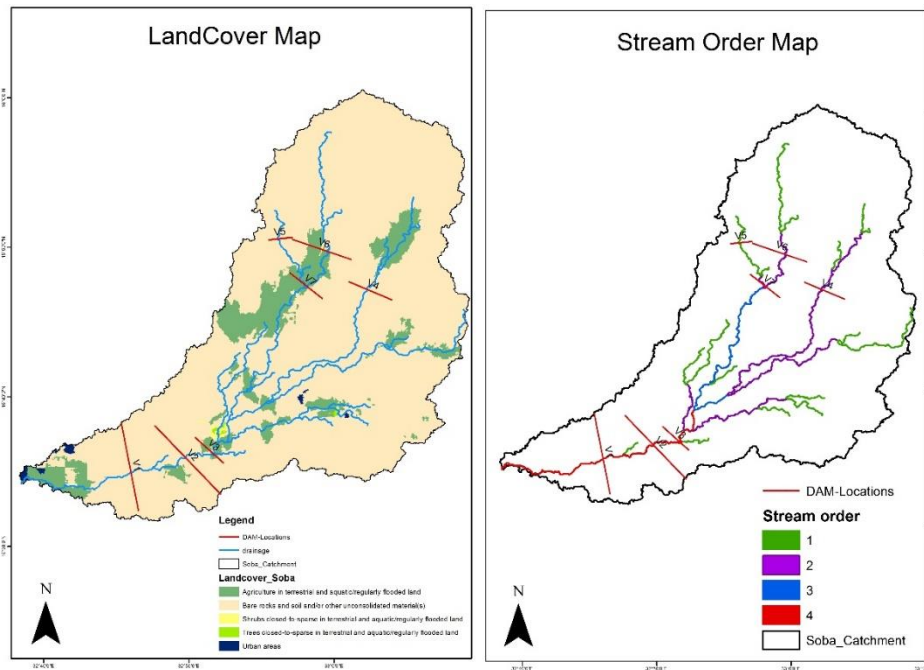


Figure 5.10 LandCover and Stream Order Map



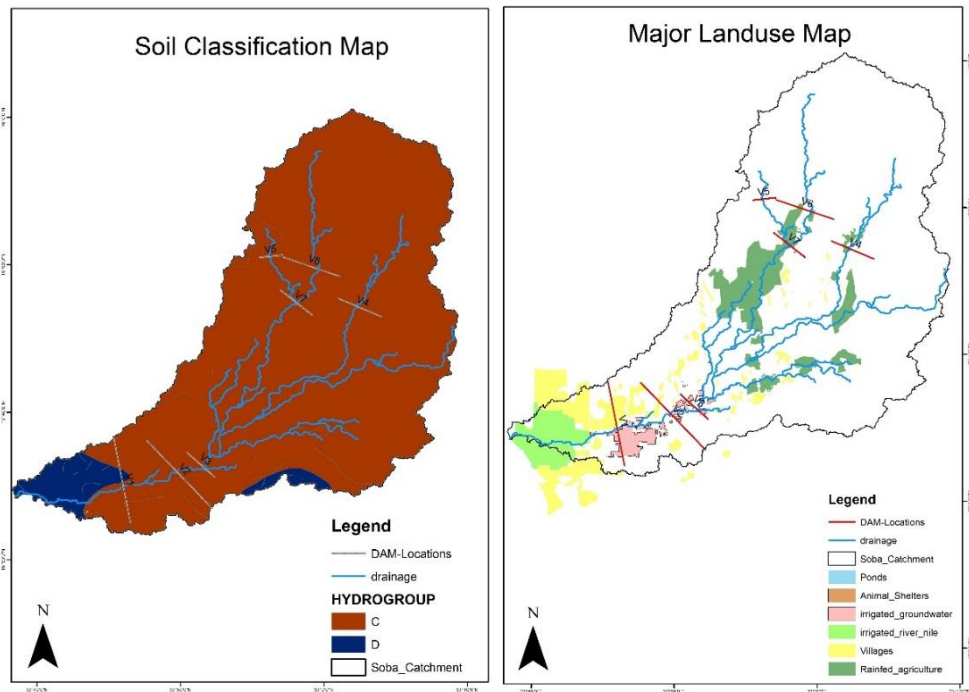


Figure 5.11 Soil and Landuse Map

- The cross-section has been prepared for each proposed sites of dam, then the layer of lakes has been exported into Google Earth to extract the affected areas of villages and agricultural lands and grasslands:-

Proposed DAM Site 1:

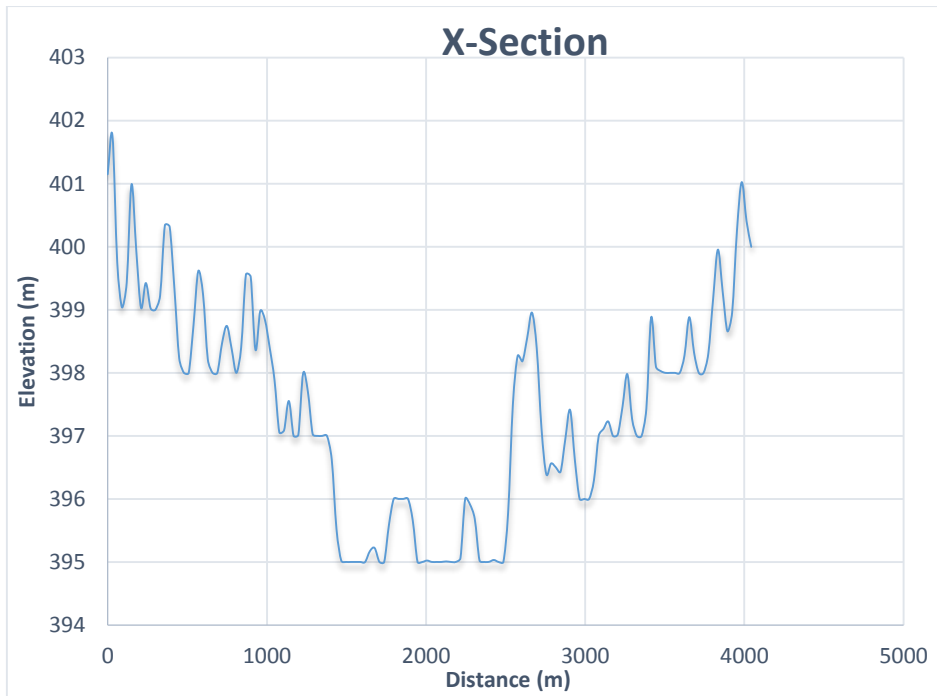


Figure 5.12 Cross Section of Proposed DAM Location 1

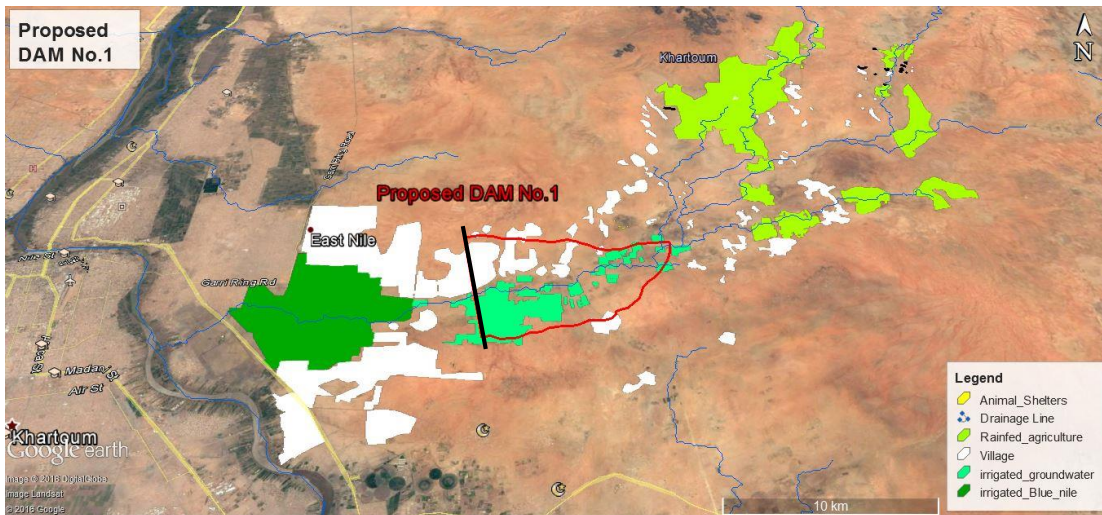


Figure 5.13 Proposed DAM Location 1

Proposed DAM Location 2:

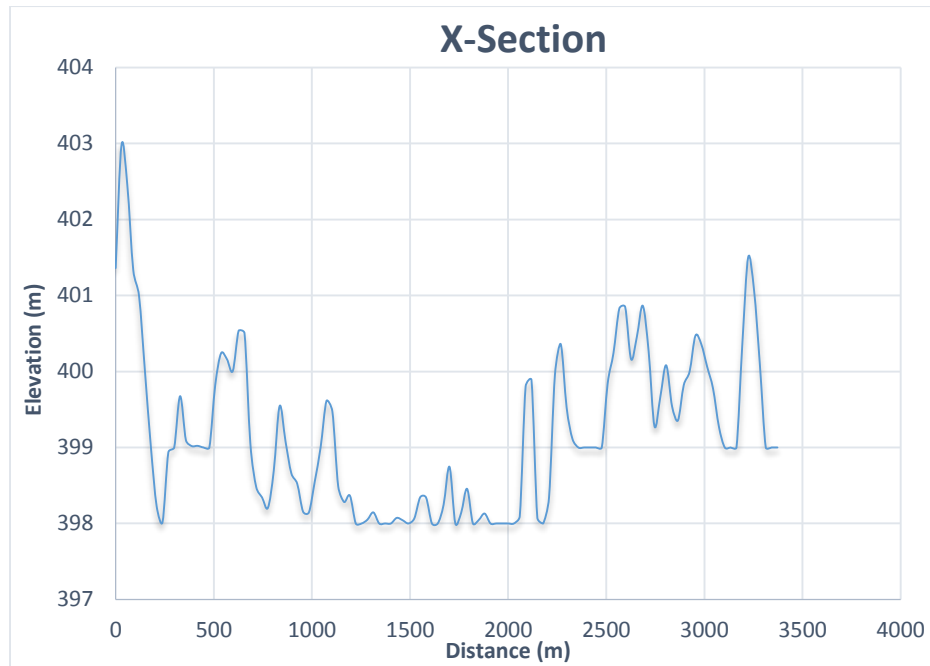


Figure 5.14 Cross Section of Proposed DAM Location 2

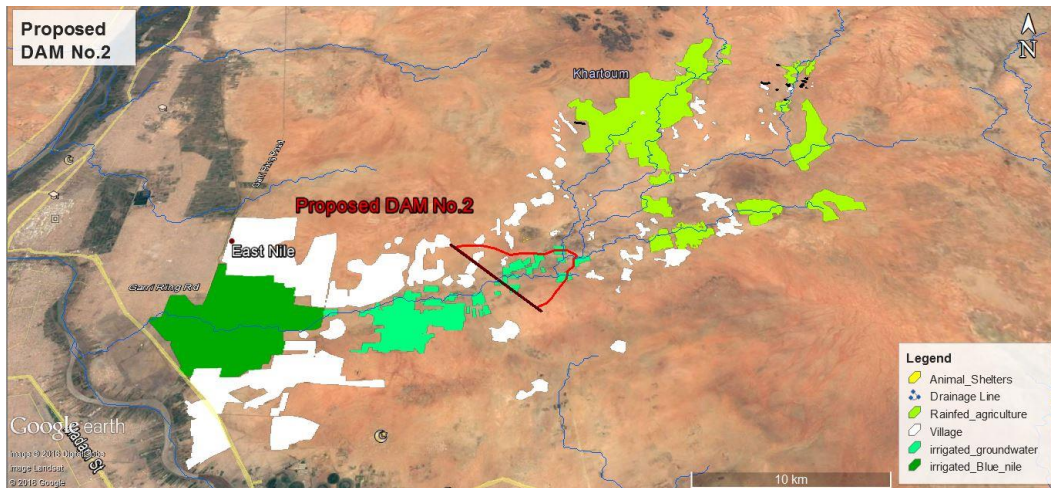


Figure 5.15 Proposed DAM Location 2

Proposed DAM Location 3:

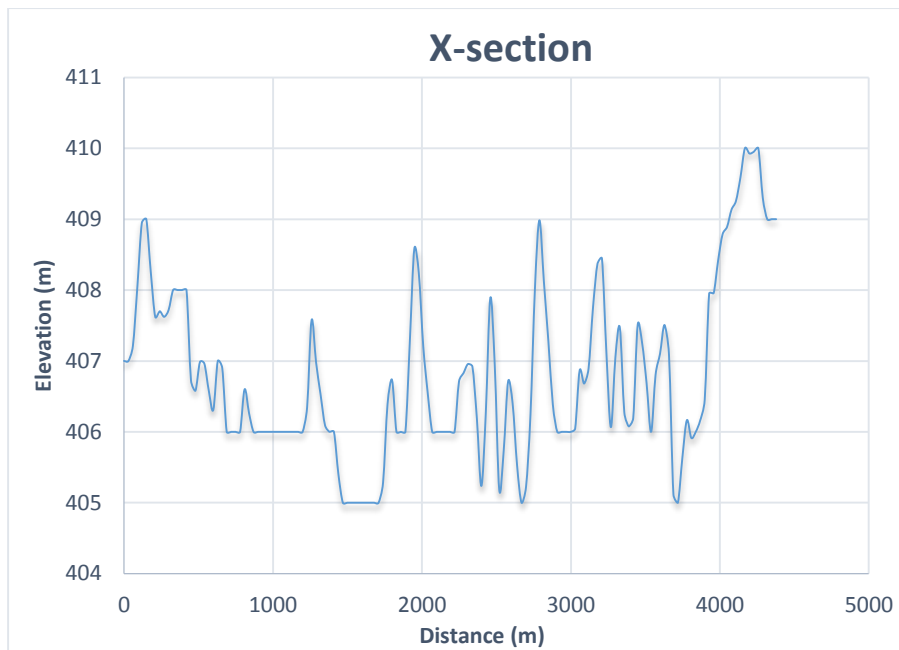


Figure 5.16 Cross Section of proposed DAM Location 3

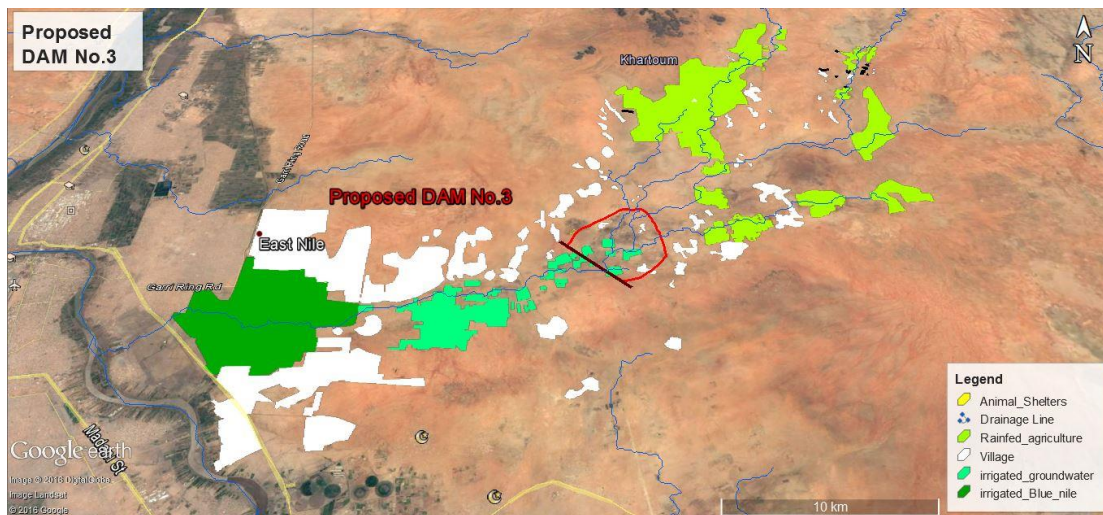


Figure 5.17 Proposed DAM Location 3



Proposed DAM Location 4:

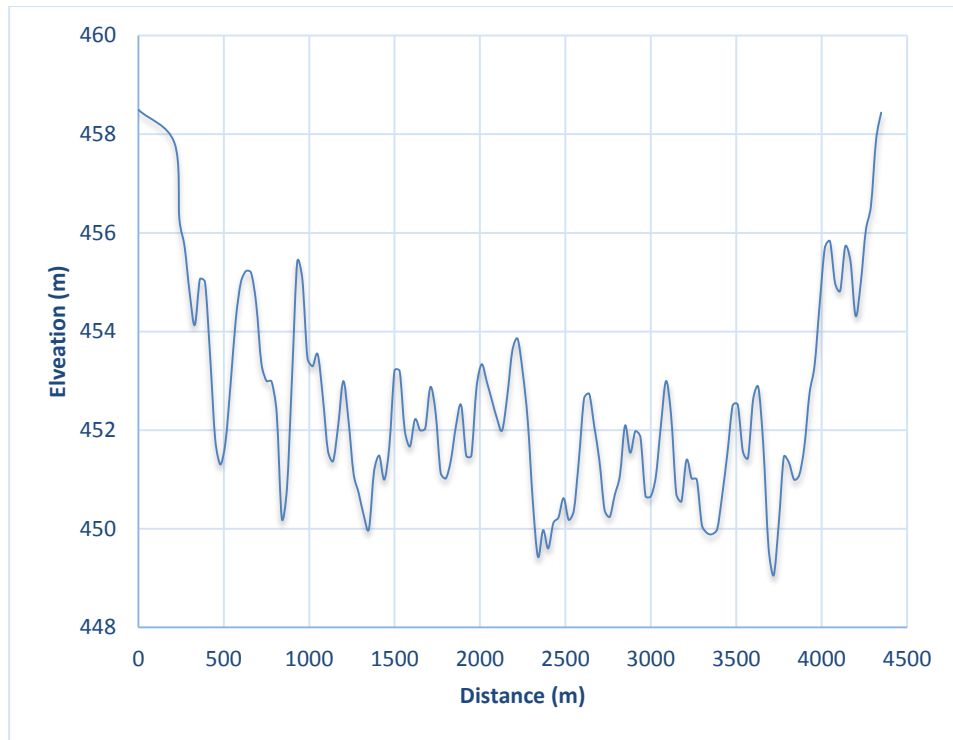


Figure 5.18 Cross Section of Proposed DAM Location 4

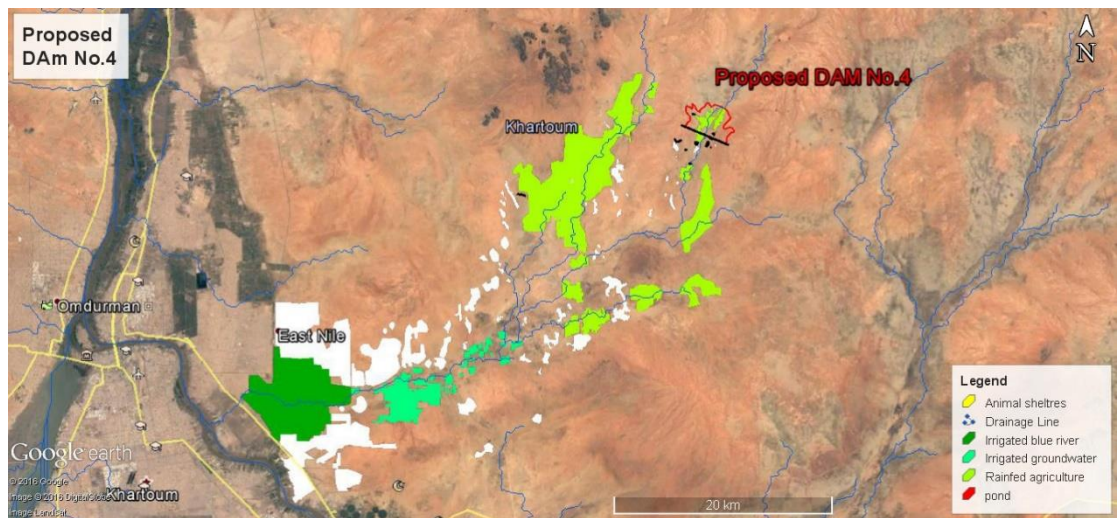


Figure 5.19 Proposed DAM Location 4

Proposed DAM Location 5:

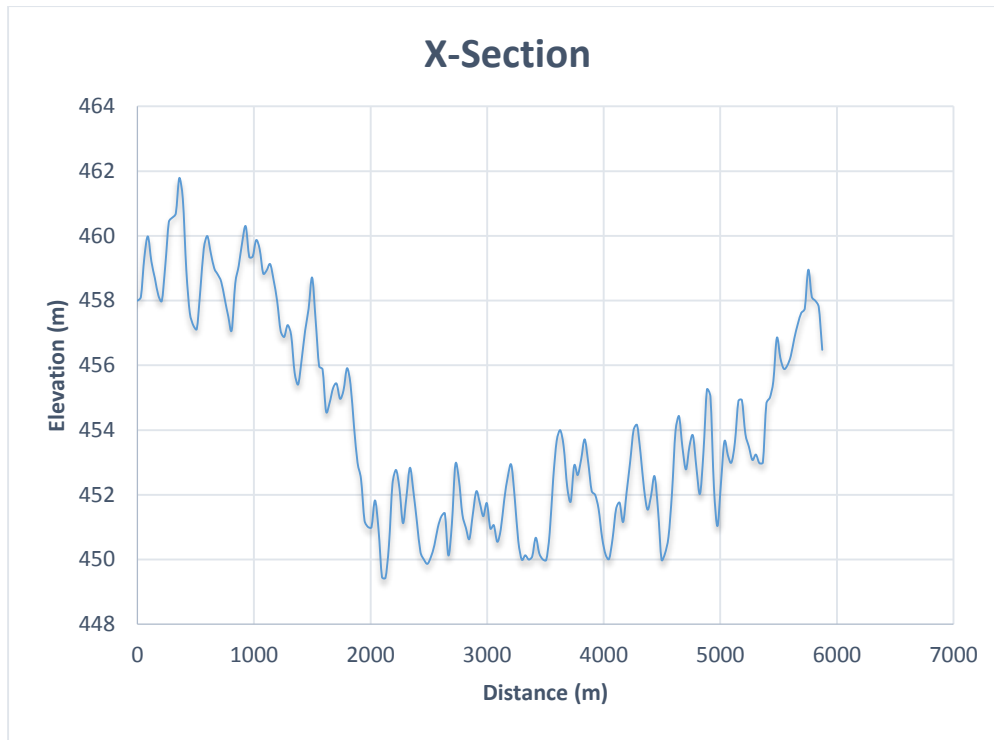


Figure 5.20 Cross Section of Proposed DAM Location 5

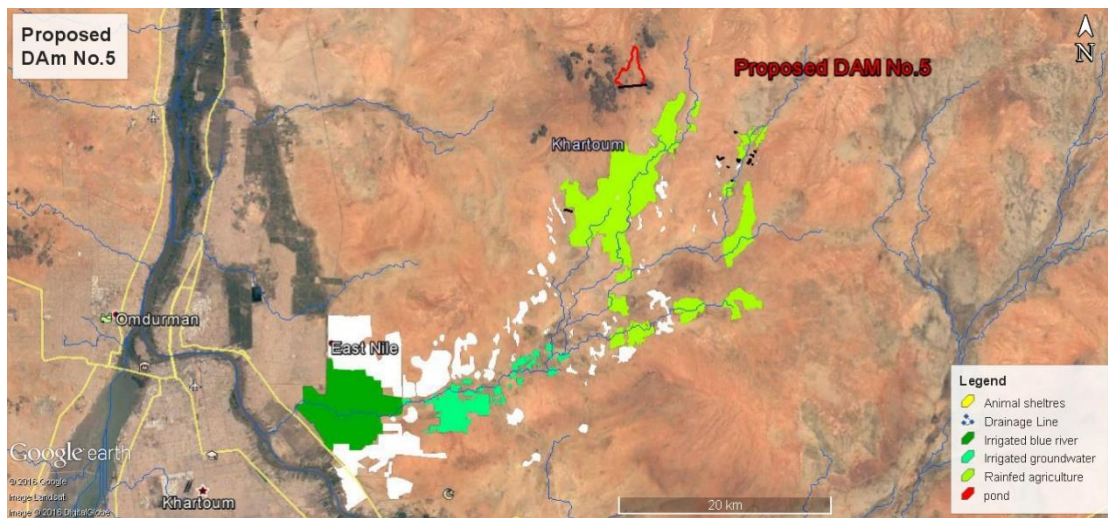


Figure 5.21 Proposed DAM Location 5

Proposed DAM Location 6:

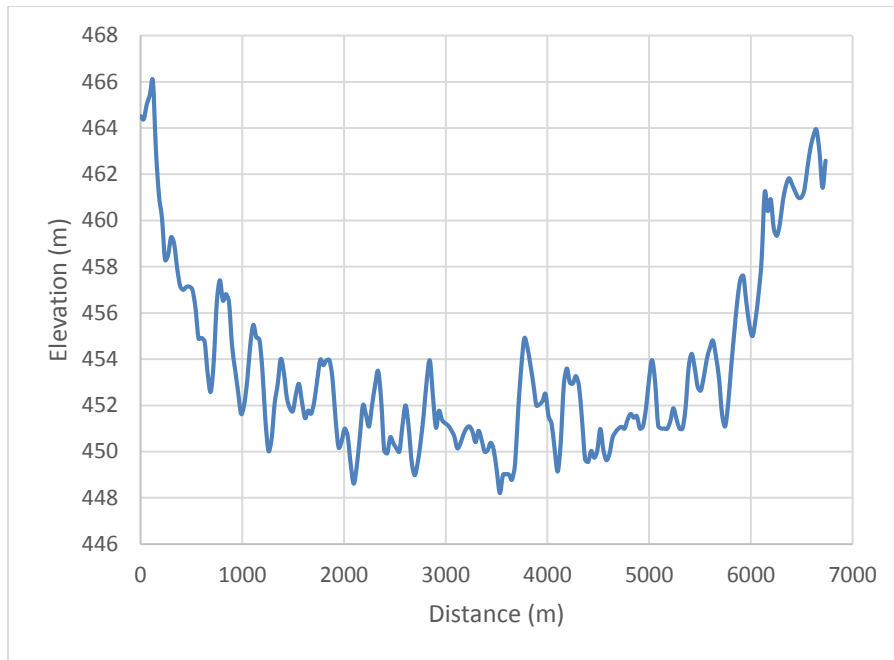


Figure 5.22 Cross section of Proposed DAM Location 6

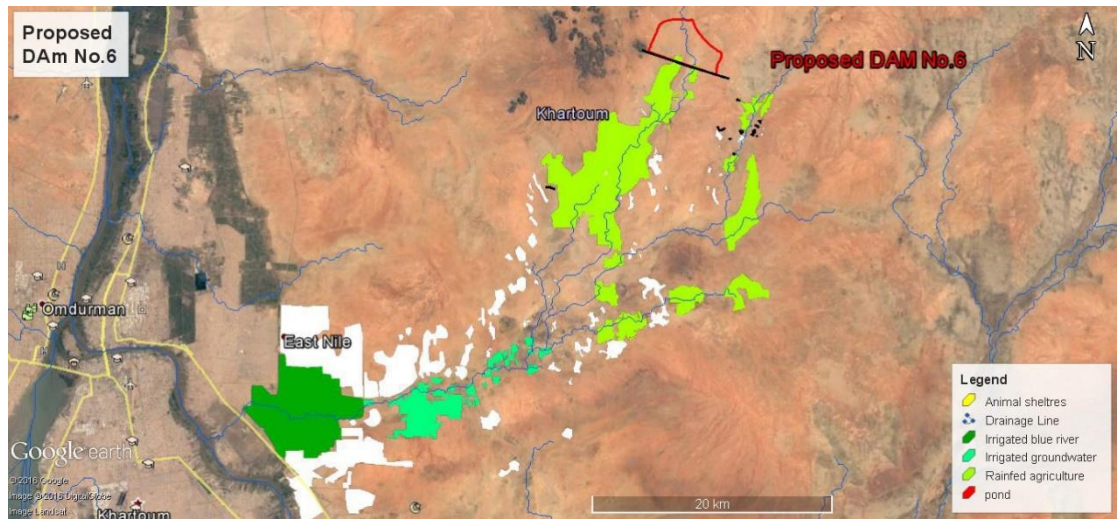


Figure 5.23 Proposed DAM Location 6

Proposed DAM Location 7:

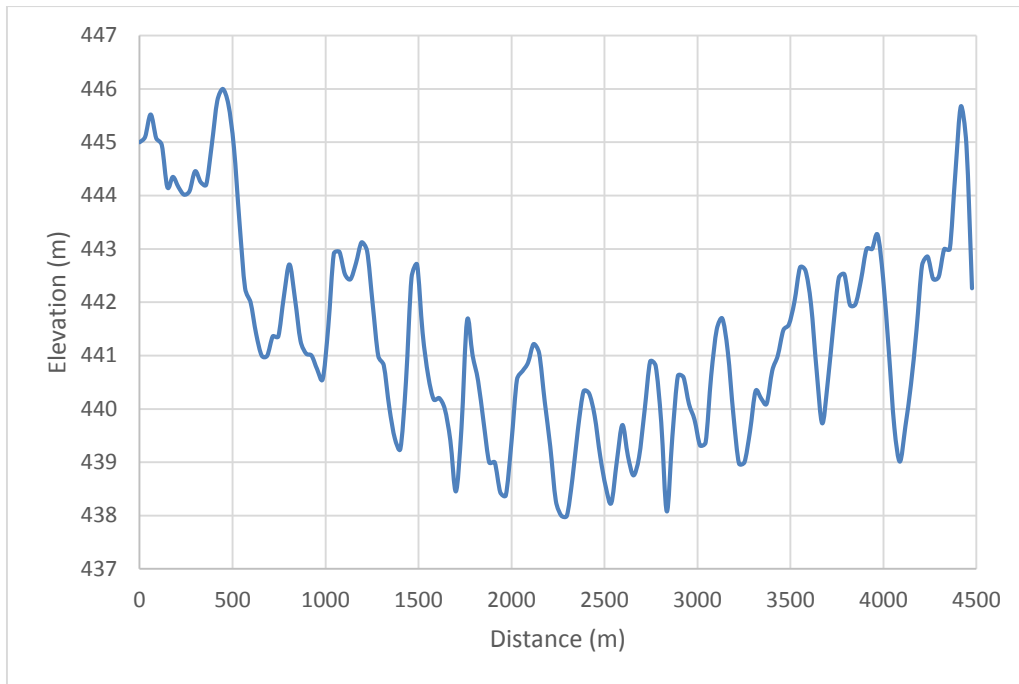


Figure 5.24 Cross section of proposed DAM Location No. 7

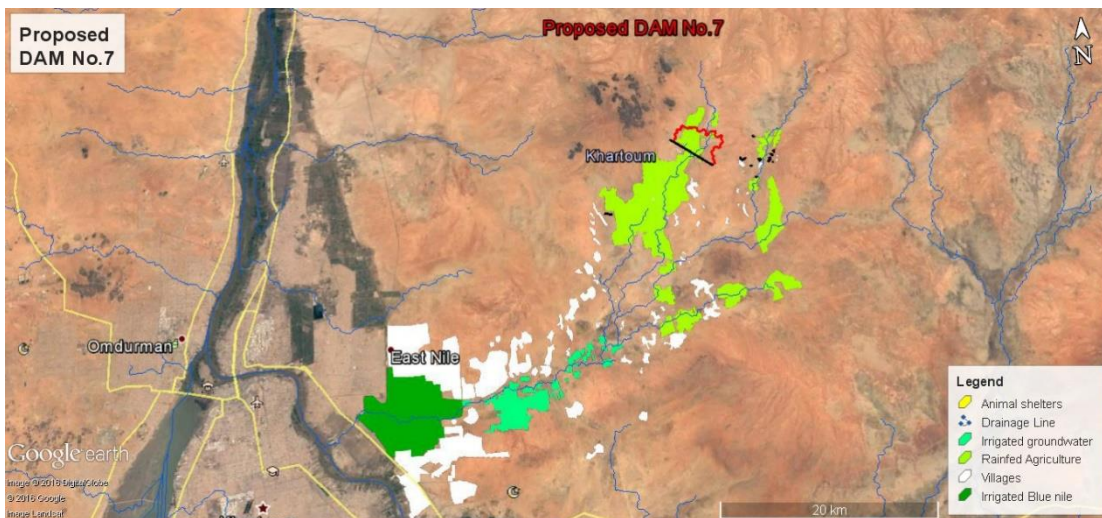


Figure 5.25 Proposed DAM Location 7



- The following table shows the effects of each proposed dam location in the study area:-

Table 5.2 Impact of Selected site of DAMs

| DAM        | potential cultivated area to be covered by lake | potential residential areas to be covered by lake | Area of reservoir |
|------------|---|---|-------------------|
| No.        | Km2   | Km2   | Km2               |
| Location 1 | 11.44   | 54.479  | 65.919            |
| Location 2 | 0.61  | 18.268  | 18.878            |
| Location 3 | 0.79  | 21.713  | 22.503            |
| Location 4 | 0.02  | 9.875   | 9.895             |
| Location 5 | 0   | 4.783   | 4.783             |
| Location 6 | 0   | 16.538  | 16.538            |
| Location 7 | 0   | 14.071  | 14.071            |

- Location of DAM number one has the following advantages and disadvantages. The main advantages of this location are: firstly the minimization of the effect of flash flood in Marabe-alshareef town and the agricultural projects near this town, secondly the lake of this dam can be used for irrigation purposes. Its disadvantages are: firstly it will cover large areas of the villages and areas that can be suitable for agriculture or grazing. Secondly the cost of the dam construction is high compared to the cost of settlement of the affected villages and compensation of agricultural lands that could be affected.
- Locations number two and three are the second best options, but they have the same disadvantages of the location of DAM one, with less affected areas, where the dam lake area is less than the first location.
- In location number four the amount of reserved water is not enough compared with the construction cost of the dam as well as the wide areas that will be negatively affected by the construction this dam.
- Location number five had been excluded because it is located in steep surface in the Valley of rank four as well as that the amount of reserved water is not feasible.
- Locations number six and seven can be considered as the third option because they can minimize the effect of flash flood with disadvantages of large area

needed for the construction of the dam, which reduces agricultural and grazing lands as well as the high cost of the dam construction compared to the compensation cost of the affected agricultural lands.

- Location of DAM number one had been selected as the best choice regarding reservoir volume which enables the storage of large water quantity. This choice has the credit of minimization of the flash flood effect and the capability of irrigation of wide agricultural and grazing lands.

# CHAPTER SIX

## CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

Identification of catchment areas for Soba valley had been defined using Shuttle Radar Topography Mission (SRTM) with a 30m resolution. Runoff model had been developed using HEC-HMS model. Various components of the model were defined according to data availability.

To run the model it is necessary to determine the parameters of each component. SCS unit hydrograph method had been selected for the loss estimation. Values of curve number (CN) obtained for each sub-basin using raster maps prepared from soil hydrologic groups and land use layer. Then initial loss values for each sub-basin were determined using an empirical formula dependent on CN values. To convert excess rainfall to runoff, values of lag time had been calculated for each sub-basin. Knowing the seasonal nature of the stream under study, base flow was neglected due to its insignificance.

For the metrological input to the model, estimated daily satellite rainfall data (TRMM) had been utilized.

Following the development of runoff model, suitable locations of retention dams had been proposed based on major landuse, slope, stream order, soil properties. A volume model had been built to calculate volume retained by the proposed dam. Then various retention dams locations had been selected to minimize the risks of flash floods. General impact for selected dam on residential and agricultural areas had been identified to further estimate the cost of the proposed dams.

## **6.2 Recommendations**

- Land use planning can play very important role to reduce the adverse effects of flooding. It is recommended to adopt an appropriate land use planning in flood prone area.
- Prepare flood inundation maps to delineate the actual flooded areas.
- Produce flood damage assessment maps.
- The development of more accurate and updated measurements (rainfall, soil, Landuse and Topography data) to establish a reliable database for further studies.
- Use other water harvesting projects to control flash floods.
- Study long term impact of earth dam.

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