UNIVERSITY OF GAZİANTEP
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DETERMINING THE HYDROLOGICAL CHARACTERISTICS OF THE GREATER ZAB RIVER BASIN BY GIS

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PESHAWA ISMAEL
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Determining the Hydrological Characteristics of the Greater Zab River Basin by GIS

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Supervisor
Assist. Prof. Dr. Mehmet İshak YÜCE

By
Peshawa ISMAEL
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Peshawa ISMAEL

ABSTRACT

DETERMINING THE HYDROLOGICAL CHARACTERISTICS OF THE GREATER ZAB RIVER BASIN BY GIS

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M.Sc. in Civil Engineering
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Water resources management is closely linked to the concept of river basin characteristics. Basin is a dynamic and very complex system which has mainly two types of characteristics; geographic and hydrologic. In this study, the hydrologic characteristics of the Greater Zab River Basin were determined by employing Geographic Information System (GIS). GIS techniques are useful not only in obtaining data from a basin; they also provide valuable contribution in performing the spatial distribution of hydrological data in assessment of water resources projects. The Greater Zab River is approximately 460 km long, flowing through Turkey and Iraq with a total catchment area of about 26,325 square kilometres (km^2). The headwater of the Greater Zab River originates in the mountainous area near Lake Van, Turkey, where it springs at an altitude of 4,168 m above sea level and joins the Tigris River in the south western of the city of Hewler (Erbil), Iraq.

The terrain pre-processing models, namely, fill sinks, flow direction, flow accumulation, stream networks, watershed boundary have been acquired from digital elevation model (DEM) by using spatial analysis tools in ArcGIS. Hydrological processing such as, map of sub-catchments, characteristics of sub-catchments, river network map and river network characteristics have been determined by employing ArcHydro tools. On the other hand hydrological analysis such as, slope map, Thiessen polygon map, Thiessen polygon areas were defined by Arc Toolbox.

The annual average discharge of the stream flow at five flow measurement stations (FMS) along the river and the annual total precipitations measured at twenty-four rainfall measurement stations in the basin were used here in order to perform the hydrological analysis of the basin. The annual average discharge values were obtained from monthly average discharge measurements while the annual total precipitations were acquired from monthly total precipitations. Based on the stream flow measurements, rainfall-runoff coefficients were estimated by rational method for five sub-basins. The rainfall-runoff coefficient for the whole basin was found to be 0.53.

Keywords: Greater Zab, Basin Characteristics, GIS, ArcHydro, Rational Method

ÖZET

BÜYÜK ZAP SUYU HAVZASI'NIN HIDROLOJIK ÖZELLIKLERININ CBS ILE BELIRLENMESI

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Su kaynakları yönetimi nehir havzası özellikleri kavramı ile yakından bağlantılıdır. Havza dinamik ve çok karmaşık bir sistemdir ve başlıca iki cesit özelligi vardır; coğrafi ve hidrolojik. Bu çalışmada, Büyük Zap Nehri Havzasının özellikleri Coğrafi Bilgi Sistemi (CBS) kullanılarak belirlenmiştir. CBS teknikleri sadece bir havzanin verilerinin elde edilmesinde yararlı değildir, aynı zamanda su kaynakları projelerinin değerlendirilmesinde hidrolojik verilerin alansal dağılımının gerçekleştirilmesinde de değerli katkı sağlar. Büyük Zab Nehri yaklaşık olarak 26.325 kilometrekarelik (km^2) su toplama alanı ve 460 km civari uzunluğun ile Türkiye ve Irak topraklarindan akar. Van Gölünun yakınlarinda yer alan ve deniz seviyesinden 4.168 m yükseklikte dağlık alanlarindan kaynaklanan Büyük Zap Nehri, Hewler (Erbil) şehrinin güney batısinda, Irak topraklarinda Dicle Nehri'ne karışır.

ArcGIS içinde yer alan alansal analiz araçları kullanılarak, arazi ön-işleme (pre-processing) modelleri, yani bosluklari doldurma (fill sinks), akış yönü (flow direction), akış birikimi (flow accumulation), dere ağları (stream networks), havza sınırları (watershed boundary), dijital yükseklik modelinden (DEM) faydalanilarak elde edildiler. Alt-havzaların haritası, alt-havzaların özellikleri, nehir ağı haritası ve nehir ağı özellikleri gibi hidrolojik işlemler ArcHydro araçları kullanılarak hesaplandı. Öte yandan, eğim haritası, Thiessen poligon haritası, Thiessen poligon alanları gibi hidrolojik analizler Arc Toolbox kullanılarak tanımlandı.

Havzanın hidrolojik analizleri, nehir uzerinde bulunan beş adet akım gözlem istasyonundan elde edilen yıllık ortalama debiler ve havzasının içinde ve etrafında bulunan yirmi dört adet yağış istasyonunda ölçülen yıllık toplam yağış verileri kullanılarak gerçekleştirilmiştir. Yıllık ortalama debi değerleri aylık ortalama debilerden, yıllık toplam yağışlar ise aylık toplam yağışlardan elde edilmiştir. Akarsu akım ölçümleri kaynak alınarak, yağış-akış katsayıları beş alt-havza için rasyonel method ile elde edilmiştir. Bütün havza için bu katsayı, 0.53 olarak bulunmuştur.

Anahtar kelimeler: Büyük Zap Nehri, Havza Özellikleri, CBS, ArcHydro, Rasyonel Method.

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To my two flowers Dlin and Dwer which they are my light of the eye.

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LIST OF SYMBOLS/ABBREVIATIONS

A	Catchment area (m^2)
$D8$	Eight direction flow model
DEM	Digital Elevation Model
C	Runoff coefficient
FMS	Flow measurement stations
GIS	Geographic Information System
i	Rainfall depth – Average areal rainffal (mm)
Φ (i)	One for cardinal neighbors cell, √2 for diagonal neighbors cell
k	Runoff coefficient at gauged site
MAP	mean annual precipitation at gauged site (mm)
MAR_u	Mean annual runoff at un-gauged site (mm)
Q	discharge (m^3/s)

CHAPTER 1

INTRODUCTIN

1.1 General overview

Water is fundamental for life and the functioning of the natural environment. The population of the world has increased from one billion to over seven billion in less than 200 years. Due to rapid increase in population and development in technology, demand for water and energy rises steadily. The amount of available fresh water is less than 1% of the total volume of water on the earth and it is unevenly distributed in time and space. The limited amount of fresh water resources are subject to severe environmental problems, therefore the assessment and management of water resources are vitally important. Poorly managed water resources can cause water scarcity and water crisis which may lead to regional social and economic crisis. Water resources management is closely linked to the concept of river basin management. The watershed based management should include planning and conserving the available resources.

Watershed is the area draining the rainwater into a stream. It can also be explained as a delineated area from which the runoff drains through a common point in the drainage system (Murthy, 2000, Bose et. al., 2012).Gaining information by employing the tools of Geographic Information Systems(GIS) is being preferred to the conventional data collection techniques (Coskun et.al., 2010; Burrough and McDonnell, 1998; Yanmaz, 2006). The scope and the scale of the water resources problems make GIS software a powerful tool for developing accurate solutions. The advent of the environmental systems research institute (ESRI) has created an opportunity to re-think the way that water resources data was represented in GIS. The result is ArcHydro, an ArcGIS data model for water resources. ArcHydro opens the way to building hydrologic information systems that synthesize geospatial and temporal water resources data to support hydrologic analysis and modelling (Maidment, 2002).

Geographic Information Systems (GIS) are increasingly being used in watershed management (Burrough and McDonnell, 1998; Guertin et al., 2000).The benefits associated with the use of GIS in the watershed and hydrologic analysis include the improved accuracy, less duplication, easier map storage, more flexibility, ease in data sharing, timeliness, greater efficiency and higher product complexity (Ogden et al., 2001).Watershed analysis refers to the process of using Digital Elevation Models(DEM)and raster operations to delineate drainage area and to derive topographic features such as stream networks (Kang, 2008).The availability of the inexpensive computational power has boosted the growth of digital-terrain-based analysis and modelling techniques in various engineering and scientificfields (Sivapalan and Kalma, 1995; Band and Moore, 1995; Wood et al., 1988).

In recent years, DEMs have been widely used as input data for defining the flow directions in distributed hydrological models for discharge simulations due to their high efficiency in representing the spatial variability of the earth’s surface (Beasely et al. 1980; Beven and Kirkby 1979; Fortin et al, 2001).Numerous grid (DEM) based algorithms used to determine flow direction have been developed and implemented in many GIS software for watershed and hydrological analysis (O’Callaghan and Mark 1984; Quinn et al, 1991; Fairfield and Leymarie 1991; Costa-Cabral and

Burges 1994; Tarboton, 1997).

Compared to traditional terrestrial analysis methods, the digital elevation models (DEM) generated from high resolution satellite imagery offer the essential information in a rapid, accurate and reliable mode. The data used here was30-m spatial resolution digital elevation model (DEM),the monthly average discharge of the stream flow and the monthly total precipitations from the precipitation observation stations in the study area. Stream networks were delineated from DEM data using GIS software. The basin parameters obtained from DEM were drainage area, total river length, main channel slope, main channel length and basin slope map. The primary objective of this study indicates relationship between GIS analysis and engineering hydrology**.**

Using ArcGIS, ArcHydro tools and digital elevation model (DEM) raster data in efforts to evaluate watershed parameters and provide hydrologic analysis for Greater Zab River Basin**,** the largest tributary of the Tigris River in terms of water yield. The headwaters of the Greater Zab River originate in the mountainous area characterized by steep slopes, near Lake Van, Turkey, at an altitude of 4,636 m above-sea-level. The Greater Zab has five main tributaries, namely, Rubari Sheen, Rubari Chama, Rubari Rawanduz, Zey Bestora and Zey Khazir. This perennial stream has a total length of 460 km and flows mainly in northern Iraq and joins the Tigris River in south-western of the city of Hewler.

1.2 Objective and Scope

The main objective of this study is to determine the hydrologic characteristics of the Greater Zab River Basin by employing Geographic Information System (GIS). Data layers for all of the Greater Zab River Basin were acquired. These layers include basin boundaries, the length of the main river, digital elevation models (DEMs), digital raster graphic maps, basin slope map, stream network, flow measurements stations, meteorological stations and Thiessen polygon area map for 24 rainfall stations in and around the basin.

A quantitative relationship between the stream flow and precipitation in the basin was also defined by rational method, based on measured data of ten years. Rainfall-runoff coefficients were estimated by the rational method for four sub-basins and the whole basin, based on the annual average discharge of the stream flow at five flow measurement stations (FMS) located on the main river and its tributaries and the annual total precipitations measured at twenty-four rainfall measurement stations in the basin. The areal average precipitation values for each sub-basin were determined by Thiessen Polygon Method by employing GIS software, while the stream discharge values were obtained from flow measurement stations.

1.3 Outline of the thesis

Chapter 1-Introduction: is devoted to the presentation of the research topic and the identification of the general scope and specific objectives. Knowledge, aim, and objectives of the thesis were introduced.

Chapter 2-Literature review: This chapter traces the background on practical application of GIS for watershed delineation and previous studies on Digital elevation model (DEM), Hydrologic conditioning digital elevation model, Runoff Hydrology and Estimation Water Resources in River Basin.

Chapter 3-Study area: This chapter general the background of the study area about geography, claimant, geology characteristics and water resource management of the Greater Zab river basin

Chapter 4-Methodology: In this chapter addresses the broad scope of the kinds of processes and analyses that can be accomplished with ArcGIS tools

Chapter 5-Results and discussion: This chapter presents and discusses the results obtained from train DEM Pre processing to identify the river basin boundary, watershed processing and hydrological analysis of the study area.

Chapter 6-Conclusions: General conclusions are drawn regarding the overall results

CHAPTER 2

LITERATURE REVIEW

2.1 General background

The delineation and parameterization of watershed characteristics is a significant study area in hydrology (Band, 1986; Zevenbergen and Thorne, 1987; Chorowicz, Ichoku, Riazanoff, Kim and Cervelle, 1992). The delineation of river basin includes the representation of a set of measurable physical properties. These properties are then used in a variety of models to extract other characteristics and also to establish the reaction of the drainage system to other variables. The practice of parameterization comprises the delineation of the drainage network on a base map. Parameters such as channel lengths and angular measurements are acquired after laying out the drainage network on the map (Garbrecht and Martz, 1992).

The extracted parameters depend on the extraction method and the model for which they are determined. These parameters can be achieved either manual or by the use of Geographical Information System (GIS). Manual methods are very tiresome, require rigorous work and prone to errors due to significant human contribution and tedious nature of the work (Band, 1986). Whereas the GIS-based techniques provide relatively accurate results and they are user-friendly.

2.2. Overview of GIS application

Geographic Information System (GIS) is a computer based information system used to digitally represent and analyse the geographic features present on the surface of the Earth and the non-spatial attributes linked to the geography under investigation.

The key tool to study the spatial relationship between man and the environment is a geographical map. Information system is a continuous chain of data collection, storage of data, analysis of data and use the derived information in some decision-making processes (Star and Estes, 1990). Digital representation in GIS is converting analogue smooth line into a digital form. The fundamental key of associating any database to GIS is being able to geo-referencing every object present on the Earth. Term database is a collection of information about things and their relationship to each other and geo-referencing refers to the location of a layer or coverage in space defined by the co-ordinate referencing system. GIS is a manual or automated system, which can store, retrieve, manipulate, and display environmental data in a spatial format. It has the capabilities to use different set of operation for working with spatially referenced geo-data. It uses several manual data elements like maps, aerial and ground photograph, statistical report etc. Nowadays the applicability of GIS can be found in many fields of study mainly the town planners, engineers, architects and scientists use GIS for measuring, mapping, monitoring and modelling environmental features and process such as studies on environmental impact or protection, emergency management, transportation planning, physical planning, landuse planning or zoning, non-point source pollutants, monitoring hazardous waste sites etc. Thus, GIS is continuous process of data acquisition, pre-processing, data management, manipulation and analysis and product generation (Star an d Estes, 1990; Congalton and Green 1995; Sivertun 1993).

A GIS could be fed with relevant information in a standardized form to produce computerized maps and further used for integrated analysis. For instance, the information for a river basin in GIS could be points (gauge station, rainfall station), lines (main-river, stream) and polygons (river basin boundary). GIS allows the manipulation of each datum in its entire spatial and temporal context .With this the analysis could be initiated for decision makers (World Bank, 1990).

GIS was acknowledged first by Canada Geographic Information system, CGIS (Star and Estes 1990). The main aim of CGIS was to analyze Canadian land inventory data and to find marginal lands. Thus, the first GIS application was developed to deal with environmental problems. It was first implemented in 1964 (Deuker, 1979). The commercial development of GIS took place in 1970 during operations of image processing and remote sensing. Several institute and organization were keen in using GIS. Environmental System Research Institute (ESRI) in California was among them. They used spatial GIS software like ArcView, ArcMap, MapInfo, IDRISI etc. (Star and Estes 1990). The main disadvantages of GIS methods are that, the process of data collection and the software are often expensive.

2.3 GIS applications in Water Resources Engineering

Planning and designing a project in water resources engineering typically involve the use of maps at various scales and the development of documents in map formats. River basin studies may cover a portion of a country or it may include several countries or jurisdictions. There are numerous applications of GIS in a river basin surveys; delineating the watershed and its hydrologic characteristics so that models of rainfall-runoff processes can be applied to examine the impacts of land-use changes. Cities and man-made facilities located along the river and across the basin are linked together by transportation and pipeline networks. All of these data sets must be established in a common geo-reference framework so that overlays of themes can be made and the coincidence of features can be identified in the planning and designing phase of the water resources projects. GIS offers an integrating data and modelling environment for the conduct of these activities, collect and archive data on the environment. Location of measurements, distance and flow by various devices are typically handled in digital formats and quickly integrated into a spatial database. Data processing, synthesis and modelling activities can be drawn on these data by using GIS, analysed results can be archived as well. The GIS spatial and characteristic databases can then be used to generate reports and maps, often interactively, in order to support decision making on design alternatives. Further, maps are a powerful communication medium; thus this information can be presented in public forums so that general public concerned with planning and design choices can be informed and be involved in controversial projects (Johenson, 2009). GIS emerged as a considerable support tool for hydrologic modelling, during the 1990s. In particular, GIS offered a reliable method for delineation of watershed and stream network by using digital elevation models (DEMs) of land-surface terrain. Standardized GIS data sets for land cover, soil properties, gauging station locations, and climatic variables were developed. GIS data pre-processors were developed to prepare input data for watershed delineation (Maidment, 1998).

2.4 GIS Data model for Surface water hydrology

A data model is a set of rules to identify and symbolize features of the real world called entities into digitally and logically represented spatial objects consisting of the attributes and the geometry. The attributes are characterized by thematic or semantic structures, while the geometry is represented by geometric-topological structures. There are two basic categories of data involved; spatial and attribute. Spatial data include the locations of features, such as the latitude/longitude of dams, gauging stations, etc. Spatial data are often represented as objects such as points, lines, and polygons, which are used to represent the different types of features. For example, the location of a flow measurement station is a point, a stream path is a line or vector, and a basin boundary is a polygon. Spatial data may also be represented as fields or images which might be derived from satellite imageries. Attribute data include numerical and character type data that characterize the resource. Geographic data are characterized by a series of attribute and behavioural values that define their spatial (location), graphical, textual and numeric dimensions (Worboys, 1995). These include identifiers, names and physical capacities for features of the water resources system, such as dams and reservoirs, pipelines, drainage basins, pumps and turbines. Time-series data on river flows, reservoir releases, pumping rates and other time variables are also managed in the attribute database (Johnson, 2009).

2.5 Raster and vector data

Data in GIS can be represented in either a raster or vector format. A raster-based system displays, locates and stores graphical data by using a grid of cells. Each grid cell is represented by a unique reference coordinate at either the corner or centroid of the cell. In addition, each cell has discrete attribute data assigned to it (Foote, 1996).

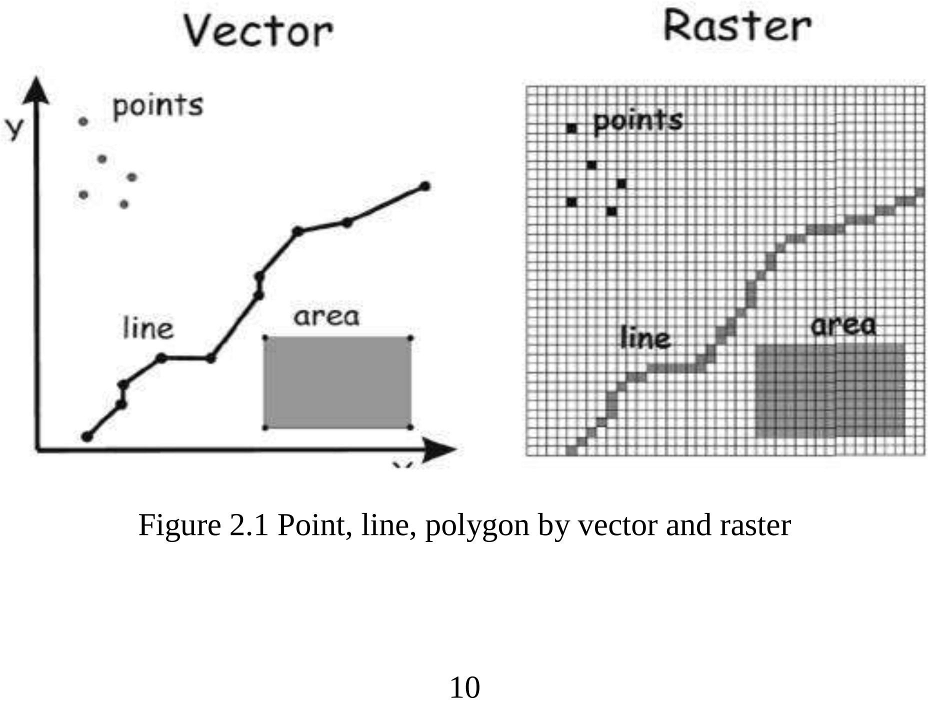


Figure 2.1 Point, line, polygon by vector and raster

The raster or field model, which is often defined on an (x, y) grid with each cell or pixel (i.e. picture element), specifying the value of the data. The uniform grid is also referred to as a raster data structure (Johnson, 2009). An example of such data is a Digital Elevation Model (DEM). In contrast, vector based systems display graphical data as points, lines or areas with attributes. Cartesian coordinates (i.e. x and y) and computational algorithms of the coordinates define points in a vector system. For example, lines are represented as a series of points, while areas are stored as a series of points with the beginning and end points at the same node, so that the shape is closed. The graphical output is very similar to hand-drawn maps (Foote, 1996).

A key aspect of the vector data model is that the topology of relationships between features to be established. Topology refers to the relationships or connectivity between spatial objects. The geometry of a point is given by two-dimensional (2-D) coordinates (x,y), while line, string and area are given by a series of point coordinates.

In vector data model, geographic objects are represented as features that have shape and size. The three basic types of vector shapes are points, lines and polygons, although there are variations of these types. For example, rivers and roads are represented as line features, buildings are represented as polygon features and cities are represented as point features or in some cases as polygons. Apart from geometry, each feature can also be attributed with non-spatial information. Only features of one shape type can be collected together for storage. These storage types can be classified as file-based storages e.g. shape-files and coverages (Kola, 2004).

2.6 Digital Elevation Model (DEM)

Digital Elevation Models (DEM) are raster geographic digital representation of the Earth’s surface (Hengl and Reuter, 2008) developed by numerous data providers like USGS, ERSDAC, CGIAR and Spot Image (Kessler, 1992). Digital elevation model (DEM) data consist of a sampled array of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system. The grid cells are spaced at regular intervals along south to north profiles that are ordered from west to east (Mudgal, 2005). One of the most important data sets needed for watershed delineation is an accurate representation of the land surface (Doyle, 1978). In a GIS framework, a DEM contains such information. A DEM consists of a sampled array of elevations for ground positions that are normally at regularly spaced intervals as shown in Figure 2.2. They are generated in a variety of ways for a different map resolutions or scales. DEMs are point elevation data stored in digital computer files. These data consists of x, y grid locations and point elevation or z variables. For most parts of the world, DEM data provide a high-quality and high-resolution elevation data (Jarvis et al., 2004). Digital Elevation Models (DEM) is a commonly used digital elevation source and an important part of using for watershed characterization. Many agencies provide DEM data with 90m, 30m, 10m and even 1m resolutions. The point elevation data are very useful as an input to the GIS. This data is used to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature in process of watershed delineation (Ganole, 2010)

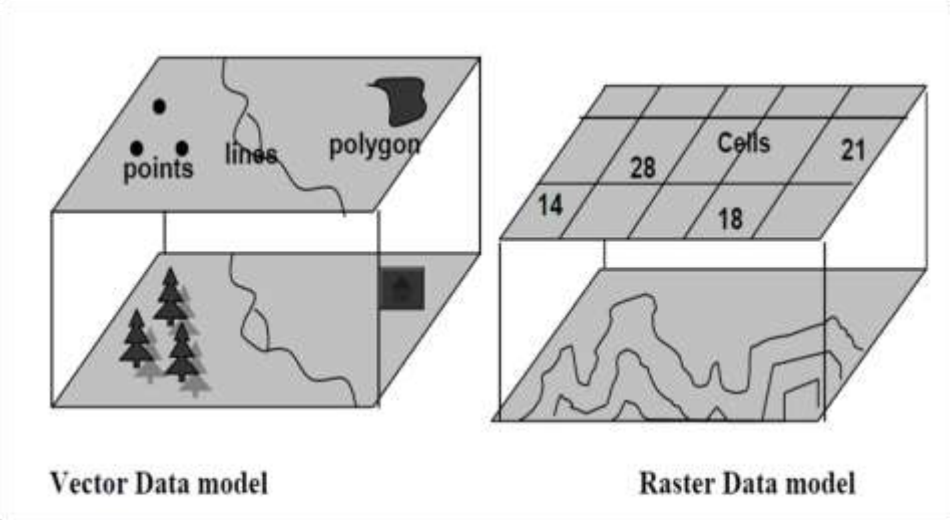


Figure 2.2 Vector and raster model diagram

The most common example is the land surface terrain characterized by DEMs digital elevation models, represented as elevation grids in the field model. DEMs as grid structures comprise a square grid with the elevation of each grid square (Figure 2.3). Each grid element is called a pixel for picture element. Location is established by the row and column locations within the grid, given information on the grid boundary coordinates (Johnson, 2009).

67	56	49	46	50
53	44	37	38	48
58	55	22	31	24
61	47	21	16	19
53	34	12	11	12

Figure 2.3 Sample representation of a DEM (Maidment, 1998)

2.7 Hydrologic conditioning of DEM

Depressions, sometimes referred to as sinks or pits, are ubiquitous in a DEM. Depressions are cells or groups of neighbouring cells that do not have an outlet. They are cells that are surrounded by higher elevation values, creating an area of internal drainage. Topographic depressions in a DEM can represent real depressions in the landscape or artefacts. Artefact depressions are errors in the elevation data (Hengl and Reuter, 2008). There are numerous sources for artifact depressions, mostly stemming from an error in data collection techniques or input errors (Reiger, 1998; Walker and Wilgoose, 1999; Aguilar et al., 2005). Artifacts can also be caused by interpolation during the DEM creation process (Aguliar et al., 2005; Chaplot et al., 2006), by the averaging or rounding of elevation values for each cell (Bolstad and Stowe 1994; Lindsay and Creed, 2005) or can be due to the limited vertical and horizontal resolution of the elevation data (Martz and Gerbercht, 1993; Wolock and Price, 1994; Thompson et al., 2001).

Real depressions are sinks in a DEM that represent actual topographic features. Although real depressions are not as common as artifact depressions, they do exist in some geomorphological landscapes such as glacial landscapes and karst or in human-modified landscapes, from anthropogenic features such as ditches, detention basins and quarries (Mark, 1984; Zanbergen, 2010). Before using DEMs for hydrological applications, artifact depressions need to be removed. Hydrologic conditioning of DEMs ensures the removal of all depressions and flat areas. Depressions and flat areas are quite problematic for hydrological modelling because they often artificially truncate flowpaths and alter flow direction (Thompson et al., 2001; Lindsay and Creed, 2005).

Hydrologically sound DEMs are depression-less, thereby allowing all cells to be connected to an outlet. Currently, there are many techniques used to hydrologically condition a DEM, with each technique having its own novel procedure for resolving depressions (O'Callaghan and Mark, 1984; Marks et al., 1984; Band, 1986; Jenson and Domingue, 1988; Martz and Gerbercht, 1993). It is important to keep in mind the manner in which these artifacts are resolved, as it determines the quality of the hydrological parameters extracted from a DEM (Band, 1986).

2.8 Run-off hydrology

Although gross watersheds are the plane areas that on the basis of topography contributes all water to a specified stream cross-section, only a fraction of the gross watershed actually produces runoff that enters local surface waters most of the time (Dingman, 2002). The portion of the watershed that actually contributes runoff to the outlet is called the effective watershed (PFRA, 1983). Gross watershed boundaries also contain areas that do not contribute runoff even under extremely wet conditions. Godwin and Martin (1975) referred to these areas as dry drainages. While gross watersheds and dry drainages are defined based on topography alone, the extent of effective watersheds is conditional upon additional hydrological factors such as soils, precipitation and vegetation (PFRA, 1983).

All of the water that passes through the outlet of a watershed originates as precipitation. A portion of all precipitation is evaporated and returns to the atmosphere. Another portion percolates through the soil under the force of gravity, eventually becoming part of the groundwater. Following underground flow paths, groundwater either exfiltrates, to become surface water or it may discharge directly into a surface water body (i.e, stream). A third portion of the precipitation flows above ground. This portion of the precipitation that reaches the stream channel is referred to as runoff (Strahler and Strahler, 1996). The timing, magnitude and quality of stream flow at the watershed outlet are therefore, dependent upon the flow pathway taken through the landscape (Dingman, 2002). Runoff contributing areas within a watershed are primarily the result of two processes. The first process called infiltration-excess (or Hortonian flow) occurs when the precipitation intensity exceeds the rate of water infiltration (Juracek, 2000; Dingman, 2002). The area contributing runoff to a stream via infiltration-excess flow is called the critical source area (CSA) (Quinn, 2002). The second process of runoff contribution to a stream is called saturation-excess overland flow. Saturation-excess runoff occurs when precipitation falls on areas where the water table is located at the land-atmosphere interface (Juracek, 2000; Dingman, 2002). The area contributing runoff to a stream via saturation-excess overland flow is referred to as the variable source area (VSA) (Quinn, 2002). Usually non-point source pollutants are transported from the land to a water body through via runoff (Cooke et al., 2002). This study is concerned solely with the determination of overland flow paths governed by topography and does not consider evaporation or infiltration.

2.9 Watershed delineation

Watershed is an area, which catches the water from precipitation and then it is drained by a river and its tributaries. It is a resource region where the ecosystem is closely interconnected around a basic resource of water. The watershed or river basin is therefore an ideal management unit. The watershed provides a powerful study and management unit, which integrates hydrological, ecological, geological, geographical and cultural aspects of the land **(**Ma, 2004**)**.

A watershed also called a drainage basin or catchment is defined as the area that on the basis of topography contributes all water to a particular stream cross-section. The characteristics within the watershed (climate, geology, soils, topography, land use and land cover) control the flow pathways, rates of movement, magnitude and quality of stream flow. Because the processes that determine the fate of water in the land phase of the hydrological cycle operate at the watershed scale, effective water management strategies must also take this perspective (Dingman, 2002).

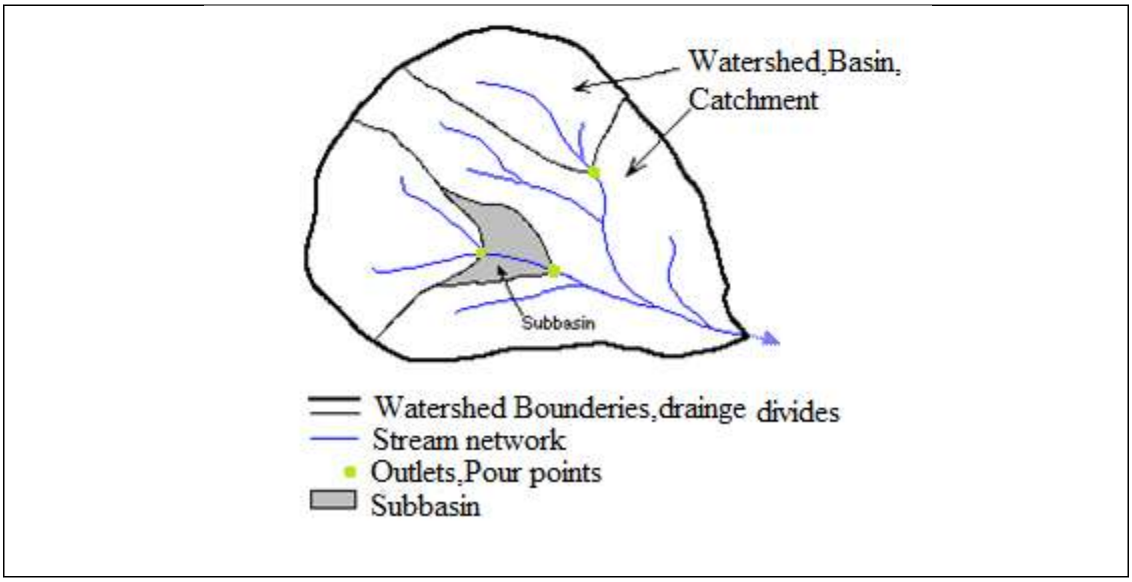


Figure 2.4 An example of watershed (ArcGIS 9.3)

Generally, watersheds were delineated by using paper topographic maps or stereoscopically viewed air photographs. Watersheds were delineated starting at the watershed outlet and tracing elevation contour lines at right angles. Constant visual inspection was often necessary to ensure that an imaginary rain droplet would flow down slope to the outlet location, assuming the ground surface was impermeable (Dingman, 2002). Manual delineation of watersheds is, however, tedious, prone to errors and subject to individual judgment (Band, 1986). With the advent of

Geographic Information Systems (GIS), the increased processing power of computers and the availability of digital elevation models (DEM) have made automated watershed delineation possible. In addition to the speed advantage automated watershed delineation has over manual procedures, deriving watersheds with a GIS application also has the advantage of reproducibility and ease of distribution (Tribe, 1992).

Automated watershed delineation within a GIS is based upon digital representations of the landscape referred to as DEMs. DEMs enable the determination of flow pathways in the landscape because overland and near surface flow pathways are controlled by topography (Moore et al., 1991).

The algorithms used to derive flow pathways in the GIS environment are commonly referred to as routing or flow direction algorithms. Since the development of the D-8 algorithm (Jenson and Domingue, 1988), it has been incorporated in a number of watershed parameterization and hydrologic models. The concept of this method is that each cell in a DEM is assumed to flow to one of the eight neighbouring cells according to the direction of steepest slope. The D-8 algorithm has been employed in a number of DEM-based models. Among the noted ones is the Watershed Delineator developed by ESRI which can be used for delineating streams and watersheds (Djokic et.al, 1997).

Automated extraction of watersheds or surface drainage, channel networks, drainage divides and other hydrographic features from DEMs is a standard surface-processing routine in modern GIS. The eight-direction or D8 method is the most common approach to identify the direction of flow from a grid cell (Figure 2.5). Using an iterative approach similar to the spread and seek functions, the D8 defines the drainage network from raster DEMs based on an overland flow analogue. The method identifies the steepest downslope flow path between each cell of a raster DEM and its eight neighbors, and defines this path as the only flow path leaving the raster cell. The method also accumulates the catchment area downslope along the flow paths connecting adjacent cells. The drainage network is identified by selecting a threshold catchment area at the bottom of which a source channel originates and classifying all cells with a greater catchment area as part of the drainage network. This drainage network identification approach is simple and directly generates connected networks (Johnson, 2009).

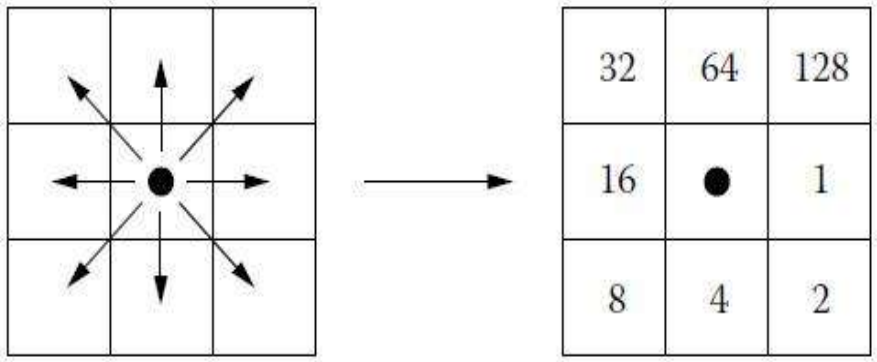


Figure 2.5 D8 direction scheme for terrain processing

Flow direction algorithm is essentially the transfer of water from a pixel into one and only one neighbour, which has the lowest elevation (Lyons, 2003). The Deterministic 8 Neighbour (D8) or steepest decent algorithm was developed by O’Callaghan and Mark (1984), It is the most basic flow algorithm as it permits flow from one cell to the neighbouring cell with the steepest down slope gradient (lowest elevation value). The aspect (measured in degrees clockwise from north) marks the direction of steepest descent from each grid cell and it is the direction from which water would flow from that grid cell. The calculation of steepest gradient is as follows:

$$S = max_{i=1,8} \frac{z_9 - z_i}{h \, \emptyset \, (i)} \qquad 2.1$$

Where, Φ (i) = 1 for cardinal neighbors (grid cells where i= 2, 4, 6, and 8), Φ (i) = √2 for diagonal neighbors (to account for extra distance travelled for those cells) and z = elevation of a particular cell. This algorithm works best to simulate flow for rivers and streams in valleys. Upslope contributing area and specific catchment are easily derived from D8 considering that all flow from one pixel is routed to the steepest downslope pixel. By mapping the direction of overland flow drainage networks, watershed boundaries can be easily delineated. The disadvantages of D8 are that it generalizes flow direction from one grid cell to another and therefore cannot model divergent flow (Tribe, 1992; Wilson et al., 2007). The well-known expression of this limitation is the parallel flowpaths in either the cardinal or diagonal direction (Tribe, 1992). Although there are many limitations to the D8 algorithm, however it is extremely useful in extracting river network maps, longitudinal profiles and basin boundaries (Jenson and Dominique, 1988; Mouton, 2005).

2.10 Estimation water resources in river basin

Evaluation of water resources can only be done at basin level (FAO, 1997). According to the CA (2007), river basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body.

An important consideration in water resource assessment is to estimate how much flow is available at the outlet of a river catchment. The volume of water reliably available on an annual or seasonal basis can be determined from the available data in case of gauged rivers and for completely ungauged rivers the runoff coefficient method can be employed (Goldsmith, 2000). According to (DFID, 2004), when this is the case, then data from the gauging site should be used to estimate mean annual runoff (MAR) at unguaged site, provided that the following requirements are met; (i) Catchment characteristics should be similar, (ii) The distance between the centroids of the catchments should be less than 50 km, (iii) At least ten years of mean monthly flows should be available. Otherwise, the simplest method of estimating mean annual runoff in un-gauged site was established in applying a runoff coefficient to the mean annual rainfall as shown below in the following steps.

a- The first step to determine the mean annual runoff (mm) at the gauged site as

$$\mathrm{MAR}_g=\mathrm{K} * \mathrm{MAP} \qquad 2.2$$

Where:

MAR_g is the mean annual runoff at gauged site (mm),
MAP is the mean annual precipitation at gauged site (mm)

K is the runoff coefficient at gauged site.

$$\mathrm{K}=\frac{MAR_g}{MAP} \qquad 2.3$$

b- The second step in determining MAR at un-gauged site as

$$MAR_u= k *MAP_g \qquad 2.4$$

MAR_u= Mean annual runoff at un-gauged site (mm)

The mean annual or monthly runoff depth obtained from equitation (2.4) at un-gauged site can be converted to mean monthly runoff considering, average areal monthly rainfall and catchment area of both gauged and ungauged sites (Jamshid, 2003). Estimation of areal rainfall over a given catchment is therefore, useful for estimating the total runoff generated from the entire catchment. There are several methods of determining the spatial distribution of rainfall. All of them yield slightly different variations of rainfall patterns across an area.

The Thiessen Polygon Method is a widely recognized scheme proven to be reasonably accurate for estimating average areal precipitation distributions. The primary assumption in the Thiessen Polygon Method is that areas closest to a precipitation station are most likely to experience similar rainfall conditions to those measured at the station (Chow *et al., 1988).* Thiessen polygons can be constructed by using the GIS to determine the spatial distribution of storms for computation of spatially variable excess rainfall. Grids of rainfall can also be computed and mapped for selected storm events (Melesse, 2002).

CHAPTER 3

STUDY AREA

3.1 General

The Euphrates and the Tigris are the two great rivers that define the ancient Mesopotamia. The Tigris River has about twenty tributaries thus, sub-basins. Although most of these basins are located within the borders of Turkey, a number of them are shared between Turkey and Iraq or between Iran and Iraq. The tributaries that significantly contribute to the total flow of the Tigris River are the Batman, the Garzan, the Botan, the Feesh Khabour, the Greater Zab, the Lesser Zab and the RubariSirwan (Diyala).In general, the last four tributaries exhibit similar flow regimes, with normal fluctuations of wet and dry years around the mean annual flow. Although the Lesser Zab and the Rubari Sirwan have been dammed since the 1960s, there is currently no evidence of a regulated stream-flow regime. Water resources management differs from one basin to another one.

The Greater Zab is by far the most important tributary of the Tigris River located within the borders of Iraq, since it has the largest discharge compared to all other branches. The contribution of the Greater Zab River to the total discharge of the Tigris River is estimated to be about 33% of the river flow at Baghdad (ESCWA - BGR, 2012). The Greater Zab is unregulated up till now, several dams have been planned to be constructed on the river and its tributaries including the Bekhme Dam. A number of dams and regulators on the Lesser Zab and the Rubari Sirwan serve local peoplefor irrigation purposes. No specific water agreements govern the Feesh

Khabour, the Greater Zab, the Lesser Zaband the Rubari Sirwan tributaries (ESCWA - BGR, 2012).

Figure 3.1 General location for study area

3.2 Geography

The latitudes and the longitudes of the Greater Zab River Basin are 35°46 - 38°24N and 43°18’ - 45°4’E, respectively. The area drained by the Greater Zab River is to the east of the Tigris River. The river originates from the mountainous area of the south-eastern of Turkey where it springs at an altitude of 4,168m above sea level. The catchment has a total area of about 26,325 km^2, 35% of the basin is located within the borders of Turkey, 62% in Iraq and 3% in Iran . Most of the precipitation in the Greater Zab River Basin takes place in winter and spring. The annual average rainfall ranges from 350 to 1000 mm. The distribution of the precipitation during each season of a year is 48.9, 37.5, 12.9and 0.57% in winter, spring, autumn and summer respectively (Al-Dulaimi, 1991; Mohammed, 1989).The Greater Zab has five main tributaries; these are Rubari Sheen, Rubari Chama, Rubari Rawanduz, Zey

Bestora and Zey Khazir. The first three tributaries are perennial streams however Zey Bestora and Zey Khazir are ephemeral rivers and they dry in summers and autumns. The Greater Zab joins the Tigris River at the south-western city of Hewler (Arbil), Iraq (Figure 3.2).

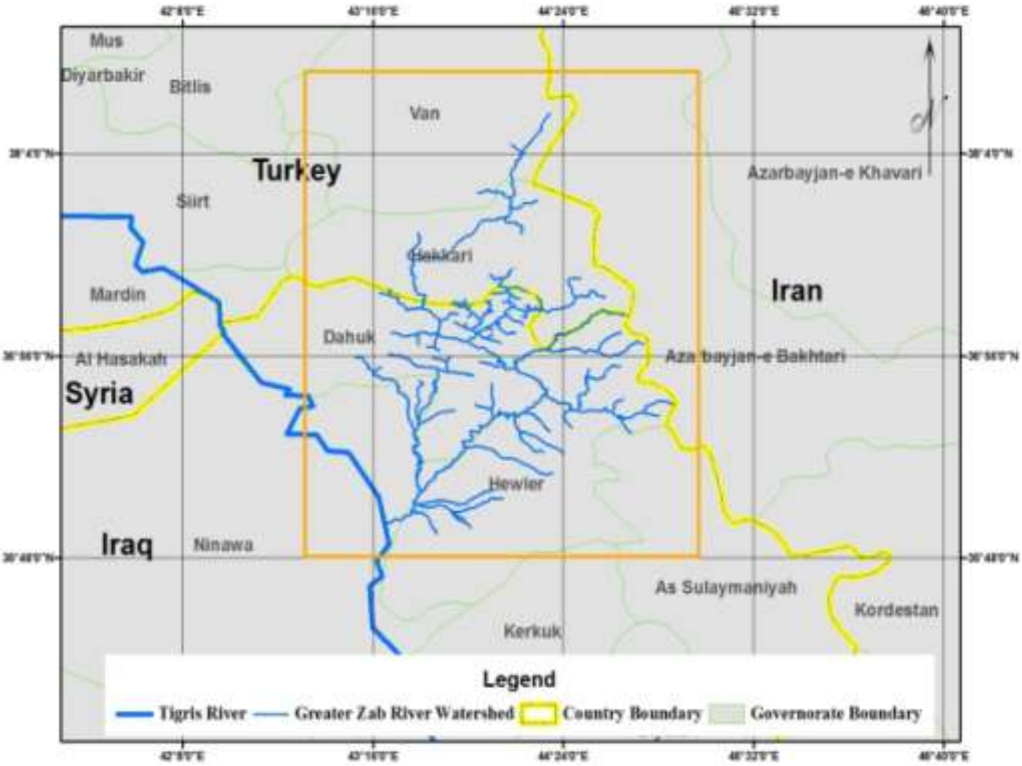


Figure 3.2 Geographical location for study area

3.3 Climate characteristics

The climate of Greater Zab River Basin is generally characterized by warm dry summers and cold winters. The transition periods in spring and autumn are very short. Precipitation is concentrated during winter seasons, November to April, which contributes around 85% of the annual total. A significant percentage of the annual precipitation is therefore received as snow, except in the lowland regions where snowfall still occurs nevertheless it is less important. The lowland plains have a semi-arid climate. The main sources of the humidity of the region is the

Mediterranean cyclones that move eastwards during winters. However, Arabian Sea cyclones from southerly directions can also cause abundant precipitation as they carry large amounts of moisture. In the summer maximum temperatures in the lowland areas exceed 45°C and dust storms are common phenomena.

Precipitation generally increases with the change in elevation, from Southwest to Northeast. The average annual precipitation is between 300 to 500 mm in the lowland plains, 400 mm in the city of Hewler. Some even lower values less than 250 mm had been recorded in Maxmur district. In most of the central karstified zone the average annual precipitation changes from 500 to 900 mm. There are considerable variations according to the local topographic conditions. Although there are no measurements, it is likely that higher values of precipitation may occur at high elevations. Average annual precipitation is between700 to 1200 mm in the high mountainous region along the borders of Iraq-Turkey and Iraq-Iran. Annual average precipitations of above 1000 mm have been recorded in Mergasur metrological station.

3.4 Hydrological characteristics

The Greater Zab and its tributaries cover a basin area of around 26,325 $km^2$where 35% of the catchment is located within the borders of Turkey and the remaining portion is situated in Northern Iraq. Total annual precipitation ranges between 350 mm and 1,000 mm from location to location depending on the elevation above the sea level. The high-flow season for the Greater Zab Basin is spring period. Peak flows usually take place in May. The Greater Zab supplies the Tigris River with an average annual flow volume of $292m^3/s$ which is measured at Gwer flow measurement station (FMS) between the period of 2005 and 2010. According to some estimates, 33% of the Tigris flow at Baghdad originates from the Greater Zab. The annual river flow time series shows a normal fluctuation with no obvious trend of wet and dry years around the mean annual flow.

3.5 Geological characteristics

The geology of the valleys of the Great Zab Basin is composed of gravel, conglomerate and sandstone. The basin corresponds to three main geological and geomorphological areas. (i) A high mountain zone equivalent to the geological "thrust zone" with limited groundwater storage but high precipitation and significant snow storage. The area is sparsely inhabited and characterized by steep slopes and narrow valleys. (ii) The mid-high mountainous region with low folded area where the reliefs are dominated by the elongated mountain ridges that are often crossed by the rivers through narrow canyons which offer suitable sites for dam construction. On one hand the area is very heterogeneous from a hydrological point of view with canyons and dry valleys.

On the other hand these regions are very rich in high-yield karstic springs. The springs which are fed by large subterranean karstic systems, may yield several m^3/s throughout the year. (iii) The lowland plains, with a typical elevation of between 300 and 600 m. The area is partly agricultural land, partly eroded 'bad land'. These regions include both densely populated areas like the regional capital city of Hewler and sparsely inhabited areas. Significant parts of the plains are comprised of with the highly productive groundwater aquifers which are partly covered by fluvial deposits and terraces or less permeable layers. Groundwater resources in the area, which are mostly of good quality nonetheless limited due to low precipitation 300 to 500 mm/year, are being used intensively through several thousands of deep wells. Most of the lowland tributaries are seasonal wadis, without permanent base flow during the dry seasons.

3.6 Water resource management

The Greater Zab River Basin is mainly shared by Turkey and Iraq. Both countries have a number of planned water resources projects to be built on the river and its tributaries. State’s Hydraulic Works (DSI) of Turkey plans to construct Çukurca and Doğanlı Dams near Çukurca and Hakkari Dam near the city of Hakkari. Hakkari Dam Hydroelectric Power Plant (HEPP) is in final design stages with an installed capacity of 321.79 MW whereas Çukurca and Doğanlı Dams will generate 245 MW and 462 MW power, respectively (EİE ,1978, EİE ,1987, EİE ,1996, Tip,2006)

Iraq has planned to build three dams in the basin these are Bekhme, Mandawaand Khazir-Gomel dams. Mandawa and Khazir-Gomel dams are still in the planning phase (ESCWA - BGR, 2012).Plans to build a dam on the Greater Zab at Bekhme Gorge for flood control and irrigation were first proposed in 1937. The feasibility study had determined that the site was not suited for dam construction and the plan was abandoned. In 1976 another study proposed three different locations on the Greater Zab including the site suggested in the earlier study. The site was eventually chosen to be Bekhme Gorge, in 1989.The construction of multi-purpose Bekhme Dam was commenced and interrupted by the outbreak of the Gulf War in 1990.The dam remains unfinished up to date. In post-2003 Iraq, efforts to rebuild Bekhme Dam have intensified and it is expected to be built soon. Bekhme is expected to be a 230 m high rock-fill dam with an underground hydroelectric power station housing six turbines with a total capacity of 1,560 MW, the largest in Iraq. The reservoir that would have been created by Bekhme Dam would have a storage capacity of 17 cubic kilometres and would have flooded numerous villages and the archaeological site of Shanidar Cave.

Table 3.1.Water Resources projects on the Greater Zab River (ESCWA - BGR, 2012)

Country	Name	River	Completion Year	Background Information
Iraq	Bekhme Dam	Greater Zab	Scheduled 2015	Partially constructed
Iraq	Mandawa Dam	Greater Zab	Scheduled 2015	---------------------------
Turkey	Cukurca Dam	Greater Zab	Planned	HEPP capacity245MW
Turkey	Doganli Dam	Greater Zab	Planned	HEPP capacity245MW
Turkey	Hakkari Dam	Greater Zab	Planned	HEPP capacity245MW

3.7 Data

The data used in this study was 30-m spatial resolution digital elevation model (DEM) generated from high resolution satellite imagery which offer the essential information in a rapid, accurate and reliable mode. The monthly average discharge of the stream flow and the monthly total precipitations from the precipitation observation stations in the study area. The river discharge data at the flow measurements stations (FMS) located within the borders of Iraq were obtained from the Directorates of Irrigation and Surface Water of Hewler and Dohuk cities. Whereas the data of the FMS 2620, situated within the borders of Turkey was obtained from general directorate of electric power resources survey and development administration (EIE).

The monthly average discharge data taken into account for this study covered the period of 2001-2010 (Table 3.2).Precipitation and other climatic parameters have been measured by a reasonably dense network of meteorological stations. In total 24 meteorological stations located in the Greater Zab River Basin were employed in determining the average annual areal precipitation (Table 3.3). The climatological stations which have a long period of records, located within the borders of Iraq, suffer from discontinuity due to the unstable situations in the region. Numerous meteorological stations, situated in the area have been established just after year 2000. It is also worth mentioning that most of the stations in Northern Iraq are of agriculture-meteorological type, established by the Ministry of Agriculture and Directorate of the Water Recourses Management of city of Hewler, with the cooperation of Food and Agriculture Organization (FAO) of the United Nation, during the year 2001(Abbas Kh. A. 2008).

Efforts had been taken to select the station sites to be geographically distributed well, fulfilling World Meteorological Standards. (Tables 3.2 and 3.3) provide an overview of Hydrological and metrological data availability.

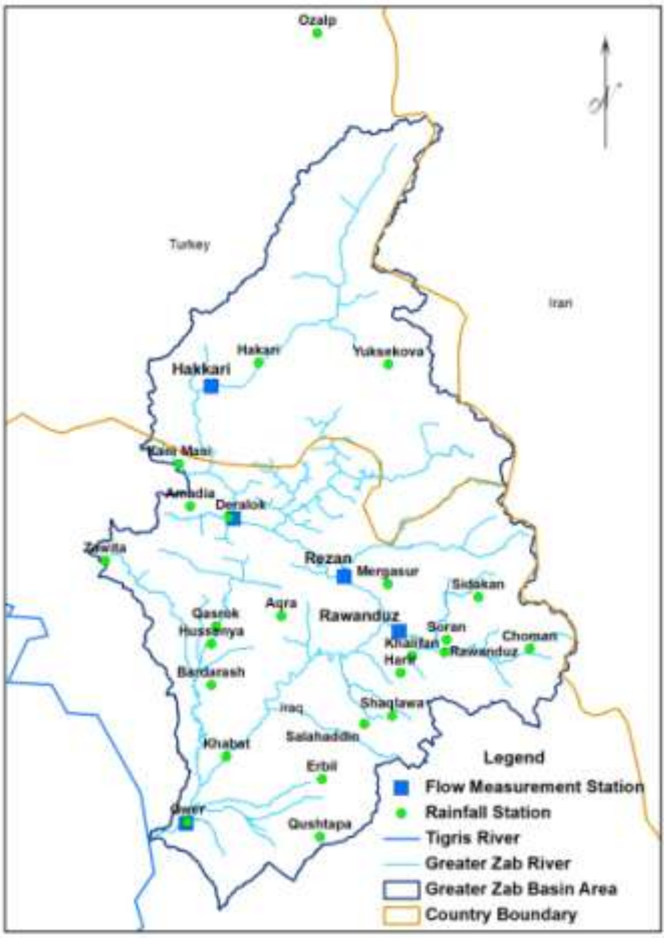


Figure 3.3 location of flow measurement station and rainfall measurement station

Table 3.2 Flow measurement stations in the study area

Catchments	Lon.	Lat.	Elev.(m)	Data Used	Ann Ave. Disc. (m^3/s)
Gwer	43.489	36.0437	202	2005 - 2010	292
Rawanduz	44.347	36.683	444	2001 - 2010	34.6
Rezan	44.122	36.864	471	2001 - 2010	32.2
Deraluk	43.664	37.51	610	2004 - 2009	75
Hakari	43.565	37.486	1072	2001 - 2005	52

Table 3 3 Meteorological stations in the study area

Rainfall Stations	Lon.	Lat.	Elev.(m)	Data Used	# of year Data Used
Erbil	44.039	36.196	420	2001 - 2010	10
Salahaddin	44.209	36.378	1087	2001- 2010	10
Khabat	43.650	36.266	252	2001 - 2010	10
Qushtapa	44.32	36.004	398	2001 - 2010	10
Shaqlawa	44.321	36.406	975	2001 - 2010	10
Harir	44.355	36.548	742	2001 - 2010	10
Khalifan	44.401	36.604	687	2001 - 2010	10
Soran	44.543	36.658	679	2001 - 2010	10
Choman	44.881	36.628	1090	2001 - 2010	10
Mergasur	44.301	36.840	1204	2001 - 2010	10
Sidakan	44.671	36.798	1020	2001 - 2010	10
Rawanduz	44.534	36.617	677	2001 - 2010	10
Gwer	43.494	36.047	210	2005 - 2010	6
Bardarash	43.584	36.501	379	2001 - 2010	10
Amedi	43.487	37.089	1202	2001- 2010	10
Aqra	43.866	36.732	636	2001 - 2010	10
Kani Masi	43.438	37.229	1269	2001 - 2010	10
Zawita	43.141	36.904	890	2001 - 2010	10
Deralok	43.646	37.055	645	2001 - 2010	10
Qasrok	43.599	36.695	419	2001.-.2010	10
Hussenya	43.582	36.636	368	2001 - 2010	10
Hakkari	43.8	37.6	1728	2001 - 2010	10
Yuksekova	44.3	37.6	1875	2001 - 2010	10
Ozalp	44	38.7	1987	2001 - 2010	10

CHAPTER 4

METHODOLOGY

4.1 General scheme of the methodology

Performing hydrologic modelling involves delineating river basin boundary and getting some basic watershed properties. This includes the area of watershed, slope, flow length, and stream network density (Venatesh, M., 2009). ArcGIS software it is a main software to performed this study, With the availability of digital elevation models (DEM) and ArcHydro extension tools in ArcGIS, watershed properties can be extracted by automatic procedures.

Methodology in this study it have three main processes. The first process in determining basin characteristics is executing terrain pre-processing models, namely, fills-sinks, flow direction, flow accumulation, stream networks and watershed boundary definition which are attained from digital elevation model (DEM) by ArcGIS hydrology tools.

The process step is hydrological processing such as, map of sub-catchment, characteristics of sub-catchment, river network map and river network characteristics that have been delineated by employing ArcHydro extension tools. The third step is accomplishing hydrological analysis like; slope map, Thiessen polygon map, Thiessen polygon area values and runoff coefficient by Arc Toolbox (Figure 4.1).

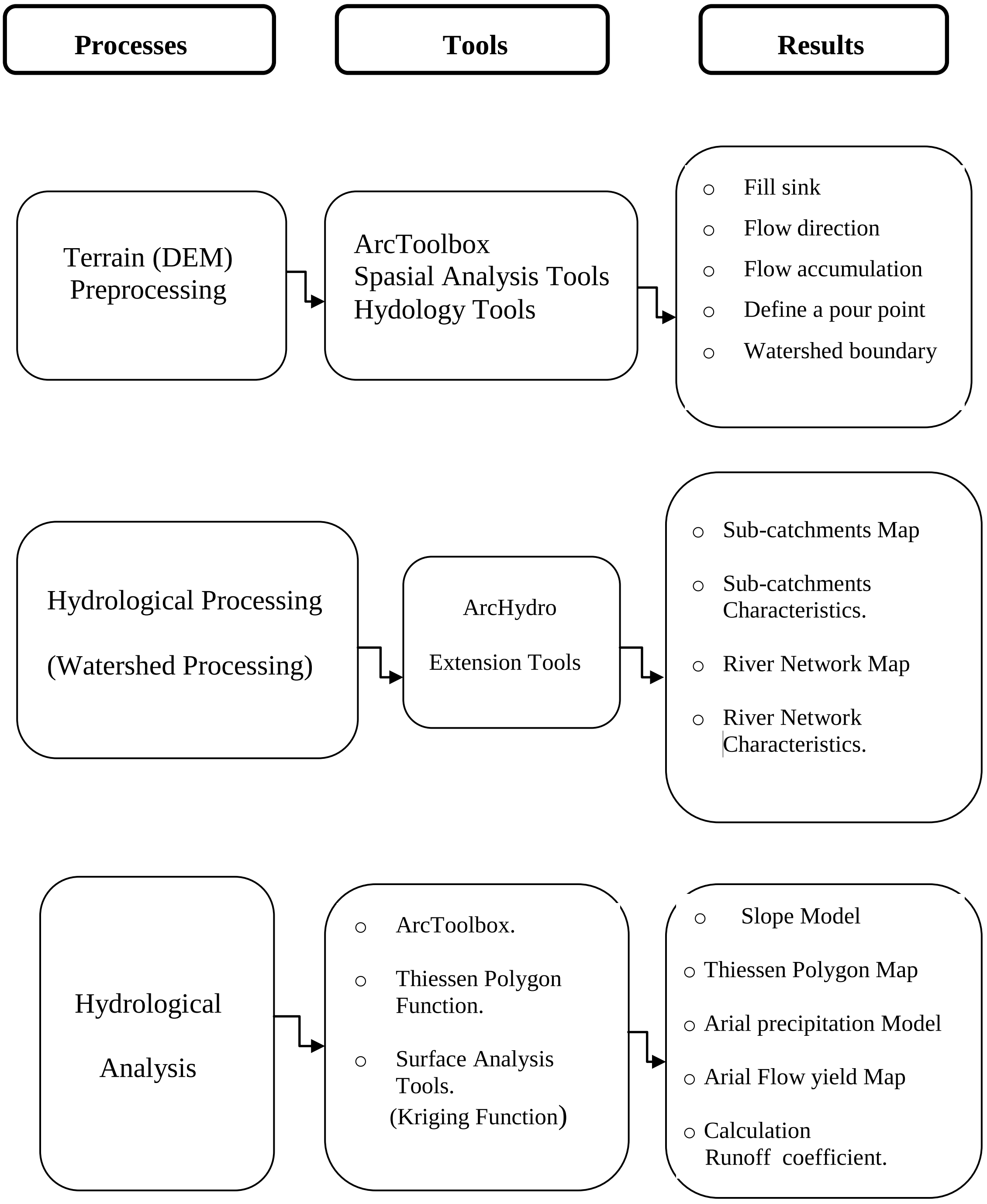


Figure 4.1. Methodology for the GIS processes

4.2 Software

ArcGIS software components which were used in this study to generate sets of digital maps for selected study area, the Greater Zab River Basin, were Arc-Map, Arc-Catalog, Spatial analysis–Hydrology tools and ArcHydro extension tools. The maps generated from digital elevation model (DEM) include drainage lines, river basin boundary, sub-catchments, digital slope map, Thiessen polygon map, areal distribution of precipitation and areal distribution of flow yield of the basin. A brief description of each GIS function components and extension are given below.

Arc-Map is the principal application used in ArcGIS to create and manipulate data sets display maps, assign symbols, analyse spatial data and edit query in collection of layers.

Arc-Catalog is a database administration application which helps organize and manage diverse types of geographic information. Arc-Catalog helps users to browse, search, view and manage data.

Arc-toolbox is the central place to manage and execute geo-processing tools such as data conversion, overlay processing, buffering, surface analysis and file transformation. Hydrology tools which are part of Arc-toolbox were used, in this study, to delineate the river basin boundary of the Greater Zab.

Arc-Hydro is an extension tool in ArcGIS which is used for hydrological processing to create, manipulate and display hydro features and objects in the study area.

4.3 Digital Elevation Model (DEM)

Digital Elevation Models (DEMs) are raster geographic digital datasets of elevations in x,y,z coordinates. The terrain elevations for ground locations are sampled arrays of regularly spaced elevation values referenced horizontally either to a Universal Transverse Mercator (UTM) projection or to a geographic coordinate system (Kessler, 1992; Doyle, 1978).The grid cells are spaced at regular intervals along south to north profiles that are ordered from west to east.There is no common practice of the terms digital elevation model (DEM), digital terrain model (DTM) and digital surface model (DSM) in the literature. In most cases the term digital surface model signifies the earth's surface, including all objects on it. However the digital terrain model characterizes the plain ground surface without any objects like plants and buildings.

DTM is frequently used as a standard term for DSMs and DTMs, only demonstrating height information without any further definition about the surface. Some descriptions equalize the terms DEM and DTM or express the DEM as a subset of the DTM, which also indicates other morphological parameters. There are also explanations equalize the terms DEM and DSM. Nonetheless, most of the data suppliers (USGS, ERSDAC, CGIAR, Spot Image) use the term DEM as a common term for DSMs and DTMs.

4.4 Terrain (DEM) Pre-processing

Terrain Pre-processing was applied to the Digital Elevation Model (DEM), which has a larger coverage area than the study area in order to identify the boundary of the river basin as a pre-requisite for the hydrological processing. All of the steps in the terrain pre-processing menu should be performed in sequential order, from top to bottom. Hydrology tools, which are spatial analyses tools describing the physical components of a surface in ArcGIS were used for this processing. Hydrology tool functions in sequence are; load DEM, fill sinks, determine flow direction, calculate flow accumulation, define pour apoint, delineate the watershed boundary and create stream networks. Several hydrology tools and their brief descriptions are given in Table 4.2. There are two ways of defining a sub-catchment, one of them is applying a threshold when defining the streams and the other one is defining a pour point first and then delineating the watershed (Figure 4.3).

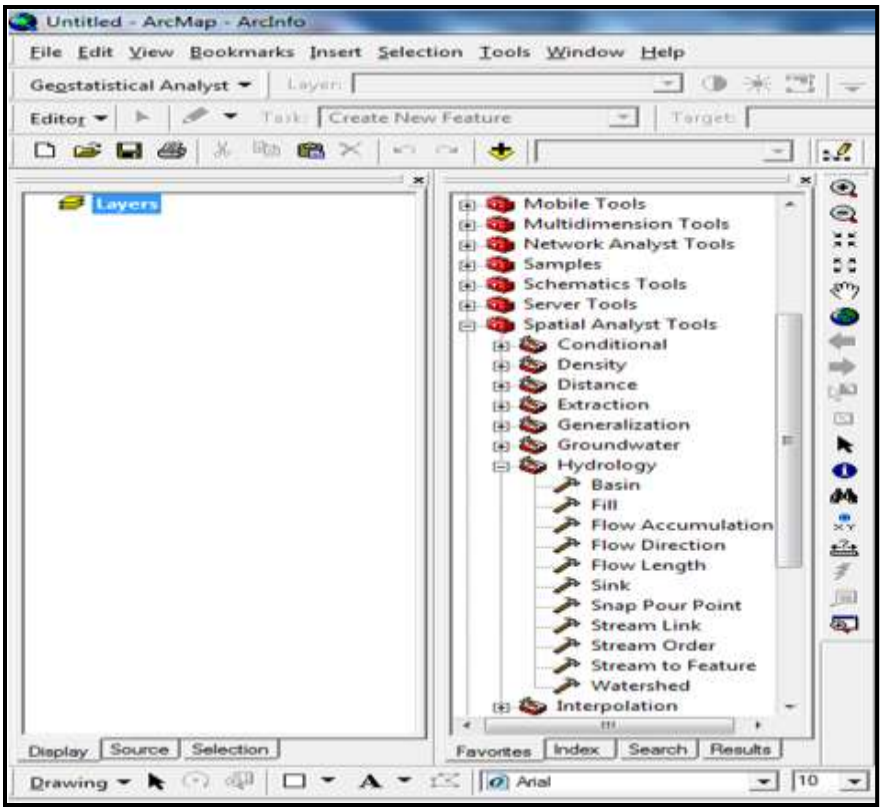


Figure 4.2. Hydrology functions in spatial analysis tools in Arctoolbox.

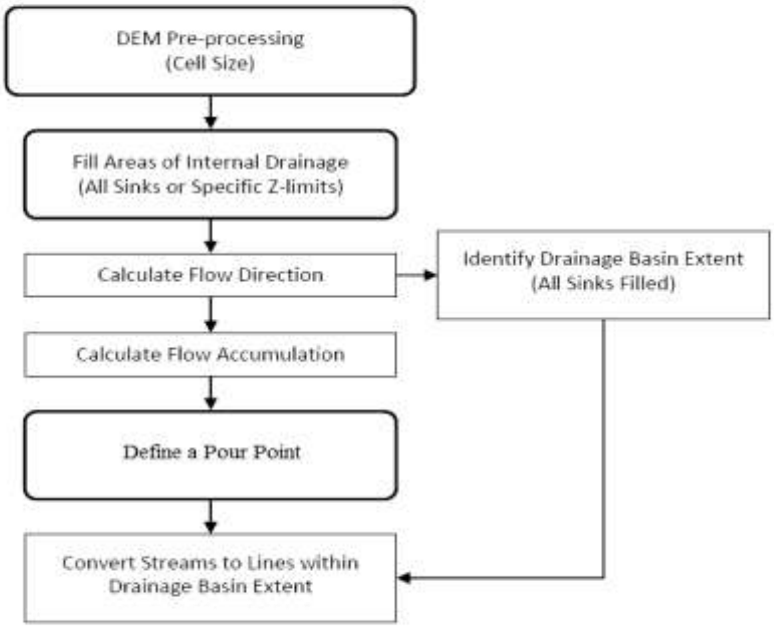


Figure 4.3 The process of defining river basin boundary from DEM by ArcGIS

Terrain Pre-processing tools are a set of functions used for processing DEM based data needed for watershed delineation and watershed characteristic extraction.

Table 4.2. A brief description of functions in Hydrology tools

Functions	Description
Fill	Fills sinks in a surface raster to remove small imperfections in the
FlowDirection	Creates a grid of flow direction from each cell to its steepest down slope neighbour.
Flow Accumulation	Creates a raster of accumulated flow to each cell by accumulating the weight for all cells that flow into each downslope cell.
StreamShape	Converts a grid representing a raster linear network to a shapefile
Snap Pour Point	Snaps selected pour points to the cell of highest flow accumulation within a specified neighbourhood.
Watershed	Determines the contributing area above a set of cells in a grid

4.5 Hydrological processing

The first step of hydrologic processing is delineating the watershed boundary, determining stream direction, calculating flow accumulation and defining some basic watershed properties such as area, slope, flow length and stream network density.

Traditionally this has been done manually by using contour maps. In this study, Geographical Information System (GIS) and ArcHydro tools were used for the delineation of the watershed and the sub-watersheds. The main aim for hydrological processing is to define the sub-catchments and acquire data for these sub-catchments. In the hydrological processing the functions such as; fill sinks, flow direction, flow accumulation, stream definition, drainage line processing, drainage point processing, catchment grid delineation, catchment polygon processing, defining sub-catchment and longest flow path, must be used to determine the geomorphologic parameters of the basins and the sub-basins.

4.6. Hydrological Processing Using ArcHydro

The DEM data set was pre-processed by using ArcHydro tools before being used as a base data set for the virtual terrain. ArcHydro does this processing step by step. The steps in terrain processing include filling topographic depressions to map water flow. These depressions are called sinks and are natural occurrences in the landscape. GIS uses cell-based calculations for filling these sinks. ArcHydro is a graphical user interface (GUI) based tool which is incorporated in ArcMap.

The terrain processing is accomplished by choosing options from a menu. These options include filling sinks, calculating flow directions and flow accumulation, stream definition and stream segmentation for delineating watershed. Figure 4.4 shows ArcHydro tool bar menu.

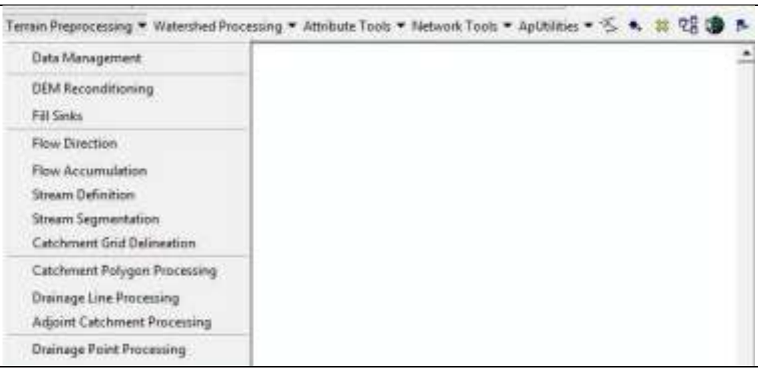


Figure 4.4 ArcHydro tool bar menu

Sinks are assumed to be errors in the DEM data. These errors are in the form of very low elevation values relative to the surrounding cells. Sinks are filled by raising the elevation of the pit cells so it is equal to the elevation of the lowest point of the surrounding cells.

It is necessary to fill the sinks before getting flow directions, because water gets caught in these depressions and does not flow to the river, which gives errors while calculating flow accumulation and flow direction. Sinks are filled by clicking on Fill Sinks in the Terrain Pre-processing menu. The raw DEM is added as input for processing. By default, it will pick the DEM from the open map document. The output of Hydro DEM is Fil as shown in Figure 4.5.

DEM: DEM-Greter Zab Basin
Hydro DEM: Fil

Figure 4.5 Filling sinks in ArcHydro

The next step is to determine flow direction, which is further used to find flow accumulation. The flow direction is defined as the direction in which flow moves to one from the eight neighboring cells (D8 model) based on the cell that has the steepest slope. This is done by selecting Flow Direction in the Terrain Pre-processing menu and then inputting sink-filled DEM as Hydro DEM for processing (Figure 4.6).

Hydro DEM: Fil
Flow Direction Grid: Fdr

Figure 4.6 Flow direction dialog in ArcHydro

The Flow Accumulation Grid is created by an accumulation of cells upstream of each cell (Figure 4.7).

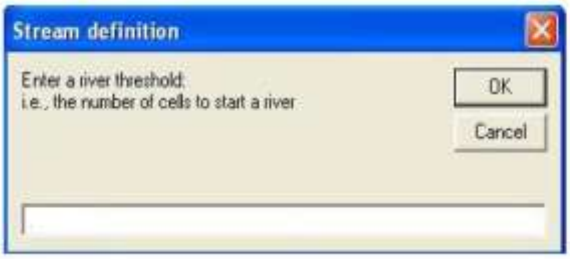
Flow Accumulation

Flow Direction Grid: Fdr

Flow Accumulation Grid: Fac

Figure 4.7 Flow accumulation dialog box in ArcHydro

After determining the Flow Accumulation Grid, the next step is obtaining the stream definition. A selected minimum threshold value is used to identify the stream network. This threshold value defines the number of cells that are contributing to a single cell to form a stream (Figure 4.8). This is accomplished by selecting Terrain Pre-processing, then the Stream definition option and providing the Flow Accumulation Grid as input.



Stream definition

Enter a river threshold:
i.e., the number of cells to start a river

Figure 4.8 Stream definition

The next step is stream segmentation, which converts the stream into a vector representation from the grid. This step is required for catchment grid delineation. The catchment grid delineation can be defined as dividing the watershed into various sub-basins based on topographic and hydrographic characteristics of the catchment. This is done by selecting Catchment Grid Delineation from the Terrain Pre-processing pull down menu and providing input for the Flow Direction Grid and Stream Segmentation Grid. The output from this processing is a catchment grid, as shown in (Figure 4.9).

Flow Direction Grid: Flow Direction Grid
Link Grid: Stream Segmentation Grid
Catchment Grid: Cat

Figure 4.9 Catchment grid delineation

In order to covert this grid format into vector representation, polygon processing is done on the watershed grid. The input for the watershed polygon processing is the watershed delineation grid, which is converted into a shapefile representing the delineated watershed (Figure 4.10). The Terrain Pre-processing tool in ArcHydro delineates the catchment area into sub-basins, which further enhances the profound watershed analysis.

Catchment Grid:
Catchment: Catchment

Figure 4.10 Catchment polygon processing

4.7 Hydrological analysis

Hydrological analyses are complex by nature due to random distribution of hydrological and meteorological parameters in time and space. For design of all sorts of hydraulic structures a comprehensive hydrograph of runoff is not always required. The peak of the hydrograph is sufficient for design of some structures. Thus, the maximum value of the flood runoff hydrograph is the design discharge. Several methods for evaluating a design discharge have been developed. In this study, rational method which estimates the peak discharge was used to define the rainfall-runoff coefficients for a number of sub-basins and the whole of the Greater Zab River Basin. Both the inherent assumptions of this method and the results have been shown to be acceptable for various engineering projects. In rational method, it is assumed that the rainfall intensity is constant at all time, the rainfall is uniformly distributed in space and the storm duration is equal to or longer than the time of concentration t_c. The time of concentration is defined as the time for the runoff to become established and flow from the most remote part of the drainage area to drainage outlet.

The method was applied to the sub-catchments where the annual average discharge measurements were available. Annual average discharge values for these flow measurement stations were acquired from monthly average discharge measurements. The total annual precipitations were achieved from 22 meteorological stations in the basin by using Thiessen polygon method. The annual average discharge at a desired ungauged site or at a proposed dam project location can be roughly estimated by employing the rainfall-runoff coefficient and the area of each sub-catchment. The rainfall-runoff coefficients for sub-catchments were determined by rational method.

$$C = \frac{Q}{iA} \qquad 4.1$$

where C is runoff coefficient, Q is discharge (m^3/s), i average area rainfall (mm) and

A is the catchment area (m^2).

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Terrain (DEM) Pre-processing

Terrain Pre-processing uses digital elevation model (DEM) of the study area in order to identify the boundary of the Greater Zab River Basin as a necessity for the hydrological processing. The processes were performed in successive order. Figure 4 shows the digital elevation model which covers an area larger that the Greater Zab River Basin while fill sink tool applied DEM is illustrated in Figure 5. Flow direction, flow accumulation, stream network, pour point and delineated watershed are presented in Figures 5.1 – 5.7.

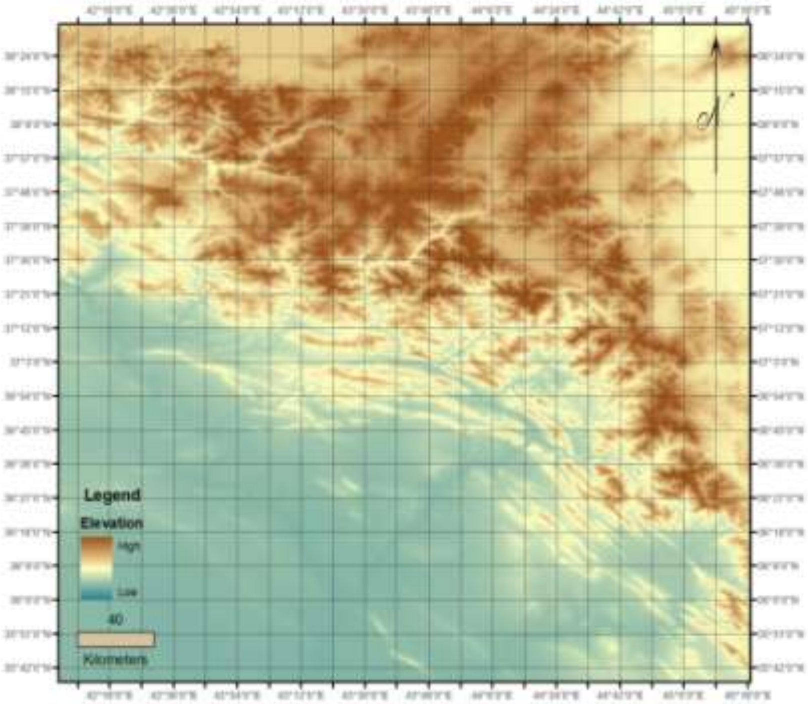


Figure 5.1 Terrain DEM lager than Study Area

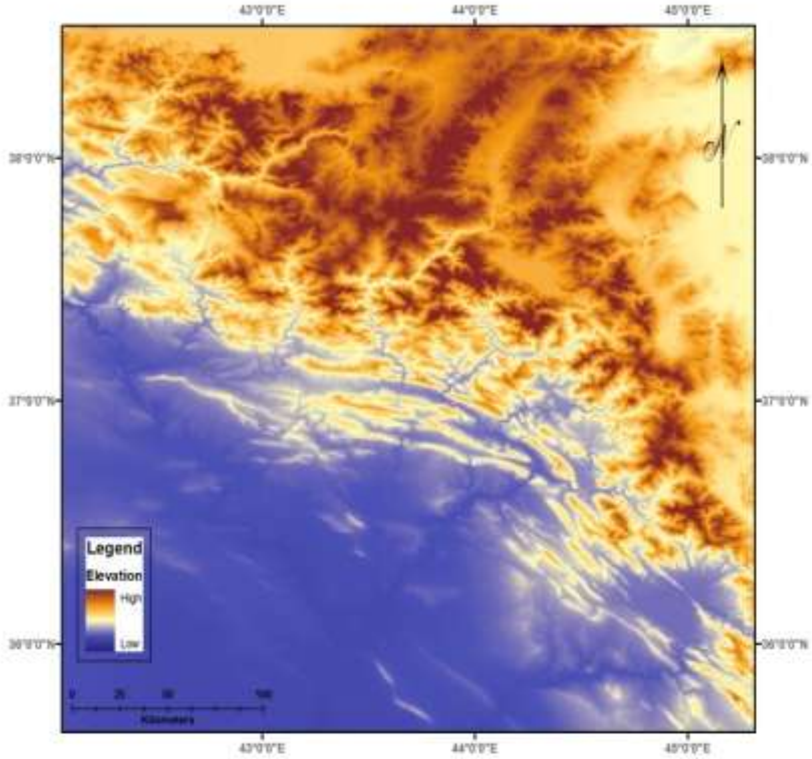


Figure 5.2 Filled sink

5.1.1 Flow direction

According to Kang (2008) a flow direction raster shows the direction of water which flows out of each cell of a filled elevation raster. There are eight distinct values in the flow direction raster as illustrated in (Figure 5.3). Each value indicates the direction code showing the direction of flow out of each cell. ArcGIS uses the eight direction (D8) flow model. This method assigns a cell's flow direction to one of its eight surrounding cells that have the steepest distance-weighted gradient. The eight output directions relate to the eight adjacent cells into which water could flow. Flow direction was determined from the elevation differences between the neighbouring raster cells.

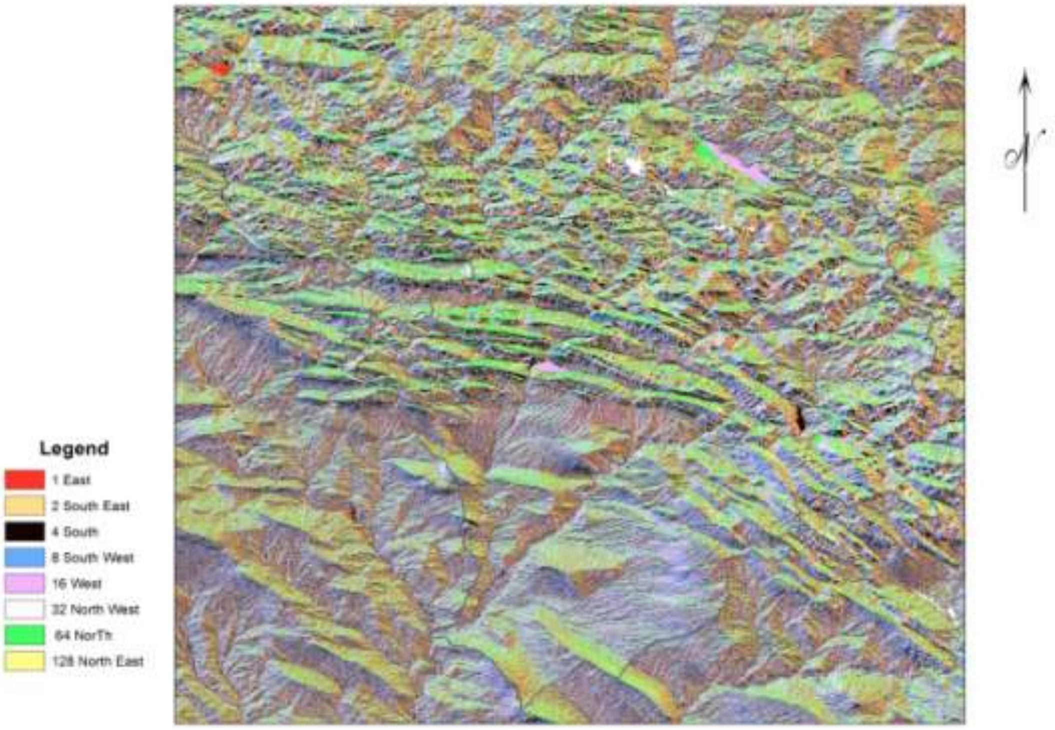


Figure 5.3 Flow Direction

5.1.2 Flow Accumulation

The raster of accumulated flow to each cell which is defined by accumulating the weight for all cells that flow into each downslope cell is the result of Flow Accumulation. Cells with undefined flow direction will not contribute to any downstream flow they will only collect flow. The accumulated flow is based on the number of cells flowing into each cell in the resultant raster. Cells having high flow accumulation values are concentrated flow areas and generally correspond to stream channels, whereas cells with a flow accumulation of zero output identify ridges since they represent local topographic highs (Kang, 2008). Flow accumulation was computed by using Flow Direction outputs. Stream Network was defined from flow accumulation values of each cell (Figure 5.4 – Figure 5.5).

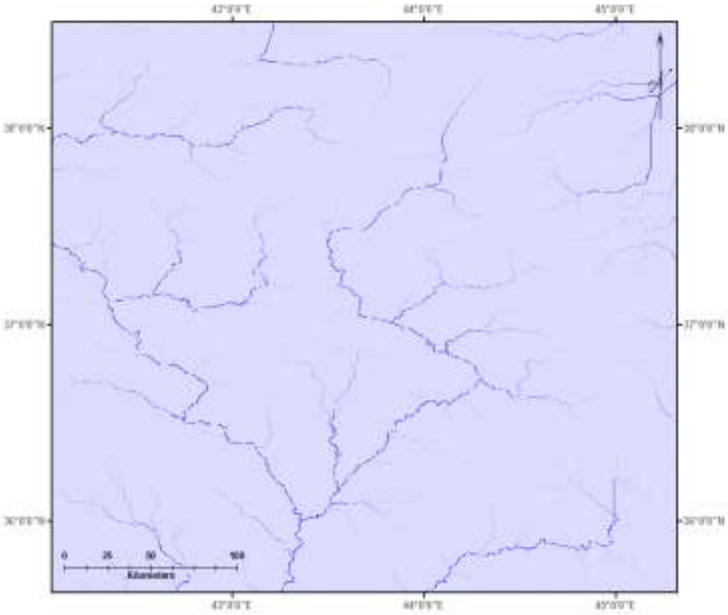


Figure 5.4 Flow accumulation

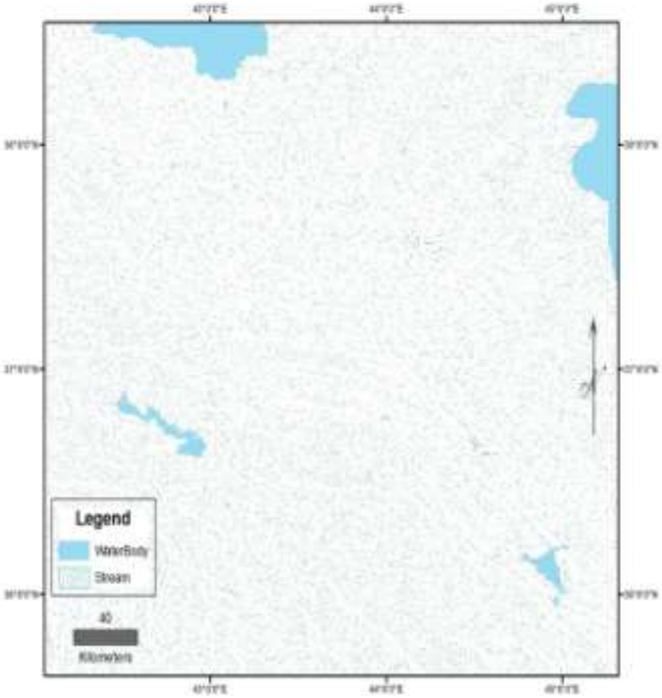


Figure 5.5 Stream Network

5.1.3 Define pour point

Watersheds are physically delineated by the area upstream of a point of interest which is known as outlet point, pour point or discharge point. A pour point is the point at which water flows out of the contributing area surrounded by ridge line. Ridgelines are boundaries which separate watersheds from each other. The pour point may be a gauge station, a dam or any subjective point on the river network. In this work the pour point is a point in the lowest area that intersects with the Tigers River.

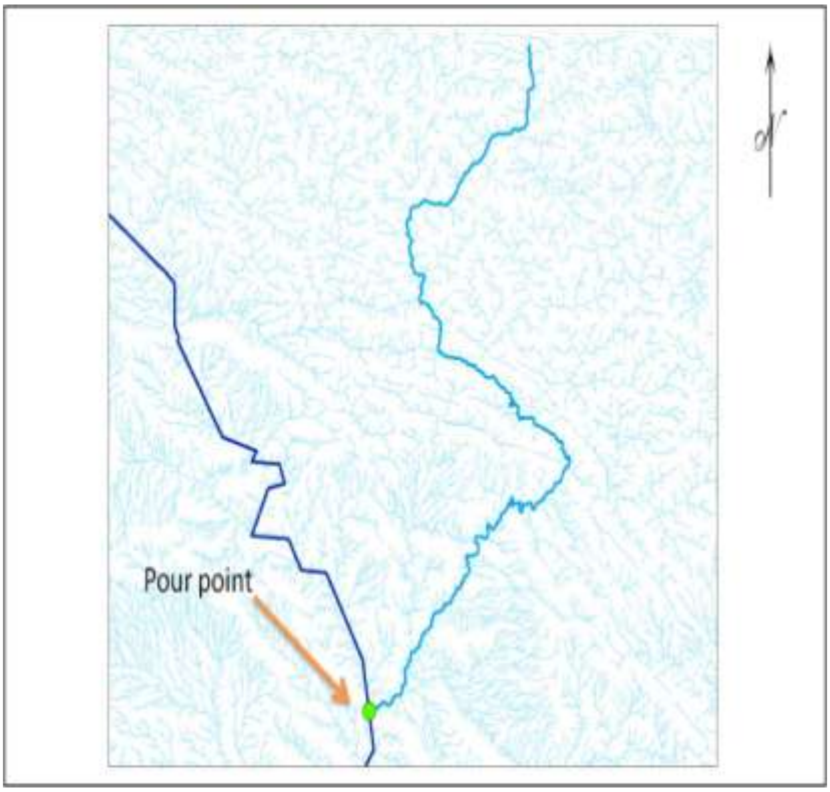


Figure 5.6 Define Pour point

5.1 4 Watershed delineation

A Watershed is an upslope area of land where surface water from rain and melting snow or ice joins and flows to a particular cross-section of a stream which is named as the drainage point, the exit, the outlet or the pour point of the basin. At the pour point of a river the flow of water meets other water-bodies, like a river, lake, reservoir, estuary, wetland, sea, or ocean. A watershed, also called basin, catchment, drainage area or contributing area, simply could be a part of a larger watershed. The Greater Zab River Basin is a part of the Tigris River Basin. The boundaries between watersheds are called drainage divides or ridge lines. Watersheds are physically delineated by the area upstream from the outlet point. Watersheds can be delineated both manually on paper maps and digitally in a GIS environment. In GIS applications the Watershed function uses a raster of flow direction to determine contributing area. Either a flow accumulation threshold or the pour points should be used to delineate watersheds.

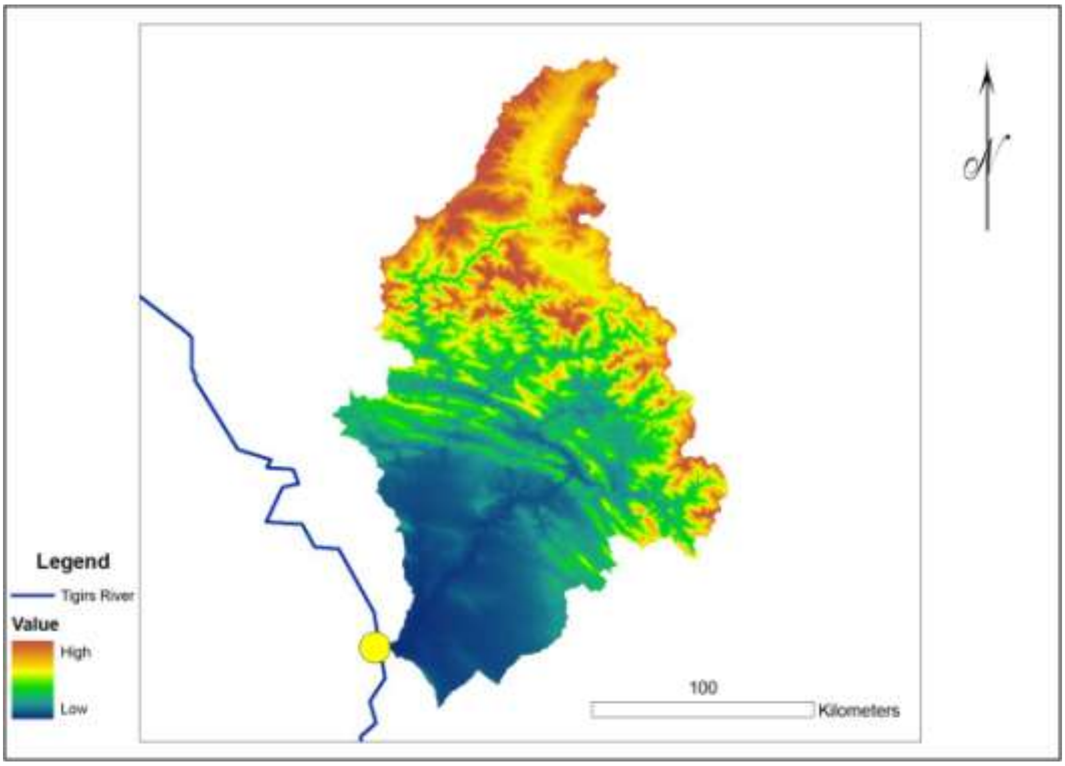


Figure 5.7 Delineating boundary of the Geate Zab river basin

When the threshold is used to define a watershed, the pour points for the watersheds will be the junctions of a stream network derived from flow accumulation. The features identify the pour points, when a feature dataset is used to define a watershed. The watershed map for the Greater Zab River Basin was delineated by employing the flow direction raster acquired previously and a defined pour point (Figure 5.7). The total area of river basin was estimated to be about 26,325 km^2.

5.2 Hydrological processing of the basin

The hydrological processing of the Greater Zab River Basin starts with filling all of the sinks in the raster data if there are any, after delineating the boundaries of the basin (Figure 5.8). If a cell is surrounded by high elevated cells, the water is expected to be trapped in that cell and cannot flow further. Next, the flow direction and the flow accumulation grids are calculated based on the flow path of the steepest decent (Figures 5.9 and 5.10). The function stream definition was used to extract the stream grid from flow accumulation grid for all the cells (Figure 5.11). Then, drainage points of all stream tributaries that are associated with the sub-catchments were defined (Figure 5.12). The location of the drainage points are the outlet of each stream tributary. One of the aims of the hydrological processing is to delineate the sub-catchments and acquire hydrological data for the sub-catchments in the Greater Zab River Basin (Figure 5.13 and Table 5.1). A total number of 59 sub-basins have been identified. Area of sub-basins ranged from 2078 km^2 to 26 km^2 where total watershed area of the Greater Zab River Basin was found to be 26,325 km^2. The longest flow path of the sub-basins ranged from 89 km to 10 km. However the average slope of the sub-basins varied from 0.131 % to 8.84 %.

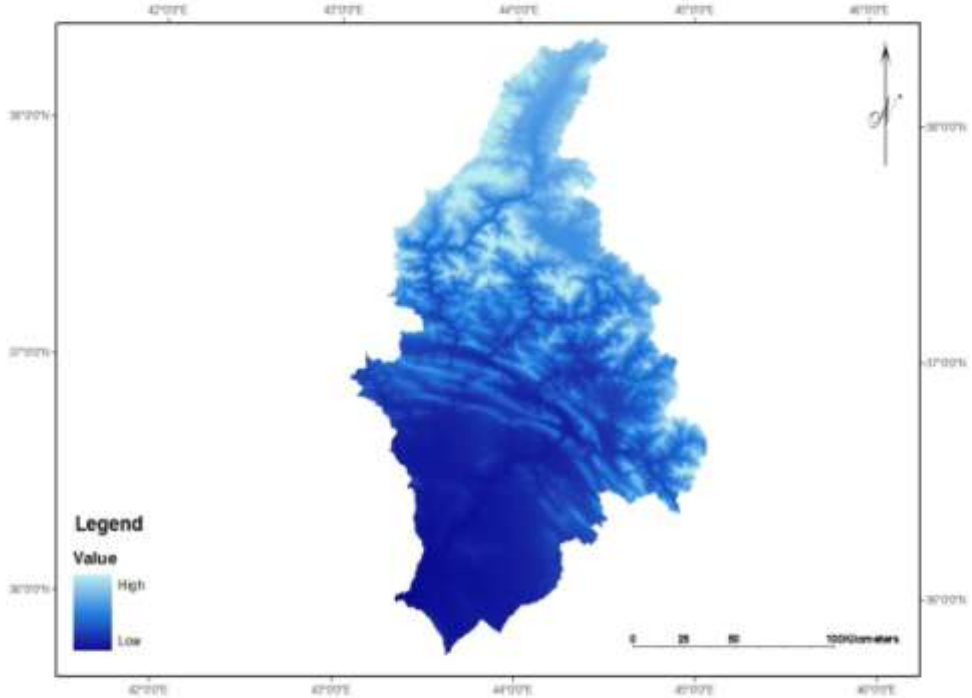


Figure 5.8 Fill sinks of the Greater Zab river basin

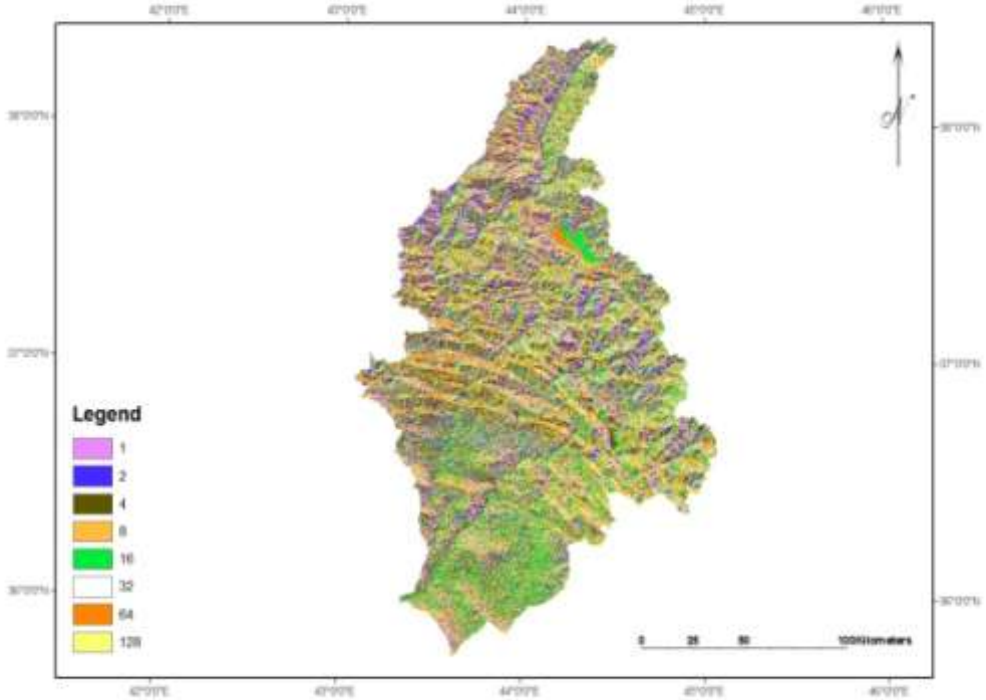


Figure 5.9 Flow direction of the Greater Zab river basin

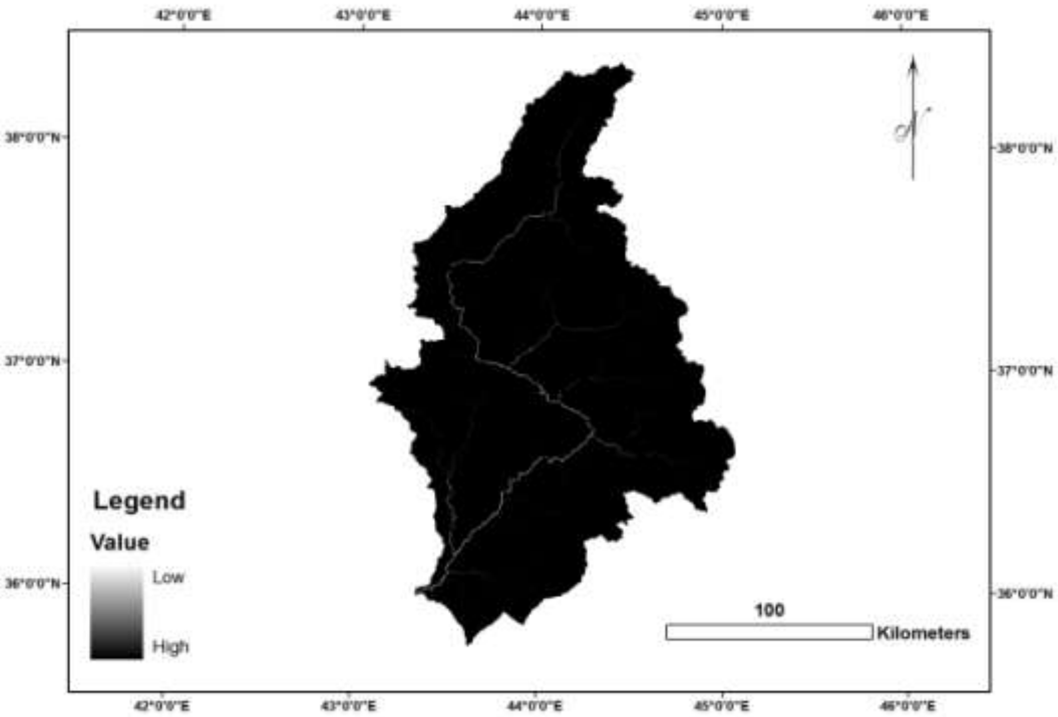
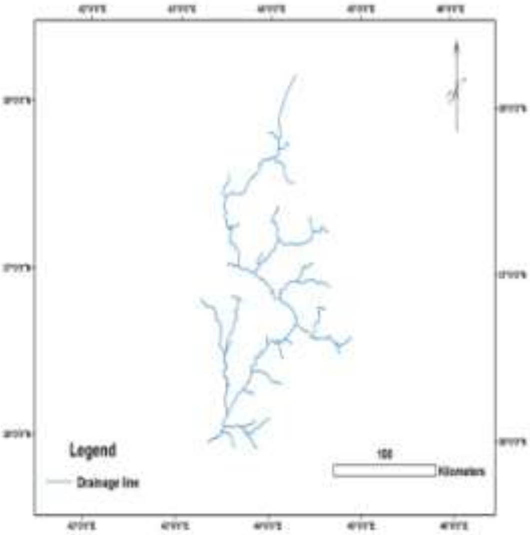


Figure 5 10 Flow accumulation of the Greater Zab river basin



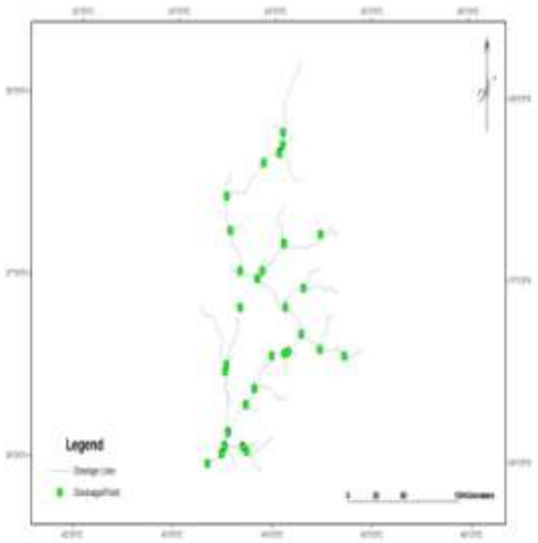


Figure 5.11 Stream Definition

Figure 5.12 Drainage points processing

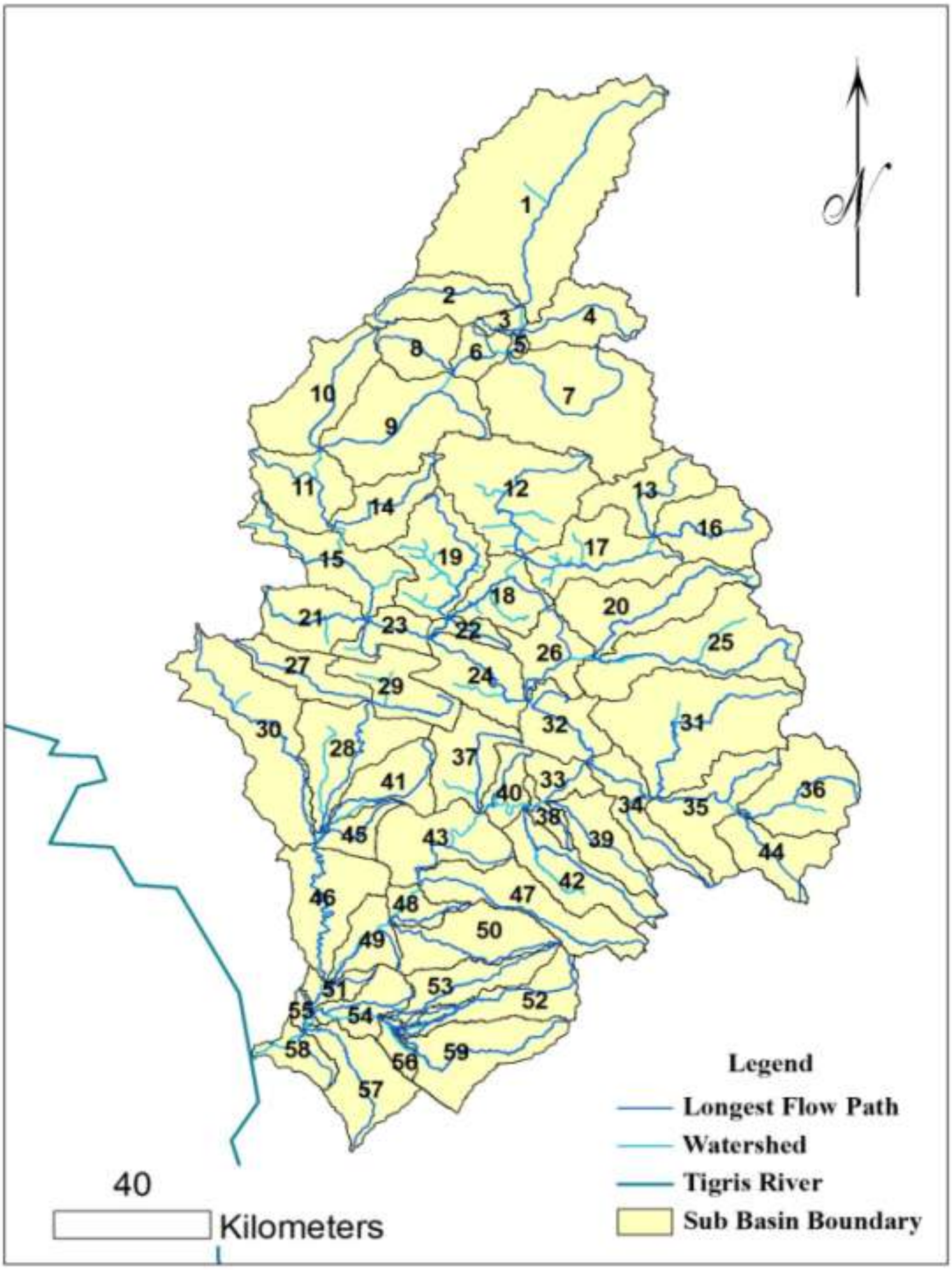


Figure 5.13 Delineating Different sub catchments boundary

Table 5.1 Hydrological features of the Greater Zab River sub-catchments

Sub-basin	Area of sub-Basin (km^2)	Min. Elev.(m)	Max. Elev.(m)	Longest Flow Path (km)	Longest Flow Path Slope (%)
1	2078	1815	2825	84	1.2
2	364	1809	3437	56	2.91
3	69	1738	3152	16	8.84
4	381	1734	3412	44	3.81
5	26	1566	2401	10	8.35
6	155	1409	2973	25	6.26
7	1200	1566	3530	64	3.07
8	288	1372	3520	30	7.16
9	854	1176	3980	63	4.45
10	590	1176	3221	47	4.35
11	432	808	3110	44	5.23
12	949	887	2346	62	2.35
13	405	1120	2556	37	3.88
14	364	806	3191	48	4.97
15	507	623	2540	58	3.31
16	447	1082	3066	46	4.31
17	544	747	3060	50	4.63
18	329	584	2342	40	4.4
19	563	592	3381	54	5.16
20	638	580	3248	69	3.87
21	383	617	1909	41	3.15
22	100	544	2183	30	5.46
23	225	544	1756	36	3.37
24	435	441	1406	44	2.19
25	891	589	2749	71	3.04
26	318	454	2095	42	3.91
27	316	485	1538	46	2.29
28	565	320	485	49	0.337
29	393	485	1363	32	2.74
30	953	313	1067	89	0.847
31	1137	530	3099	71	3.62
32	351	392	1381	40	2.47
33	174	361	398	16	0.231
34	366	406	2294	66	2.86
35	527	611	2792	48	4.54
36	563	745	2260	43	3.52
37	402	317	1477	37	3.14
38	91	358	918	23	2.43
39	350	379	1428	42	2.5
40	189	319	1532	27	4.49
41	342	314	831	54	0.957
42	475	360	1685	61	2.17
43	529	261	650	38	1.02
44	359	727	1744	32	3.18
45	168	309	522	35	0.609
46	563	212	304	70	0.131
47	602	280	1685	69	2.04
48	146	250	419	28	0.604
49	252	215	486	32	0.847
50	497	250	1045	59	1.35
51	114	208	350	24	0.592
52	375	262	1040	70	1.12
53	337	260	938	56	1.21
54	251	208	397	34	0.556
55	48	196	258	16	0.388
56	125	248	348	27	0.37
57	462	199	447	49	0.506
58	184	197	368	19	0.9
59	562	203	826	68	0.916

5.3 Hydrological analysis of the basin

The Greater Zab River Basin was hydrological analysed in order to determine the slope map, Thiessen polygon map, Thiessen polygon areas, the runoff coefficients of a number of pre-defined sub-basins, the long-term annual average discharge for a proposed dam location in the study area.

5.3.1 Slope model of the basin

The Slope function in Arc GIS calculates the maximum rate of change between each cell and its eight neighbours. The steepest downhill descent from a cell is identified by the maximum variation in elevation over the distance between the cell and its neighbours.

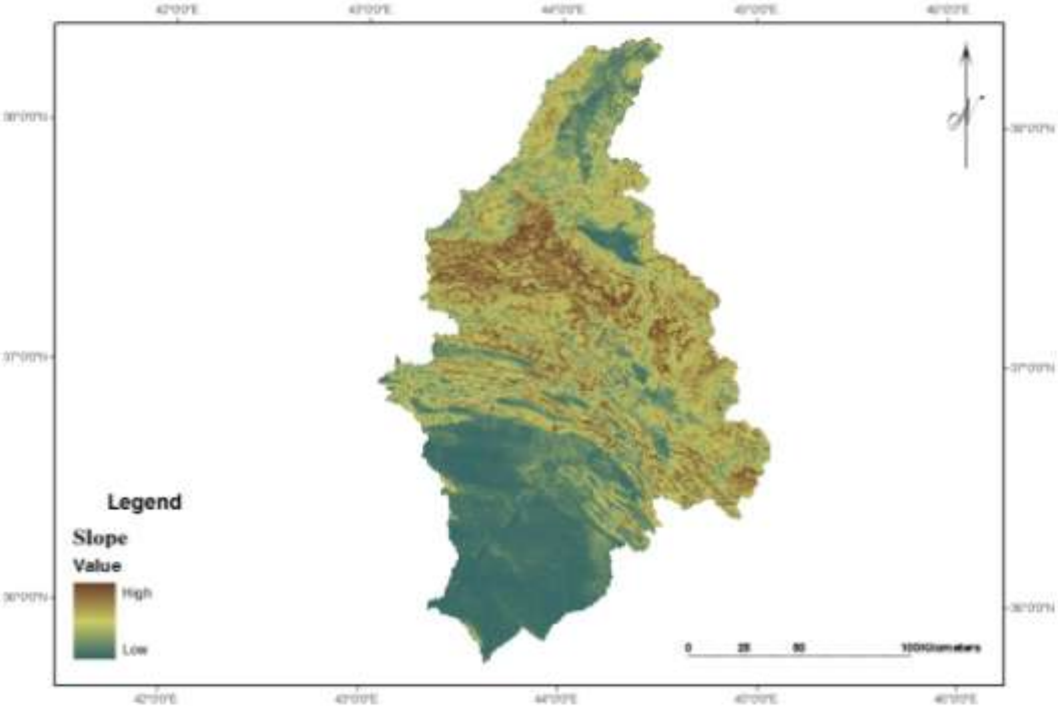


Figure 5.14 Slope map of the Greater Zab river basin

Every cell in the output raster has a slope value. The slope raster can be calculated in two types of units; percent or degree.The higher the slope value, the steeper the terrain and the lower the slope value the flatter the terrain. The northern part of the Greater Zab River Basin, particularly areas close to the border between Turkey and Iraq, seems to have high slope raster values indicating mountainous and steep terrain. Whereas southern sections of the basin have low slope raster values representing flat landscape (Figure 5.14).

5.3.2 Distribution map of precipitation and discharge yield of the basin

The rainfall regime in the Greater Zab River Basin is highly affected by the orographic features; consequently, the rainfall amount is increasing as moving from south west to the north east part of the basin. The orographic effect on rainfall distribution is confirmed by the spatial distribution of rainfall, with lower values found in Khabat rainfall station, the mean rainfall amount is 298 mm with elevation of 252 m above the sea level, and the maximum rainfall of 1223 mm at Mergasur rainfall station with elevation of 1204 m above the sea level. The rainfall season in the Greater Zab River Basin region usually starts from October and lasts until end of May, about eight months. The mountainous areas with high slopes seem to receive more precipitation and provide more surface runoff than the rest of the basin. Figure 5.15 demonstrates areal distribution of annual total precipitation. The maps were produced spatially interpolated by the ordinary kriging. Kriging is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z-values. The z values are the annual total precipitations measured at 22 meteorological stations in and around the basin. Figure 5.16 demonstrates the average annual discharge yield of the study area, which represents the flow from the watershed itself, i.e. the runoff that is directly generated within the area of the watershed. The maps were produces by using Ordinary Kriging, the z values are the average annual discharge yield of each sub-catchment.

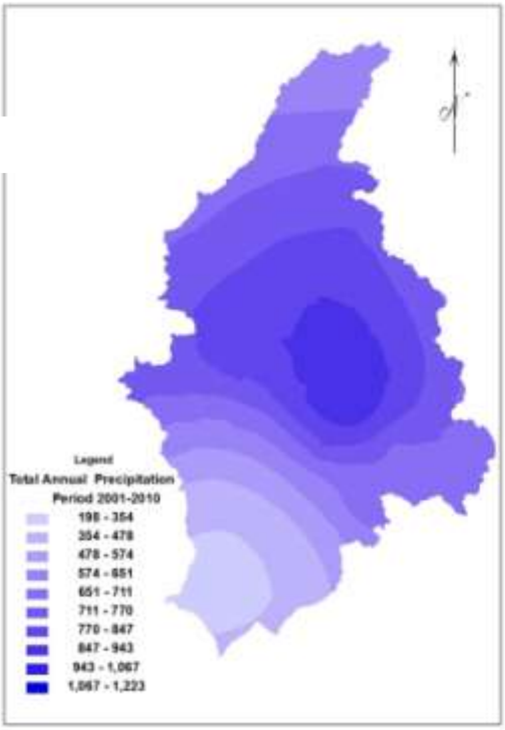


Figure 5.15 Areal distribution of precipitation

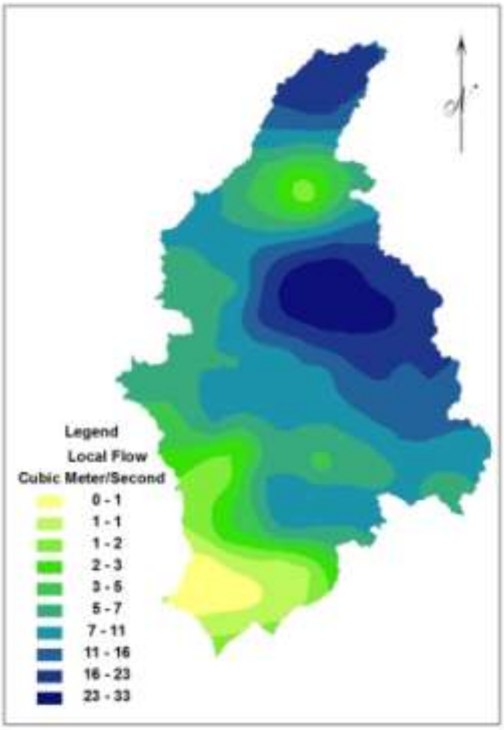


Figure 5.16 Areal yield of basin

5.3.3 Thiessen Polygon of the basin

In order to evaluate the areal distribution of precipitation from 24 rain gauges located within and surrounding the Greater Zab River Basin, it is necessary to use interpolation methods. The Thiessen polygon method, which is widely used in engineering praxis, was employed here. The catchment was divided into polygons known as Thiessen polygons (Figure 5.17).

Thiessen polygons, also known as Voronoi diagrams, represent individual areas of influence around each rainfall gauge station. The Thiessen Polygons are generated in raster format in ArcGIS spatial analysis which needs to be converted into a vector format. Rainfall of each rain gauge is extrapolated to its corresponding polygon. A point belonging to a given polygon is expected to be closer to that rain gauge than any other rain gauges.

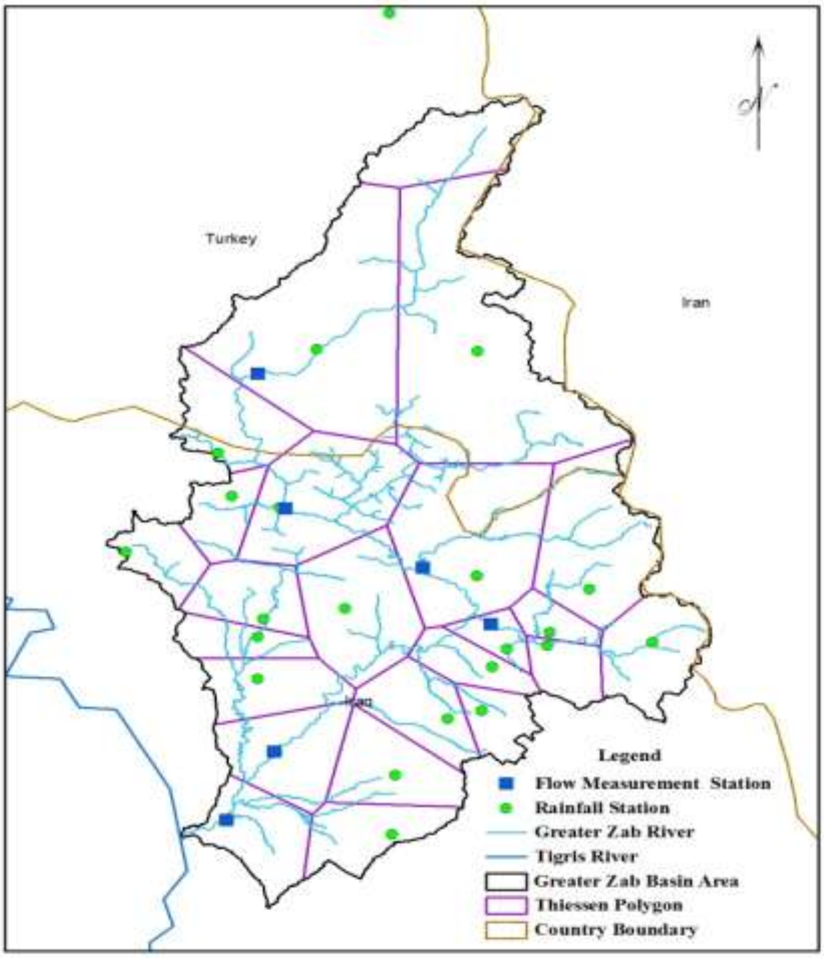


Figure 5.17 Thiessen polygon of the study area

5.3.4 Calculation of rainfall-runoff coefficients

The annual average discharge of the stream flow and the annual total precipitations measured at 24 meteorological stations in and around the basin were used here in order to determine the rainfall-runoff coefficient of the sub-basins by the rational method. Thiessen polygon method was employed in order to find out the influence area of each meteorological station in the sub-basins. The annual total precipitations were obtained from monthly total precipitations while, the annual average discharge flows were acquired from monthly average discharge data. The rainfall-runoff coefficients of five sub-catchments were evaluated. The rainfall-runoff coefficients were found to be 0.438, 0.436, 0.535, 0.500 and 0.530 for Hakkari, Deraluk, Rezan, Rawanduz and Gwer sub-catchments respectively (Figures 5.17-5.21 and Table 5.2).

5.3.4.1 Calculation of rainfall-runoff coefficient of the Hakkari sub-basin

A Digital Elevation Model (DEM) was used to delineate the sub-basin for the flow measurement station labelled as 2620 and located near the city of Hakkari. The discharge data was obtained from EIE, Turkey. The sub-basin area was found to be about 5319 km^2, with the annual average flow discharge of around $52m^3/s$. The stream discharge data taken into account was for the period of 2001 to 2005, which was obtained from monthly average discharge values. Three rainfall stations were found to be influencing the area in and around the sub-basin. The Thiessen polygon method was employed to determine the areas under the effect of each station and then the annual average areal precipitations. The rainfall-runoff coefficient, which was estimated by the rational method for Hakkari sub-basin, was found to be 0.438 (Figure 5.18).

5.3.4.2 Calculation of rainfall-runoff coefficient of the Deraluk sub-basin

Delineation of Deraluk sub-basin was achieved by choosing the flow measurement stations located on the river near Deraluk as the pour point. The sub-basin has an area of 7702 km^2, with an annual average stream discharge flow of about $75m^3/s$ for the period of 2004 – 2010 which was acquired from monthly average discharge values. There are six rainfall stations influencing the sub-basin area, the Thiessen polygon method was used to obtain the polygon areas and the annual average areal participation of the sub-basin. The rainfall-runoff coefficient was found to be 0.436 for the sub-basin (Figure 5.19).

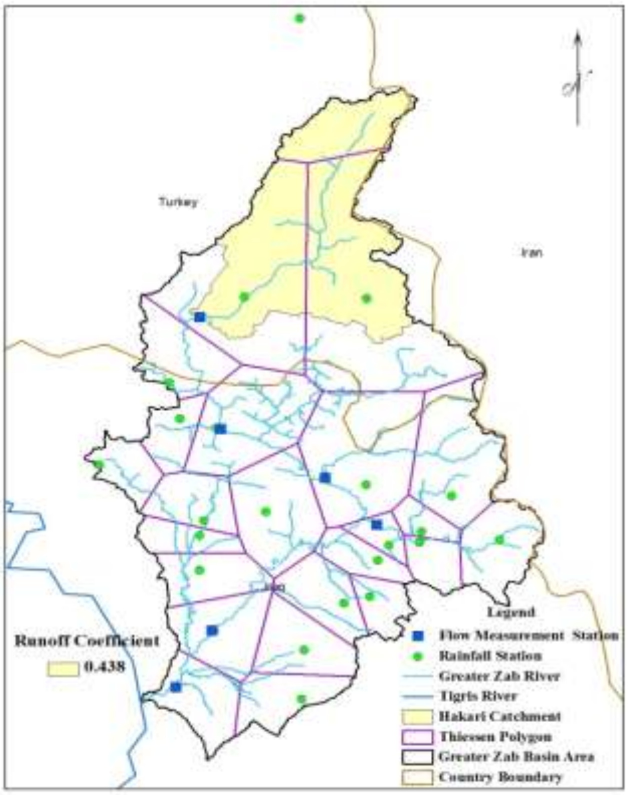


Figure 5.18 Hakkari sub-basin

Table 5.2 Hydological characteristics of the Hakkari sub basin

RainFall Station	Polygon Area Km^2	Rainfall Depth mm	Average Areal Rain Fall 705 mm Average Annual Discharge 52 (m^3/s) Average Total Volume of Discharge 1645 * 10^6 m^3 Rain Fall-Runoff coefficient 0.438
Yuksekova	2279	791	
Ozal	985	788	
Hkari	2055	453	
		687	
		779	
		720	
Total area	5318		$C = \frac{Q}{iA}$

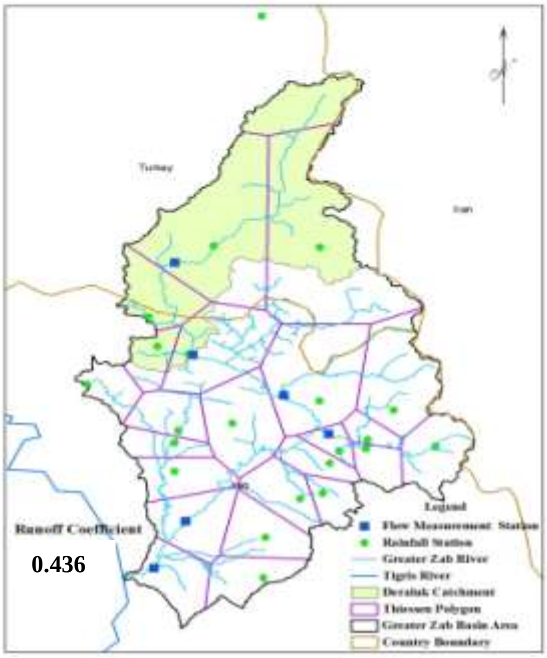


Figure 5.19 Deraluk sub-basin

Table 5 3 Hydrological characteristics of the Deraluk sub basin

RainFall Station	Polygon Area Km^2	Rainfall Depth mm	Average Areal Rain Fall 705 mm
Yuksikova	2281	791	Average Annual Discharge 75 (m^3/s) Average Total Volume of Discharge $2373.4 * 10^6$ m^3 Rain Fall-Runoff coefficient 0.436
kanimasi	945	788	
Ozalp	985	453	
Hakkari	2813	687	
Deraluk	323	779	
Amedi	355	720	
Total area	7702		$C = \dfrac{Q}{iA}$

5.3.4.3 Calculation of rainfall-runoff coefficient of the Rezan sub-basin

Rezan bus-basin was delineated by employing the DEM data and the GIS software, choosing Rezan flow measurements station as the pour point. The sub-catchment area was calculated to be about 1849 km^2, with the annual average stream discharge flow of about 32.2 m^3/s, for the period of from 2001 to 2010. The annual average discharges were obtained from monthly average discharge values. Two rainfall stations influence the sub-basin. The Thiessen polygon method was used to obtain the polygon areas and the annual average areal precipitation. The rainfall-runoff coefficient for this sub-basin was found to be 0.542 (Figure 5.20).

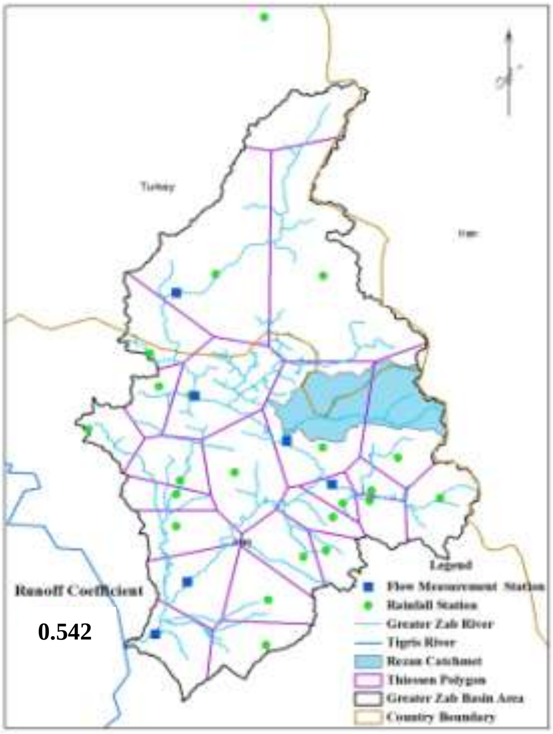


Figure 5.20 Rezan sub-basin

Table 5.4 Hydological characteristics of the Rezan sub basin

Rain Fall Station	Polygon Area Km^2	Rainfall Depth mm	Average Areal Rain Fall 1012 mm Average Annual Discharge $32.2\ (m^3/s)$ Average Total Volume of Discharge $1016.4 * 10^6\ (m^3)$ Rain Fall Runoff coefficient 0.542
Mergasur	1039	1223	
Sidakan	810	743	
Total area	1849		$C = \frac{Q}{iA}$

5.3.4.4 Calculation of rainfall-runoff coefficient of the Rawanduz sub-basin

Rawanduz sub-basin was determined by choosing the Rawanduz flow measurement station as the pour point. The sub-basin area was measured to be about 2906 km^2, with the annual average stream discharge flow of about 34.6 m^3/s, for the period of from 2001 to 2010. The annual average discharges were obtained from monthly average discharge values.

The Thiessen polygon method was used to obtain the polygon areas influenced by the seven rainfall stations located in and around the sub-basin and then the annual average areal precipitation. The rainfall-runoff coefficient was estimated to be 0.502 (Figure 5.21).

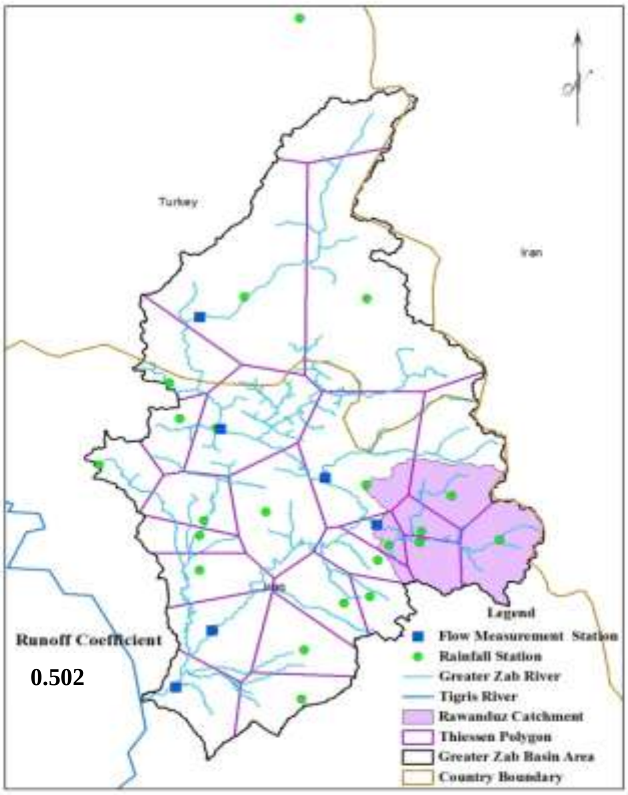


Figure 5.21 Rawanduz sub-basin

Table 5.5.Hydological characteristics of the Rawanduz sub basin

RainFall Station	Polygon Area Km^2	Rainfall Depth mm	Average areal rainfall 747 mm Average annual discharge 34.6 (m^3/s) Average total volume of discharge $1091 * 10^6$ (m^3) Rainfall-runoff coefficient 0.502
Sidakan	732	743	
Choman	981	706	
Harir	58	574	
Shaqlawa	0.2	779	
Rawanduz	432	692	
Soran	303	651	
Xalifan	171	724	
Mergasur	229	1224	
Total area	2906		$C = \frac{Q}{iA}$

5.3.4.5 Calculation of rainfall-runoff coefficient of the Gwer sub-basin

Gwer sub-basin was determined by choosing the Gwer flow measurement station as the pour point(Figure 5. 22).

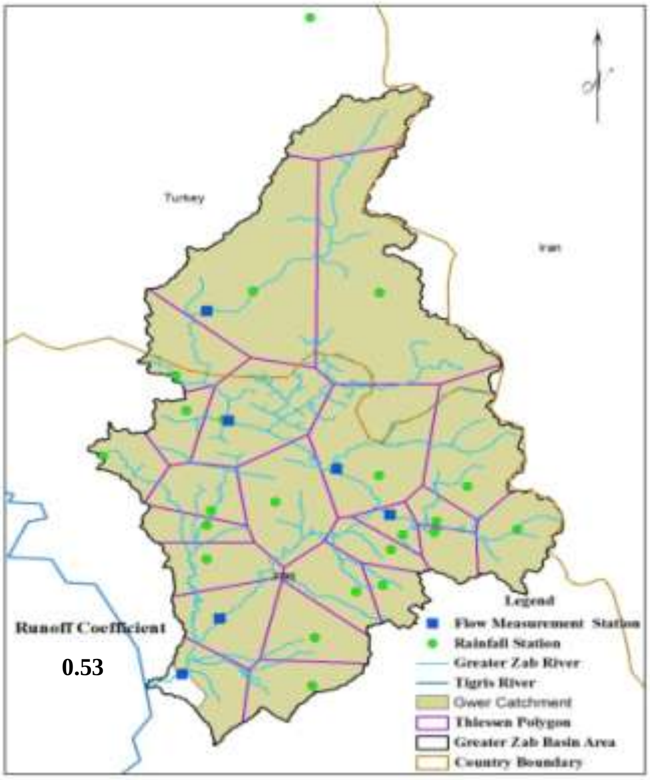


Figure 5.22 Gwer sub-basin

. The sub-basin area was measured to be about 26140km^2, with the annual average stream discharge flow of about 292 m^3/s, for the period of from 2005 to 2010. The annual average discharges were obtained from monthly average discharge values. The Thiessen polygon method was used to obtain the polygon areas influenced by the twenty four rainfall stations located in and around the sub-basin and then the annual average areal precipitation. The rainfall-runoff coefficient was estimated to be 0.53

Table 5.6 Hydrological characteristics of the Gwer sub basin

RainFall Station	Polygon Area Km^2	Rainfall Depth mm	
Yuksekova	3922	772	Average areal rainfall 665 mm Average annual discharge 292 (m^3/s) Average total volume of discharge $9209 * 10^6$ (m^3) Rainfall-runoff coefficient 0.53 $C = \frac{Q}{iA}$
Hakari	3257	767	
Mergasur	2208	1181	
Sidakan	1635	669	
Deraluk	1670	760	
Akre	1427	589	
Ozlap	986	459	
Choman	981	642	
Kanimasi	945	785	
Salahadin	794	521	
Harir	475	515	
Shaqlawa	444	698	
Xabat	1028	259	
Rawanduz	432	648	
Hawler	924	330	
Amedi	525	732	
Soran	303	597	
Xalifan	286	650	
Bardarash	779	407	
Hussenya	460	546	
Qasrok	716	530	
Gwer	692	191	
Qushtapa	742	285	
Zawita	510	702	
Total area	26,141		

Table 5.7 Calculated runoff coefficient for sub-catchments

Catchment’s	Average Annual precipitation (mm)	Area km^2	Discharge (m^3/s)	$C=Q/(i*A*10^3)$
Gwer	664	26140	292	0.530
Rawanduz	737	2906	33	0.502
Rezan	1012	1849	33	0.542
Deraluk	705	7702	75	0.436
Hakari	705	5319	52	0.438

Table 5.8 Computation of average precipitation in the sub basin using Arithmetic mean method

Sub basin	# of rainfall station in the sub basin	Computation average precipitation by arithmetic mean method (mm)
Hakari	2	763
Deraluk	4	753
Rezan	There are no station	
Rawanduz	6	790
Gwer	23	599

5.3.5 Estimation the long-term annual average discharge for a proposed dam

Estimating the annual average discharge as well as discharge variation within certain periods of time is crucially important in planning phase of a water resources project. Most of the time, these kinds of projects are carried out at the sections of rivers where flow measurements do not exist or they may not be observed for a long enough period.

The discharge observations of the closed flow measurement station are carried to that particular cross-section by a number of different statistical methods. When the project is a dam these discharge data will be used in determining the design flow of the spillway, the volume of the reservoir, the height of the dam, the amount of the energy can be generated, etc. The dam location is the point at which water flows out of a particular sub-basin. The contributing area or the sub-catchment which supply water to the project location is delineated from a raster data of flow direction by using watershed function in ArcGIS. The selected project location is the cross-section which has been proposed for a dam project named Mendawa Dam by the authorities (Figure 5.23).

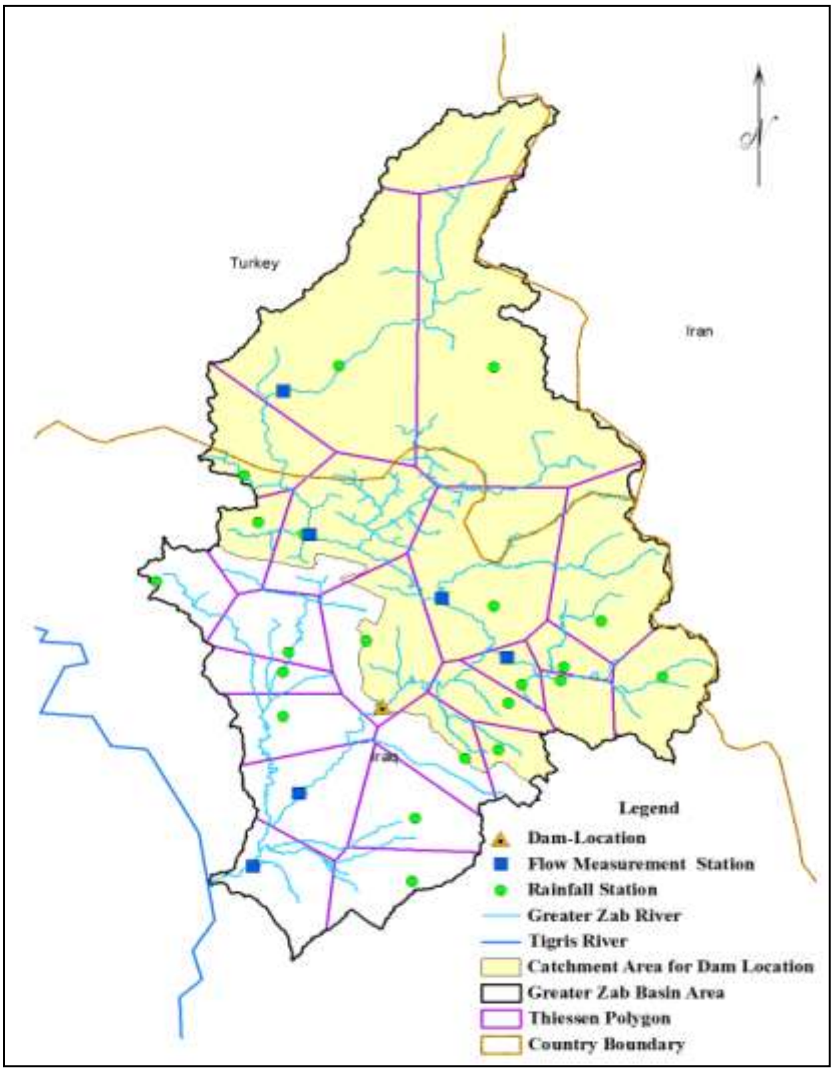


Figure 5.23 Dam project location and contributed area

A rainfall-runoff coefficient for the contributing area to Mendawa Dam was determined to be 0.488 by employing the coefficients determined earlier for Hakkari, Deraluk, Rezan, Rawanduz and Gwer sub-basins, their areas and a weighted average method (Table 5.9). Among these sub-catchments Gwer was partially included in the dam site contributing area while the other four sub-catchments were totally included. The discharge values of the stream at project site were evaluated by employing the meteorological stations within and nearby the sub-basin and the rainfall-runoff coefficient. The average annual discharge was found to be 232 m^3/s by using rational method Table (5.9).

Table 5.9 Estimation the long-term annual average discharge for a proposed dam

Propose Dam project name dam project	Average Areal Rainfall (mm)	Contributed Area (km$^{2)}$	Averge Annual Discharge calculation (m^3/s)	Runoff coefficient
Mandawa	792	18657	232	0.488

CHAPTER 6

CONCLUSION

Water resources management is indisputable connected to the perception of river basin characteristics. In this paper, the hydrological characteristics of the Greater Zab River Basin were studied by employing Geographic Information System (GIS). Spatially and temporally highly variable hydrological characteristics of the river basin were noted to be more precisely determined through GIS for assessment of water resources projects. The Greater Zab River is roughly 460 km long, flowing through Turkey and Iraq with a total catchment area of about 26,325 square kilometres (km^2). The headwaters of the Greater Zab River originates in the high mountains near Lake Van, Turkey, where it springs at an altitude of 4,168 m above sea level and joins the Tigris River in the south western of the city of Hewler (Erbil), Iraq. The study plainly displayed that interactive integration of spatial and non-spatial data in GIS environment gives a powerful tool for numerous applications in watershed hydrology. Computing and analysing the watershed parameters manually is tiresome, time consuming and error-prone.

The study proved that GIS is flexibility and relatively easy to apply on large study areas in order to gather data and information in a common database for characterization of watersheds and spatial analyses in a relatively short time and in a cost-effective manner. The boundary of the Greater Zab River Basin was delineated based on the pre-processing digital elevation model (DEM) analysed in GIS environment. The annual average discharge of the stream flow at five flow measurement stations (FMS) along the river and the annual total precipitations measured at twenty-two meteorological stations located within and surrounding the basin were used here in order to perform the hydrological analysis of the basin. The annual average discharge values were obtained from monthly average discharge measurements while the annual total precipitations were acquired from monthly total precipitations. Based on the stream flow measurements, rainfall-runoff coefficients were estimated by rational method for five sub-basins. The rainfall-runoff coefficient for the whole basin was found to be 0.53.

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