CHAPTER ONE

1. INTRODUCTION

1.1.Background: -

Water is life, its use and development underpins the social and economics of all international societies. Runoff is an important parameter in water resources applications. Its estimation is based on rainfall storms, including peak discharges needed for engineering design purposes. It is important to predict capacity to design and operate hydraulic structures such as: dams, culverts, reservoirs, spillways, flood canals, irrigation and drainage systems in towns, airports etc. Methods used for estimation of wadi runoff depend on data availability required degree of accuracy, importance of project concerned, catchment area and its type.

1.2.Study Area: -

The study area is Great Dar Fur area which is well and internally known area located in Western Sudan. Sudan, is one of the largest country in Africa, covers an area of about 1,886,068 square kilometers km^2 between latitudes 8 and 22 degrees north of the Equator and longitudes 22 and 38 easts. As shown in figure (1.1). It borders seven countries and shares surface and groundwater with 12 countries. It has a population of about 42 million.(Review, 2017)

Great Dar Fur is surrounded by Northern State and Libya in the North, Libya and Chad in the West, North Bahr El Ghazal, Northern and Western Kordofan in the South, Northern, and Western Kordofan in the East. Its altitude ranges from 380 m to 3001 m above sea level. Insufficient drinking water is a major problem for users, especially during summer season.(Abdel-Magid and Shigidi, 2010)

Fig.No. (1.1): Sudan New Political Map

The topography of Dar Fur region is generally flat. However, this topography contains many hills (Goz) and mountains. Jebel Marra, which is about 3000 m above MSL, is an important topographic feature in Darfur. It extends for 115 km from North to South, and 45 km from East to West. (Barsi, 2010)

The climate of Dar Fur varies from arid in the far North to semi-arid in the South. It is characterized by high temperatures, high evaporation (typically 4 to12 mm/day) and regular seasonal, but highly variable, rainfall.

An annual precipitation in Dar Fur states ranges from 200 mm to 900 mm. Rainfall feeds a great number of seasonal wadis, which flow several times during the rainy season from June to September. In the South and Jebel Marra, they

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flow during the whole season (Ibrahim, 2004).The rainy season is from May to October, followed by dry spells between November and March.(UN, 2004)

Water remains in large ponds for 1 to 3 months after the rainy season has come to an end. Darfurians use this water for domestic purposes, their animals drink of it and the small fields are irrigated with it. By building small dams and digging hafirs (dammed water reservoirs), the people are able to store the seasonally flowing water to bridge the dry season. At present, most of these old hafirs need desilting and regular maintenance.(Abdel-Magid, 2007)

Socially the greater Darfur region witnesses of numerous numbers of tripe and clans sharing land for livelihood activities.

For the Education, there are approximately 2.65 million out of 8 million residents of Darfur are children (COUNCIL, 2008)from 874500 are primary school age, there is significant numbers of Universities in Elfasher, Nyla, Geniana, Zalingi, and ELdean from which (99000 person) of Darfur youth it is expected to attend university.

The most recent communication means in Greater Darfur are Satellite means Mobile Thurya and Electronic communication technology. The Radio and the television are the most wider coverage communication media among the urban and rural communities.

Accessibility means in Darfur are Rail way from Khartoum to Nyala via Kordofan, uncompleted constructed roads within entire towns and link between the capitals of the Greater Darfur states additional to three international airports in Elfasher, Nyala and Elgenina.

Darfur Region is composed of three states Western, Northern and Southern States as shown in figure (1.2)

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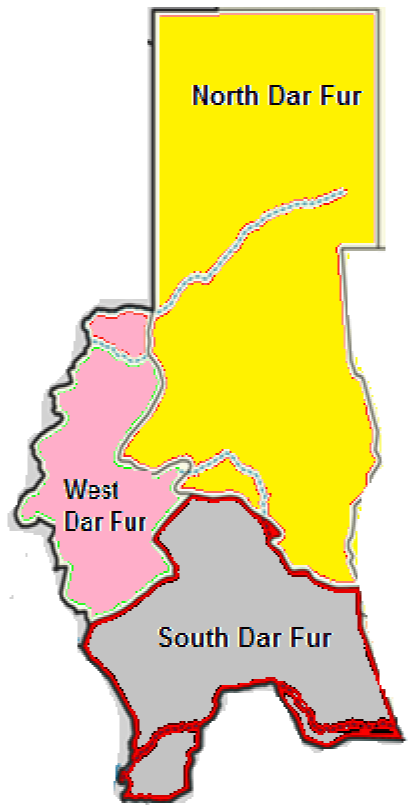

Fig (1.2): locations of study area

West Dar Fur State has a total area of 150,000 km², with population 1,693,000 in 2003, its capital is Al-Ginaina Town. West Dar Fur State, gets its water from seasonal streams running from Jebel Mara and from underground sources. It has arable area about 8 million feddans, 3 million of which are exploited. The major wadis are Azum and Kaja, the surface area of Azum wadi based on summation of the main major small wadi areas is 36965 km2(Yousif, 2011), 36700 km^2 (Barsi, 2010),40393 km^2 (Ali, 2014)and drains from the higher western slopes of Jebel Marra from altitudes of 2600m to 600m(Yousif, 2011), ,the surface area of Kaja is 42850 km^2 (Barsi, 2010), 47337 km^2 (Ali, 2014). The measured discharge flow is 487 million cubic meter per year(Ali, 2014).

North Dar Fur State lies in the far western part of the Sudan. Most of the state terrain consists of hills the height of which ranges from 610 to 915 meters above

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sea level. The northern part of the state is arid. The State has an area of 260,000 square kilometers, with population of 1,603,000, 80% of which is rural based, and its capital is Al-Fashir

Rains and underground water are the main water sources for the state. It has arable area about 7.7 million feddans. The major wadis are El Ku and Howar, El Ku area is 28000 km2 drains from the eastern slopes of Jebel Marra with the main tributaries of Wadi Golo, Wadi Keira and Wadi Abu Hamra (Yousif, 2011 , Barsi, 2010) and Howar area is 12200 km^2 (Barsi, 2010).

South Dar Fur State area is 139,800 square kilometers with Population of 1.2 million, and its capital is Nyala.

Rain is the main source for water in the state, besides the seasonal rivers and underground water. It has an agricultural area of about 24 million feddans.

The major wadis are Nyala ,Ibra ,Kaya , Bulbul and Negida, Wadi Nyala surface area is 8389 km2 drains from the higher southern slopes of Jebel Marra from 2800m to 600m (Yousif, 2011). Nyala Catchment Area (km^2) 4080 Km2(Barsi, 2010),the Ibra area is Wadi Ibra Surface area of about 15180 Km2 drain starts at the southern slopes of Jebel Marra with eight major tributaries, of which Wadi Kaya and Wadi Bulbul are the most important . (Yousif, 2011),the Ibra , Kaya ,Bulbul ,and Negida areas are 1900 Km^2 , 2200 Km^2 ,4600 Km^2,and 3060 Km^2 (Barsi, 2010) respectively.

The drainage system for three Darfur states Western, Northern and Southern as shown in Figure (1.3).

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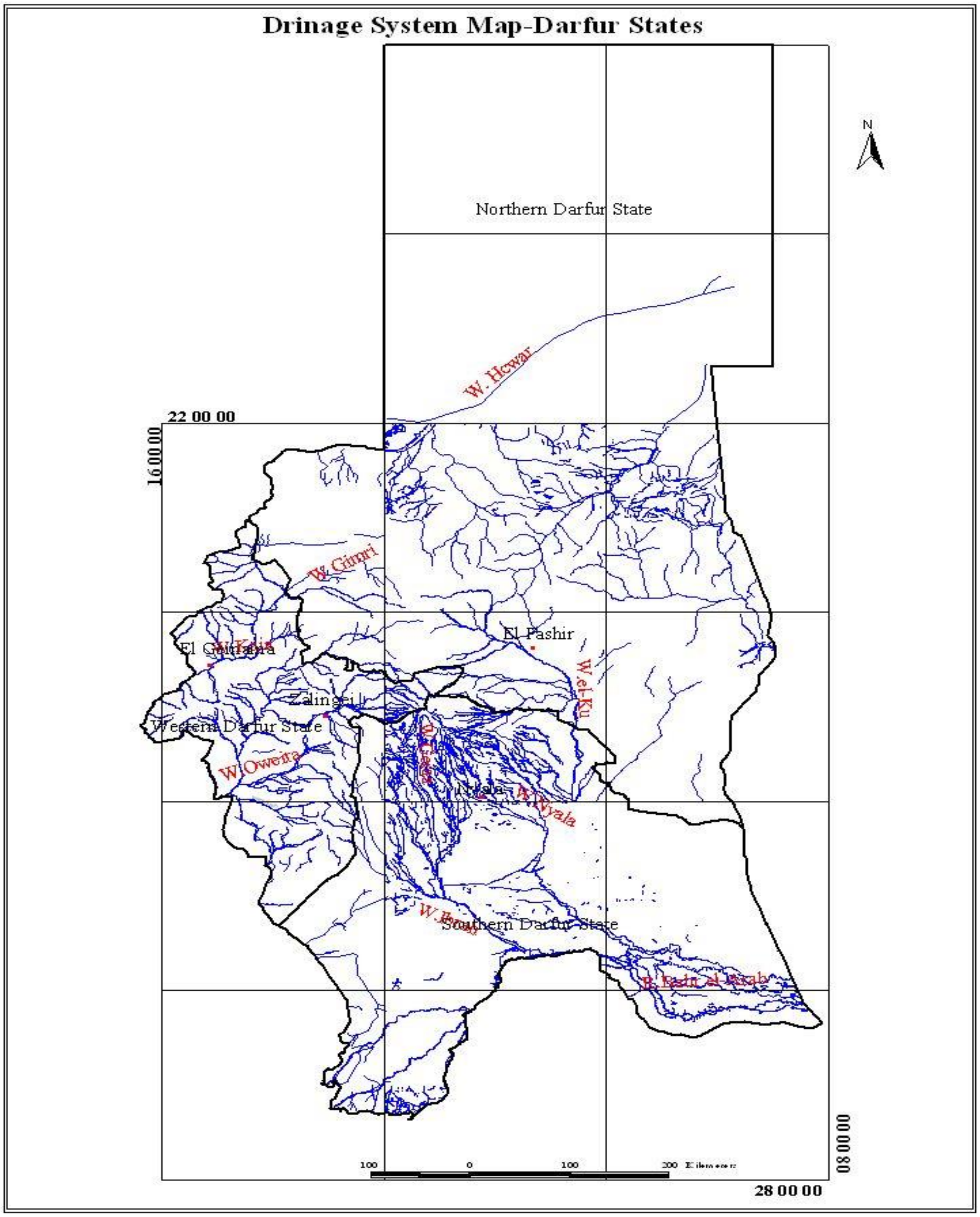

Fig.No. (1.3): Drainage system of Darfur state

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1.3.Statement of the Problems: -

- ❖ Lack of appropriate water resource management, and sustainable development of groundwater resources.
- ❖ Inefficient institutional framework, associated with limited access to clean water sources (26 %) for the population.
- ❖ Lack of data on factors influencing rainfall.
- ❖ Lack of accuracy in measured and calculated runoff of wadi system.
- ❖ Current empirical methods to estimate runoff (rational formula or SCS-CN) are based on estimating soil moisture, land use and in-channel storage. These parameters are difficult to predict and their use in predicting runoff results in error in the runoff estimate.

1.4.Research Objectives: -

1.4.1. General Objectives: -

To design an apply a technique to predict the rainfall- runoff of wadi system in Dar Fur for purpose of design and operation of engineering and agricultural projects.

1.4.2.Specific Objectives: -

- ❖ Collect, analyze and map rainfall data using appropriate statistical analysis and GIS software.
- ❖ Predict rainfall runoff equations for wadi system Dar Fur in states using suitable statistical software, and verify the predicted runoff equations by some gauged station in study area. `
- ❖ Calculate total expected annual wadis discharge for wadi system in Dar Fur area.

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1.5.Structure of Research: -

In this chapter one, a general background of the subject of study was clearly defined. This was followed by a comprehensive description of the study areas of Great Dar Fur three states. Statement of the problems and the objectives, including both main and specific objective were presented. The chapter is concluded by the structure of the research.

In chapter two the available literature about hydrology, hydraulics statistical analysis and modeling techniques including GIS used in the study area were described. Previous research related were presented.

The adopted methodology with the equipment's and materials used in the study were clearly presented in chapter three. Related theories are presented and explained thoroughly in chapter three. A flow chart is presented to summarize the research activities. Data such as rainfall and analysis and digital maps are collected and analyzed thorough GIS software.

Chapter four presented the results and discussions consisting of correlation of rainfall and runoff for wadi system in Dar Fur. Estimation of the ungauged streams and wadis was made.

Chapter five presented the conclusions and recommendations. It revealed the main research findings and need further studies.

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CHAPTER TWO

2. LITERATURE REVIEW

2. 1.Rainfall Gauges Types and Measurements: -

Rainfall is the main source of runoff. There is a unique significant relationship between rainfall and runoff. When rain falls, the water is intercepted by the leaves and stems of vegetation, known as interception storage. The water will infiltrate through the soil until it reaches a stage where the rate of rainfall intensity exceeds the infiltration capacity of the soil. The infiltration capacity of soil may vary depending on the soil texture and structure. For instant, soil composed of a high percentage of sand allows water to infiltrate through it quite rapidly because it has large, well connected pore spaces. Soils dominated by clay have low infiltration rates due to their smaller sized pore spaces. However, there is actually less total pore space in a unit volume of course, sandy soil than that of soil composed mostly of clay. The gauges used for measuring rains should be placed in suitable locations. To avoid incorrect readings the following should be considered:

1. The rain gauge should represent the rainfall falling on the surrounding area. This is difficult to attain because of the wind effect. This effect is minimized, by choosing a gauge site with small wind speed.
2. The gauge should be horizontally exposed over ground level.
3. The gauge site should be protected from wind by trees wind shield.
4. The height of the shield above the gauge should be at least half the distance from the gauge to the shield, but not exceed the distance from the gauge to the shield, making an angle ranging from 30 to 45 between top of the gauge and top of the shield.

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There are a variety of rainfall gauge types. These include non-recording (Symons's), recording types (Weighting, Float Gauge, Tipping – Bucket Gauge, Distrometers and Acoustic Type**)** and Automatic-radio-reporting rain-gauge.

2. 2.Surface Runoff and Measurements: -

Surface runoff refers to the portion of rainwater that is not lost to interception, infiltration, evapo-transpiration or surface storage and flows over the surface of land to a stream channel. During a rainstorm, a certain portion of rainfall is intercepted by vegetation canopy. What is left over falls directly onto the soil as through fall. Intercepted rainwater either evaporates or in cases of heavy and continuous rainfall events, when canopy storage capacity is exceeded, intercepted rainwater falls to the ground as leaf drainage or stem flow. The amount of rainwater that is lost due to interception depends on the vegetation cover and the rainfall pattern. Rainwater retained in vegetation canopy that ultimately evaporates is referred to as interception loss.

Rainfall that is not lost to interception and reaches the soil surface either infiltrates into the soil, is stored in surface depressions or evapo-transpires. The remaining excess rainwater travels over land as surface runoff. Surface runoff occurs either when the soil is saturated from above or from below.(Solomon, 2005).The term runoff can be applied to stream or river discharge. Runoff is expressed in terms of volume per unit of time and its generation largely depends on the amount of rain water that reaches the earth's surface. The runoff generation in the area is also associated with the peat soil layering as the deeper layers may be an important overall contributor to runoff. The various factors, which affect the runoff from a drainage basin, depend upon the characteristics presented in table (2.1), and figure (2.6)

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Table No. (2.1): Factors Affecting Runoff(Raghunath, 2006)

Storm characteristics	**Meteorological characteristics**
Type or nature of storm and season Intensity Duration Areal extent (distribution) Frequency Antecedent precipitation Direction of storm movement	Temperature Humidity Wind velocity Pressure variation
Basin characteristics	Storage characteristics
Size Shape Slope Altitude (elevation) Topography Geology (type of soil) Land use /vegetation Orientation Type of drainage net Proximity to ocean and mountain Ranges	Depressions Pools and ponds / lakes Stream Channels Check dams (in gullies) Upstream reservoir /or tanks Flood plains, swamps Ground water storage in pervious deposits (aquifers)

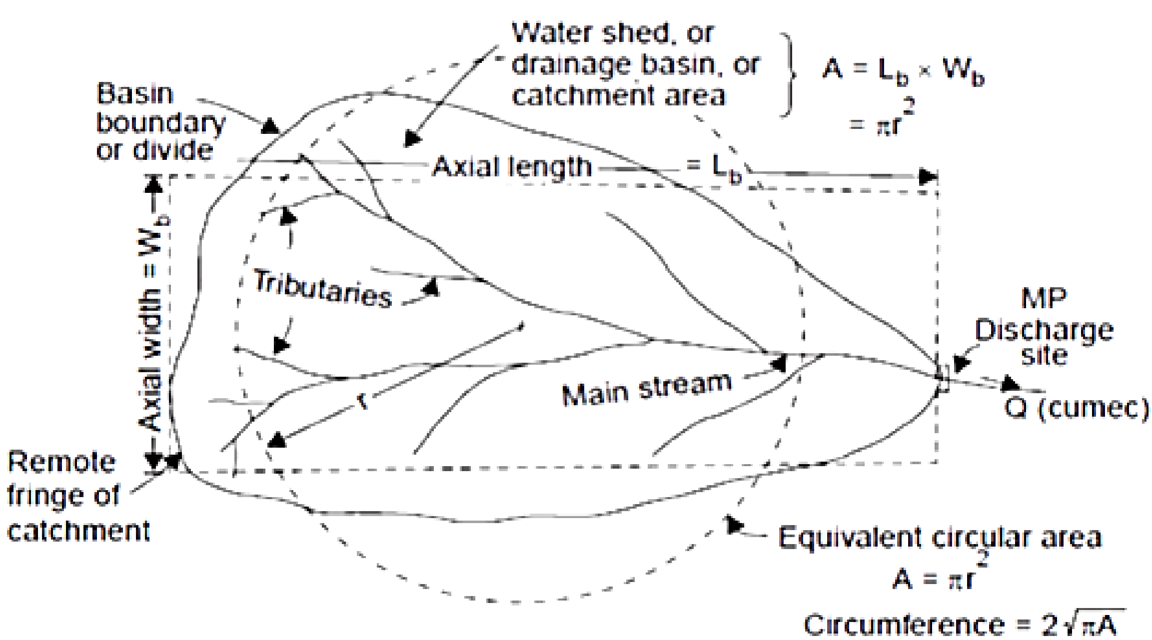

Fig.No (2.1): Drainage Basin Characteristics (Raghunath, 2006)

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The drainage net characteristics may be physically described by, the number of streams, their lengths, density, and drainage density.

The stream density of a drainage basin is expressed as the number of streams per square kilometer. The stream discharge flow rate measurement is expressed in cms, (cubic meter per second) or cfs (cubic feet per second). The surface discharge is an important environmental variable to measure for several key reasons. It is used to estimate drought-flows (also called 'low flows') and flood frequency from a time-series of stream discharge. The rate of evapo-transpiration from catchment vegetation can be estimated from the same time-series within a water-balance equation. The multiplication of a concentration of suspended-sediment or a solute with the stream discharge gives the mass of that suspended or dissolved constituent moved over time. Such calculations are important in erosion studies, nutrient budget estimation, and pollution studies. The stream discharge can be measured by using volumetric gauging, float gauging, current meter, dilution gauging (constant injection or gulp methods), or slope-area methods. The choice of a method depends on the characteristics of the stream and application. (Ryan and Boyd, 2002).

2. 3.Methods of Estimation of Runoff from Rainfall: -

These methods include rational estimates, experimental (empirical) equations, statistical analysis, and use of hydraulic models.

Analysis of runoff, volume of runoff, and time distribution of flow is fundamental. Most drainage facility designs require determination of a peak flow rate while others require a runoff hydrograph that provides an estimate of runoff volume. Peak flow rates are most often used for design of bridges, culverts roadside ditches, and small storm sewer systems. Drainage systems involving

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detention storage, pumping stations and large or complex storm sewer systems require the development of a runoff hydrograph to estimate volume of runoff.

The relationship between the precipitation on a drainage basin and the runoff flow from a basin is complex. Little data is available about the factors influencing the rainfall - runoff relationship leading to inexact solutions. Any hydrologic analysis is only an approximation and errors are unavoidable in the estimation of peak runoff that affects the hydraulic designs. Low peak runoff flow prediction can result in a structure that is undersized and may contribute to flood risks, while high peak runoff flow prediction may lead to an oversized drainage facility that costs more than necessary.(Minnesota, 2000)

The different methods used for estimation depends on the required accuracy degree, importance of project concerned, catchment area and its type. It is necessary to know volume of available data its accuracy quality, required time span for peak discharge and design flow.

a) Rational Estimates: -

The rational estimate is used for surface runoff and precipitation for design of sewerage systems in certain localities with time changes or future expansions. It is well known as one of the basic approaches to compute storm water flows from rainfall by relating peak runoff to rainfall intensity through a proportionally factor. Experience has shown that it provides satisfactory results on small catchments of about not more than 80 hectares only. For larger catchments storage and timing effects become significant and the hydrograph method is needed. It can be expressed by a formula as given in equation (2.1): -

$$Q = \frac{C\,I\,A}{360} \quad ---(2.1)$$

Where:
Q = Calculated flow rate (m3/s).

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C = Runoff coefficient.

I = Rainfall intensity (mm/h).

A = Area of catchment involved (ha).(Mockus, 2004)

b) Use of hydraulic models (SCS method): -

The Soil Conservation Service (SCS) model developed by United States Department of Agriculture (USDA) computes direct runoff through an empirical equation that requires rainfall and a watershed coefficient as inputs. The general equation for the SCS curve number (CN) express the relation between rainfall, runoff, and retention (the rain not converted to runoff) for a simple storm, at any point on the mass curve can be expressed as: -

$$\frac{F}{S} = \frac{Q}{P} - - - - (2.2)$$

Where:

F = actual retention after runoff begins

S = potential maximum retention after runoff begins ($S \geq F$)

Q = actual runoff

P = rainfall ($P \geq Q$)

These parameters are also depending on other equations. (Mockus, 2004)

c) Experimental (Empirical) Equations: -

These equations which differs greatly from one to another are used for design of catchment areas. There is a need to realize incurred limitations and areas of applications before selection and use of a particular equation. Examples of these equations rational methods are the Time of Concentration method, Thomas J. Mulvany method, Chow, Burkly-Ziegler Formula, Unit-Hydrograph, USDA-SCS and Statistical Methods. Bransby-Williams, Yen and Chow's, and Kerby's Formula.

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1. **Bransby-Williams (1977) Formula**

$$t_c = \frac{58L}{A^{0.1}S^{0.2}} - - - - -(2.3)$$

Where:

t_c = Time of concentration (min)

L = Mainstream length (km)

A = Catchment area (km^2)

S = Equal Area Slope (m/km)

2. **Yen and Chow's (1983) Simplified Formula**

$$t_0 = 1.2\left(\frac{\eta L_0}{S_0^{0.5}}\right)^{0.6} - - - - -(2.4)$$

Where:

t_0 = Time of overland flow (min)

n = Manning's resistance coefficient for overland surface.

L_o = Length of overland plane (m)

S_0 = Overland slope (m/m)

3. **Kerby's Formula**

$$t_0 = 1.45\left(\frac{N_k L_0}{S_0^{0.5}}\right)^{0.467} - - - - -(2.5)$$

Where:

t_0 = Time of overland flow (min)

N_K = Kerby's resistance coefficient.

L_o = Length of overland plane (m)

S_0= Overland slope (m/m) (Abustan et al., 2008)

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4. **The rational method (Time of concentration method, Lloyd Davies method):**

Influencing factors include: rainfall intensity and duration, storms, distance travelled by water before reaching sewer, permeability, and slope of catchment area, shape and size of drainage zone. The methods are applicable to areas not greater than 15 km^2 as shown in equation 2.1.in which Q = C I A

Other empirical methods for estimating peak runoff include:

a. **Creage Formula**

$$Q = 1.3\acute{C}(0.386A)A^{\frac{0.938}{0.048}} ----(2.6)$$

b. **Burkl-Ziegler Formula**

$$Q = 0.7CIA[SIA]^{0.25} ----(2.7)$$ (Abdel-Magid, 2007)

d) **Statistical Analysis: -**

Statistical Analysis depends on observed data for a reasonable period of time. The importance of acquiring good data with a size that justifies its use, accountability, and predictability are prerequisite, in estimating runoff from catchments. This is because it is not feasible to collect a long stream flow record at each site at which flow characteristics may not be needed. Some other ways of estimating flow characteristics at ungauged sites must be used. A widely applicable technique, called Regional Analysis, relates flow characteristics at gauging stations to the physical and climatic characteristics of their catchment areas. These characteristics, obtained from maps and weather records, can also be obtained for the ungauged stream basins, and thus permit computation of flow characteristics from the regional relations.

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Regional analysis is concerned with defining flow variability in space. It's first estimated flow characteristics is computed from gauging station records. The variability among these flow characteristics is made up of two components:

Variation among sites due to differences in catchment characteristics.

Variation due to time sampling at the gauged sites.

A regionalization procedure should explain the variation due to catchment characteristics (catchment Size, Slope) and should average the variation due to time sampling. In theory, this is done by the multiple regression method. But in practice, multiple regression does not explain all the variation due to catchment characteristics, consequently the residuals from regression also include an unknown amount of variation from that source.

A region selected for analysis should be one in which only a few basin characteristics will describe most of the variability in flow. The region should contain gauged streams (preferably with long records) well distributed already by basin size. Climatic records should be adequate to define basin averages of precipitation, and maps should be enough to complete permit definition of drainage areas and channel slopes. Streams whose headwaters are outside the region should not be used.

The desired flow characteristics are computed from the stream flow records and are related by multiple regressions to climatic basin characteristics defined from weather records and maps. A log linear model is commonly used, and the reliability of the regression equation is considered to be represented by the standard error, which is usually reported in percent.(Riggs, 1989)

❖ **Multiple Regression Method**

The one of common method in statistical analysis multiple regression it is use to estimate mean annual stream flow of any stations, the Meteorological geographic characteristics, and multiple regressions model of stations upstream

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them that relates these variables can be adopted. Regional methods have been adopted for the estimation of suspended sediment in ungauged locations (ZOBANAKIS G., 2003). As mentioned previously, the independent characteristics chosen in this investigation were mean areal precipitation, catchment area and catchment mean slope. The developed empirical equation has the form:

$$Q = b_0 A^{b_1} P^{b_2} S^{b_3} L^{b_4} ----- (2.8)$$

Where: -

Q is discharge (million m3/s),

A is catchment area (km2),

P is mean annual rainfall precipitation (mm),

S is mean catchment slope (%)

L is longest flow path in catchment (km)

And b_o, b_1, b_2, b_3 , b_4 are model coefficients.

The model can be calibrated in the locations where the hydrometric stations are situated, and can then be applied to each grid cell (with input values of A, P, S, and L), on the presumption that it applies for the whole area of the water district. The empirical relation that was used acquired a more useful linear form, by taking logarithms in equation below:

$$logQ = logb_0 + b_1 logA + b_2 logP + b_3 logS + b_4 logL --- (2.9)$$

In this equation, a least-squares technique was applied in order to estimate the optimum model parameter values. The model can be calibrated in the locations of the hydrometric stations by substituting the estimated values of Q, A, P, S and L in the linearized multiple regression equation. The adopted methodology for model calibration is based on an automated trial procedure. Several combinations of the stations can be investigated in order to optimize the regression equation.

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Combination achieves maximization of the correlation coefficient R, compatibility of estimated discharges and areal precipitation. This will result in the minimization difference between estimated and observed discharges in the stations.(ZOBANAKIS G., 2003)

2. 4. Microsoft Excel tools:

XLSTAT is a Microsoft Excel statistical add-in that has been developed since 1993 to enhance the analytical capabilities of Excel. XLSTAT is modular statistical software built around XLSTAT-Pro - the core product of Add in soft. XLSTAT relies on Excel for the input of data and the display of results, but the computations are done using autonomous software components.

The use of Excel as an interface makes XLSTAT a user-friendly and highly efficient statistical and multivariate data analysis package. The quality of the computations is identical to that offered by classic scientific statistical analysis software. A large range of modules can be added onto XLSTAT-Pro for specific analytical needs.

Toolbars help the user to quickly access the various functionalities. Dialog boxes have been designed to be simple and intuitive. With the XLSTAT-Pro dialog boxes data selection is made easier as ever. Contextual help can be accessed from each dialog box.

All the XLSTAT-Pro functions have been abundantly tested against the best known statistical packages to guarantee that the results provided by XLSTAT are 100% reliable and compatible with what other packages would give. XLSTAT-Pro features The XLSTAT website offers a large panel of information.(XLSTAT, 2016)

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2. 5.GIS Software and Analysis: -

A GIS (Geographic Information System) is a powerful tool used for computerized mapping and spatial analysis. A GIS provides functionality to capture, store, query, analyze, display output geographic information.

The power of GIS came from its ability to relate different information in a spatial context and reach conclusions about these relationships. Most of the available information worldwide contains a reference location placing that information at some point on the globe. A fundamental function of GIS systems is the ability to create relationships between data of different types from visual and non-visual domains. These relationships allow GIS to store information about the entire hydrologic cycle and link it together. For example, a catchment (polygon) can be linked to its streams (polylines) which can be linked to its gauging stations (points) or rain stations and so on. This connectivity offers significant potential aid in hydrologic modeling due to the various data types that are inherent in the hydrologic cycle. (union, 2012)

During the past two decades GIS has become widely used in most fields of science. GIS is an amalgamation of cartography, statistical analysis, database technology, designed to capture, store, manipulate, analyze, manage, and present all types of geographically referenced data. GIS has become a useful and important tool in hydrology. It has become as well useful to hydrologists in the scientific study and management of water resources.

By means of ArcGIS software, one can easily make predictions about the behavior of a watershed. The objective of the GIS annalist is to determine the topographic input data for the hydrological analysis. The necessary data include the area of the catchment, the corresponding sub catchment, the longest flow path for each sub catchment, the slope of the stream (longest flow path) in each sub catchment, and land use in each sub catchment. Additionally, the GIS modeling

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visualize by maps the characteristics of the catchment which can be useful for a better understanding and interpretation of the flood event. (union, 2012).

2.5.1.Digital Image Processing:

The increasing availability of GIS data-sets has a marked effect on development of hydrologic modeling techniques. The information contained within these data-sets allows the application of geo-computational algorithms to determine topographic and hydrologic attributes of sub catchments at a scale not practicable by traditional methods. Furthermore, the abundance of extractable geo-statistics provided by these algorithms also reduces the guesswork involved in defining lag parameters for hydrologic models.(Abdel-Magid, 2007)

- **Image Interpretation:**

The main character affecting image interpretation is Resolution; which could be defined as "The ability to distinguish closely spaced objects on an image or photograph" (Ryan, 2002)

- **Shuttle Radar Topography Mission (SRTM):**

The Shuttle Radar Topography Mission (SRTM) is a joint project between NASA and NGA (National Geospatial-Intelligence Agency) to map the world in three dimensions. SRTM utilized dual Space borne Imaging Radar (SIR-C) and dual X-band Synthetic Aperture Radar (X -SAR) configured as a baseline interferometer, acquiring two images at the same time. These images, when combined, can produce a single 3 D image. Flown aboard the NASA Space Shuttle Endeavour February 11- 22, 2000, as shown in figure (2.7), the SRTM successfully collected data over 80% of the Earth's land surface, for all area between 60 degrees North and 56 degrees' South latitudes. SRTM data is being used to generate a digital topographic map of the Earth's land surface with data points spaced every 3 arc second for Global coverage of latitude and longitude

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(approximately 90 meters). SRTM data were processed from raw radar echoes into digital elevation models at the Jet Propulsion Laboratory (JPL) in Pasadena, CA. These original data files had samples spaced ("posted") at intervals of 1 arc -second of latitude and Longitude (approximately 30-meter).Data available to the geospatial data user community include 1-arcsecond (approximately 30-meter) resolution data over the United States and its territories (DEM30 for short), and 3-arc-second (approximately 90-meter)/1-arcminute (approximately 1 km) data over non-U.S. territory (DEM90 / DEM1k).The SRTM data complement other elevation data available from the http://srtm.csi.cgiar.org figure (2.8) illustrates a SRTM data map (Digital Elevation Model) with specifications in table (2.2).(Abdel-Magid, 2007)

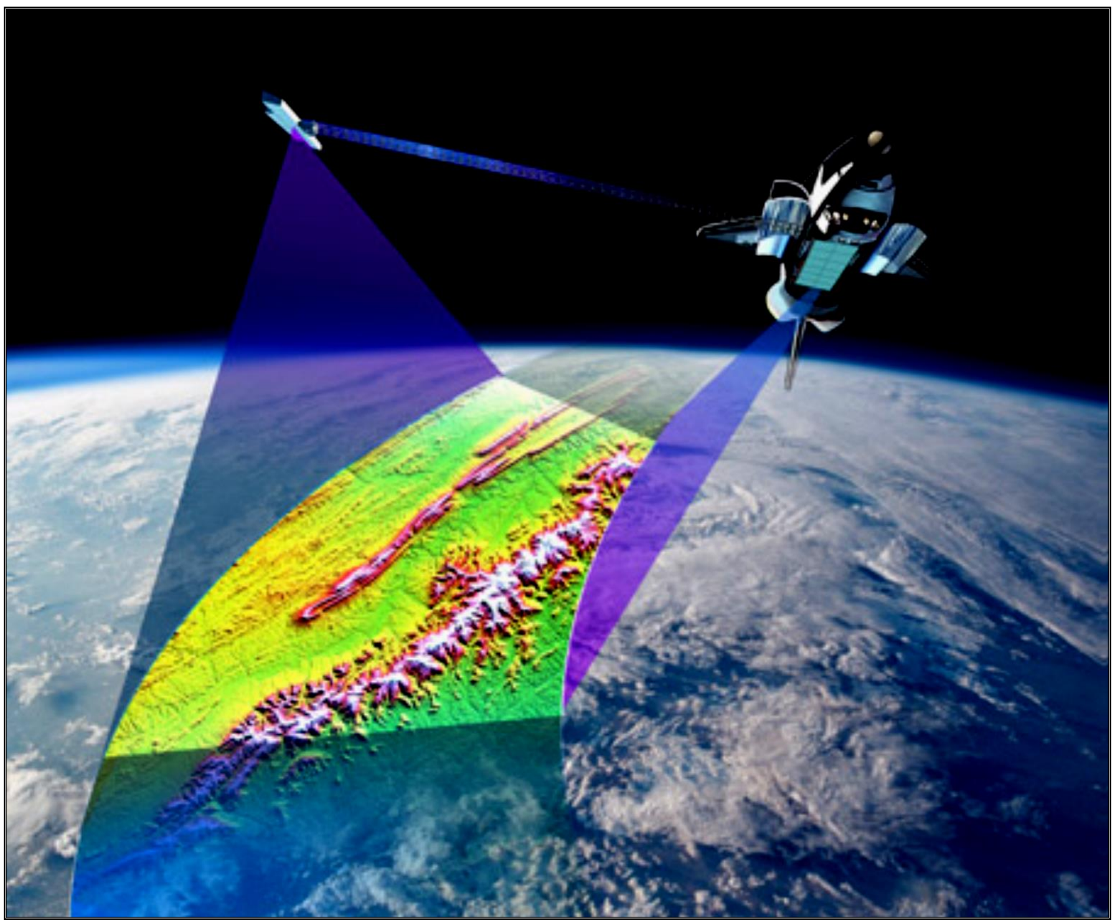

Fig.No (2.2): NASA Space Shuttle Endeavour February 11-22, 2000

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Fig.No (2.3): Row SRTM Data (Prepared by the researcher)

Table No. (2.2): Specifications of SRTM

Seamless Shuttle Radar Topography Mission (SRTM) "Finished" 3 Arc Second (~90m resolution)	
Resolution	3 arc second (approx. 90m)
Projection	Geographic
Horizontal Datum	WGS84
Vertical Datum	WGS84/EGM96 geoid
Vertical Units	Meters

2.5.2.ESRI ArcGIS v10.2 Desktop for Windows:

The ArcGIS Desktop applications include Arc Scence, Arc Map, Arc Catalog

- **Arc Scence is** the three-dimensional viewing application that is part of the ArcGIS 3D Analyst extension, allows earth scientists to create both traditional

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and unconventional three dimensional displays from real-world data.(Kennelly, 2003)

- **Arc Map** is the main mapping application which allows you to create maps, query attributes, analyze spatial relationships, and layout final projects. ArcMap is the premier application for desktop GIS and mapping. ArcMap have the capabilities of Visualizing and Creating maps
- **Visualizing maps:** In fraction of a second one will be working with its data geographically: seeing patterns couldn't be seen before, revealing hidden trends, distributions, and gaining new insights.

Creating maps: It's easy to create maps to convey desired message.

ArcMap provides all the tools needed to put data on a map and display it in an effective manner.

- **Arc Catalog** organizes spatial data contained on one's computer and various other locations allows one to search, preview, and add data to Arc Map as well as manage metadata and set up address locator services.
- **Arc Toolbox** is the third application of ArcGIS Desktop. Although it is not accessible from the Start menu, it is easily accessed and used within Arc Map and Arc Catalog. Arc Toolbox contains tools for reprocessing, data conversion, coordinate systems, projections, and more powerful way to inform and motivate others.(Briggs, 2006).Figure (2.9) shown the Arc Map, Arc Catalog, and Arc Toolbox layout.

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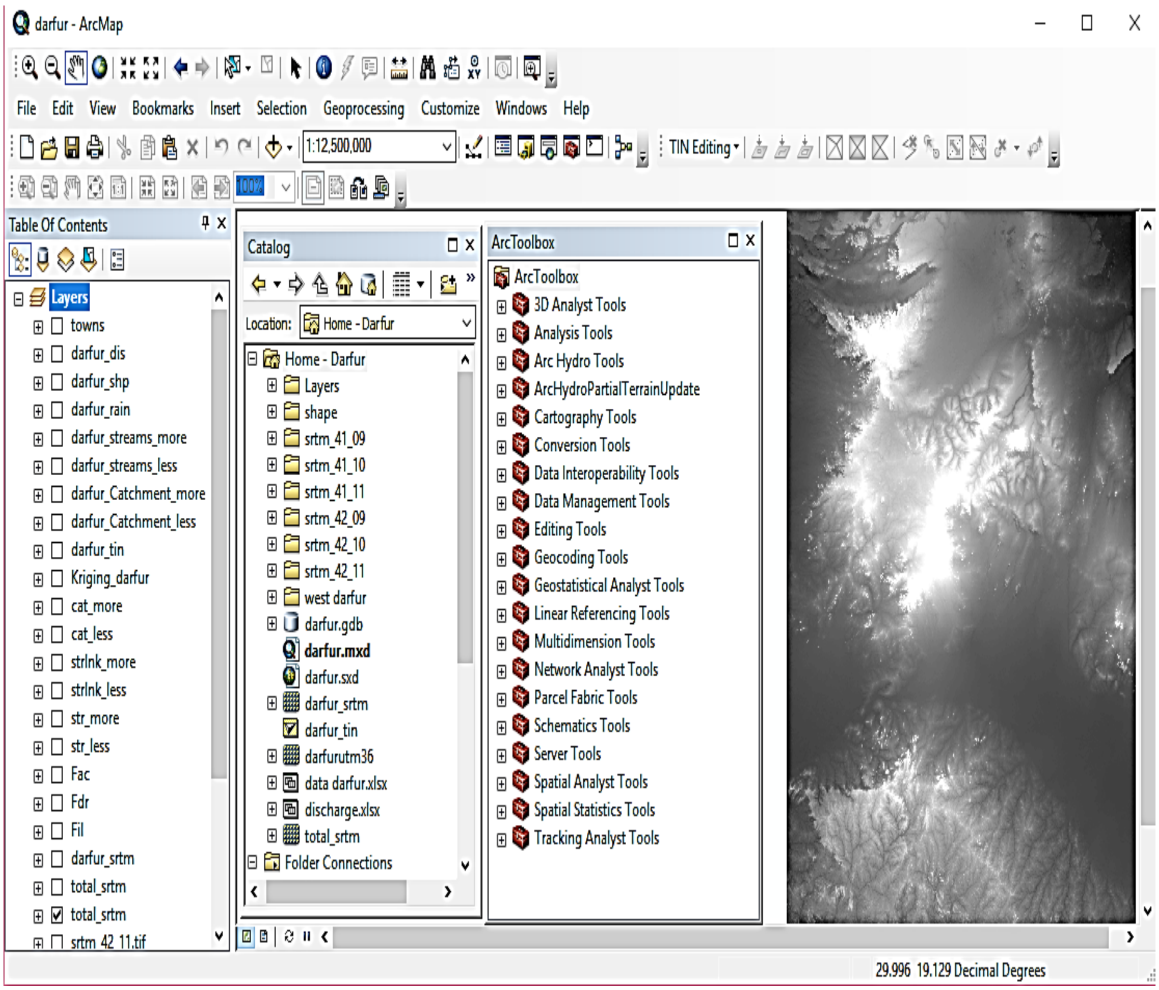

Fig.No (2.4): Arc Map, Arc Catalog, and Arc Toolbox Layout

2.5.3.GIS data structure types:

ArcGIS stores and manages geographic data in a number of formats. The three basic data models that ArcGIS uses are vector, raster, and TIN. Tabular data that can also be imported into ArcGIS.

a) Vector

Vector data models represent geographic phenomena with points, lines, and polygons. Points are pairs of x, y coordinates, lines are sets of coordinate pairs that define a shape, and polygons are sets of coordinate pairs defining boundaries that enclose areas, as shown in figure (2.10).

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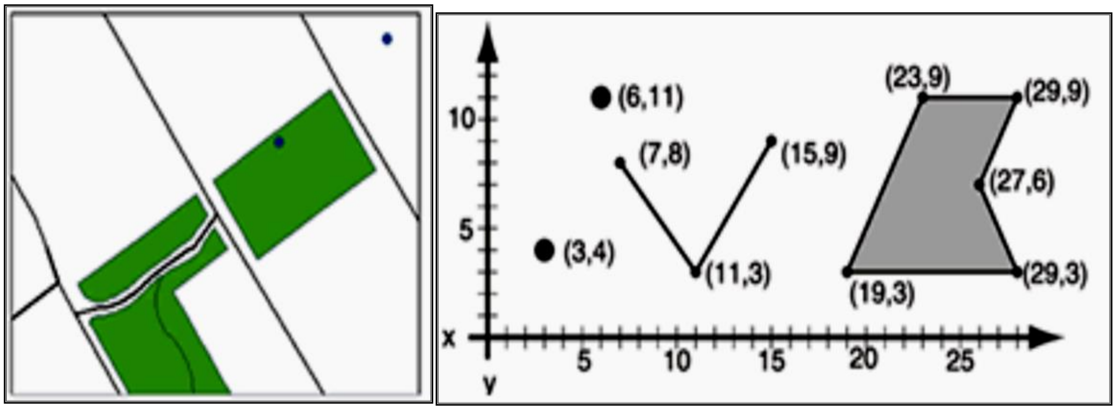

Fig.No (2.5): Vector Data Representation

Coordinates are most often pairs (x, y) or triplets (x, y, z, where z represents a value such as elevation). The coordinate values depend on the geographic coordinate system in which the data is stored.

ArcGIS stores vector data in feature classes and collections of topologically related feature classes. The attributes associated with the features are stored in data tables. ArcGIS uses three different implementations of the vector model to represent feature data: coverage's, shape files, and geodatabases.

b) Raster: A raster model (otherwise known as a raster dataset image), in its simplest form is a matrix (grid) of cells as shown in figure (2.11).

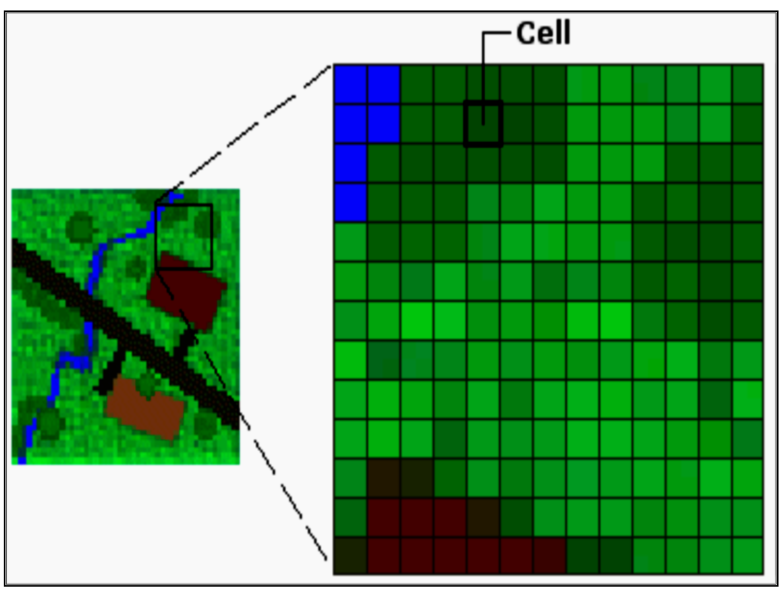

Fig.No (2.6): Raster Data Grid

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Each cell has a width and height and is a portion of the entire area represented by the raster. The dimension of the cells can be as large as or as small as needed to represent the area and the features within the area, such as a square kilometer, square meter, or even square centimeter. The cell size determines how coarse or fine the patterns or features will appear. The smaller the cell size, the more detail the area will have. However, the greater the number of cells, the longer it will take to process and it will require more storage space. If a cell size is too large, information may be lost or subtitle patterns may be obscured.(ESRI, 2004) .

c) Triangulated Irregular Network (TIN)

Heterogeneous surfaces that vary sharply in some areas and less in others can be modeled more accurately, in a given volume of data, with a triangulated surface than with a raster. That is because many points can be placed where the surface is highly variable, and fewer points can be placed where the surface is less variable. In using only the necessary points, TIN's also provide a more efficient method to store data. ArcGIS stores triangulated surfaces as TIN datasets. As with Rasters, TIN datasets can be added to a map in Arc Map and managed with Arc Catalog as shown in figure (2.12) (Briggs, 2006).

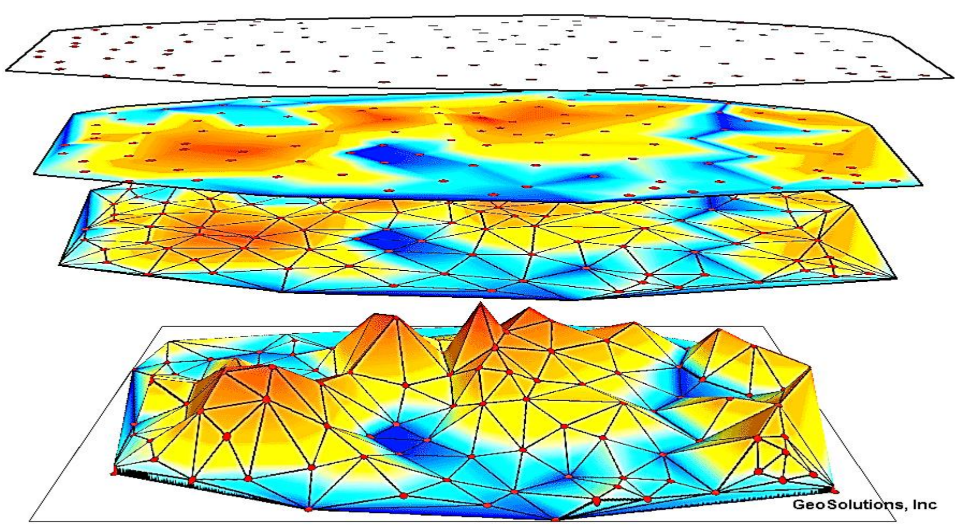

Fig.No (2.7): Triangulated Irregular Network (TIN)

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d) 3D Analyst Extension:

The 3D Analyst extension provides tools for three-dimensional (3D) visualization, analysis, and surface generation. With 3D Analyst, users can, view a surface from multiple viewpoints. One can also query a surface, create realistic perspective imaging, examine visual impact of building new structures, analyze atmospheric, surface, and subsurface pollution dispersion, and visualize income distribution in their community.

3D Analyst also provides tools for three-dimensional modeling and analysis such as view shed and line-of-sight analysis, spot height interpolation, profiling, steepest path determination, and contouring ,as shown in figure(2.13).(Abdel-Magid, 2007, ESRI, 2004)

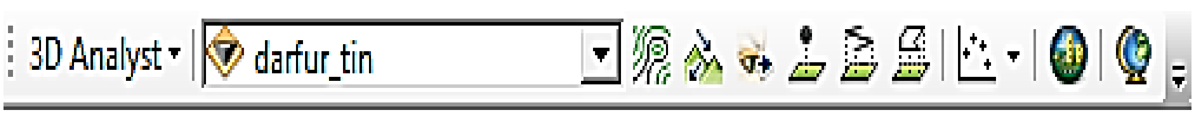

Fig.No (2.8): 3D Analyst Toolbar

e) Arc Hydro Extension:

Arc Hydro is an ArcGIS-based system geared to support water resources Applications. It consists of two key components: Arc Hydro Data Model provides a basic database design for water resources and Arc Hydro Tools a series of tools built on top of the Arc Hydro database that facilitates the analysis often performed in the water resources areas. The data model and the tools provide a foundation for water resources applications in GIS. Figure (2.14) shows the Arc Hydro toolbar.

Fig.No (2.9): Arc Hydro Toolbar

The Arc Hydro tools are a set of public domain utilities developed on top of the Arc Hydro data model. They operate in the ArcGIS environment. Some of the Functions require the Spatial Analyst extension. The tools are accessed through the Arc Hydro Tools toolbar, where they are grouped by functions into five menus, and six buttons:

- ❖ **Terrain Pre-processing:**

  This menu item contains the functions dealing with Digital Elevation Model (DEM) processing. They are mostly used once in order to prepare spatial information for later use.

- ❖ **Watershed Processing:**

It contains functions dealing with watershed and sub watershed delineation, and basin characteristic determination. They operate on top of the spatial data prepared in the terrain pre-processing stage.

- ❖ **Attribute Tools:**

It contains functions allowing generating key attributes (fields) in the Arc Hydro data model. Some of the tools require the existence of a geometric network.

- ❖ **Network Tools:**

It contains functions allowing generating or manipulating properties of geometric (hydro) network.

- ❖ **ApUtilities:**

It contains functions allowing managing Arc Hydro project properties. In general, they will be seldom used.(ArcHydro, 2016)

`

2. 6.The Previews study in Dar Fur states

The annual discharge in Dar Fur states was measured and estimated, the measured 1731.03 MCM (Azum) 487 MCM ,North 103.03 MCM ,and South 1141 (Ali, 2014) ,and estimated to be 4016 for Azum and Kaja (Ali, 2014) and then estimated to be 4942 MCM in West 4016 MCM ,North 103 MCM ,and South 823 MCM (Yousif, 2011), also 1159 MCM. West 900 MCM ,North 100 MCM ,and South 159 MCM (Barsi, 2010). The stations at annual discharge in West, North, and South Dar Fur States in past researchers are shown in Tables (2.3 to 2.7).

Table No. (2.3): Annual Discharge of The Main Wadis in North Dar Fur

Wadi	Station	Annual average discharge M.m^3
Wadi Bari	Kabkabiya	70.93
El Serief	Kabkabiya	23.27
El Ku	Dar Elsalaam	3.75
Beida	Um Kaddada	4.97
Kaj	Dar Elsalam	0.11
Total		**103.03**

Source (Ali, 2014)

Table No. (2.4): Annual Discharge of The Main Wadis in South Dar Fur

wadi	station	Longitude	Latitudes	Period of recording (Years)	Annual Discharge (M.m3)
Ebra	nashla	24º 32' 00"	10º59' 00"	28	210
Kaya	Edd ElFursan	24º20' 00"	11º30' 00"	28	157
Bulbul	Timbsko	24º 35' 00"	11º47' 00"	14	76
Sindo	Umm Higgra	23º55' 00"	11º17' 00"	16	164
El Hammra	El Hammra	25º03' 00"	12º24' 00"	17	152
Tawal	Abu Likalik	23º41' 00"	10º44' 00"	4	150
Bahar El Arab	AL Higairal	25º05' 00"	10º18' 00"	23	168
Nyala	Nyala	24º54' 00"	12º54' 00"	17	64
Total	**Total**				**1,141**

Source (Ali, 2014)

`

Table No. (2.5): Annual Discharge of The Main Wadis in West Dar Fur

Drainage Basin	Wadi	Basin Area (km²)	Calculated discharge M.m³	Measured discharge M.m³	Rainfall mm
Wadi Azum	Dbari Murni	11,640	154	150	530
	Toro	5,698	387	45	680
	Nertete	5,700	1289	14	870
	Aribo	3,067	135	58	630
	Sanit	5,874	399	-	680
	Dedari Talango	3,730	50	40	670
	Wadi Saleh	4,684	183	180	710
	Sub-total	**40,393**	**2,597**	**487**	
Wadi Kaja	Sindo	4,498	152	-	650
	WADI Aradieb	6,458	79	-	350
	WADI Aradieb Bardi	5,740	111	-	450
	WADI Gumera	1,864	46	-	450
	WADI Arada	1,849	53	-	475
	WADI Abu Sunt	7,963	239	-	500
	WADI Kaja –Mahabas	3,917	114	-	520
	Abu Surg	3,308	128	-	560
	WADI Kaja-Karagora	11,740	497	-	550
	Sub-total	**47,337**	**1,419**	-	
Azum+ Kaja	**Total`**	**87,730**	**4,016**	-	

Source (Ali, 2014)

Table No. (2.6): Annual Discharge of The Main Wadis in Dar Fur

Name of Wadis	Station	Coordinates		Average Discharge m³/s	Number of Years
		Longitude	Latitudes		
Elkua	Wadi Elkua	25º 31' 00"	13º23' 00"	4.0415285	10
El Hammra	El Hammra	23º43' 00"	10º54' 00"	116.968499	15
Bulbul	Tumbisku	24º 35' 00"	11º47' 00"	41.261081	11
Ibra	Nashala	24º32' 00"	10º56' 00"	155.444366	14
	Idd Elfirsan	24º22' 00"	11º59' 00"	42.609401	16
Kalakandi	Afindou	24º35' 00"	11º03' 00"	16.383691	18
Tiwal	Umm Hugara	23º54' 00"	11º16' 00"	107.430256	12
Abu Likalik	Abu Likalik	23º01' 00"	10º44' 00"	70.100988	8
Bahar El Arab	El Higairat	25º05' 00"	10º18' 00"	275.716342	7

Source(Ministry of Irrigation &Water Resource)

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Table No. (2.7): Estimated Discharge of The Main Wadis in Dar Fur

State	Wadi	Catch Area (km2)	Reliability 50%	
			Annual Rainfall (mm)	Annual Discharge (M. m^3)
West Darfur	Azum	36700	546	601
	Kaja	42,850	465	299
South Darfur	Nyala	4080	496	41
	Negeida	3060		31
	Ibra	1900		19
	Bulbul	4600		46
	Kaya	2200		22
North Darfur	El Ku	28000	272	76
	Howar	12200	200	24

Source (Barsi, 2010)

2. 7. Previews study using regression methods and GIS

There was a past study, the regression method was applied in order to estimate the optimum model parameter values. The independent characteristics chosen in that investigation were mean areal precipitation, catchment area, and catchment mean slope. These studies did not consider wadi length. The procedure resulted in the combination of 5 stations. This combination achieves maximization of the correlation coefficient R, compatibility of estimated discharges and areal precipitation, and minimization of the difference between estimated and observed discharges in the stations. The final form of the equation was found to be in equation (2.10) (ZOBANAKIS G., 2003)

$$Q = 1.637 \times 10^{-27} A^{1.578} P^{3.370} S^{3.959} ----(2.10)$$

The model used in this research uses the parameters shown in equation (2.8) that will consider the length in equation.

`

CHAPTER THREE

3. METHODOLOGY

3. 1.The road map: -

Materials and equipment used to analyze the problems are delineated in the road map which is the methodology adopted in this study. The problems are mainly lack of surface water and groundwater measurement, and development. Institutional problems are clearly focused on only 26 % of the population that have access to clean water**.** Data of measured rainfall and runoff is scarce. Design techniques including GIS software are used to predict the rainfall- runoff correlations to calculate the flow. The objective is to predict rainfall runoff equations for wadis in Dar Fur states, verify the predicted equations against actual data and calculate total annual wadis discharge for the three states to aid design and operation of water resource structure.

The road map covered both desk and field studies. The data used to predict wadi flow in Dar Fur regions are created in layers (catchment, stream, elevation, etc.) for satellite image (SRTM) in ArcGIS software. It includes in a best fit distribution for thirty-year rainfall data, and annual stream discharge. Mapping all data in the software with the application of multiple regression method are the general tool developed by the researcher and shown in Figure (3.1)

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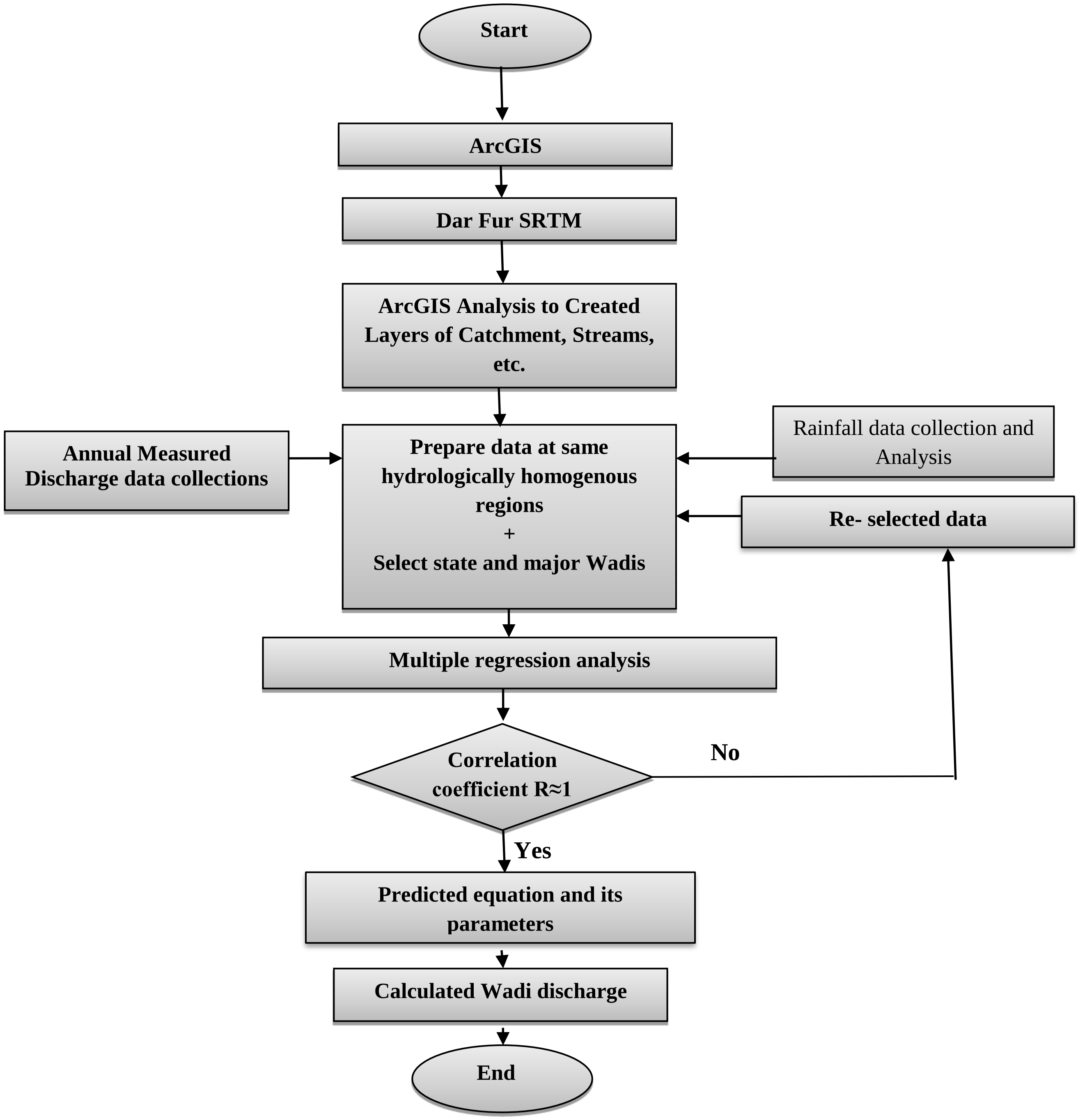

Fig.No. (3.1): Flow chart of Research General Methodology

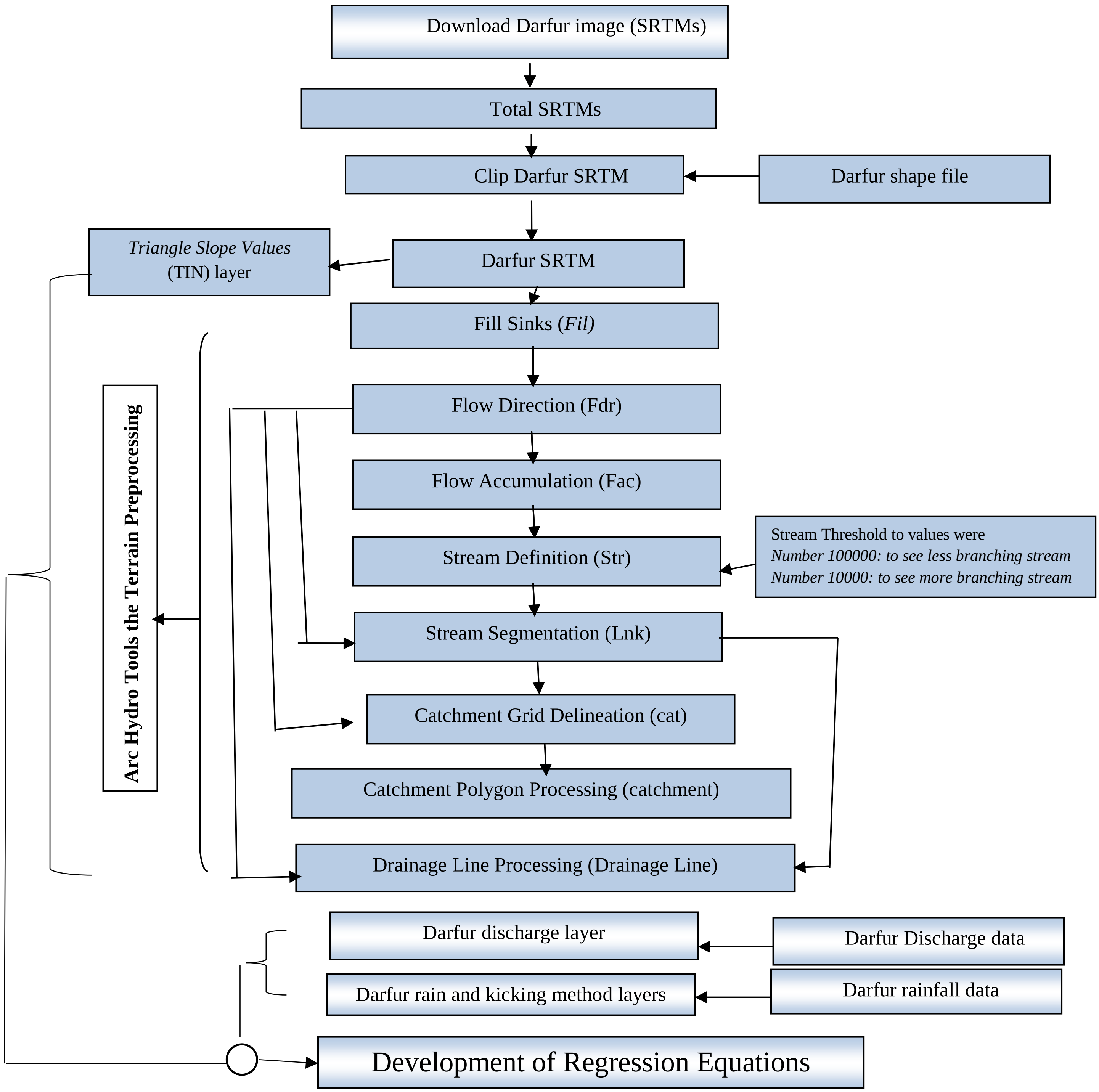

Fig.No. (3.2) The Developed ArcGIS Analysis and Layers

3. 2.ArcGIS Analysis: -

In this step download Darfur images (SRTMs) are merged and clipped by Dar Fur shape file and got final Dar Fur SRTM layer that was used to create TIN layer to identify elevation at any point, Arc hydro tools layers, developed by the researcher for purpose of generating the drainage system the following layers are developed in sequential manner after Download SRTMs Data by Coordinates

Table No. (3.1): Terrain Preprocessing Layers

layer	Function
Fill Sinks Fig (3.7)	The Fill Sinks function modifies the elevation value to eliminate these problems.
Flow Direction Fig (3.8)	This function computes the flow direction for a given grid
Flow Accumulation	This function computes the flow accumulation grid that contains the accumulated number of cells upstream of a cell, for each cell in the input grid.
Stream Definition	This function computes a stream grid contains a value of "1" for all the cells in the input flow Accumulation grid that have a value greater than the given threshold. All other cells in the Stream Grid contain no data.
Stream Segmentation	This function creates a grid of stream segments that have a unique identification. Either a segment may be a head segment, or it may be defined as a segment between two segment junctions
Catchment Grid Delineation Fig (3.9)	This function creates a grid in which each cell carries a value (grid code) indicating to which catchment the cell belongs.
Catchment Polygon Processing Fig (3.10)	This function converts a catchment grid it into a catchment polygon feature.
Drainage Line Processing Fig (3.11)	This function converts the input Stream Link grid into a Drainage Line feature class. Each line in the feature class carries the identifier of the catchment in which it resides.
Drainage Point Processing	This function allows generating the drainage points associated to the catchments.

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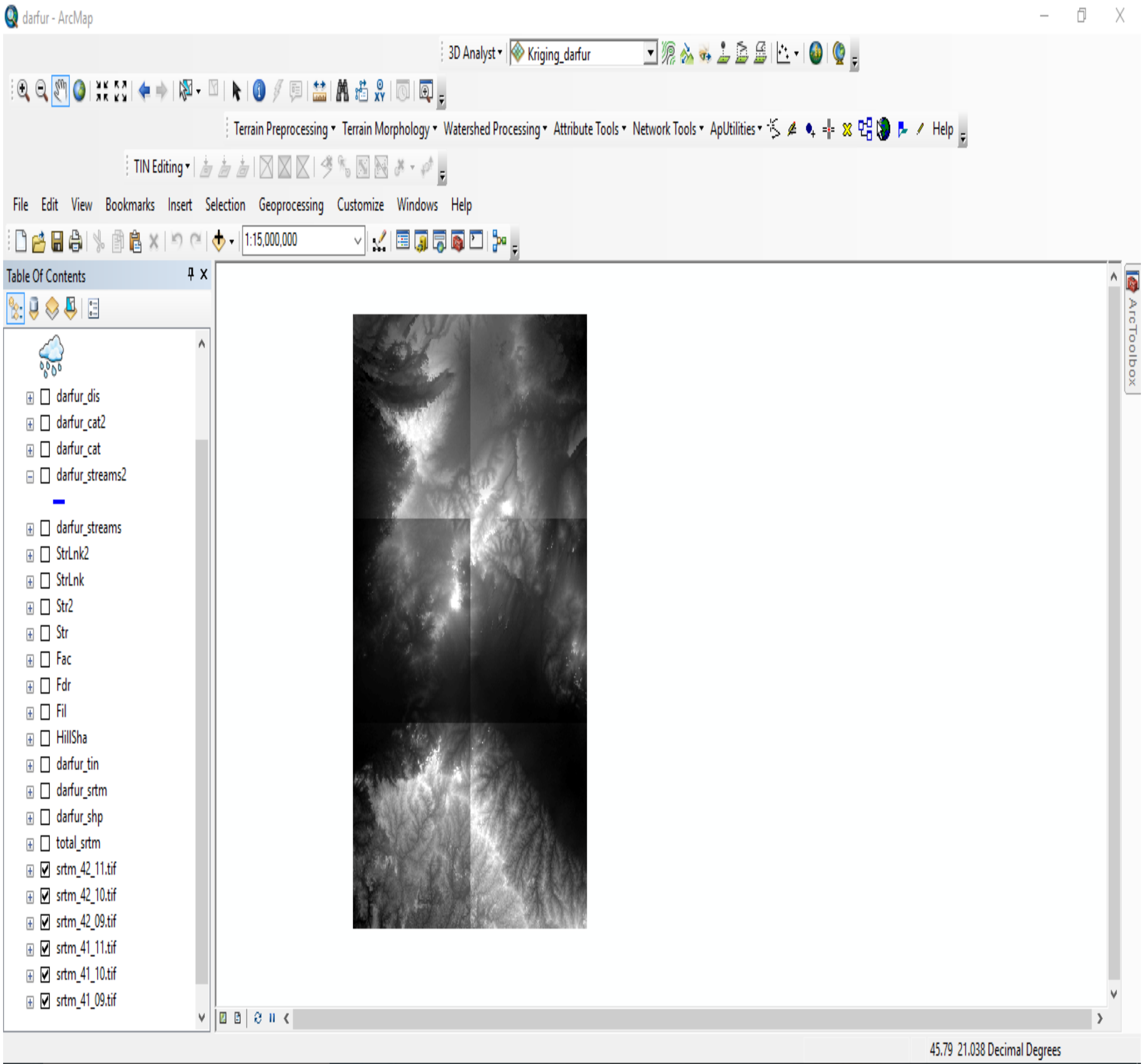

Fig.No. (3.3): SRTMs for Darfur in Arc Map

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Total SRTMs Merged and Clipped with Shape File:

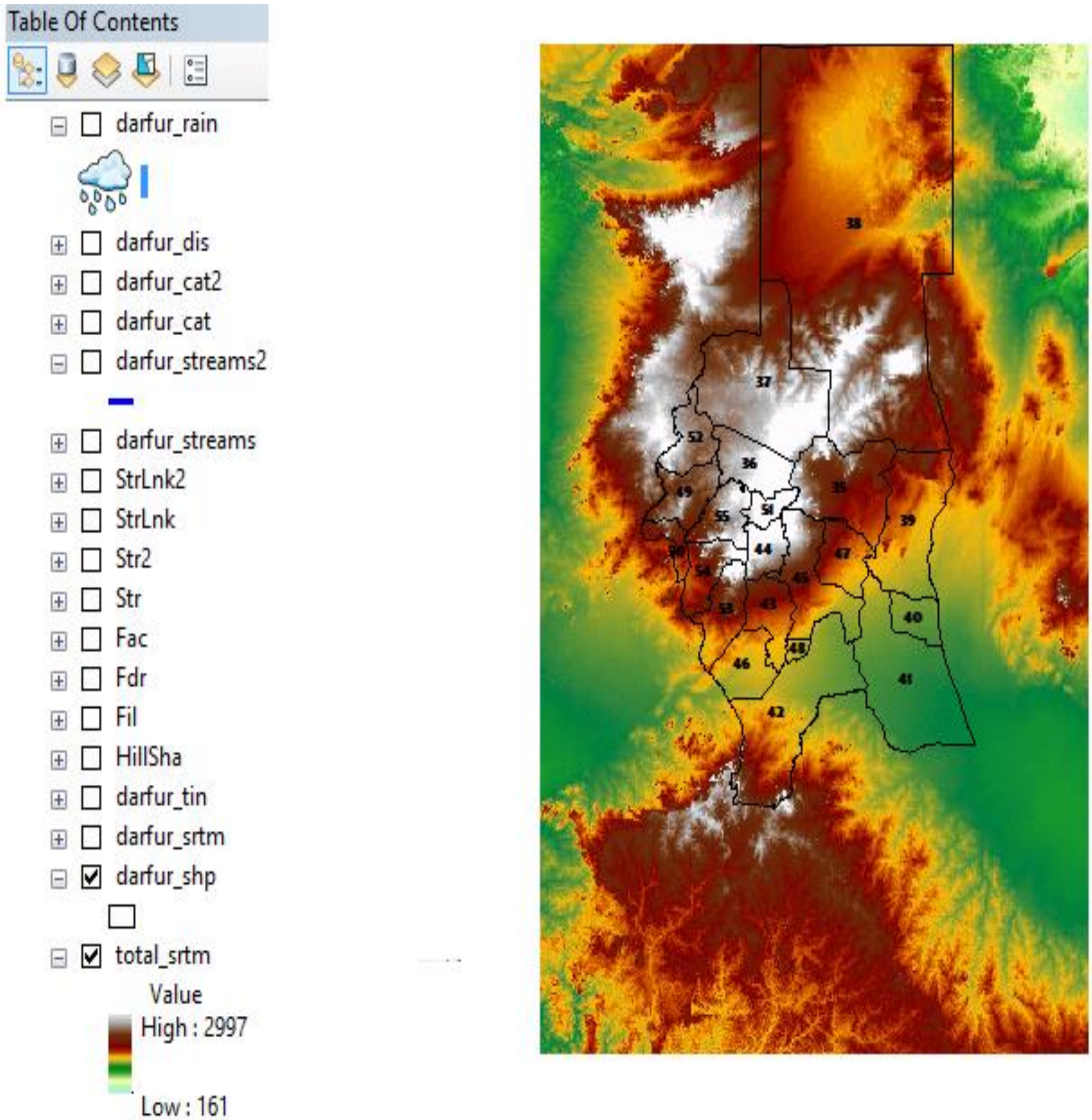

Fig.No. (3.4): Total Dar Fur SRTMs

Darfur SRTM:

Figure (3.5) represents Dar Fur SRTM.

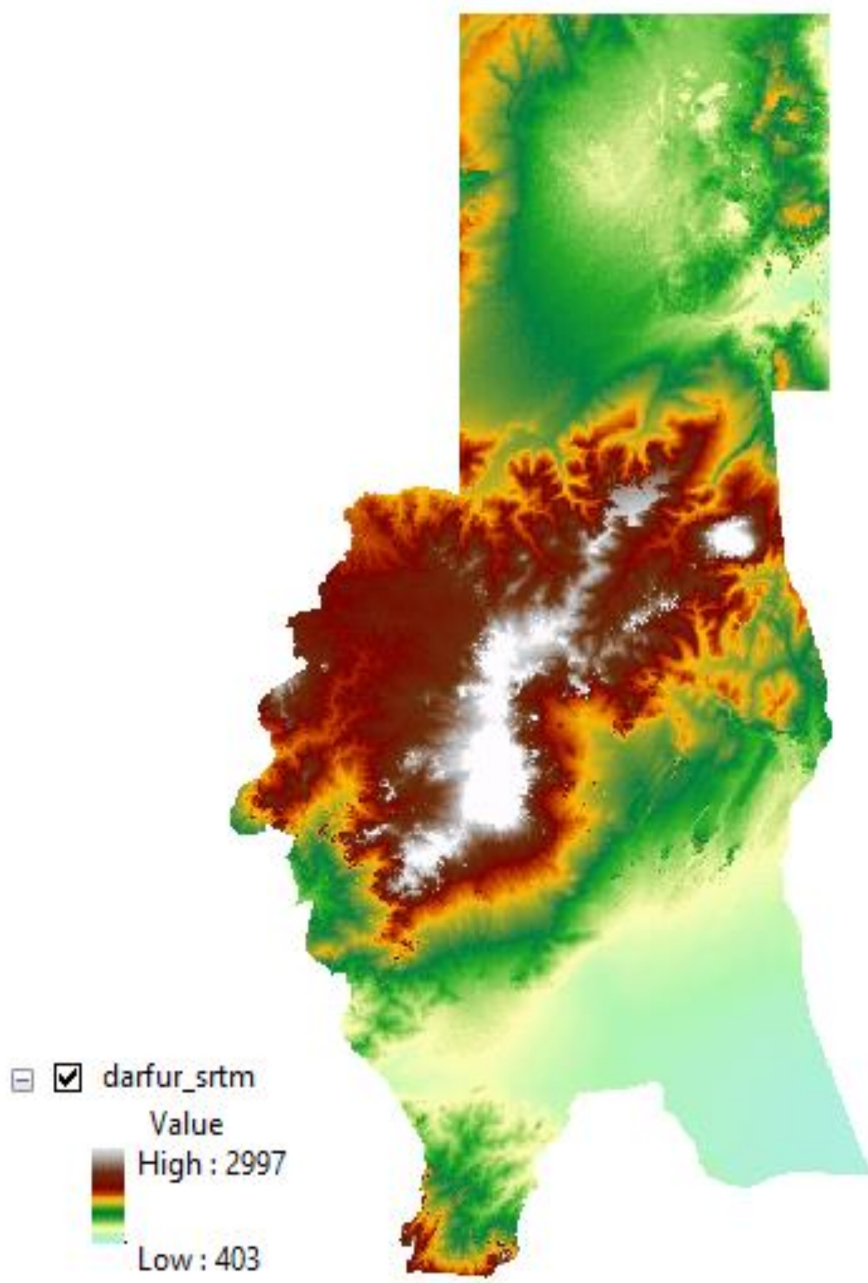

Fig.No.(3.5): Dar Fur SRTM

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Triangle Slope Values (TIN):

Figure (3.6) represents Dar Fur triangle slope values.

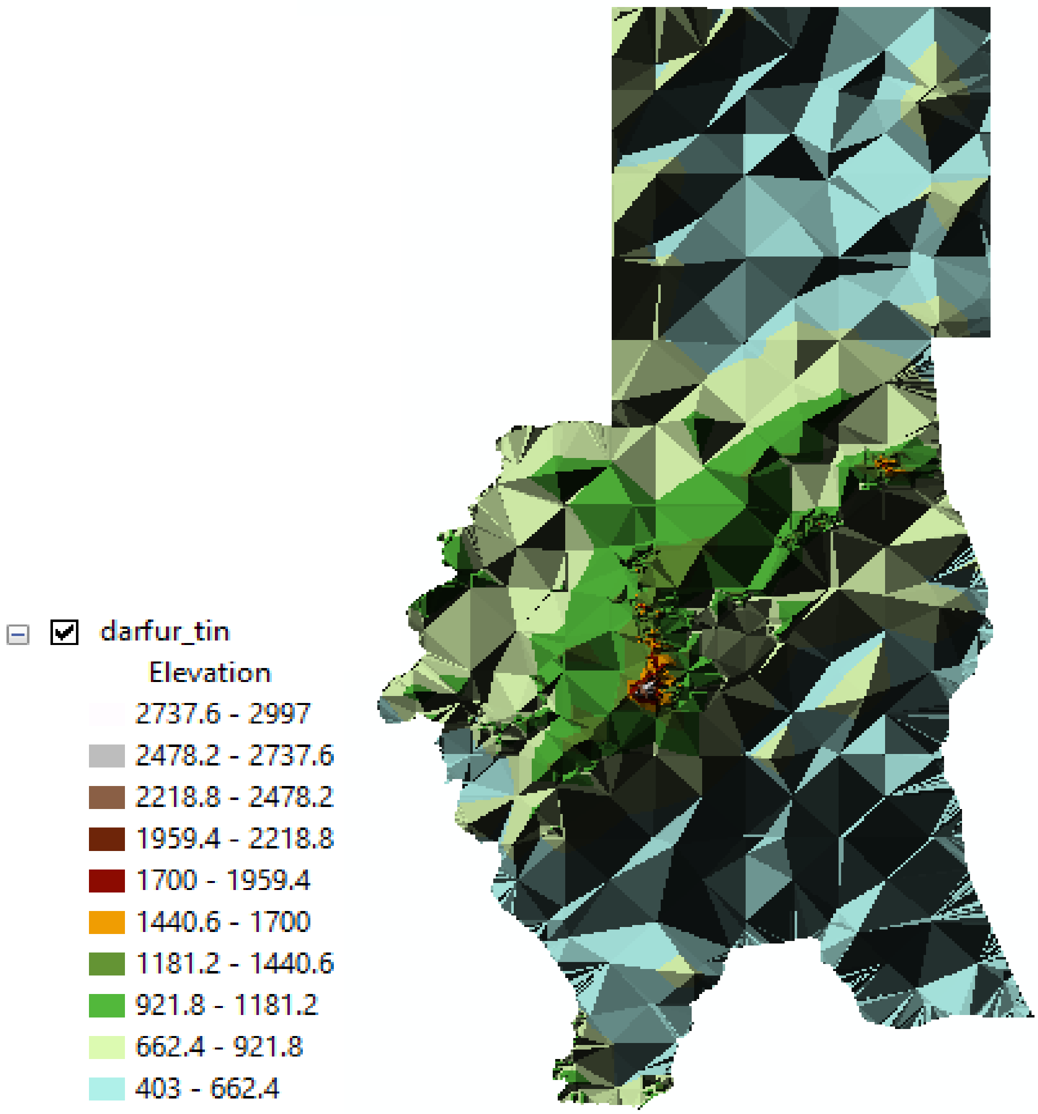

Fig.No.(3.6): Dar Fur Triangle Slope Values

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Arc Hydro Tools the Terrain Preprocessing:

Figure (3.7) represents Dar Fur Fill Sinks. Figure (3.8): Dar Fur flow direction.

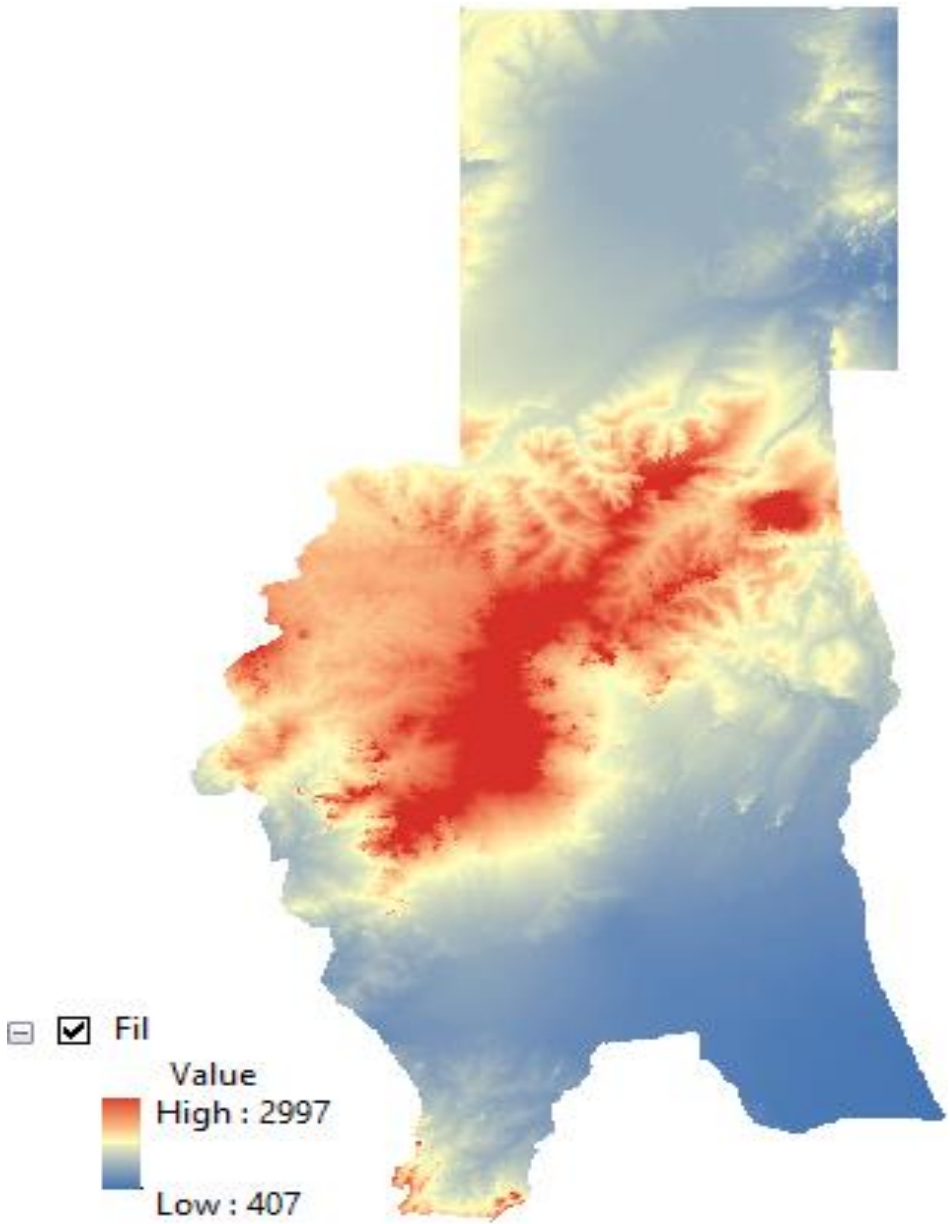

Fig.No. (3.7): Dar Fur Fill Sinks

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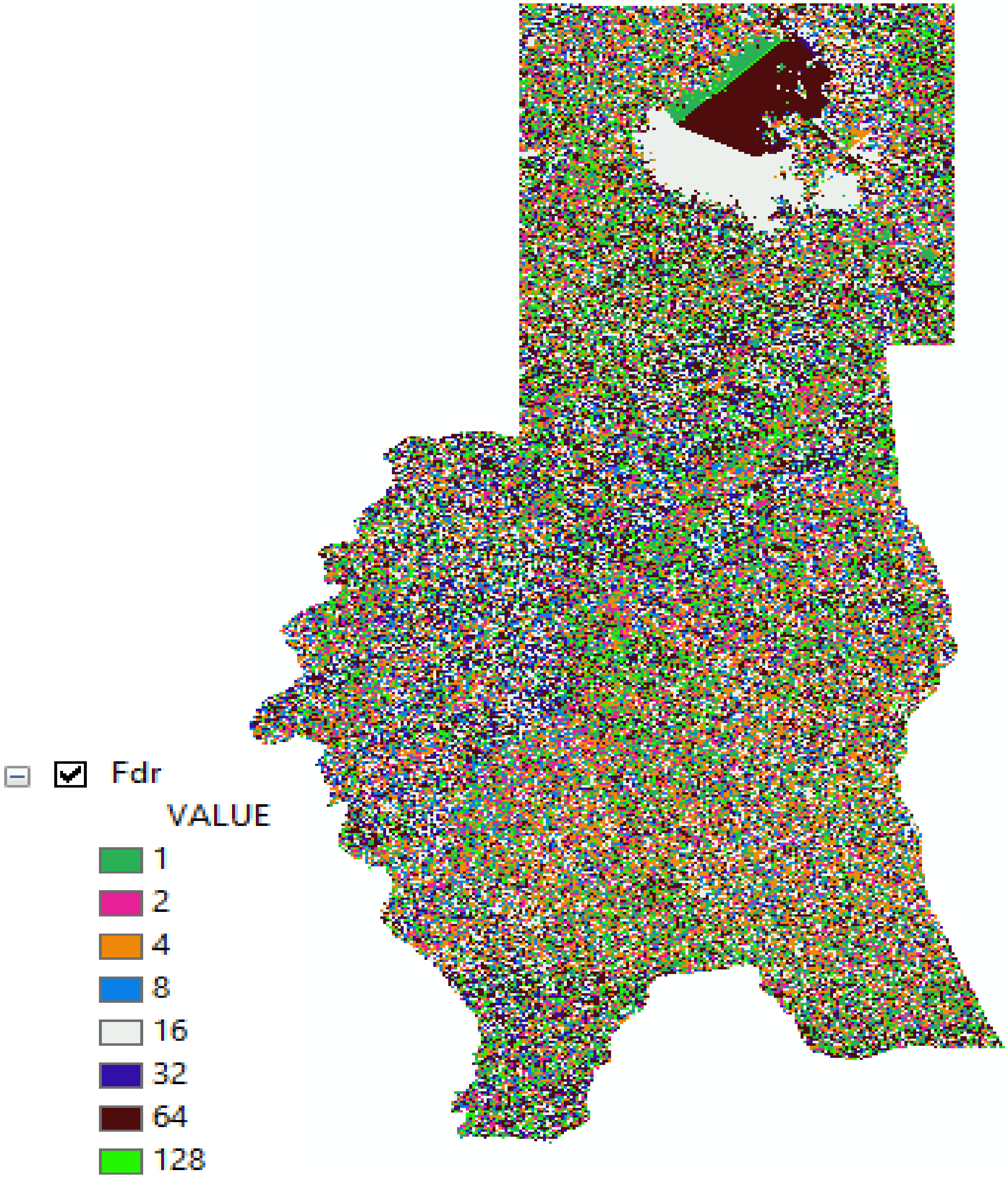

Fig.No.(3.8): Dar Fur Flow Direction

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Figure (3.9) represents Dar Fur catchment grid delineation.

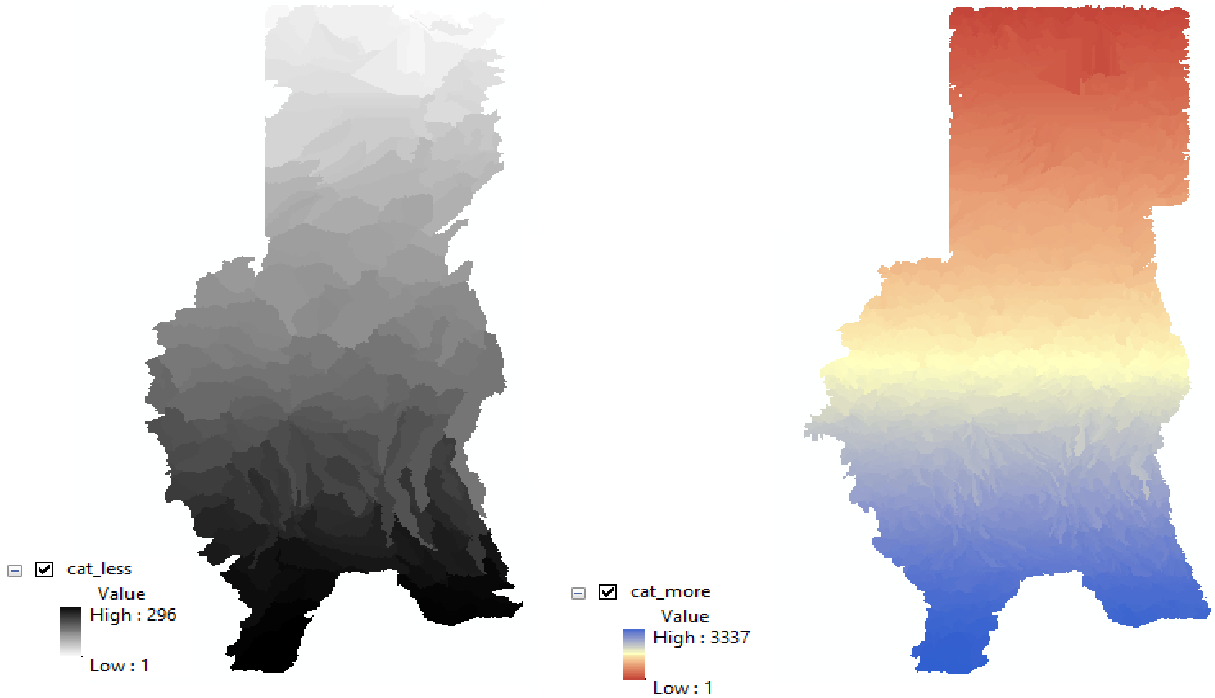

Fig.No.(3.9): Dar Fur Catchment Grid Delineation

Figure (3.10) represents Dar Fur catchment polygon.

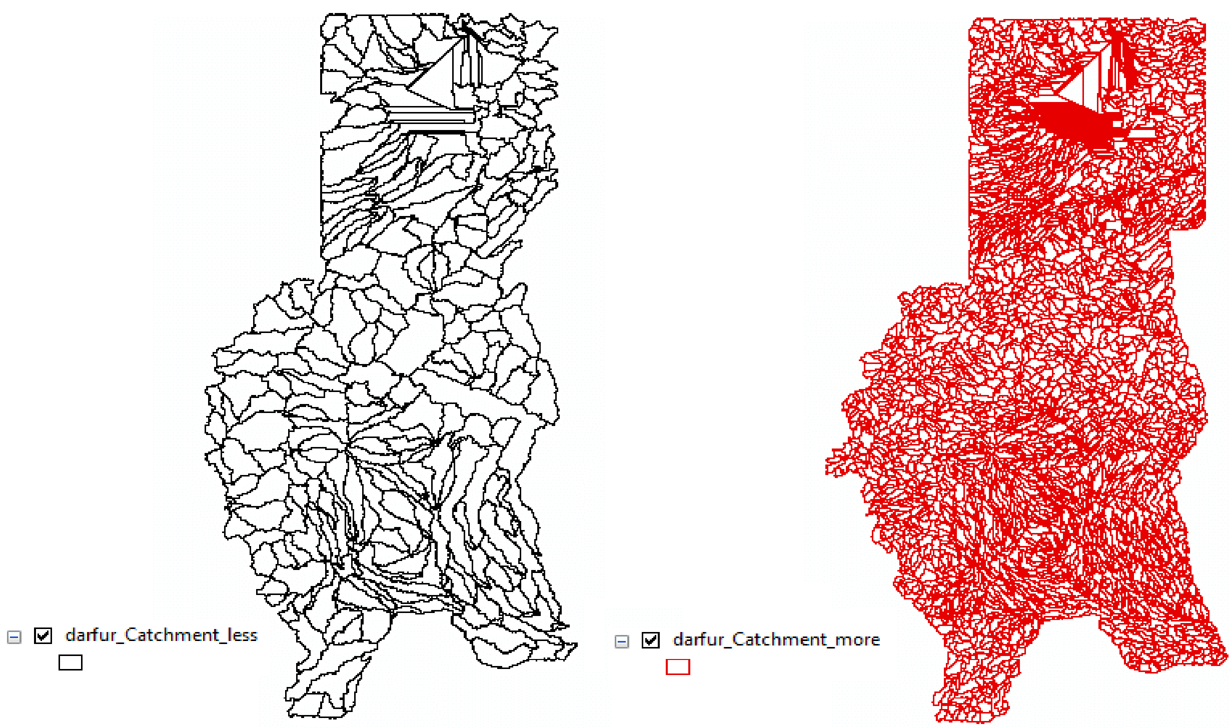

Fig.No.(3.10): Dar Fur Catchment Polygon

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Figure (3.11) represents Dar Fur Drainage Line(streams)

Fig.No.(3.11): Dar Fur Drainage Line(Streams)

Dar Fur Attributes Tables

The attributes tables for Dar Fur Catchments and streams layers was converted to UTM 36 coordinates systems. They have greater values. That lead to longer results as reported in tables (3.2), (3.3), (3.4), and (3.5).

`

Table No.(3.2): Attributes Tables of Dar Fur Catchment Less

Table

darfur_Catchment_less

OBJECTID	Shape *	HydroID *	GridID *	Shape_Length	Shape_Area	AREA_Km^2
1	Polygon	1	1	208634.348952	421789172.575101	421.7892
2	Polygon	2	2	282403.933786	918379998.657735	918.38
3	Polygon	3	3	95257.009944	61598125.108822	61.59813
4	Polygon	4	4	51056.581014	17753125.461356	17.75313
5	Polygon	5	5	20993.755765	4678788.038508	4.678788
6	Polygon	6	6	279480.568146	251620211.312805	251.6202
7	Polygon	7	7	394770.316059	1112031656.030372	1112.032
8	Polygon	8	8	434823.051015	2188914278.517576	2188.914
9	Polygon	9	9	264281.769305	1172417122.873893	1172.417
10	Polygon	10	10	437002.665541	1061959791.035678	1061.96
11	Polygon	11	11	282878.465744	1228114040.868484	1228.114
12	Polygon	12	12	161050.385748	255443925.541209	255.4439
13	Polygon	13	13	278994.964577	919421978.109254	919.422
14	Polygon	14	14	355912.035423	458610552.669636	458.6106
15	Polygon	15	15	236826.601988	1183252725.770725	1183.253
16	Polygon	16	16	376241.649019	1476348260.929018	1476.348
17	Polygon	17	17	388798.347326	1319028533.445766	1319.029
18	Polygon	18	18	429458.632706	2678174667.91285	2678.175
19	Polygon	19	19	365298.519758	2290680248.125651	2290.68
20	Polygon	20	20	444435.78401	1199237185.355678	1199.237

0 (0 out of 296 Selected)

darfur_Catchment_less

Table No.(3.3):Attributes Tables of Dar Fur Catchment More

Table

darfur_Catchment_more

OBJECTID *	Shape *	HydroID *	GridID *	Shape_Length	Shape_Area	AREA Km^2
1	Polygon	593	1	115174.837606	269878717.132362	269.8787
2	Polygon	594	2	19697.35324	6857977.240462	6.857977
3	Polygon	595	3	94321.114042	147076419.811833	147.0764
4	Polygon	596	4	83150.455217	114106323.546512	114.1063
5	Polygon	597	5	71503.773104	107223973.555237	107.224
6	Polygon	598	6	93405.697198	125780181.520514	125.7802
7	Polygon	599	7	107408.371205	184941617.610872	184.9416
8	Polygon	600	8	102552.347664	124793443.713422	124.7934
9	Polygon	601	9	24156.646816	8952015.855092	8.952016
10	Polygon	602	10	75232.944992	82535258.876627	82.53526
11	Polygon	603	11	95713.796507	97215013.883512	97.21501
12	Polygon	604	12	59833.339169	37956558.380382	37.95656
13	Polygon	605	13	107427.608066	117094618.488979	117.0946
14	Polygon	606	14	143904.370928	424391426.318765	424.3914
15	Polygon	607	15	163411.923976	312156244.022364	312.1563
16	Polygon	608	16	71571.41428	39617276.758843	39.61728
17	Polygon	609	17	70455.768469	106396886.671999	106.3969
18	Polygon	610	18	97194.19378	122684722.090563	122.6847
19	Polygon	611	19	120700.494686	290479294.706036	290.4793
20	Polygon	612	20	236964.106241	543073414.151282	543.0734

37 (1 out of 3337 Selected)

darfur_Catchment_more

`

Table No.(3.4):Attributes Tables of Dar Fur Streams Less

Table

darfur_streams_less

OBJECTID *	Shape *	arcid	grid_code *	from_node *	to_node *	HydroID *	GridID *	NextDow	Shape_Length	length Km
1	Polyline	1	2	3	2	297	2	-1	4365.8777	4.365878
2	Polyline	2	1	4	1	298	1	-1	12409.264321	12.40926
3	Polyline	3	4	5	4	299	4	298	8426.470533	8.426471
4	Polyline	4	5	6	5	300	5	299	5061.376068	5.061376
5	Polyline	5	7	7	5	301	7	299	14447.780583	14.44778
6	Polyline	6	6	11	6	302	6	300	13626.8182	13.62682
7	Polyline	7	3	12	4	303	3	298	27200.424989	27.20042
8	Polyline	8	13	13	12	304	13	303	1109.198488	1.109198
9	Polyline	9	12	14	12	305	12	303	7830.377963	7.830378
10	Polyline	10	9	9	16	306	9	-1	17153.331598	17.15333
11	Polyline	11	14	19	14	307	14	305	4922.438165	4.922438
12	Polyline	12	8	20	8	308	8	-1	33456.174123	33.45617
13	Polyline	13	17	10	19	309	17	307	56842.228039	56.84223
14	Polyline	14	11	21	11	310	11	302	20228.034791	20.22803
15	Polyline	15	22	22	6	311	22	300	46100.842611	46.10084
16	Polyline	16	16	15	24	312	16	320	48300.502802	48.3005
17	Polyline	17	19	18	24	313	19	320	24472.754604	24.47276
18	Polyline	18	10	25	11	314	10	302	38595.496776	38.5955
19	Polyline	19	15	26	14	315	15	305	29695.545408	29.69555
20	Polyline	20	23	17	27	316	23	326	43826.604849	43.82661

0 (0 out of 296 Selected)

darfur_streams_less

Table No.(3.5):Attributes Tables of Dar Fur Streams More

Table

darfur_streams_more

OBJECTID *	Shape *	arcid	grid_code *	from_node *	to_node *	HydroID *	GridID *	NextDownl	Shape_Length	Length Km
1	Polyline	1	5	8	5	3930	5	-1	620.575248	0.620575
2	Polyline	2	7	9	7	3931	7	-1	4696.66135	4.696661
3	Polyline	3	2	10	2	3932	2	-1	5717.185259	5.717185
4	Polyline	4	3	11	3	3933	3	-1	5956.456785	5.956457
5	Polyline	5	6	12	6	3934	6	-1	5565.923021	5.565923
6	Polyline	6	9	13	10	3935	9	3932	2866.780867	2.866781
7	Polyline	7	10	14	12	3936	10	3934	1002.735557	1.002736
8	Polyline	8	8	16	10	3937	8	3932	4271.740374	4.27174
9	Polyline	9	12	19	13	3938	12	3935	1957.009502	1.95701
10	Polyline	10	11	20	13	3939	11	3935	2176.672064	2.176672
11	Polyline	11	17	21	19	3940	17	3938	848.254568	0.848255
12	Polyline	12	4	24	4	3941	4	-1	12197.125435	12.19713
13	Polyline	13	18	23	24	3942	18	3941	11270.680804	11.27068
14	Polyline	14	16	26	19	3943	16	3938	1868.288692	1.868289
15	Polyline	15	26	29	34	3944	26	3968	1263.342234	1.263342
16	Polyline	16	1	33	1	3945	1	-1	17838.583788	17.83858
17	Polyline	17	28	32	34	3946	28	3968	7121.560764	7.121561
18	Polyline	18	21	25	36	3947	21	3954	6116.354247	6.116354
19	Polyline	19	13	15	36	3948	13	3954	6751.611475	6.751612
20	Polyline	20	24	27	37	3949	24	4014	6208.320301	6.20832

0 (0 out of 3337 Selected)

darfur_streams_more

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Figure (3:12) represents Dar Fur 3D veiwer ArcGIS Scence

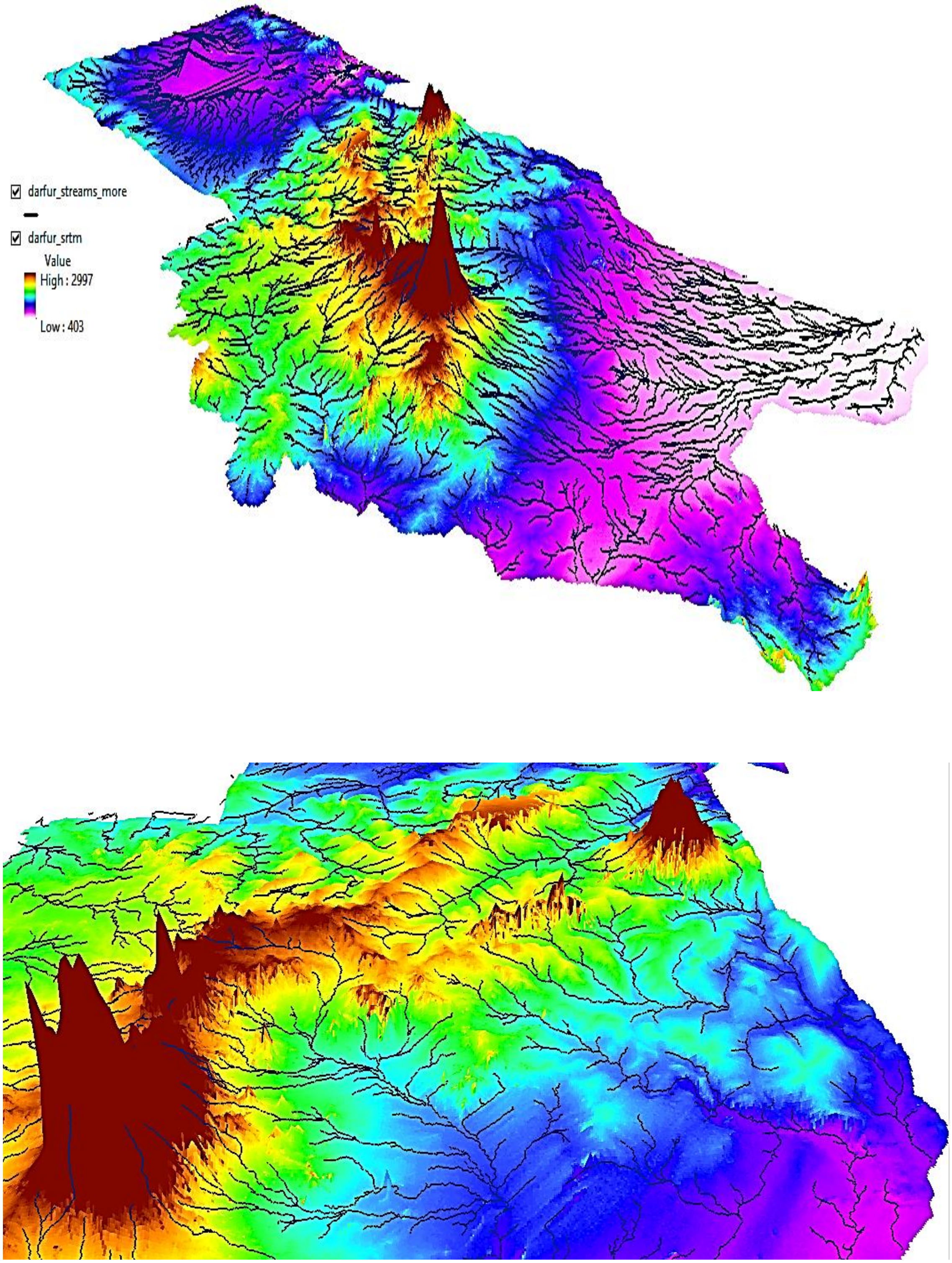

Fig.No.(3.12): Dar Fur 3D Veiwer ArcGIS Scence

3. 3.Rainfall Data Collection and Analysis: -

The rain data were collected for thirty years period daily gauge from 1/1/1984 to 31/12/2013 the data was downloaded from Texas A&M's web site at (http://globalweather.tamu.edu) the data covered all area in Dar Fur, then analyzed with excel program add in tools called XLSTAT 2016 (XLSTAT, 2016) to get a best distribution fitting (Appendix C) The table shows the average annual rainfall, best type of distribution fitting and parameter. For more information method to fit the best distribution are given in Appendix (B). Finally, in ArcGIS the Kriging method was used to distribute data to identify rainfall parameters at any specific location in the map as shown in Figure (3.13).

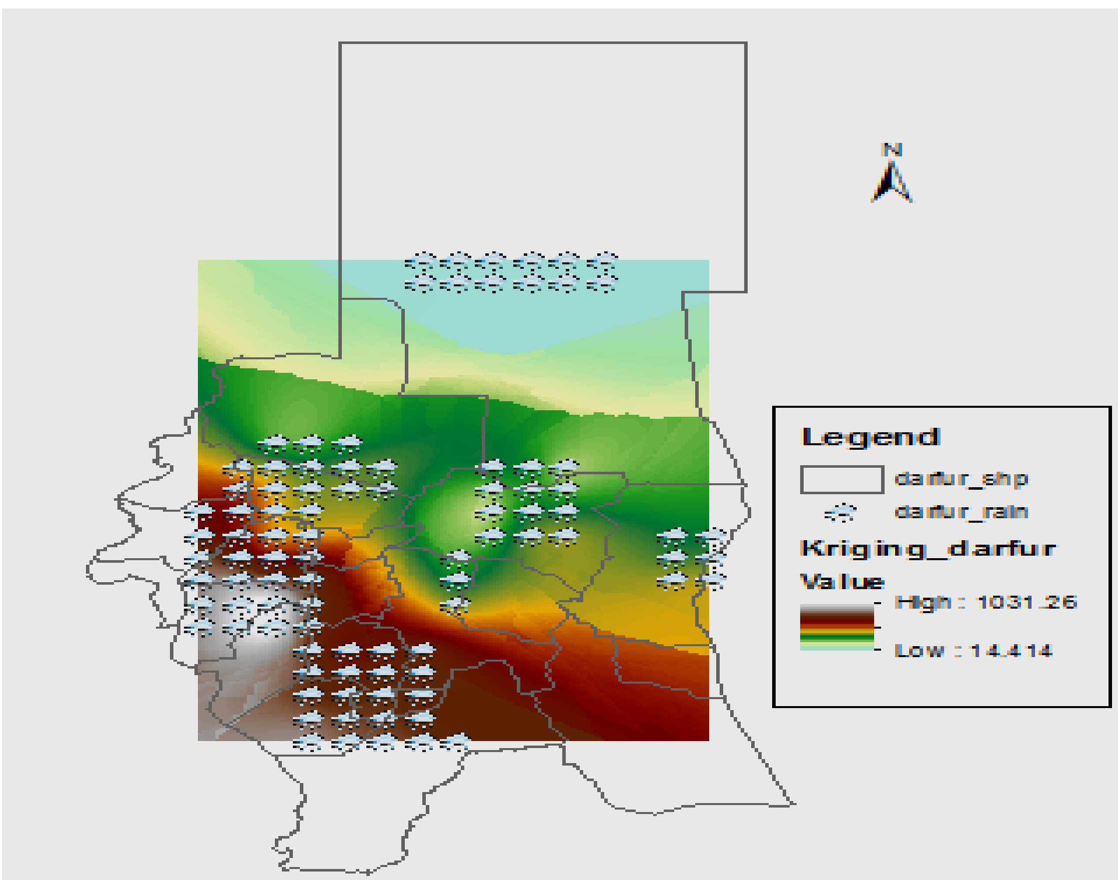

Fig.No.(3.13):Rain Data Points and Kriging Method

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3. 4._Discharge data collections:

3.4.1.discharge data were selected for these work

The annual discharge data was collected in Table (3.6) from data in Tables (2.3 to 2.7) based on major wadis.

Table No. (3.6): Summary Selected Discharge Data of Dar Fur States

state	Major wadi	Branch wadi	station	Longitude	Latitude	Annual Discharge (M.m3)
North	Azum	Bargu	Umm Sineina	23.55	13.62	**40.79**
West	Azum	Saleh	Saleh	23.38	11.99	**180.00**
		toro	toro	23.78	12.98	**45.00**
		Aribo	Aribo	23.47	12.93	**58.00**
		dodari	dodari	23.91	13.08	**40.00**
		Bari	Murnei	22.87	12.95	**150.00**
North	Azum	Bari	Kabkabiya	24.09	13.64	**70.93**
	Azum	Elserief	Kabkabiya	24.09	13.64	**23.27**
	Kaja	Abu Sunut	Ereigi	24.25	14.00	**9.93**
	Kaja	Abu Sunut	Tilfou	23.53	14.4	**2.71**
West	Kaja	Abu Sunut	Abu Gidad	23.23	14.12	**45.20**
North	Beida	Beida	Beida	25.67	14.03	**6.88**
	Beida	Beida	Um Kadada	26.98	12.96	**4.97**
	Kaj	Kaj	Dar Elslam	25.52	13.42	**0.11**
	Al Ku	Al Ku	Dar Elsalam	25.52	13.42	**3.75**
South	El Hammra	El Hammra	El Hammra	25.05	12.4	**152.00**
	Bulbul	Bulbul	Timbskuo	24.58	11.78	**76.00**
	Ebra	Ebra	Nashala	24.53	10.98	**210.00**
	Sindo	Sindo	Umm Higara	23.92	11.28	**164.00**
	Tawal	Tawal	Abu Likalik	23.68	10.73	**150.00**
	Bahr Al Arab	Bahr Al Arab	El Higairat	25.08	10.30	**168.00**
	Kaya	Kaya	Edd Elfursan	24.33	11.50	**157.00**
	Nyala	Nyala	Nyala	24.89	12.05	**64.00**

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Figure (3.14) Shows Darfur discharge stations\

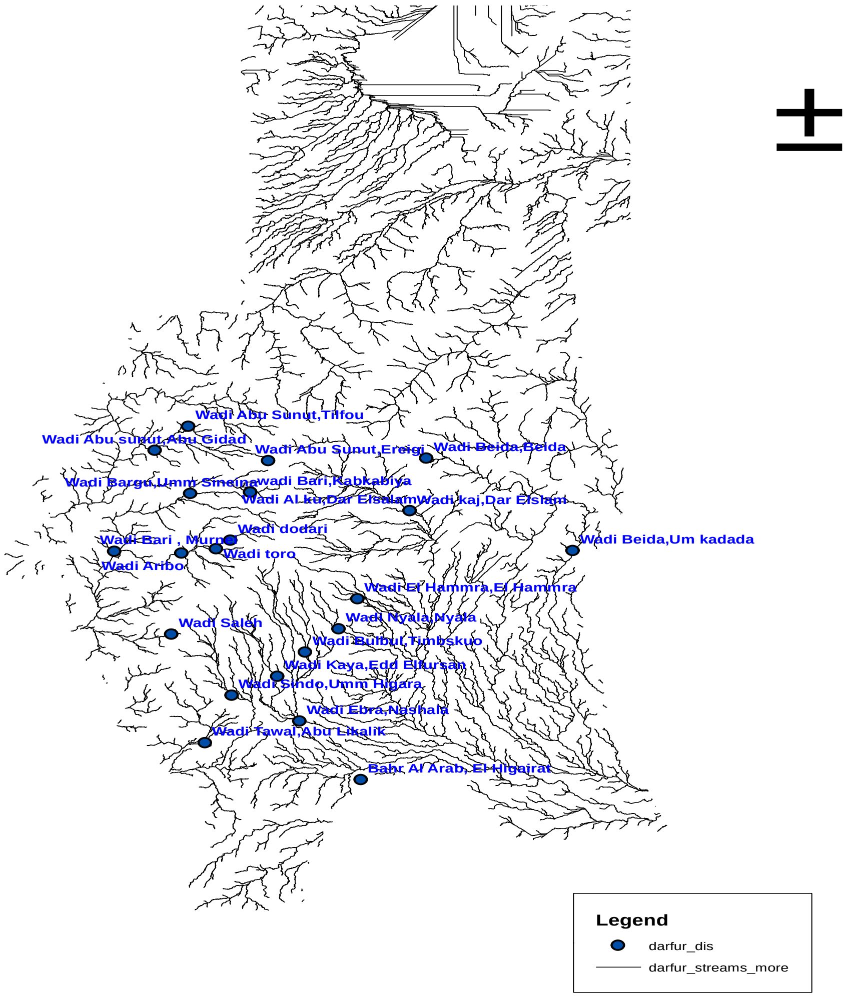

Fig.No.(3.14): Dar Fur Discharge Stations

3.4.2. Independent characteris1tics for selected Discharge Stations

The GIS tools identify in layers' streams and catchments. Kriging method and elevating (TIN) was used to get all independent characteristics such as catchment area, perception, stream length, and slop. (Table (3.6), Table (3.7) and set of Figures (3.15 to 3.37)). Table (3.7) shows the independent characteristics of selected discharge stations.

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Table No. (3.7): The Independent Characteristics of selected Discharge Stations

no	Name	Q Measured annual discharge ($M.m^3$)	Area (Km^2)	Max.Elev (m)	Min.Elev (m)	L length of flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
1	Umm Sineina	**40.7902068**	425.2775 **=425.2775**	988.376	924.398	39.01083 = 39.01083	**0.164**	**403**
2	Saleh, Saleh	**180**	110.762 206.2856 **=317.0476**	921.527	807.6355	9.133234 **=9.133234**	**1.247**	**1010**
3	Toro	**45**	409.713 44.13534 87.5951 **=541.4434**	1116.538	1054.94295	34.34349 **=34.34349**	**0.17935**	**537**
4	Aribo	**58**	150.6331 167.3272 259.9373 216.9265 217.7423 103.3358 159.6763 1.916689 4.587626 **=1282.083**	1196.834	870.829	15.59379 3.543724 28.49885 1.49503 19.9313 **=69.112694**	**0.4717**	**566**
5	Dodari	**40**	29.00483 3.376615 96.29335 85.57133 49.03279 138.241 100.6471 146.659 204.0272 135.2118 86.03657 **=1074.1**	1835.618	1095.672	21.54387 15.89203 8.548699 11.33771 2.707208 8.617367 **=68.647**	**1.0779**	**494**
6	Bari, murnei	**150**	5540.519 3231.616 1077.417 1974.184 80.09485			24.62339 12.27833 8.502731 15.47649 17.35183 28.38367 30.04008 9.666325 4.641372 12.27949 1.842471 14.24395 4.497591 9.336752 7.760497 21.51625 12.96652 15.15847		

			=11904	1370.636	736.9433	5.608045 20.94338 13.86239 3.290547 3.198742 17.79815 **=315.27**	**0.201**	**645**
7	bari,kabkabiya	**70.93**	293.1126 107.1383 104.4633 19.29989 265.8335 **=789.8476**	1361.172	1160.48433	24.62339 12.27833 8.502731 **=45.40445**	**0.442**	**369**
8	wadi elserief, kabkabiya	**23.27**	146.2845 **=146.2845**	1259.412	1159.3065	14.26003 =14.26003	**0.702**	**373**
9	abu sunut ,Ereigi	**9.928481667**	655.6033 **=655.6033**	1111.282	945.393	68.21074 =68.21074	**0.2432**	**336**
10	abu sunut ,Tilfou	**2.70799125**	37.57289 =**37.57289**	868.346	867.981	9.172147 =**9.172147**	**0.00398**	**263**
11	abu sunut ,Abu Gidad	**45.202111**	260.5066 153.5638 91.64705 126.3078 10.68566 101.6225 **=744.33341**	892.198	875.323	15.63781 19.66226 3.917465 **=39.21754**	**0.04303**	**408**
12	Beida, beida	**6.881542**	149.4211 =149.4211	860.559	813.548	15.75435	**0.2984**	**250**
13	Beida, Um Kadada	**4.97**	90.00726 **=9.03342**	547.341	546.347	9.03342 **=9.03342**	**0.011**	**308**
14	wadi kaj dar elslam	**0.11**	561.1186 **=561.1186**	726.231	684.763	38.75525 **=38.75525**	**0.107**	**263**
15	wadi Al ku, dar elslam	**3.75**	185.0641 **=185.0641**	704.802	684.763	23.8195 =23.8195	**0.08142**	**259**
16	El Hammra, El Hammra	**152**	376.2883 **=376.2883**	925.226	689.23	52.57567 **=52.57567**	**0.4489**	**345**
17	Bulbul ,Timbskuo	**76**	28.72161 85.7579 0.666243 **=115.1458**	651.989	624.474	16.18033 1.303954 **=17.48428**	**0.15737**	**628**
18	Ebra ,Nashala	**210**	15.33033 **=15.33033**	552.748	540.343	7.505935 **=7.505935**	**0.165269**	**698**
19	Sindo ,Umm Higara	**164**	208.8846 **=208.8846**	633.835	578.481	33.3864 **=33.3864**	**0.165798**	**677**
20	Tawal,Abu Likalik	**150**	232.3605 **=232.3605**	524.958	510.665	38.59894 **=38.59894**	**0.03703**	**770**
21	Bahr Al Arab ,El Higairat	**168**	179.0474 **=179.0474**	465.015	460.47	29.0266 **=29.0266**	**0.01565**	**679**
22	Kaya,Edd Elfursan	**157**	106.6786 **=106.6786**	629.57	585.217	27.71869 **=27.71869**	**0.16001**	**653**
23	Nyala,nyala	**64**	142.5252 **=142.5252**	741.514	601.076	38.60309 **=38.60309**	**0.3638**	**497**

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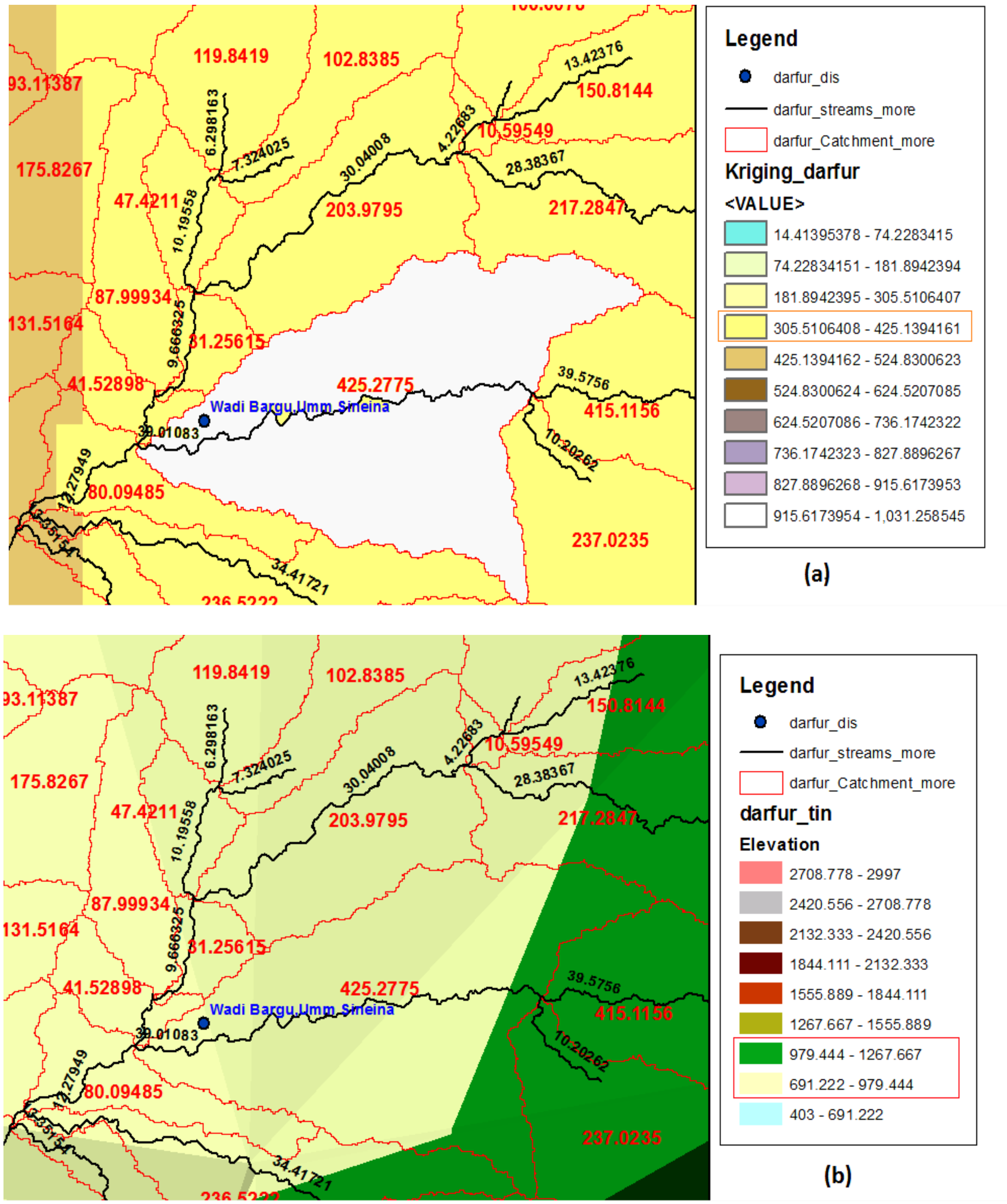

Fig.No.(3.15): wadi Bari, Umm Sineina station, (a) rain, catchment and stream length, (b) elevation

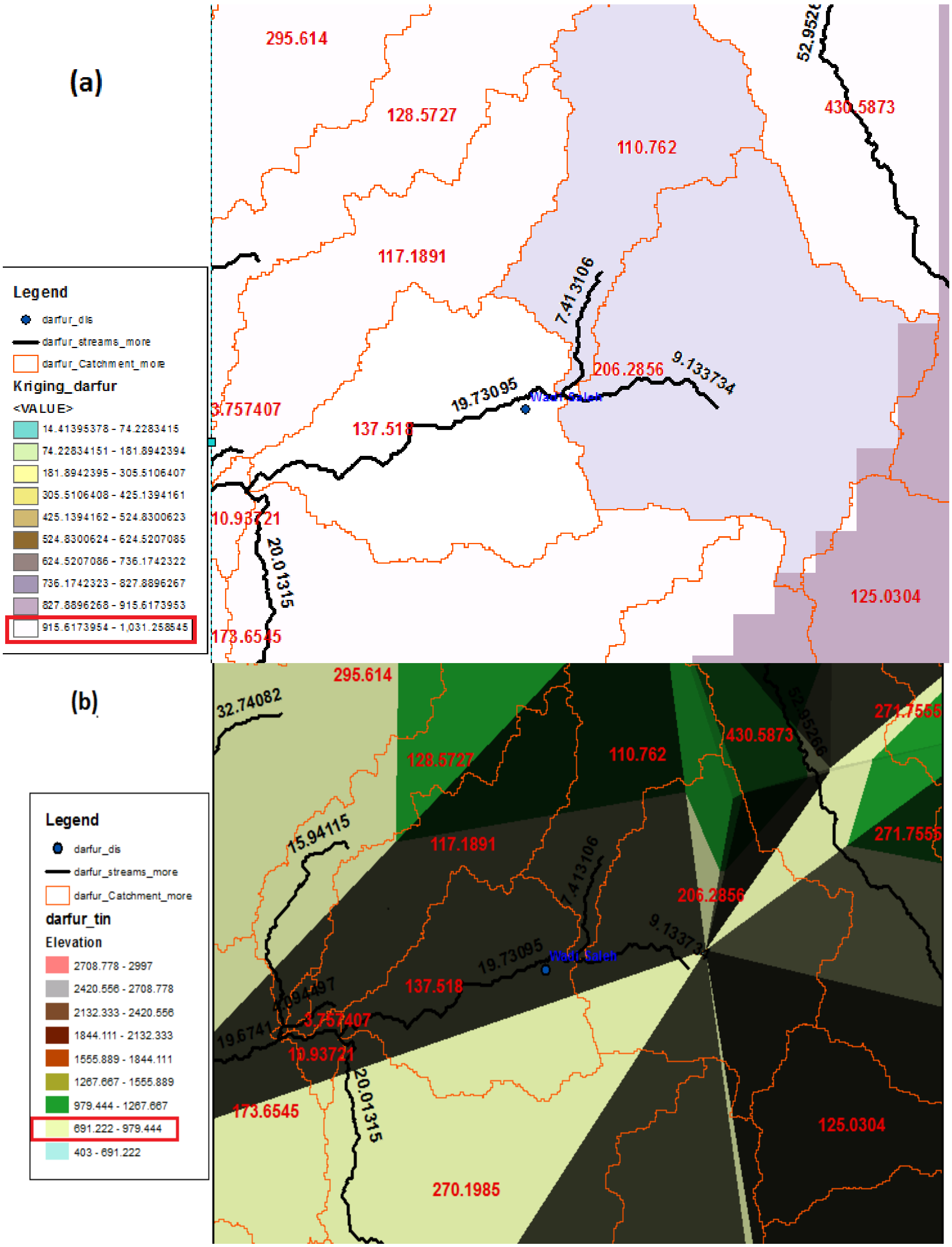

Fig.No.(3.16): Wadi Saleh, (a) rain, catchment and stream length, (b) elevation

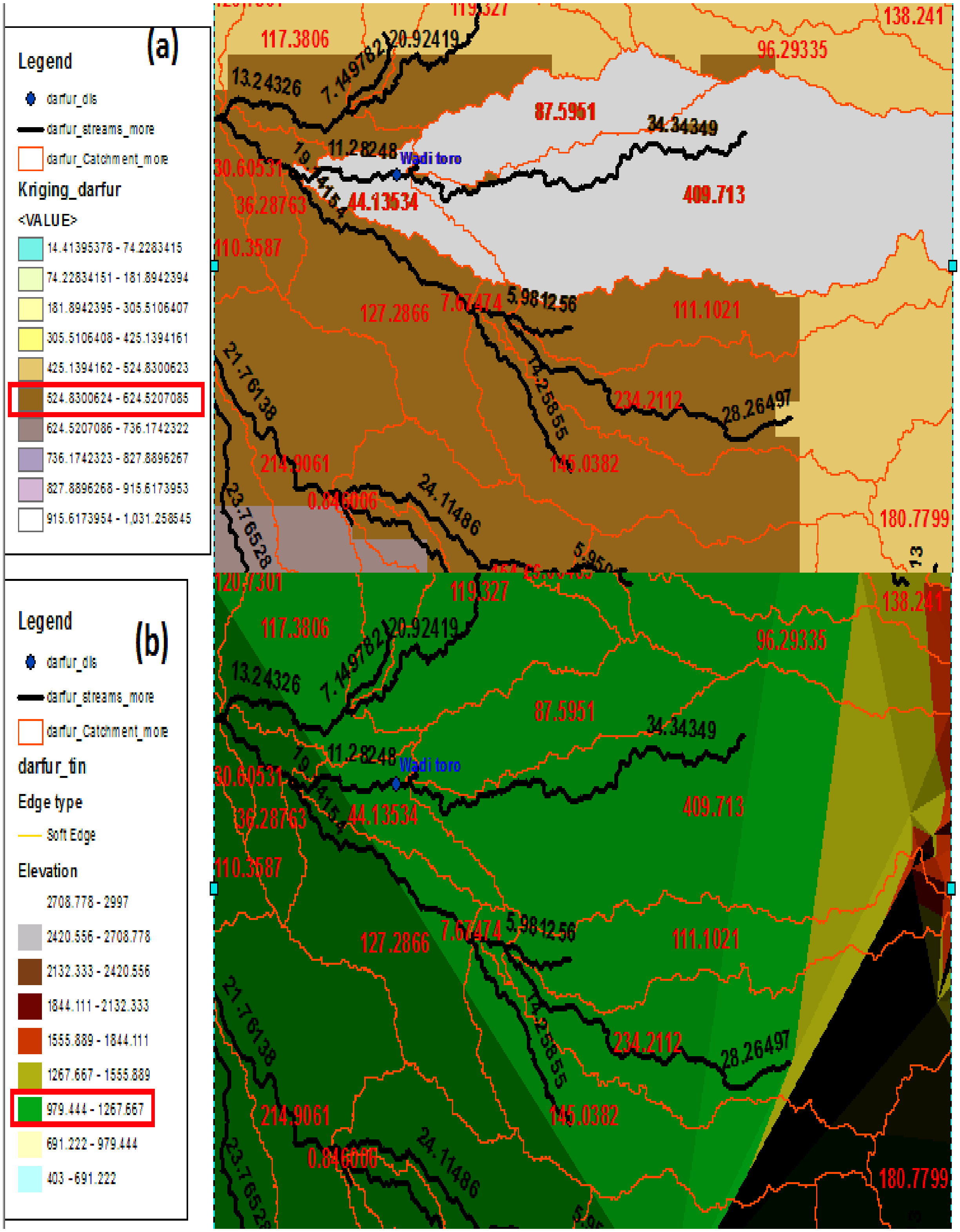

Fig.No.(3.17): Wadi Toro, (a) rain, catchment and stream length, (b) elevation

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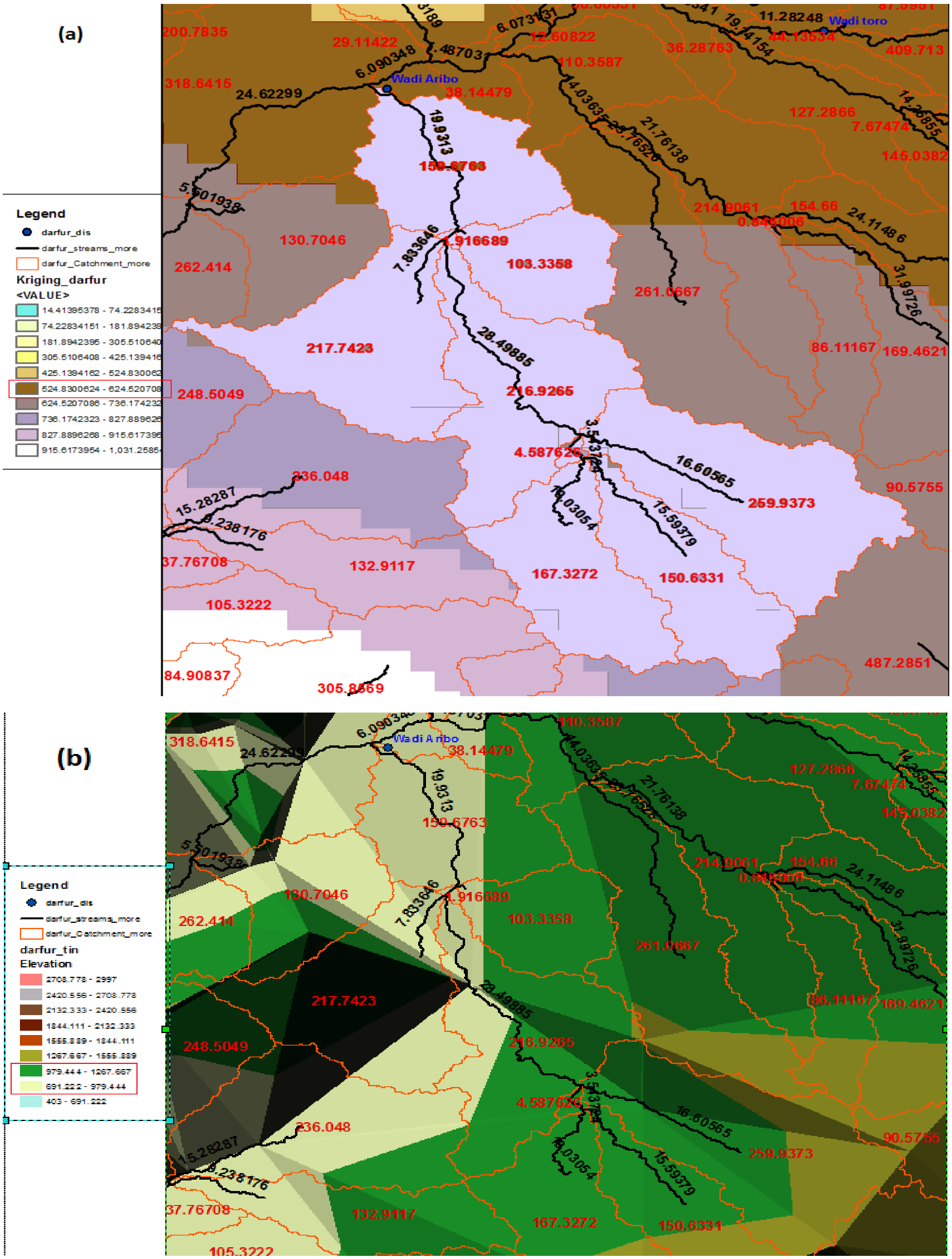

Fig.No.(3.18): Wadi Aribo, (a) rain, catchment and stream length, (b) elevation

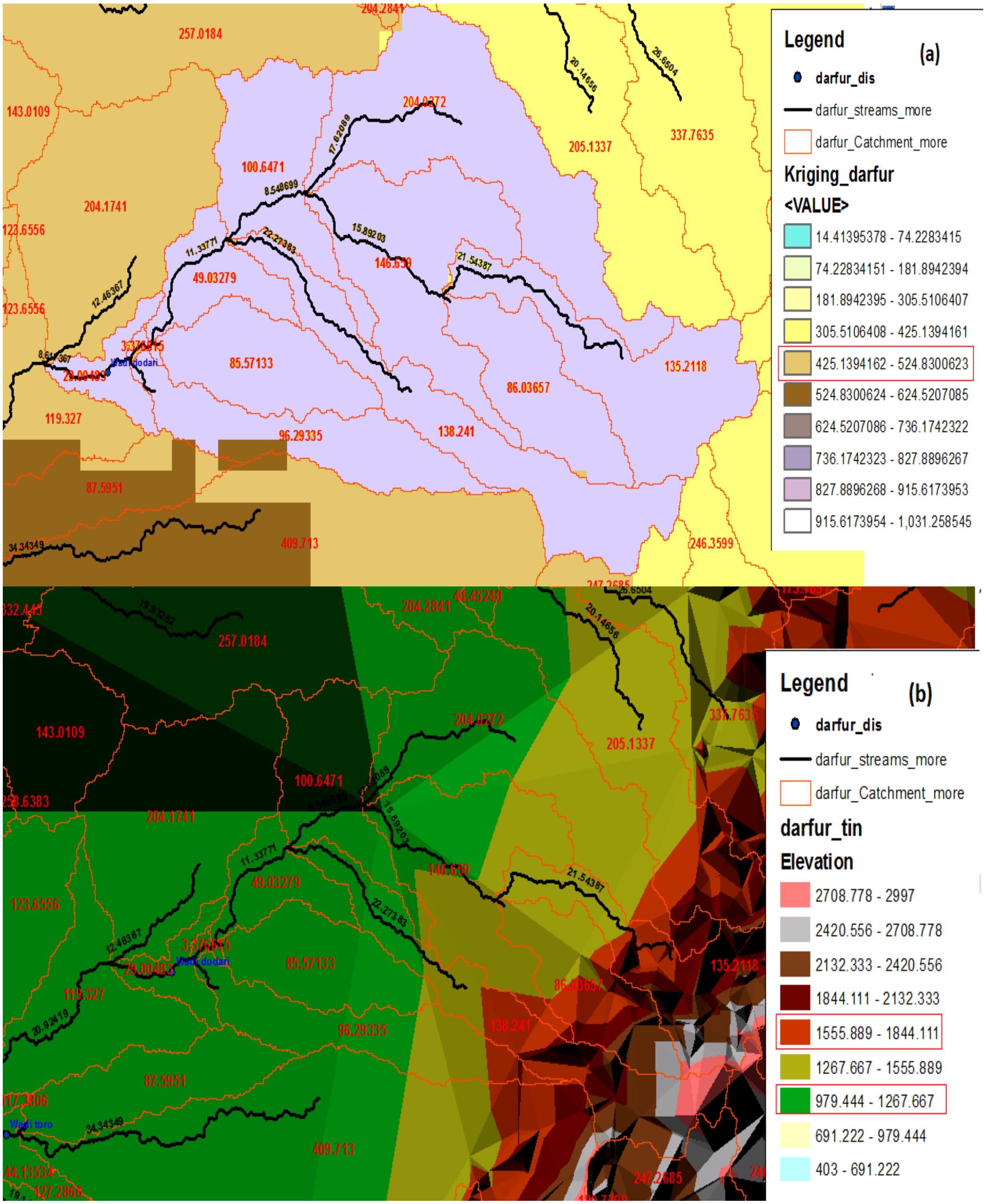

Fig.No.(3.19): Wadi Dodari, (a) rain, catchment and stream length, (b) elevation

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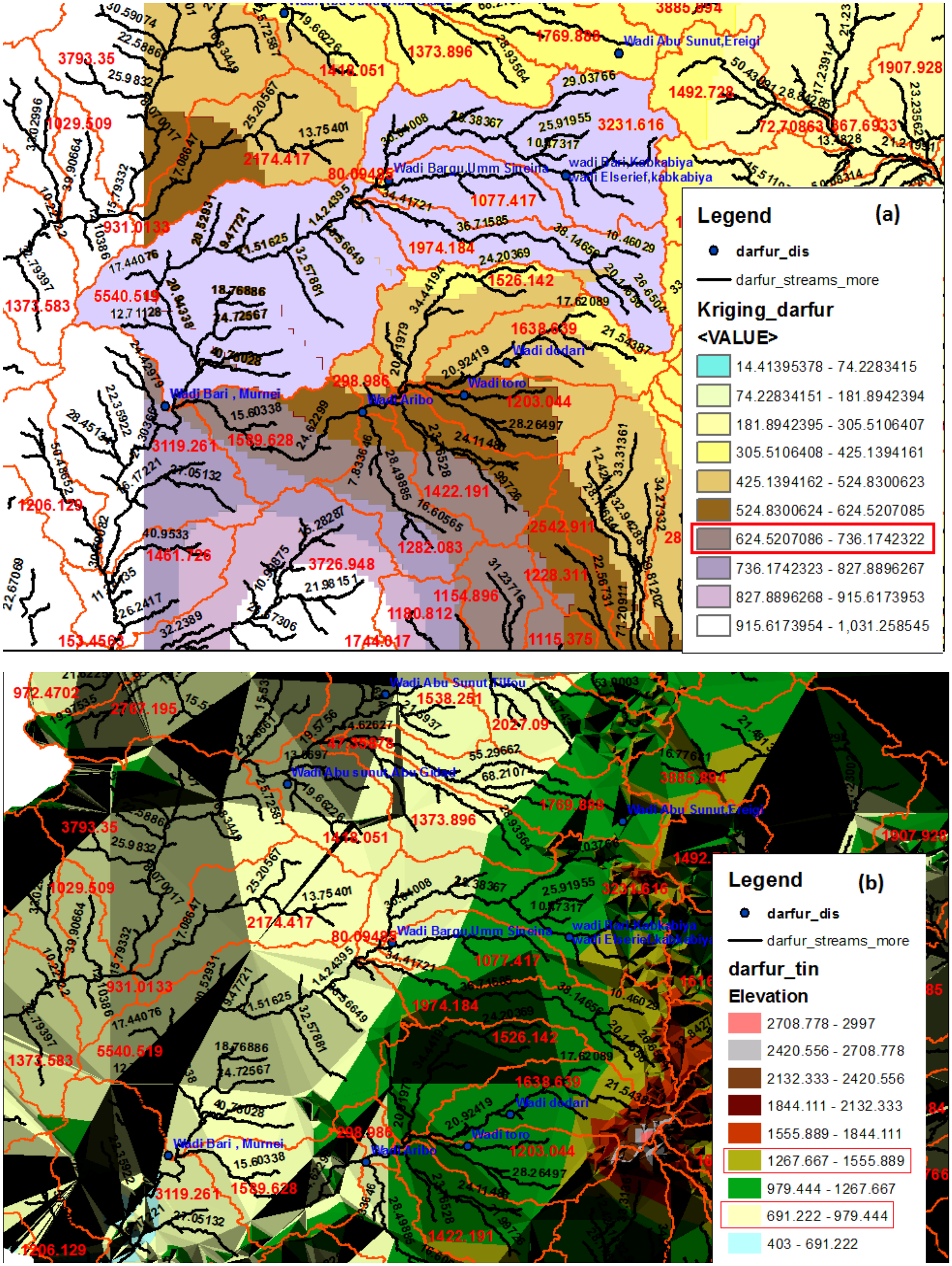

Fig.No.(3.20): Wadi Bari, murnei station, (a) rain, catchment and stream length, (b) elevation

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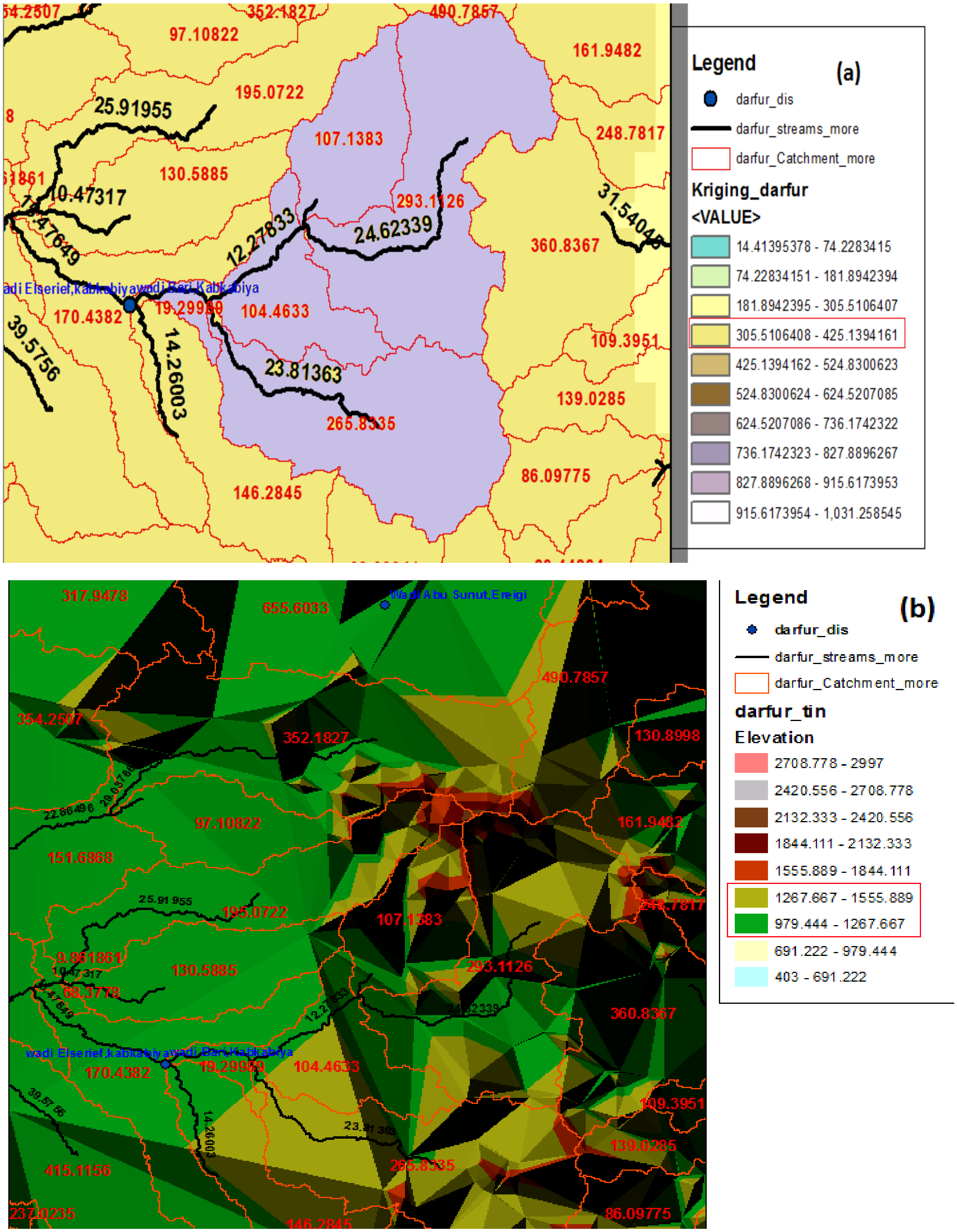

Fig.No.(3.21): Wadi Bari, kabkabiya station, (a) rain, catchment and stream length, (b) elevation

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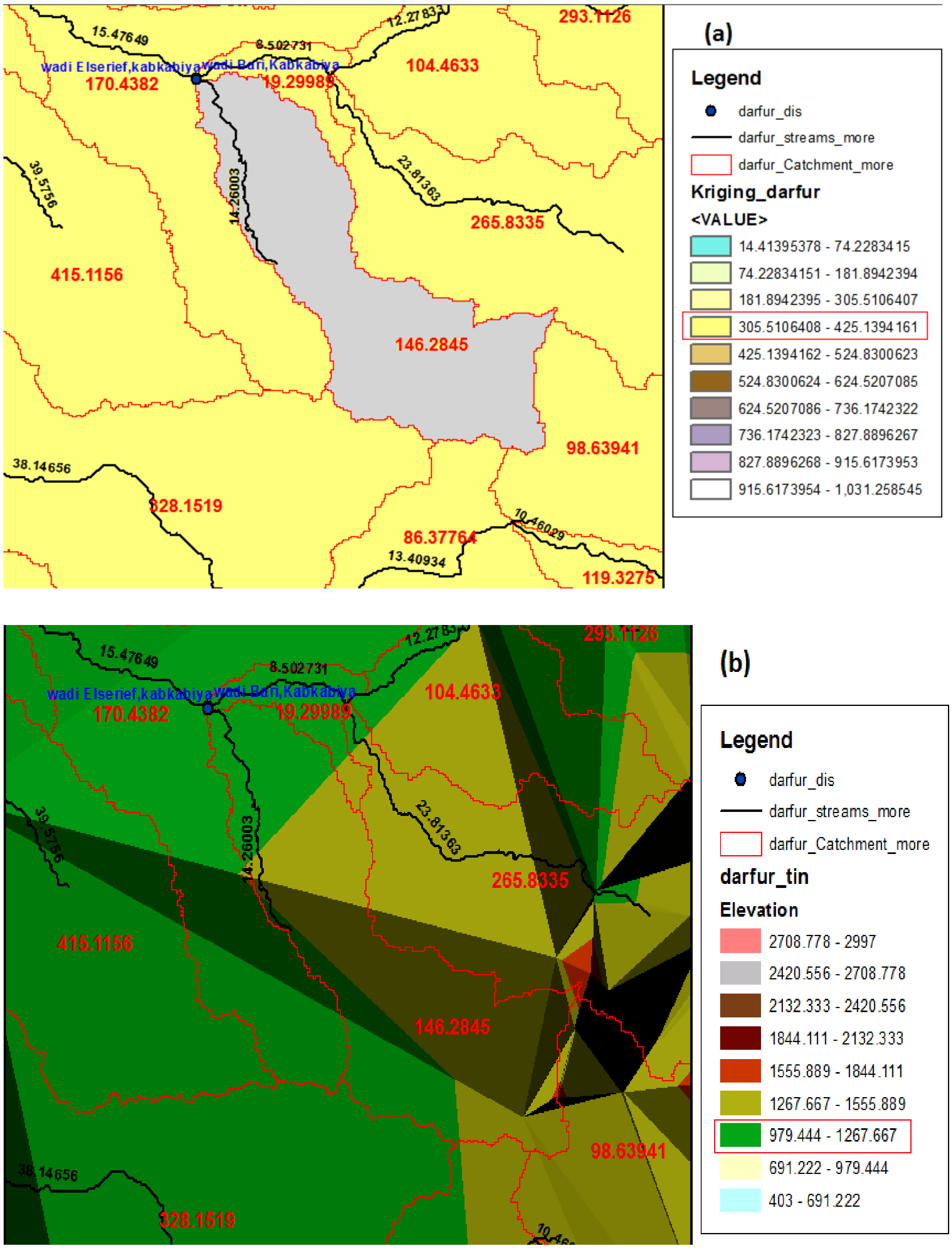

Fig.No.(3.22): Wadi Elserief, kabkabiya station, (a) rain, catchment and stream length, (b) elevation

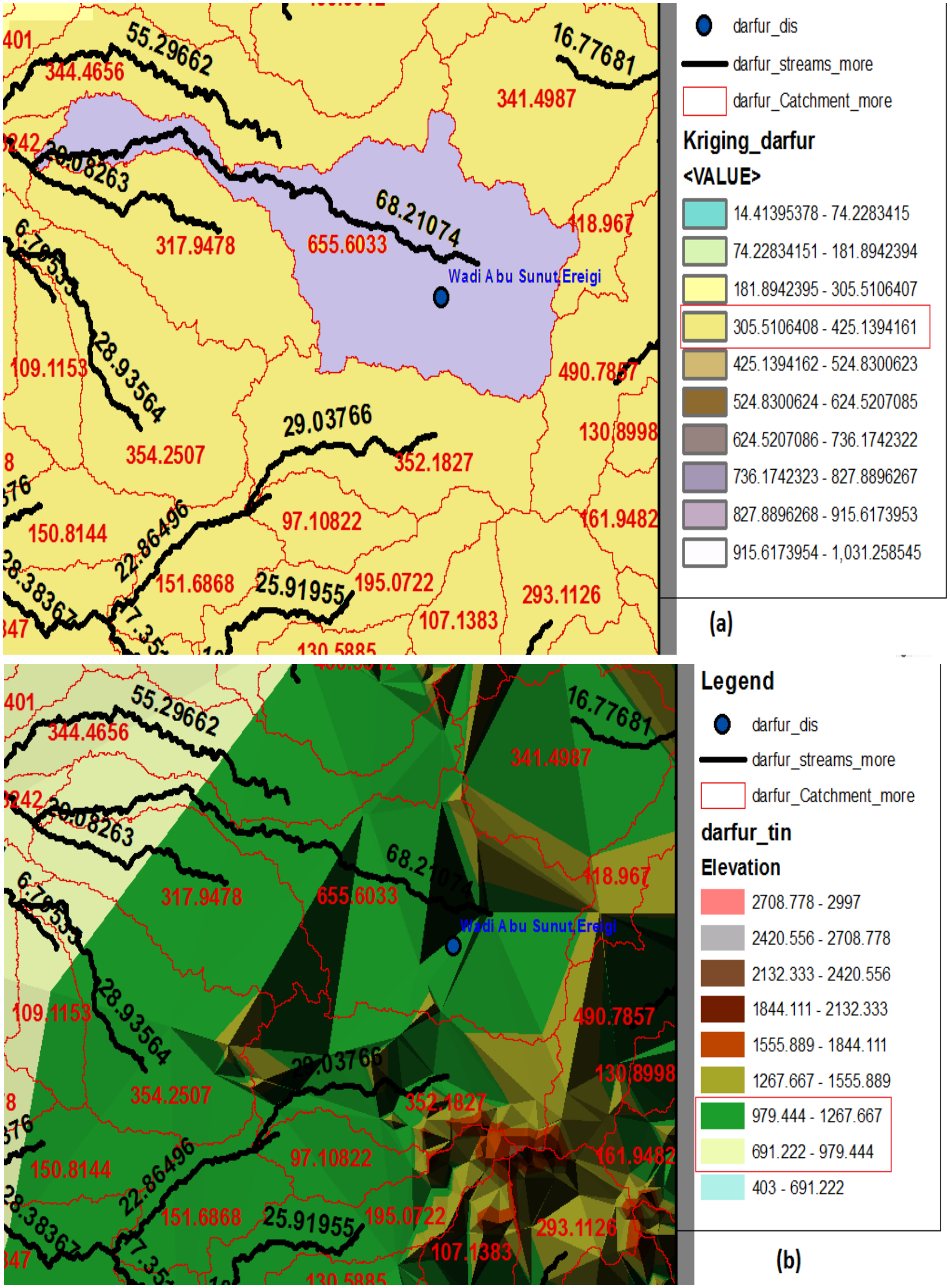

Fig.No.(3.23): Wadi Abu Sunut, Ereigi station, (a) rain, catchment and stream length, (b) elevation

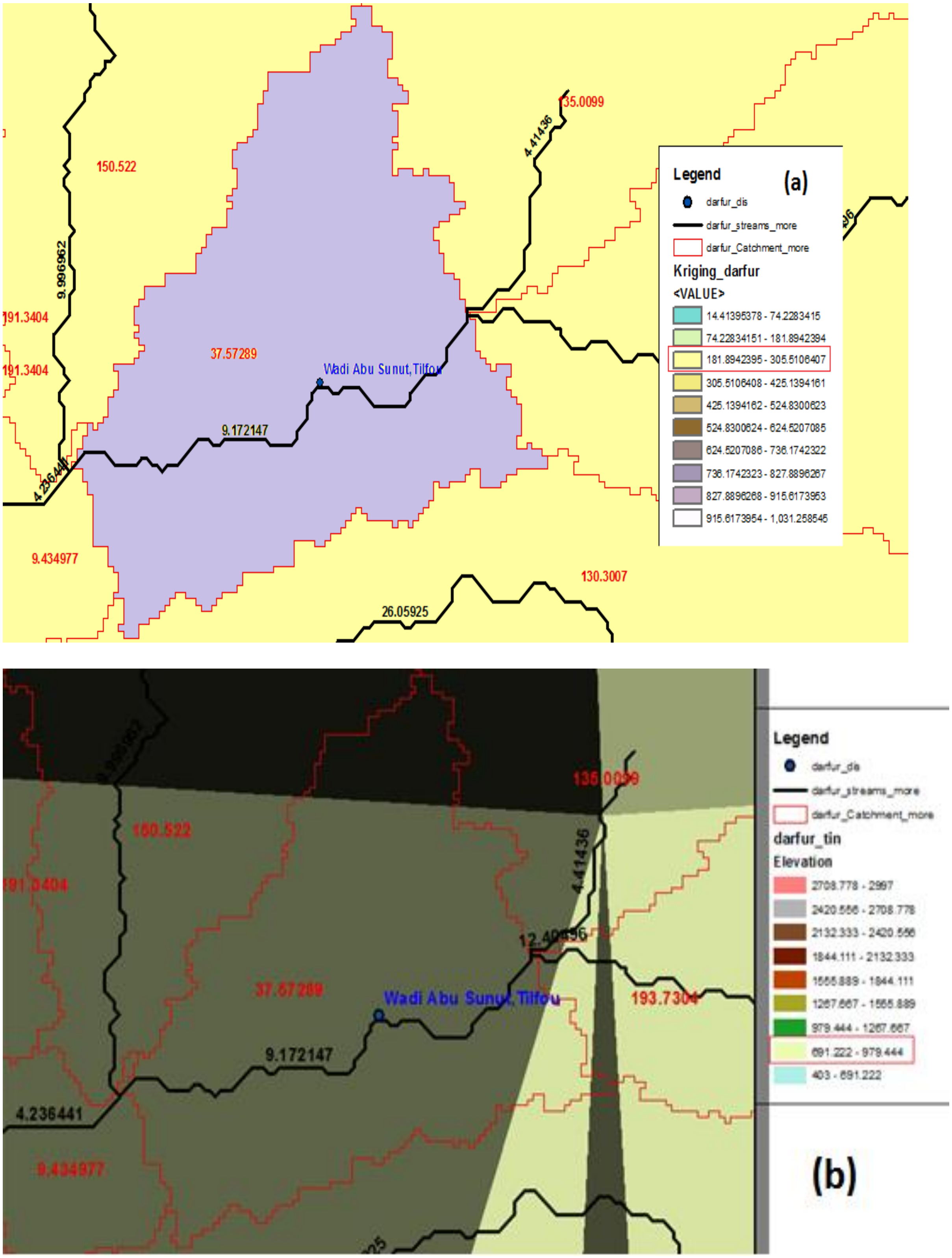

Fig.No.(3.24): Wadi Abu Sunut, Tilfou station, (a) rain, catchment and stream length, (b) elevation

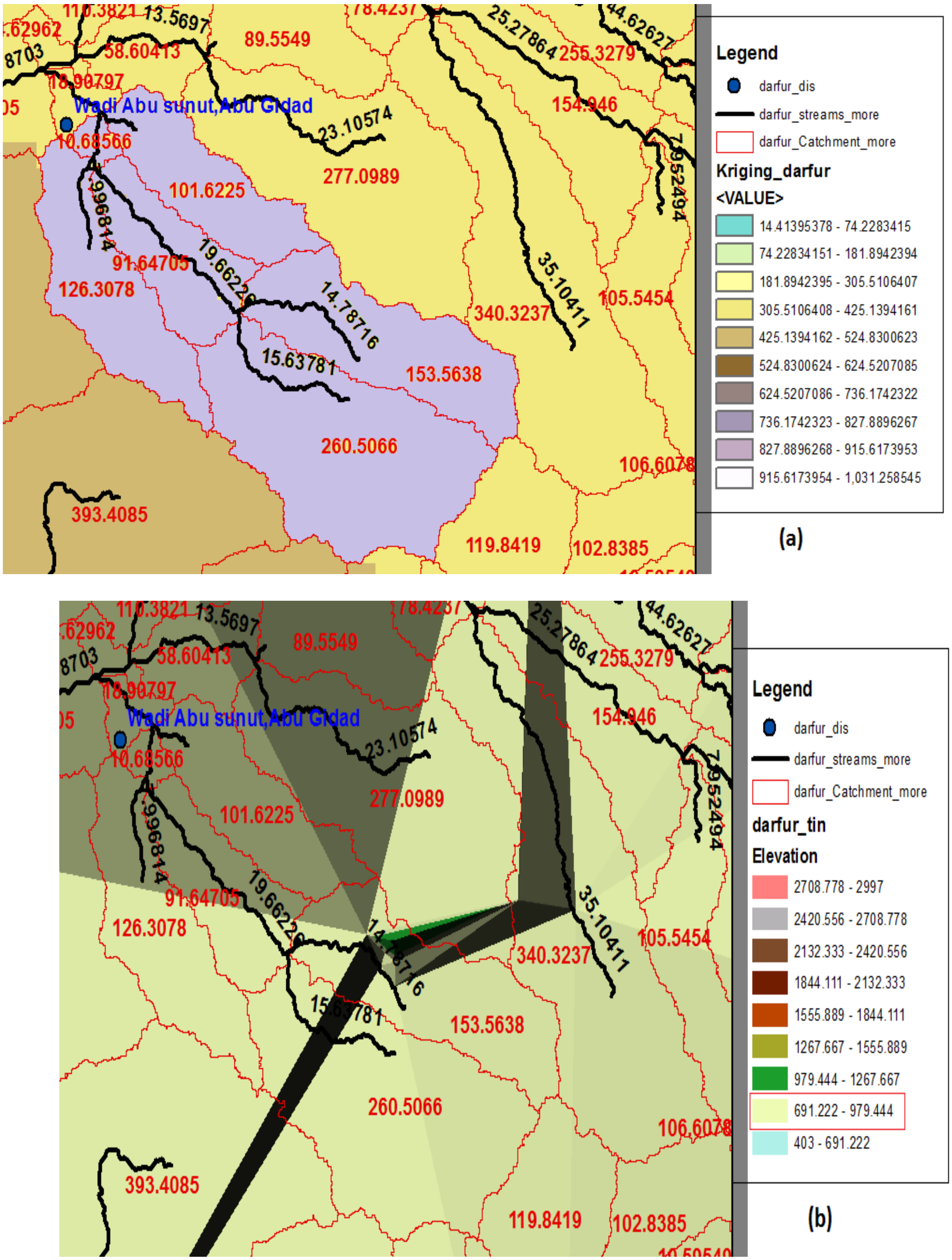

Fig.No.(3.25): Wadi Abu Sunut, Abu Gidad station,(a) rain, catchment and stream length,(b) elevation

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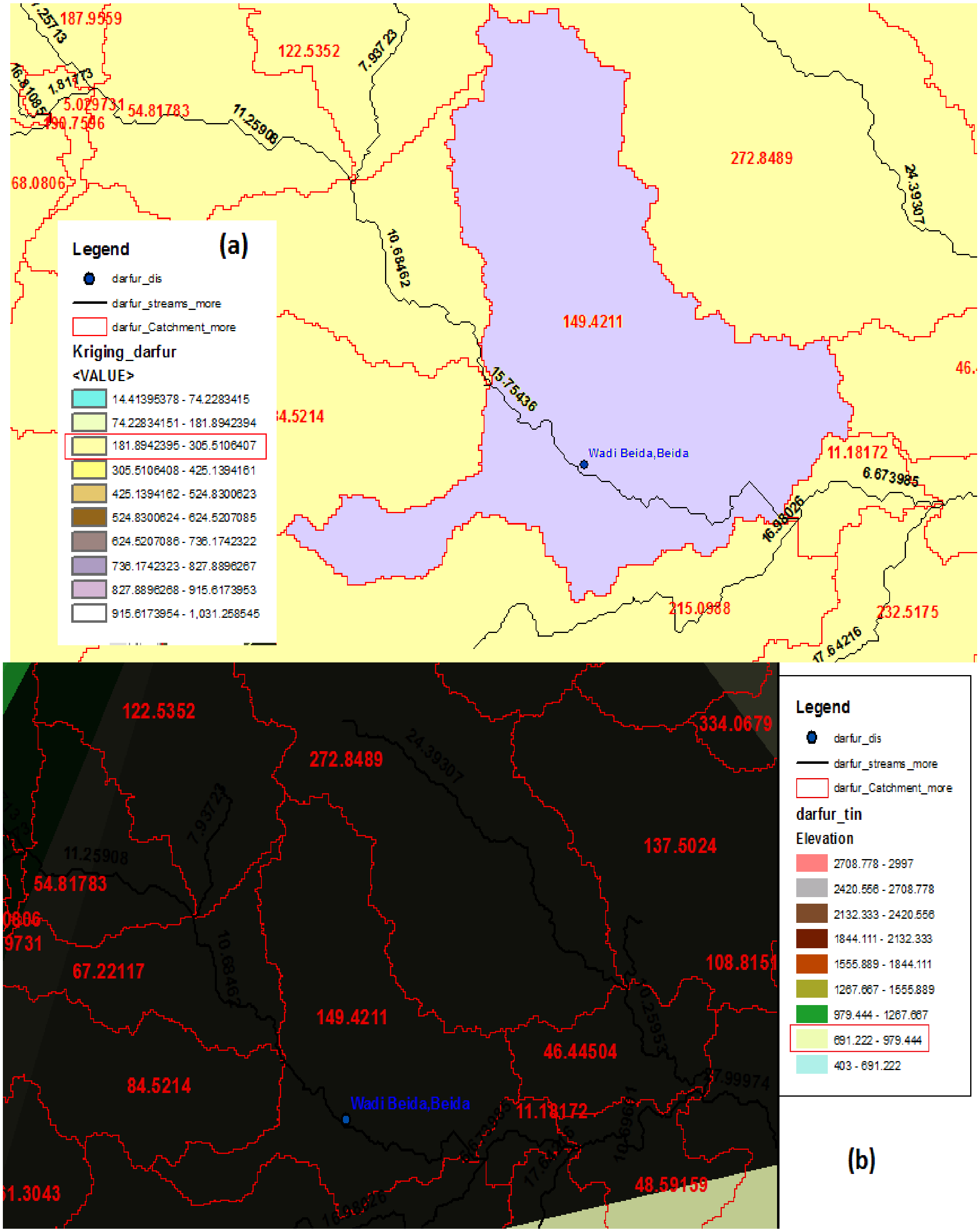

Fig.No.(3.26): Wadi beida , beida station,(a) rain, catchment and stream length,(b) elevation

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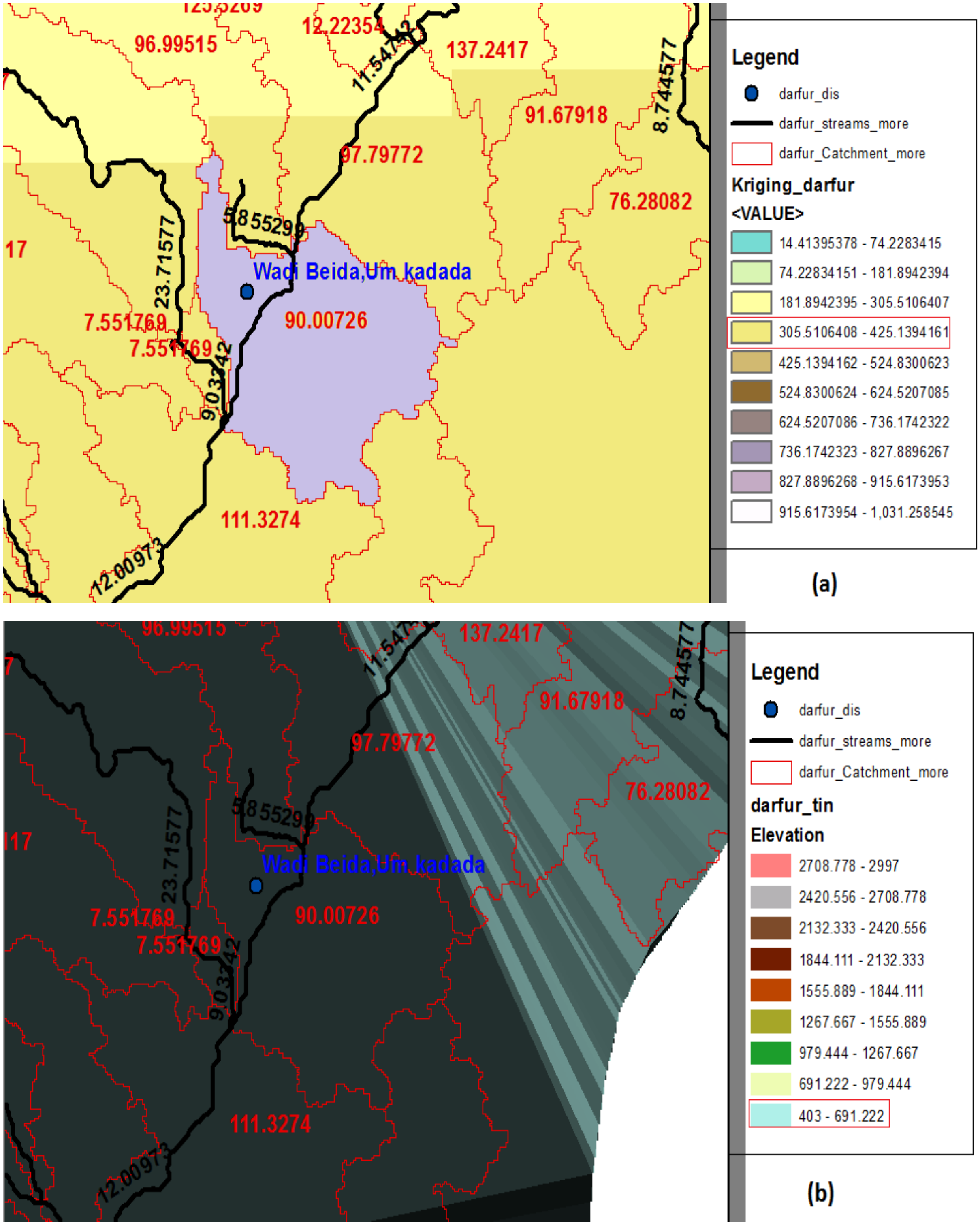

Fig.No.(3.27): Wadi beida , um kadada station,(a) rain, catchment and stream length,(b) elevation

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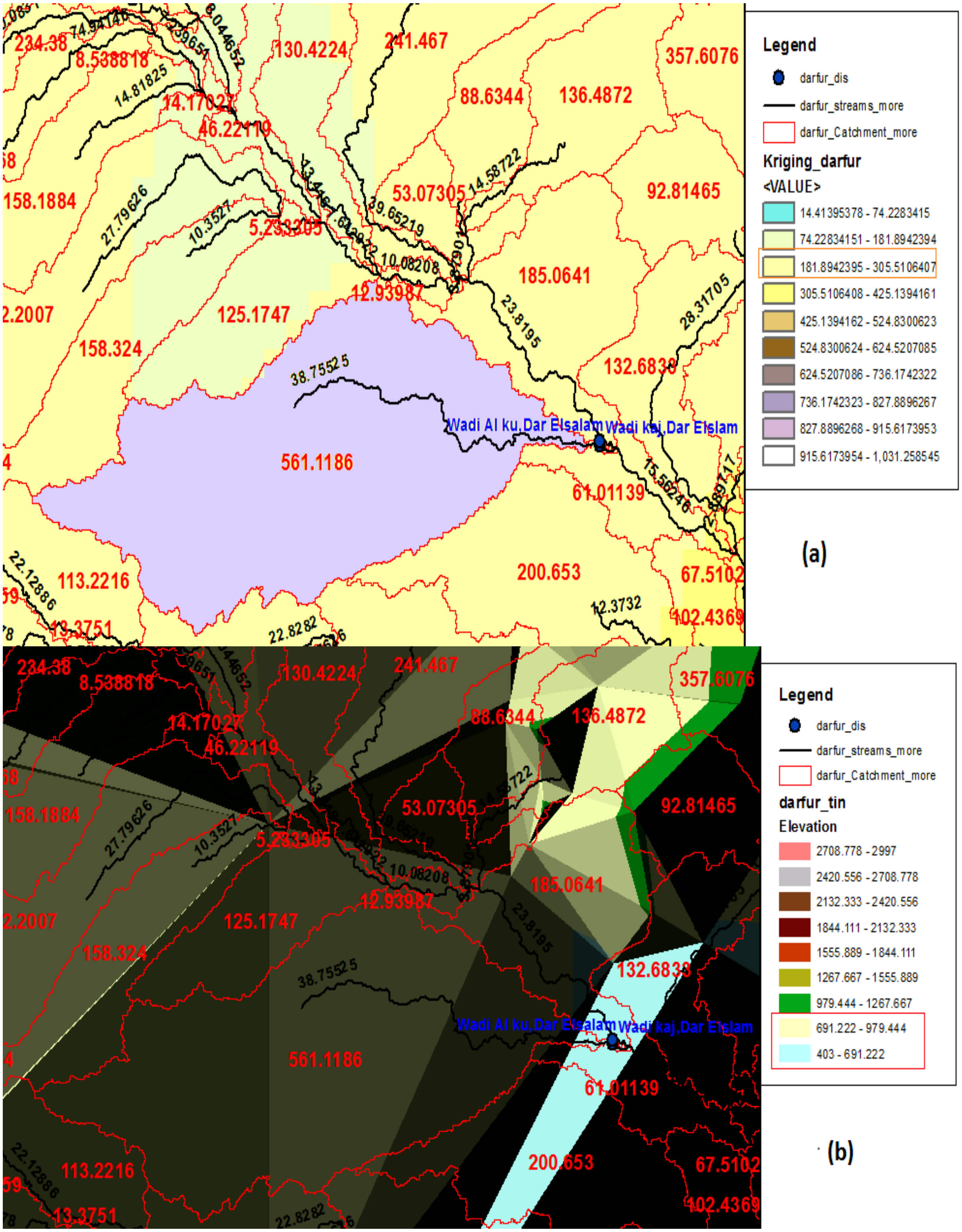

Fig.No.(3.28): wadi Kaj, dar elslam station, (a) rain, catchment and stream length, (b) elevation

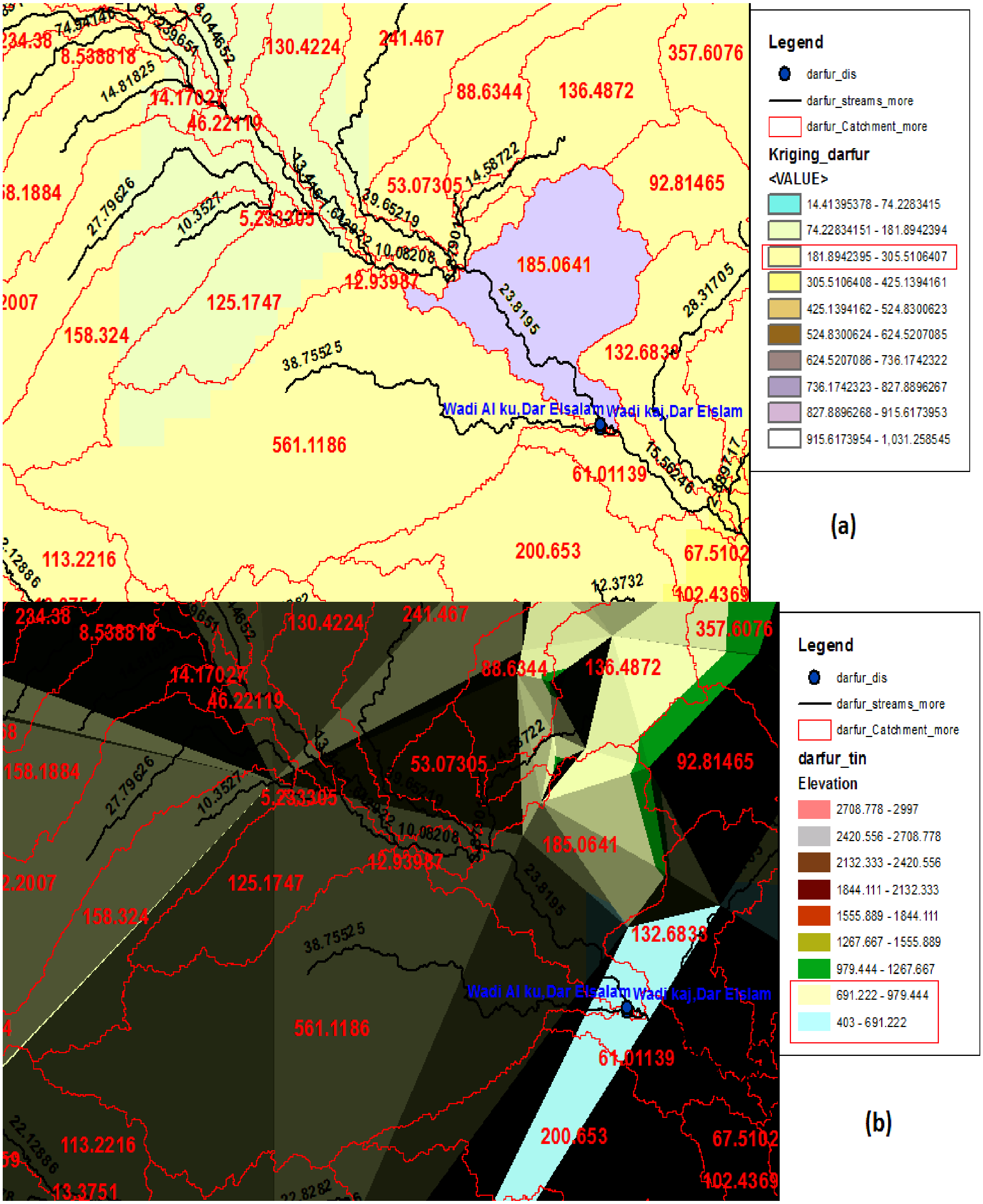

Fig.No.(3.29): Wadi Al ku, dar elslam station, (a) rain, catchment and stream length, (b) elevation

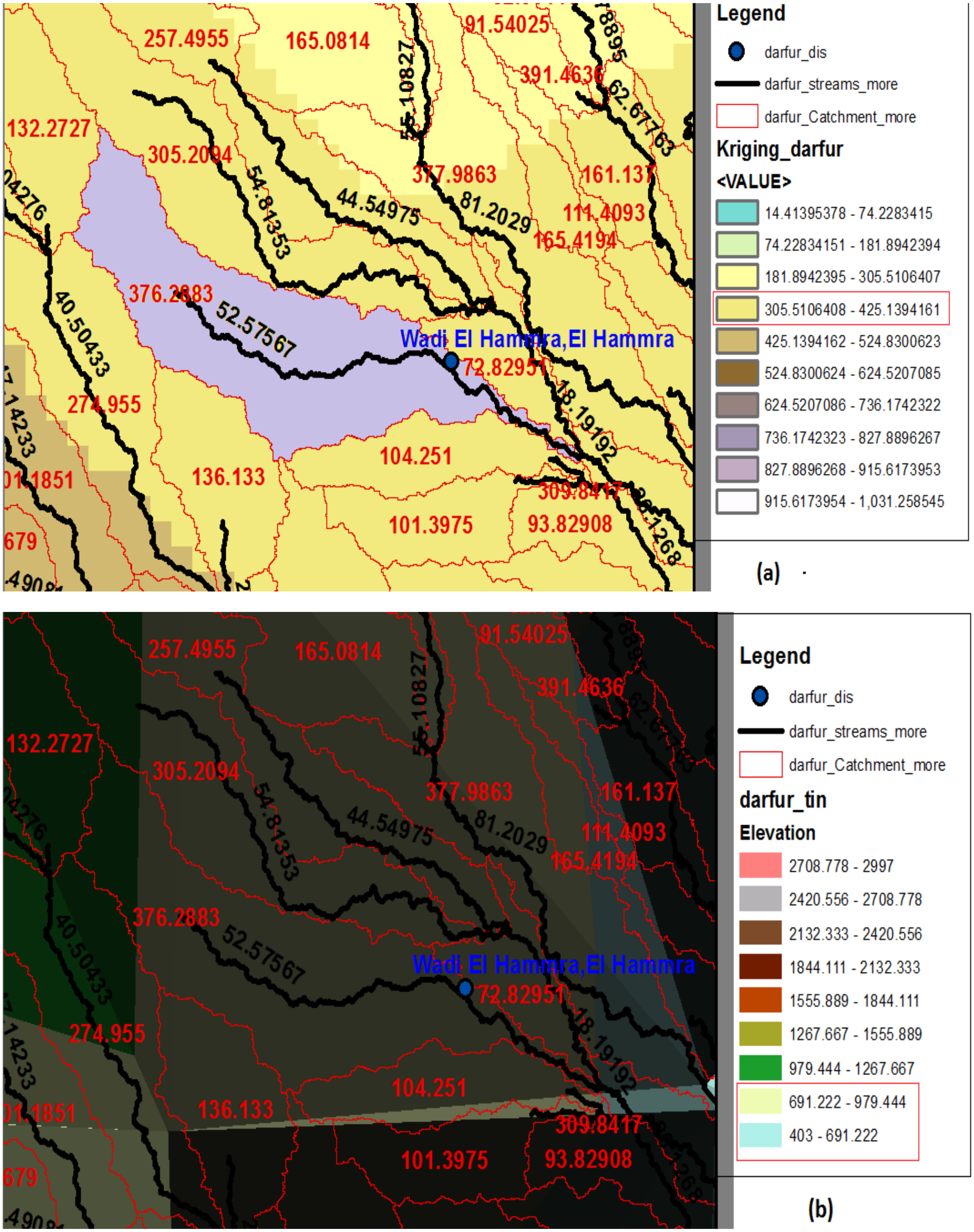

Fig.No.(3.30): Wadi El Hammra, El Hammra station,(a) rain, catchment and stream length,(b) elevation

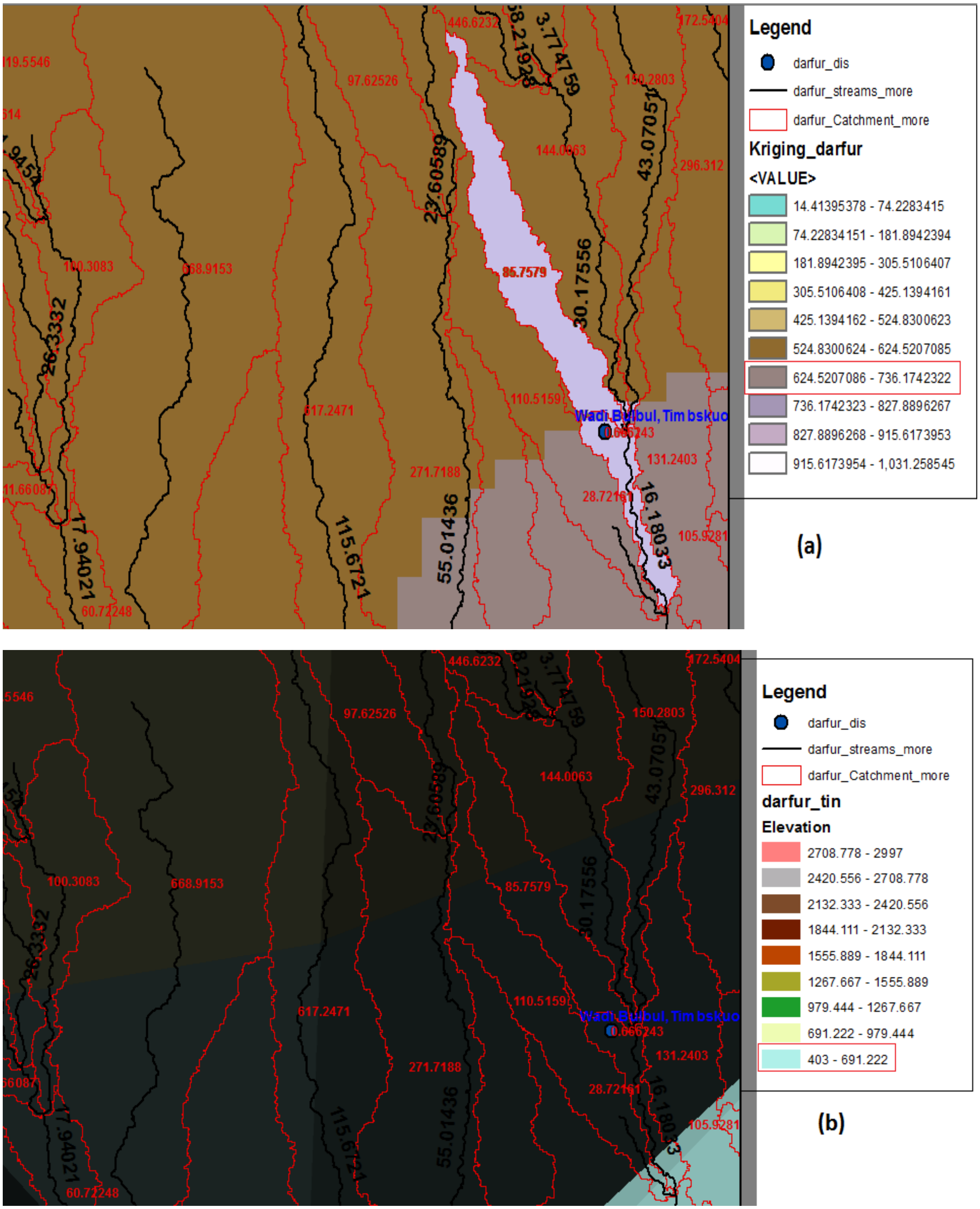

Fig.No.(3.31): Wadi Bulbul ,Timbskuo station,(a) rain, catchment and stream length,(b) elevation

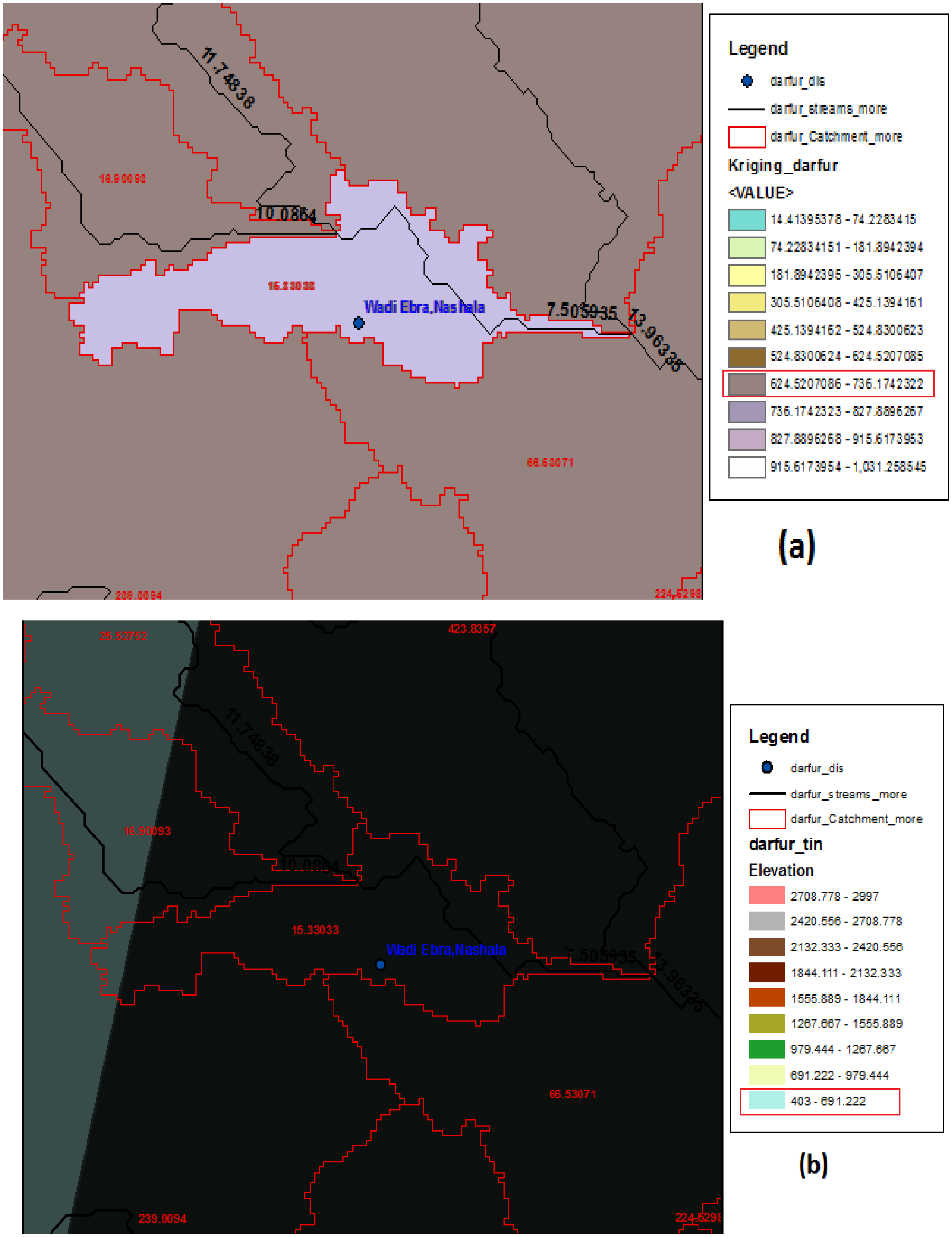

Fig.No.(3.32):Wadi Ebra ,Nashala station,(a) rain, catchment and stream length,(b) elevation

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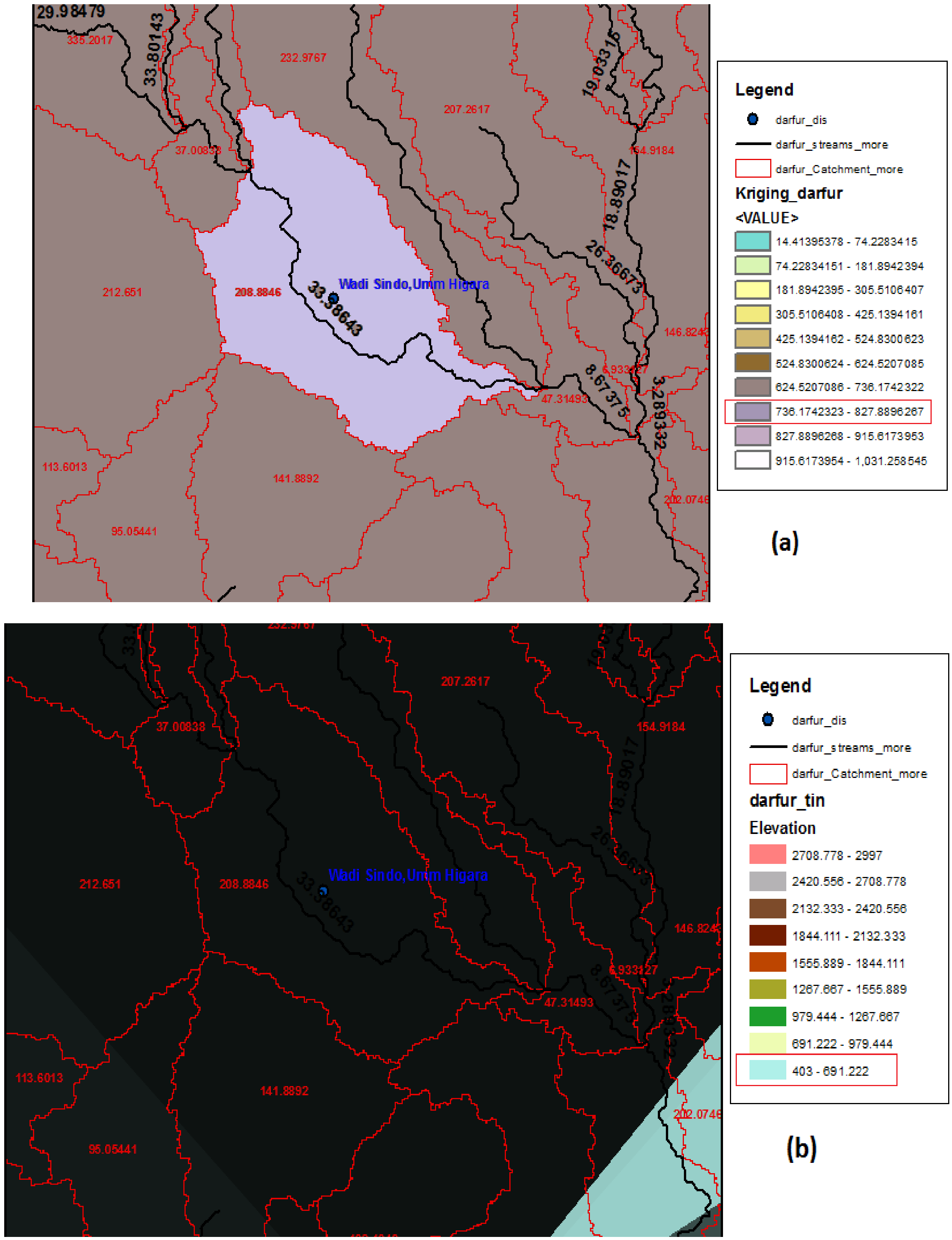

Fig.No.(3.33):Wadi Sindo ,Umm Higara station,(a) rain, catchment and stream length,(b) elevation

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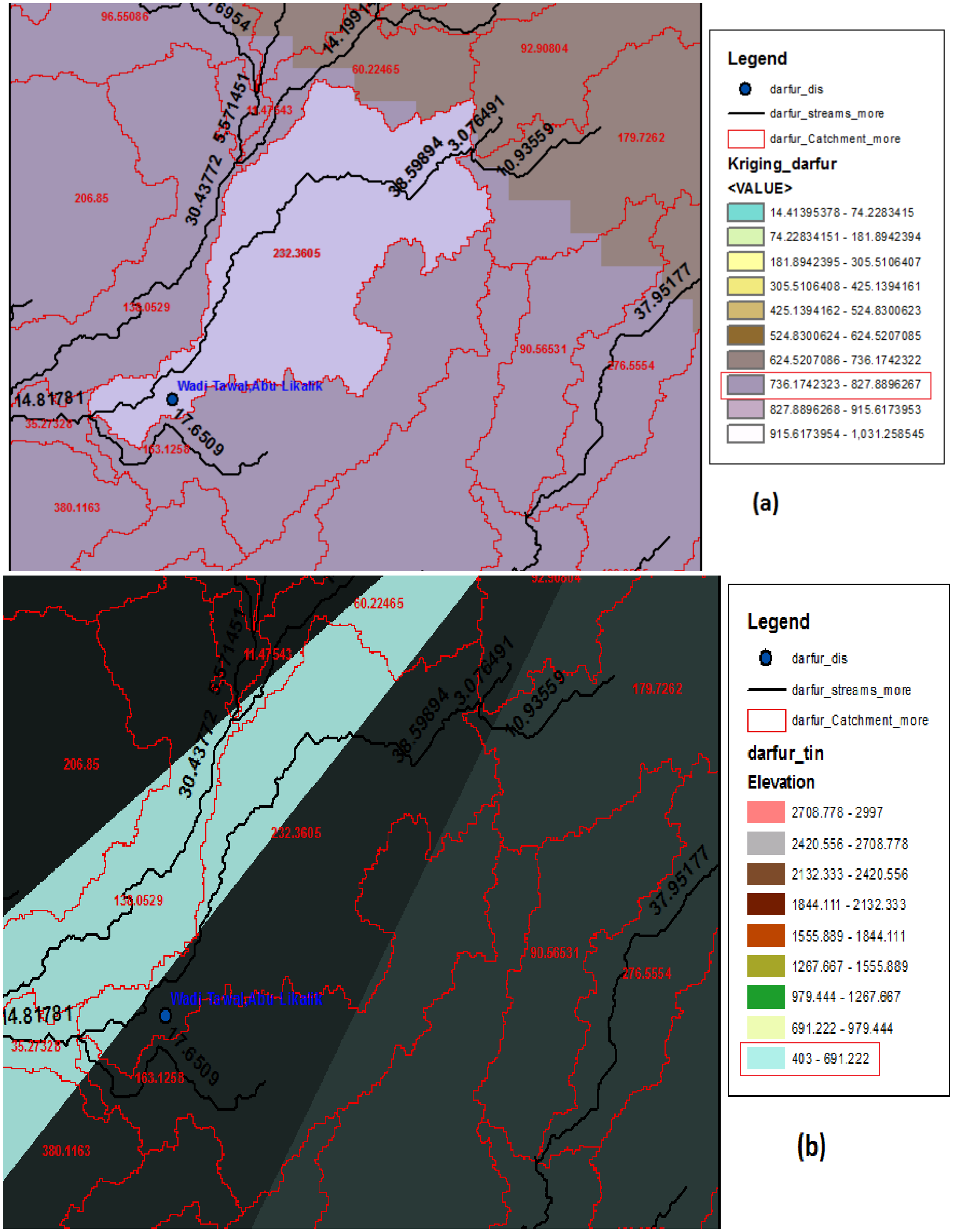

Fig.No.(3.34):Wadi Tawal,Abu Likalik station,(a) rain, catchment and stream length,(b) elevation

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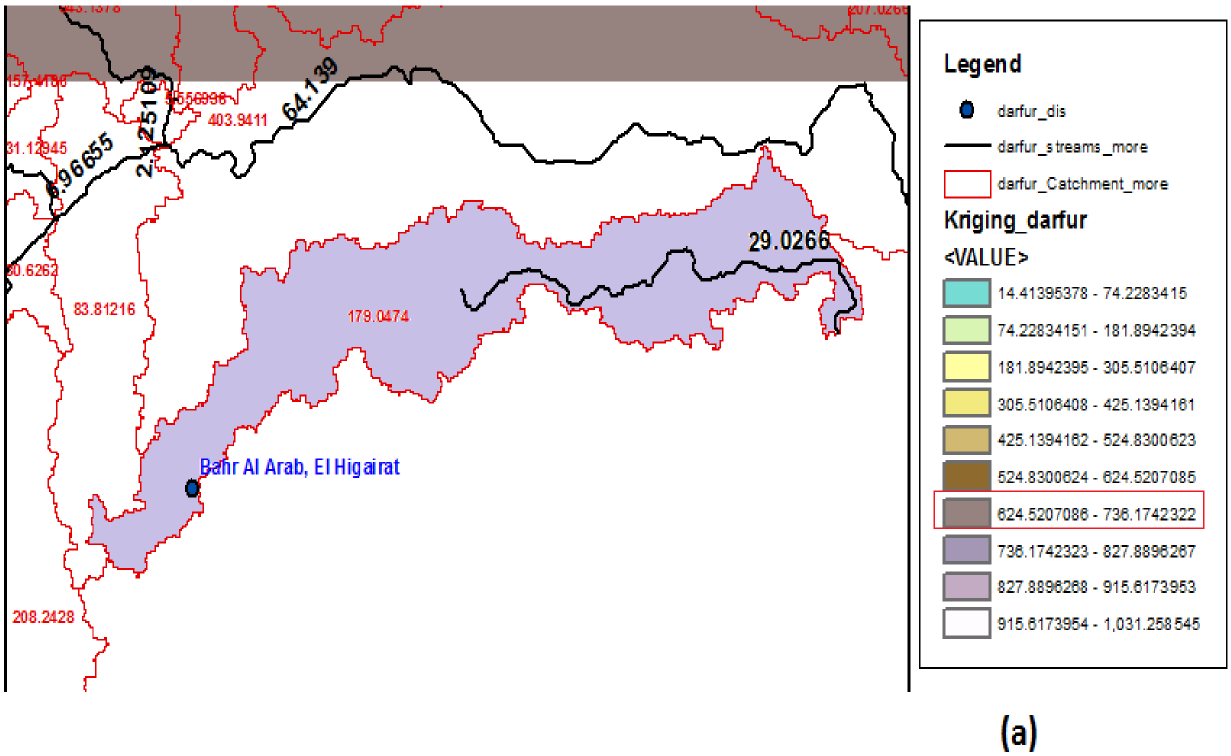

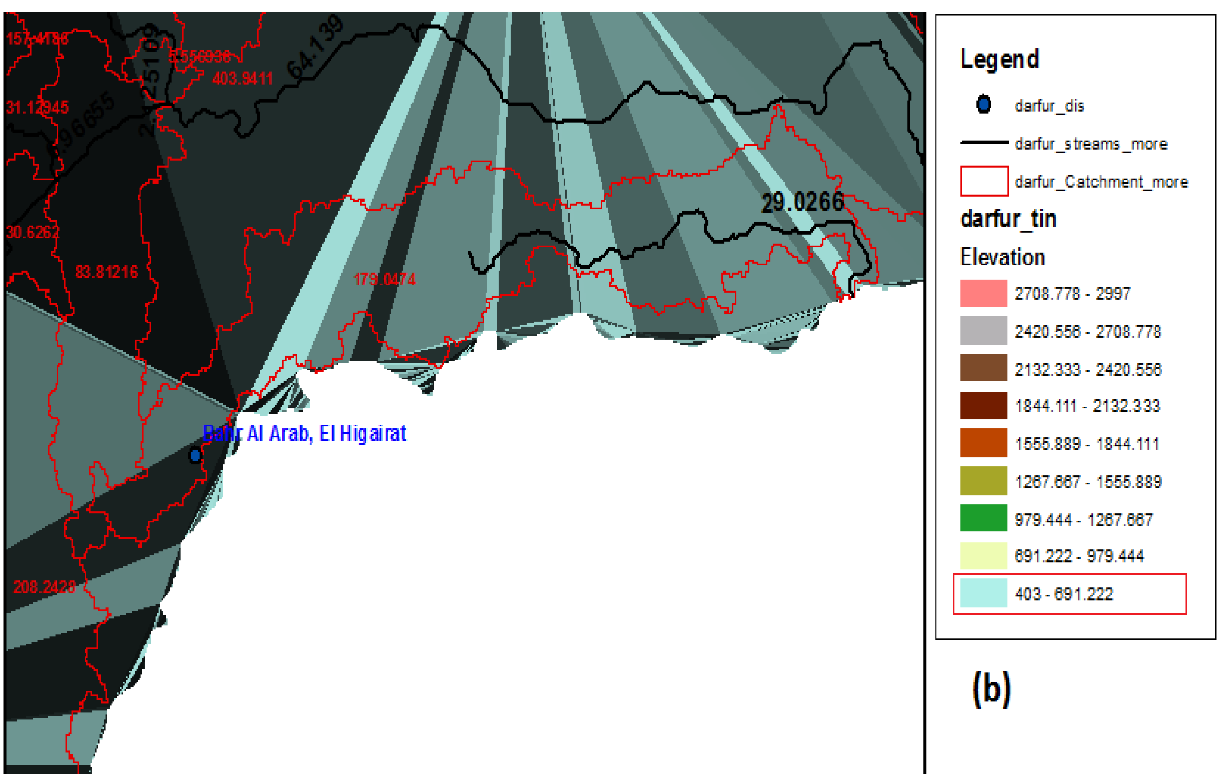

Fig.No.(3.35):Wadi Bahr Al Arab ,El Higairat station,(a) rain, catchment and stream length,(b) elevation

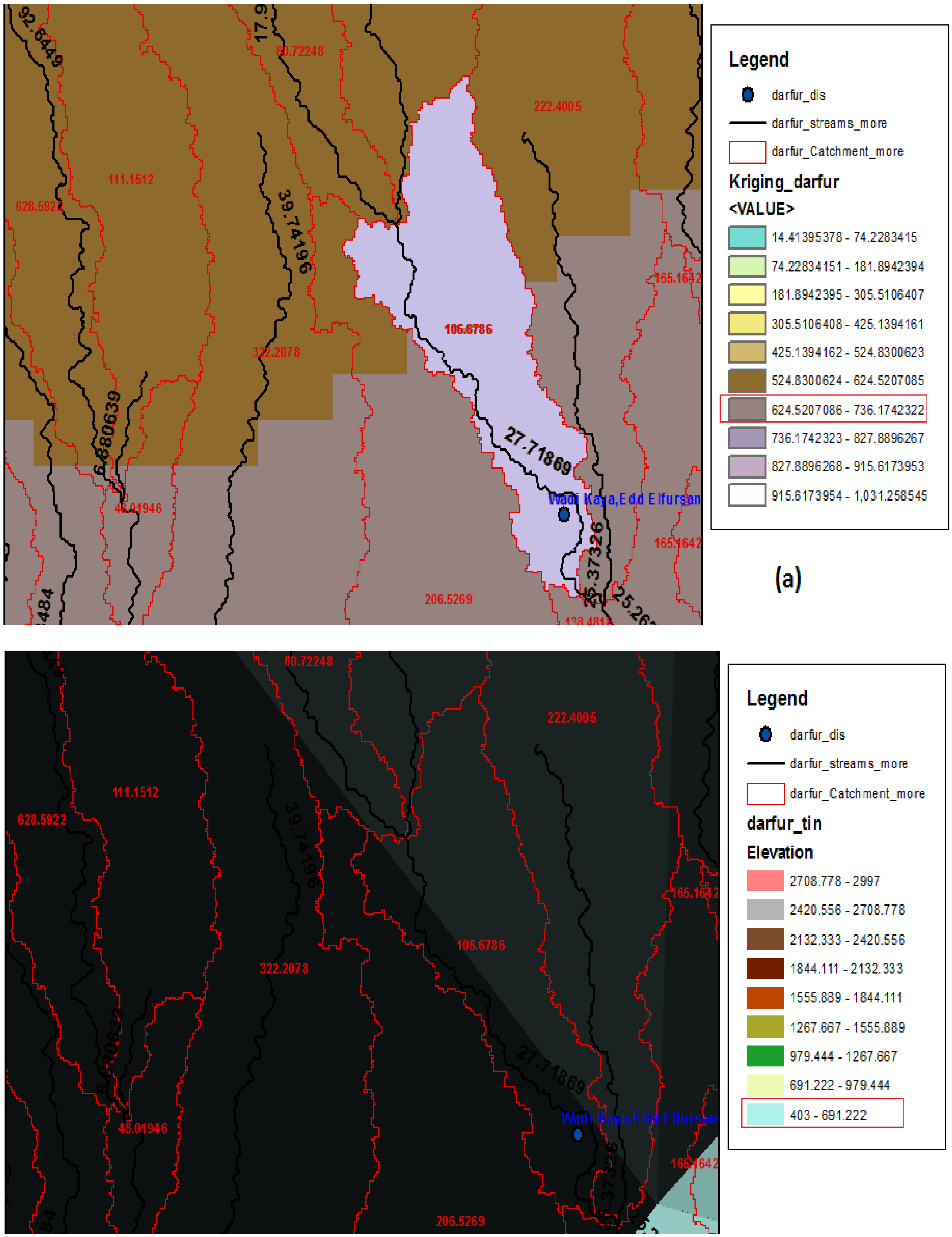

Fig.No.(3.36): Wadi Kaya, Edd Elfursan station, (a) rain, catchment and stream length, (b) elevation

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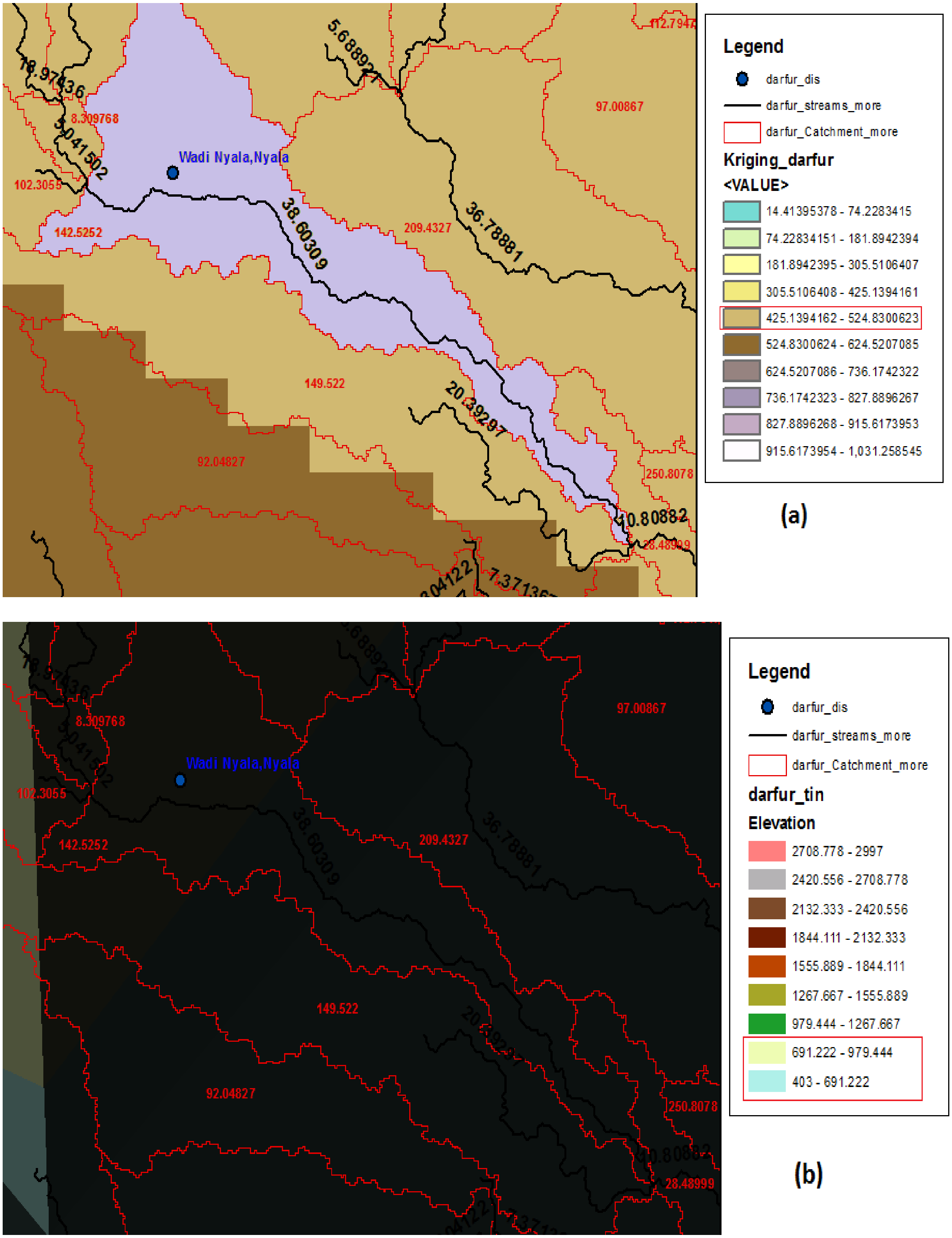

Fig.No.(3.37): Wadi Nyala, Nyala station, (a) rain, catchment and stream length, (b) elevation

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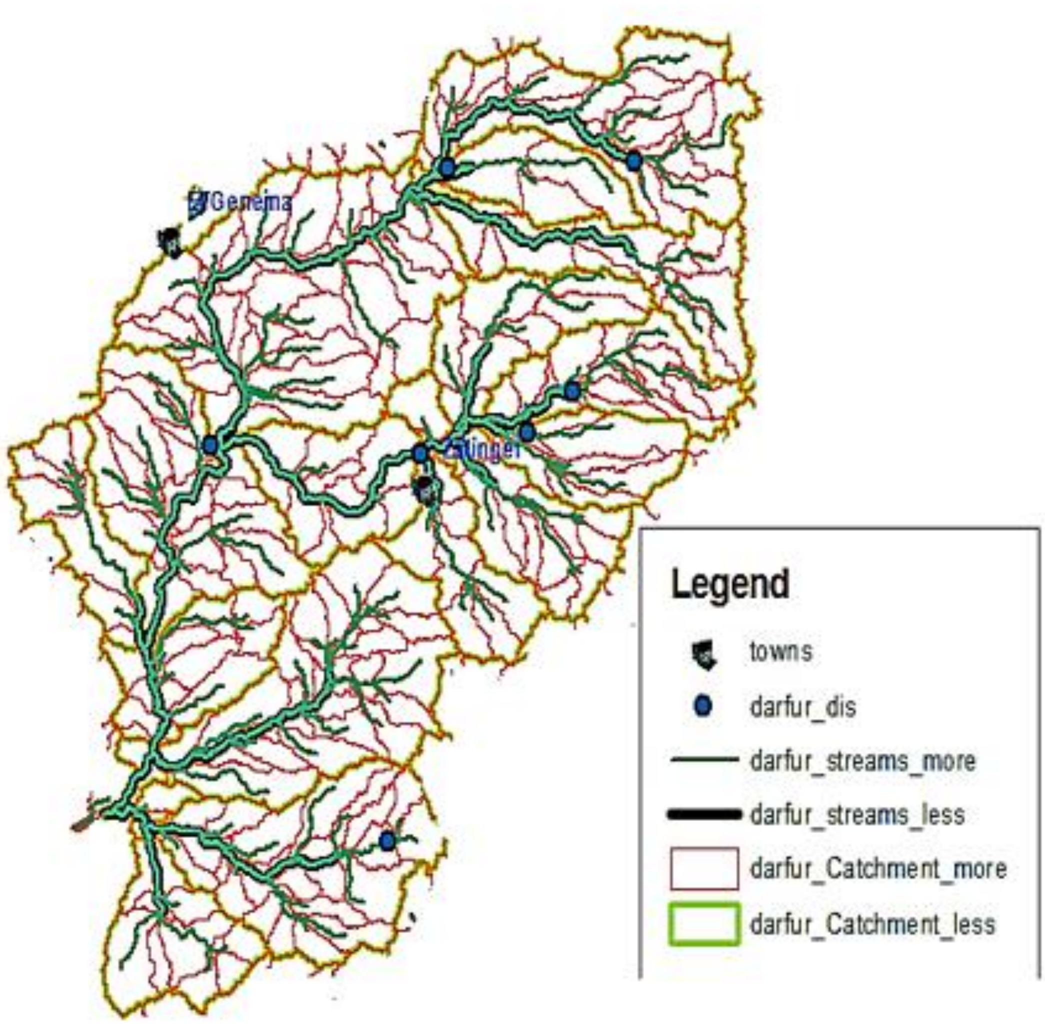
3.4.3. West Darfur State selected stations:

The major wadis are Azum and Kaja (Figures 3.38, 3.39). Wadi Azum has more gauge stations than Kaja. According to the general methodology in figure (3.1) the best selected stations. The Independent characteristics are given in tables (3.7) and (3.8). Table (3.7) shows highest and most accurate R value in regression analysis is belong to Wadi Azum, Table (3.10) was used to verify regression equation.



Figure(3.38)Wadi Azum

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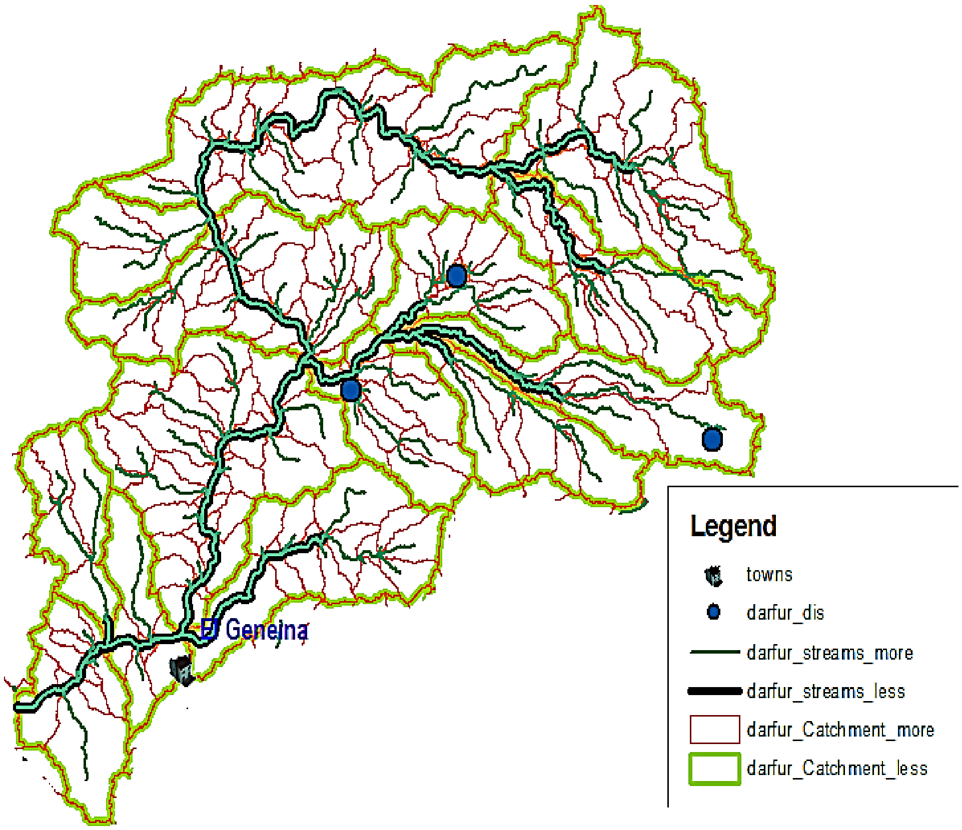

Figure (3.39)Wadi Kaja

Table (3. 8): The independent characteristics for Wadi Azum

Wadi, station	Q Measured annual discharge ($M.m^3$)	A (Km^2)	Max.Elev (m)	Min.Elev (m)	L length of flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
Wadi Saleh, Saleh	180	317.048	921.527	807.636	9.133	1.247	1011
Wadi Toro , Toro	45	541.443	1116.538	1054.943	34.343	0.179	538
Wadi Aribo , aribo	58	1282.083	1196.834	870.829	69.112	0.472	566
Wadi Dodari , dodari	40	1074.100	1835.618	1095.672	68.647	1.078	495
Wadi Bari , murnei	150	11904.000	1370.636	736.943	315.270	0.201	645
Wadi Bari, kabkabiya	70.93	789.848	1361.172	1160.484	45.404	0.442	369

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Table (3.9): the independent characteristics at log scale for Wadi Azum

W120adi , station	Log Q	Log A	Log P	Log S	Log L
Wadi Saleh, Saleh	2.255273	2.501124	3.004536	0.095866	0.960625
Wadi Toro , Toro	1.653213	2.733553	2.730378	-0.7463	1.535844
Wadi Aribo , aribo	1.763428	3.107916	2.753064	-0.32633	1.839558
Wadi Dodari , dodari	1.60206	3.031045	2.694166	0.032578	1.836622
Wadi Bari , murnei	2.176091	4.075693	2.80956	-0.6968	2.498679
Wadi Bari, kabkabiya	1.85083	2.897543	2.56698	-0.35458	1.657098

Table (3.10): verification for west Darfur equation

Years of measured	Big Wadi-small wadi station	Q Measured annual discharge ($M.m^3$)	Area (Km^2)	Max.Elev (m)	Min.Elev (m)	L length of flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
1977-1997	**Azum -wadi elserief kabkabiya**	23.270	146.2845	1259.412	1159.3065	14.260	0.702	373
1965-1973	**Kaja - wadi abu sunut Ereigi**	9.928	655.6033	1111.282	945.393	68.211	0.243	336
1965-1972	**Kaja- wadi abu sunut Tilfou**	2.708	37.57289	868.346	867.981	9.172	0.004	263
1964-1973	**Kaja -wadi abu sunut Abu Gidad**	45.202	744.33341	892.198	875.323	39.218	0.043	408
1978-2002	**Azum -wadi bargu Umm Sineina**	40.790	425.2775	988.376	924.398	39.011	0.164	403

3.4.4.North Darfur state selected stations:

The major wadis are El Ku, Howar and Wadi beida (Figures 3.40) there are another wadi such as wadi Bari and Elserief are main supply of the wadi Azum located in west and in north state. According to the general methodology given in figure (3.1) the best selected stations. The Independent Characteristics are given in tables (3.11) and (3.12). Table (3.7) shows highest and most accurate R value in regression analysis. Table (3.18) was used to verify regression equation.

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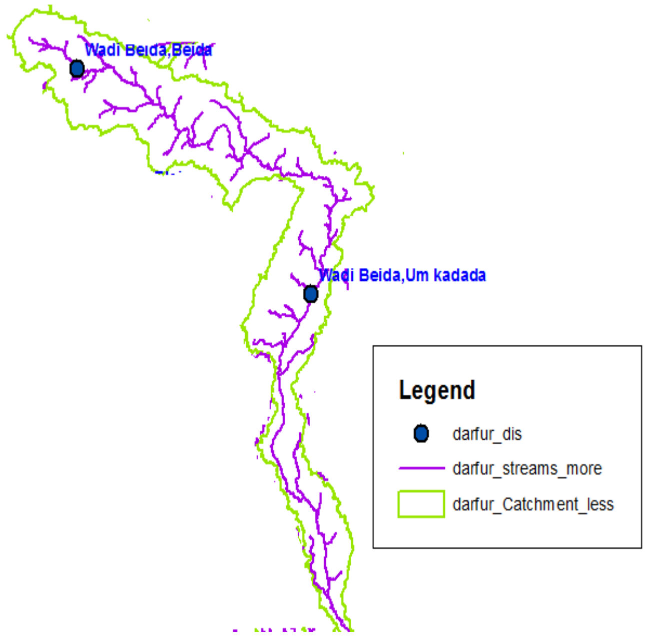

Figure (3.40):Wadi Beida

Table (3.11): The Independent Characteristics for Wadis in North Darfur

Wadi, station	Q Measured annual discharge ($M.m^3$)	Area (Km^2)	Max.Elev (m)	Min.Elev (m)	L Length of flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
Wadi Bari, kabkabiya	70.93	789.8476	1361.172	1160.48433	45.40445	0.442	369
Wadi Bargu, UmmSineina	40.790	425.2775	988.376	924.398	39.01083	0.164	403
Wadi Kaj, dar elslam	0.110	561.1186	726.231	684.763	38.75525	0.107	263
Wadi Al ku , dar elslam	3.750	185.0641	704.802	684.763	23.8195	0.08142	259
Wadi Elserief, kabkabiya	23.270	146.2845	1259.412	1159.3065	14.26003	0.702	373
Wadi Beida, beida	6.882	149.4211	860.559	813.548	15.75435	0.2984	250

`

Table (3.12): The Independent Characteristics at log scale for Wadis in North Darfur

Wadi, station	Log Q	Log A	Log P	Log S	Log L
Wadi Bari, kabkabiya	1.85082996	2.897543303	2.566979886	-0.354577731	1.657055853
Wadi Bargu, UmmSineina	1.610555907	2.628672406	2.605731058	-0.785156152	1.59117595
Wadi Kaj, dar elslam	-0.958607315	2.749054665	2.420693897	-0.970616222	1.588330543
Wadi Al ku, dar elslam	0.574031268	2.26732218	2.413429466	-1.089268902	1.376932641
Wadi Elserief, kabkabiya	1.366796383	2.165198312	2.571314419	-0.153662888	1.154120439
Wadi Beida, beida	0.837685765	2.174411929	2.398255119	-0.525201181	1.19740049

Table (3.13): Verification for North Darfur Equation

Years of measured	Wadi, station	Q Measured annual discharge ($M.m^3$)	Area (Km^2)	Max.Elev (m)	Min.Elev (m)	L length flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
1977-1997	**Azum -wadi elserief kabkabiya**	23.270	146.2845	1259.412	1159.307	14.260	0.702	373
1978-2002	**Azum -wadi bargu Umm Sineina**	40.790	425.2775	988.376	924.398	39.011	0.164	403
1965-1973	**Kaja - wadi abu sunut Ereigi**	9.9285	655.6033	1111.282	945.393	68.211	0.243	336
1965-1972	**Kaja- wadi abu sunut Tilfou**	2.708	37.57289	868.346	867.981	9.172	0.004	263
1964-1973	**Kaja -wadi abu sunut Abu Gidad**	45.202	744.33341	892.198	875.323	39.218	0.043	408
1988-1990	**Azum -Wadi Saleh, Saleh**	180.0	317.0476	921.527	807.636	9.133	1.247	1011
1988-1990	**wadi beida, um kadada**	4.970	90.00726	547.341	546.347	9.033	0.011	308

`

3.4.5.South Darfur state selected stations:

The major wadis are Nyala, Ibra, kaya, Bulbul and Negida, and wadi Nyala (figure 3.41) Shows wadi Nyala. According to the general methodology given in figure (3.1) the best selected stations. The Independent Characteristics are given in tables (3.14) and (3.15). Table (3.7) that gave high and accurate R value in regression analysis Table (3.16) was used to verify regression equation.

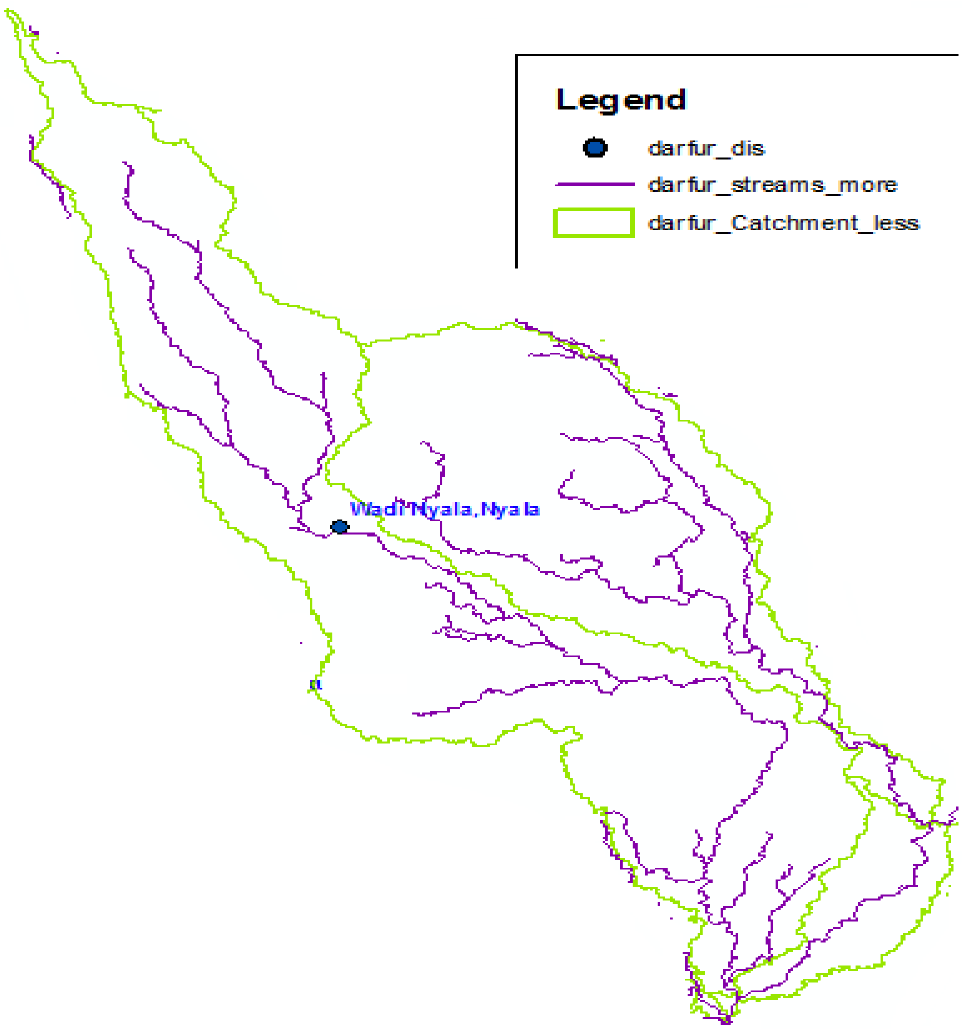

Figure (3.41):Wadi Nyala

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Table (3.14): The independent characteristics for wadis in south Darfur

Wadi station	Q Measured annual discharge (M.m3)	Area (Km2)	Max.El (m)	Min.El (m)	L length of flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
Nyla	64	142.5252	741.514	601.076	38.603	0.364	497
Wadibulubul Timbshuo	76	115.1458	651.989	624.474	17.484	0.157	628
wadi kaya EDD elfursan	157	106.6786	629.570	585.217	27.7186	0.160	653
wadi Sindo um higira	164	208.8846	633.835	578.481	33.386	0.166	677
wadi Ebra Nashala	210	15.33033	552.748	540.343	7.5059	0.165	698
wadi Tawal Abu likslik	150	232.3605	524.958	510.665	38.599	0.037	770

Table (3.15): The independent characteristics at log scale for Wadis in south Darfur

Wadi , station	Log Q	Log A	Log P	Log S	Log L
Wadi Nyala,Nyala	1.80618	2.153892	2.696469	-0.43914	1.586622
Wadibulubul , Timbshuo	1.880814	2.061248	2.798023	-0.80308	1.242541
wadi kaya, EDD elfursan	2.1959	2.028077	2.814949	-0.79585	1.442773
wadi Sindo, um higira	2.214844	2.319906	2.83084	-0.78042	1.52357
wadi Ebra, Nashala	2.322219	1.185552	2.843887	-0.78181	0.875405
wadi Tawal, Abu likslik	2.176091	2.366162	2.886684	-1.43145	1.586575

Table (3.16): Verification for South Darfur Equation

Years of measured	Wadi station	Q Measured annual discharge (M.m3)	Area (Km2)	Max.Elev (m)	Min.Elev (m)	L Length of flow path (Km)	S Slope% $\frac{(Max - Min)}{L \times 10}$	precipitation (mm)
1988-1990	**wadi beida, um kadada**	4.97	90.00726	547.341	546.347	9.033	0.011	308

`

3. 5.Multiple regression method

In order to develop multiple regression equations to suit the study area tables (3.9, 3.12, 3.15) log values were used. Applying XLSATA tools in excel program, the resulting developed regression equations are (2.8), and (2.9), respectively.

$$Q = b_0 A^{b_1} P^{b_2} S^{b_3} L^{b_4} ------ (2.8)$$

$$\log Q = \log b_0 + b_1 \log A + b_2 \log P + b_3 \log S + b_4 \log L --- (2.9)$$

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CHAPTER FOUR

4. RESULTS and DISCUSSION

4. 1.Results Darfur states equations

Regression method by used to XLSATA tools gave a below results and it is summarized in table (4.1).

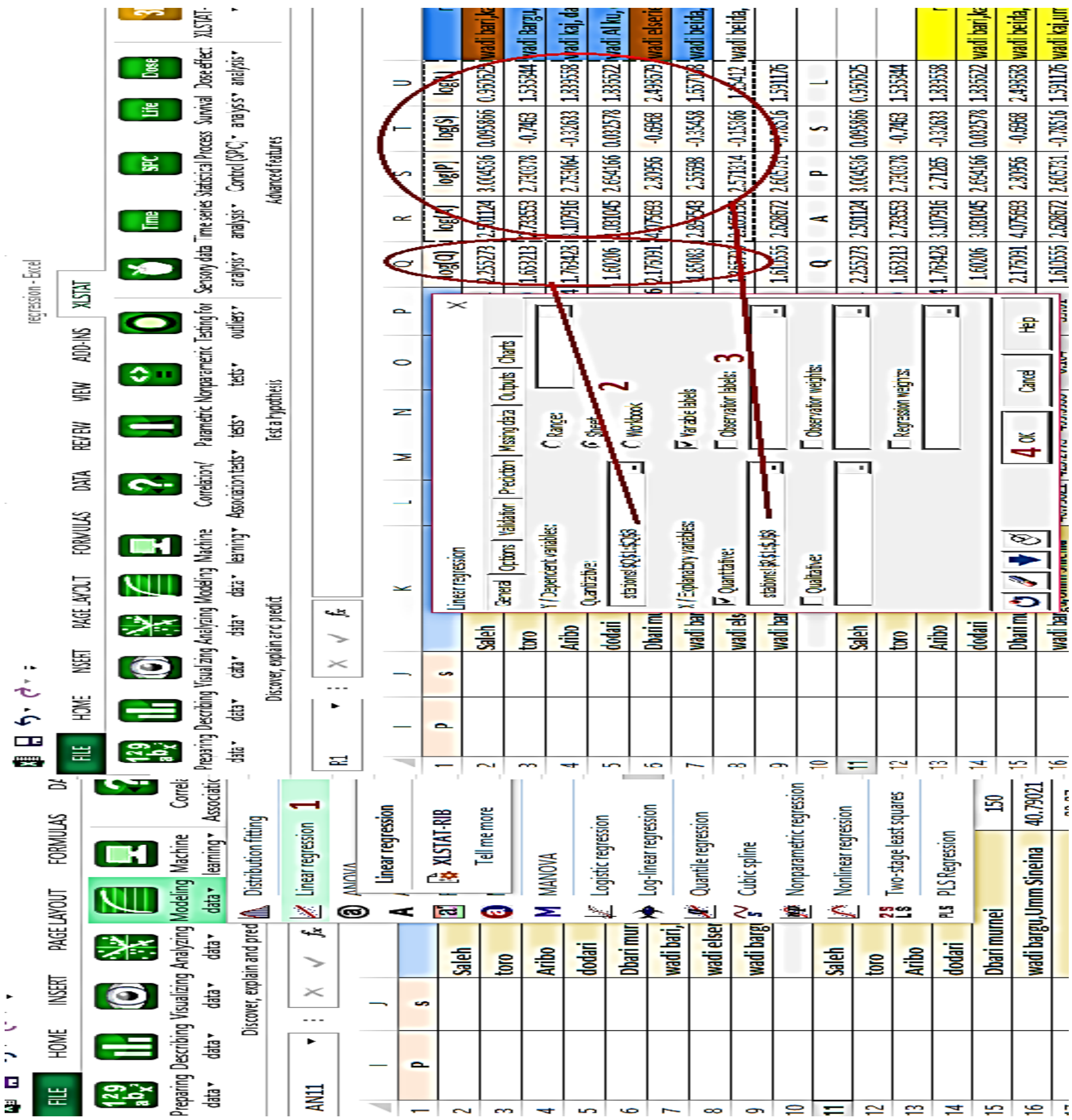

Figure (4.1):Steps using XLSATA tools

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XLSTAT 2016.02.27444 - Linear regression - Start time: 10/2/2016 at 2:44:13 PM
Y / Dependent variables: Workbook = regression.xlsx / Sheet = stations / Range = stations!$Q$1:$Q$7 / 6 rows and 1 column
X / Quantitative: Workbook = regression.xlsx / Sheet = stations / Range = stations!$R$1:$U$7 / 6 rows and 4 columns
Confidence interval (%): 95
Tolerance: 0.0001

Summary statistics (Quantitative data):

Variable	bservation	ith missin	thout miss	Minimum	Maximum	Mean	d. deviation
log(Q)	6	0	6	1.602	2.255	1.883	0.273
log(A)	6	0	6	2.501	4.076	3.058	0.544
log(P)	6	0	6	2.567	3.005	2.760	0.145
log(S)	6	0	6	-0.746	0.096	-0.333	0.352
log(L)	6	0	6	0.961	2.499	1.721	0.500

Correlation matrix:

	log(A)	log(P)	log(S)	log(L)	log(Q)
log(A)	**1**	-0.111	-0.502	0.947	0.232
log(P)	-0.111	**1**	0.310	-0.382	0.699
log(S)	-0.502	0.310	**1**	-0.554	0.094
log(L)	0.947	-0.382	-0.554	**1**	-0.084
log(Q)	0.232	0.699	0.094	-0.084	**1**

Regression of variable log(Q):

Goodness of fit statistics (log(Q)):

Observati	6.000
Sum of we	6.000
DF	1.000
R^2	0.995
Adjusted I	0.976
MSE	0.002
RMSE	0.042
MAPE	0.751
DW	3.103
Cp	5.000
AIC	-38.664
SBC	-39.705
PC	0.053

`

Analysis of variance (log(Q)):

Source	DF	m of squar	ean squar	F	Pr > F
Model	4	0.370	0.092	51.300	0.104
Error	1	0.002	0.002		
Corrected	5	0.372			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (log(Q)):

Source	DF	m of squar	ean squar	F	Pr > F
log(A)	1	0.020	0.020	11.130	0.185
log(P)	1	0.198	0.198	109.660	0.061
log(S)	1	0.000	0.000	0.172	0.750
log(L)	1	0.152	0.152	84.240	0.069

Type III Sum of Squares analysis (log(Q)):

Source	DF	m of squar	ean squar	F	Pr > F
log(A)	1	0.173	0.173	96.147	0.065
log(P)	1	0.014	0.014	7.696	0.220
log(S)	1	0.000	0.000	0.015	0.923
log(L)	1	0.152	0.152	84.240	0.069

Model parameters (log(Q)):

Source	Value	andard err	t	Pr > |t|	er bound (	er bound (95%)
Intercept	1.580	0.587	2.691	0.227	-5.880	9.040
log(A)	2.011	0.205	9.805	0.065	-0.595	4.618
log(P)	-0.744	0.268	-2.774	0.220	-4.150	2.663
log(S)	-0.008	0.065	-0.122	0.923	-0.838	0.822
log(L)	-2.206	0.240	-9.178	0.069	-5.259	0.848

Equation of the model (log(Q)):

log(Q) = 1.57996091739009+2.01127688478229*log(A)-0.743712904562729*log(P)-7.95204616685415E-03*log(S)-2.20560977060285*log(L)

Standardized coefficients (log(Q)):

Source	Value	andard err	t	Pr > |t|	er bound (	er bound (95%)
log(A)	4.014	0.409	9.805	0.065	-1.188	9.216
log(P)	-0.395	0.142	-2.774	0.220	-2.204	1.414
log(S)	-0.010	0.084	-0.122	0.923	-1.083	1.062
log(L)	-4.043	0.441	-9.178	0.069	-9.641	1.554

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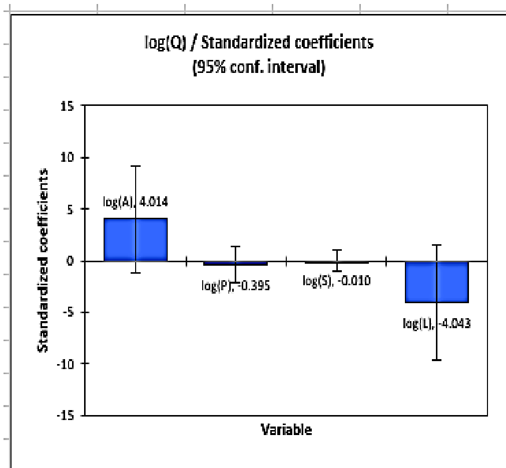

Predictions and residuals (log(Q)):

Observatio	Weight	log(Q)	red(log(Q	Residual	td. residua	ntized res	/. on pred.	ound 95%	ound 95%	n pred. (Ol	nd 95% (Ol	nd 95% (Observation)
Obs1	1	2.255	2.256	-0.001	-0.026	-1.000	0.042	1.717	2.796	0.060	1.494	3.019
Obs2	1	1.653	1.666	-0.013	-0.295	-1.000	0.041	1.150	2.181	0.059	0.920	2.412
Obs3	1	1.763	1.729	0.035	0.820	1.000	0.024	1.420	2.037	0.049	1.107	2.350
Obs4	1	1.602	1.621	-0.019	-0.456	-1.000	0.038	1.141	2.101	0.057	0.899	2.343
Obs5	1	2.176	2.182	-0.006	-0.145	-1.000	0.042	1.649	2.716	0.060	1.423	2.941
Obs6	1	1.851	1.847	0.004	0.101	1.000	0.042	1.310	2.383	0.060	1.086	2.607

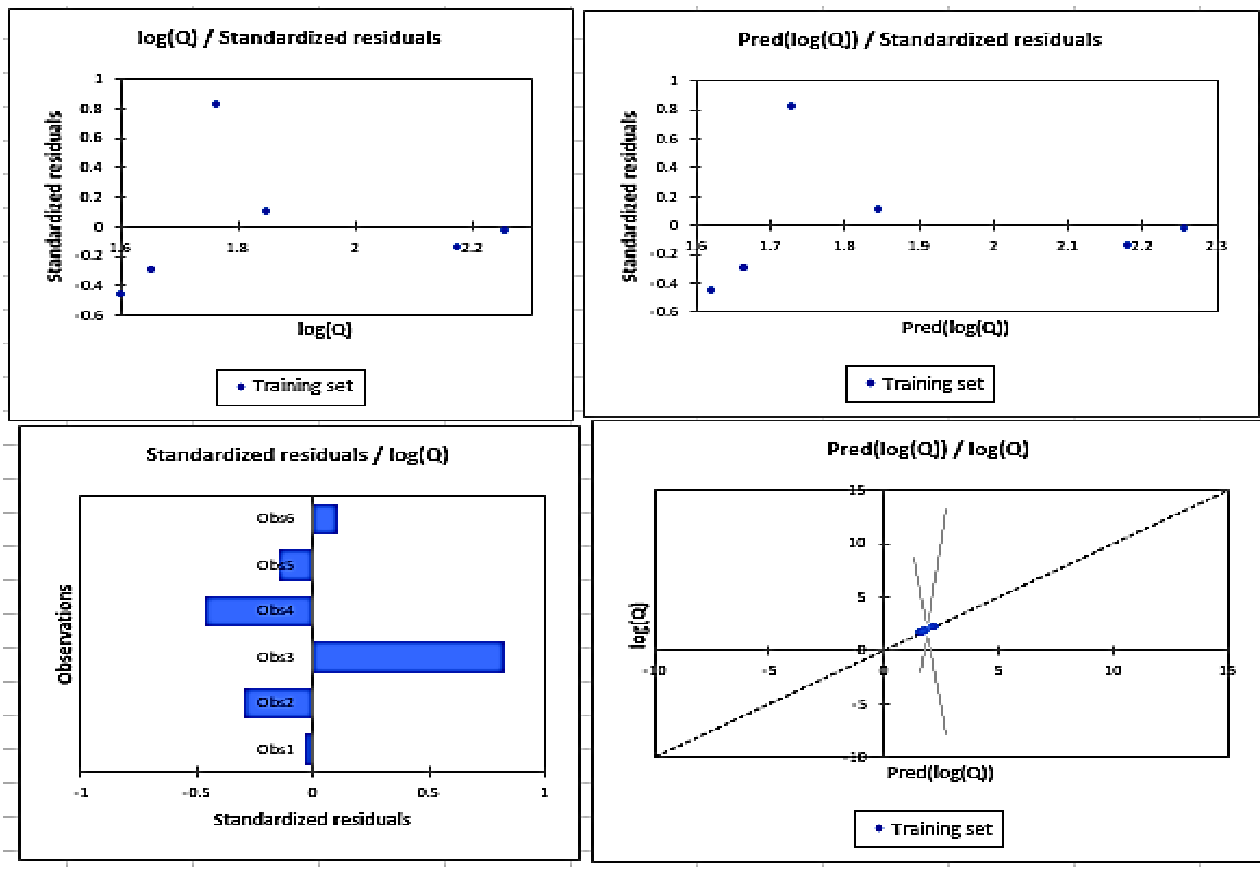

Figure (4.2): West Darfur regression result

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XLSTAT 2016.02.27444 - Linear regression - Start time: 10/2/2016 at 9:25:50 PM
Y / Dependent variables: Workbook = regression.xlsx / Sheet = stations / Range = stations!$AB$1:$AB$7 / 6 rows and 1 column
X / Quantitative: Workbook = regression.xlsx / Sheet = stations / Range = stations!$AC$1:$AF$7 / 6 rows and 4 columns
Confidence interval (%): 95
Tolerance: 0.0001

Summary statistics (Quantitative data):

Variable	bservatior	/ith missin	thout miss	Minimum	Maximum	Mean	:d. deviation
log(Q)	6	0	6	-0.959	1.851	0.880	1.019
log(A)	6	0	6	2.165	2.898	2.480	0.318
log(P)	6	0	6	2.398	2.606	2.496	0.095
log(S)	6	0	6	-1.089	-0.154	-0.646	0.364
log(L)	6	0	6	1.154	1.657	1.428	0.217

Correlation matrix:

	log(A)	log(P)	log(S)	log(L)	log(Q)
log(A)	1	0.328	-0.145	0.957	-0.035
log(P)	0.328	1	0.532	0.275	0.733
log(S)	-0.145	0.532	1	-0.375	0.619
log(L)	0.957	0.275	-0.375	1	-0.055
log(Q)	-0.035	0.733	0.619	-0.055	1

Regression of variable log(Q):

Goodness of fit statistics (log(Q)):

Observati	6.000
Sum of we	6.000
DF	1.000
R^2	0.99988
Adjusted I	0.999
MSE	0.001
RMSE	0.025
MAPE	0.971
DW	1.907
Cp	5.000
AIC	-44.837
SBC	-45.878
PC	0.001

`

Analysis of variance (log(Q)):

Source	DF	m of squar	ean squar	F	Pr > F
Model	4	5.188	1.297	2014.066	0.017
Error	1	0.001	0.001		
Corrected	5	5.189			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (log(Q)):

Source	DF	m of squar	ean squar	F	Pr > F
log(A)	1	0.006	0.006	9.596	0.199
log(P)	1	3.225	3.225	5007.614	0.009
log(S)	1	0.146	0.146	226.664	0.042
log(L)	1	1.811	1.811	2812.390	0.012

Type III Sum of Squares analysis (log(Q)):

Source	DF	m of squar	ean squar	F	Pr > F
log(A)	1	1.941	1.941	3013.370	0.012
log(P)	1	0.188	0.188	291.514	0.037
log(S)	1	1.950	1.950	3028.410	0.012
log(L)	1	1.811	1.811	2812.390	0.012

Model parameters (log(Q)):

Source	Value	andard err	t	Pr > |t|	er bound (	er bound (95%)
Intercept	19.217	0.758	25.343	0.025	9.582	28.852
log(A)	-17.644	0.321	-54.894	0.012	-21.728	-13.560
log(P)	-4.828	0.283	-17.074	0.037	-8.422	-1.235
log(S)	6.705	0.122	55.031	0.012	5.157	8.253
log(L)	29.291	0.552	53.032	0.012	22.273	36.309

Equation of the model (log(Q)):

log(Q) = 19.2167788061508-17.6439358144317*log(A)-4.82840342010337*log(P)+6.70518582252513*log(S)+29.2911679055926*log(L)

Standardized coefficients (log(Q)):

Source	Value	andard err	t	Pr > |t|	er bound (	er bound (95%)
log(A)	-5.513	0.100	-54.894	0.012	-6.789	-4.237
log(P)	-0.449	0.026	-17.074	0.037	-0.782	-0.115
log(S)	2.397	0.044	55.031	0.012	1.844	2.950
log(L)	6.241	0.118	53.032	0.012	4.746	7.737

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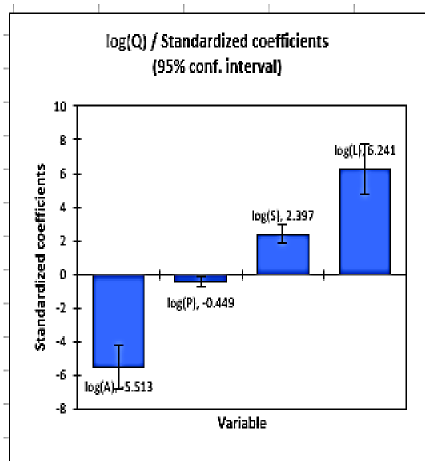

Predictions and residuals (log(Q)):

Observatio	Weight	log(Q)	red(log(Q	Residual	td. residu	ntized res	/. on pred.	ound 95%	ound 95%	n pred. (O	nd 95% (O	nd 95% (Observation)
Obs1	1	1.851	1.858	-0.007	-0.278	-1.000	0.024	1.548	2.168	0.035	1.411	2.305
Obs2	1	1.611	1.598	0.013	0.498	1.000	0.022	1.318	1.878	0.034	1.171	2.025
Obs3	1	-0.959	-0.960	0.001	0.037	1.000	0.025	-1.282	-0.637	0.036	-1.415	-0.504
Obs4	1	0.574	0.587	-0.013	-0.531	-1.000	0.022	0.314	0.861	0.033	0.165	1.010
Obs5	1	1.367	1.374	-0.007	-0.284	-1.000	0.024	1.065	1.683	0.035	0.927	1.821
Obs6	1	0.838	0.824	0.014	0.557	1.000	0.021	0.556	1.091	0.033	0.404	1.243

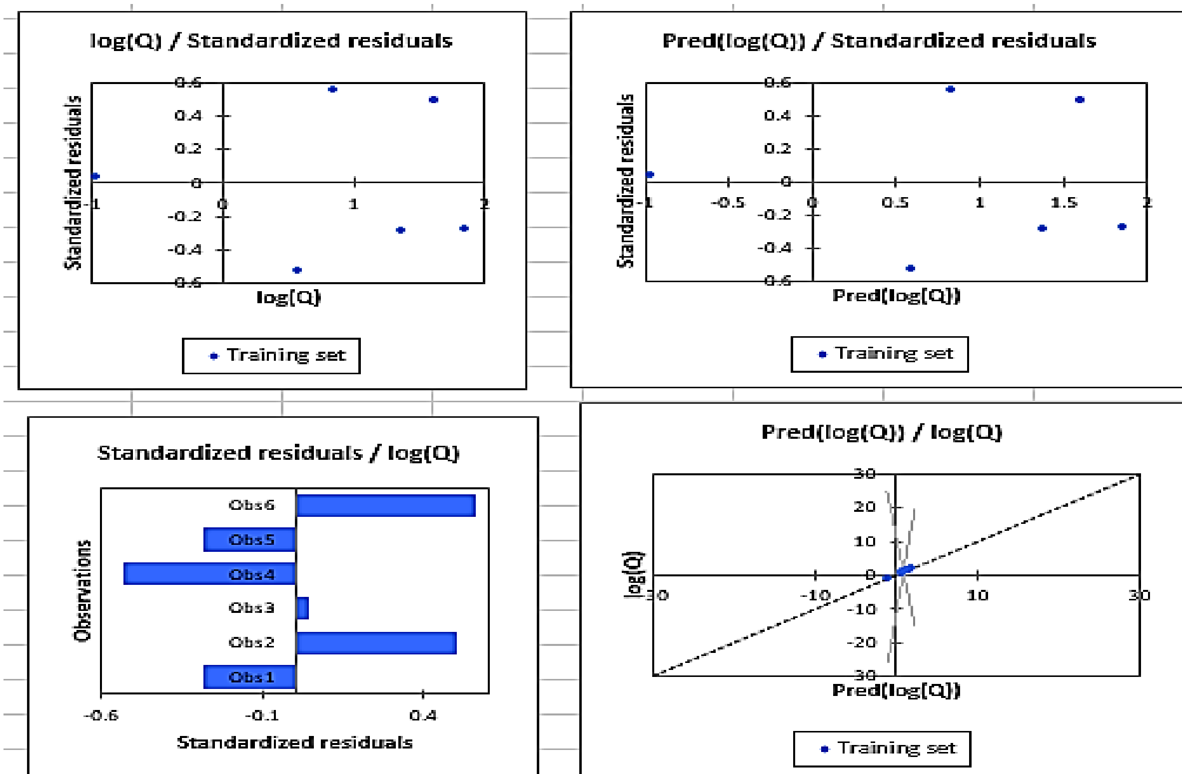

Figure (4.3): North Darfur regression result

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X / Quantitative: Workbook = regression.xlsx / Sheet = stations / Range = stations!$AN$1:$AQ$7 / 6 rows and 4 columns
Confidence interval (%): 95
Tolerance: 0.0001

Summary statistics (Quantitative data):

Variable	bservation	vith missin	thout miss	Minimum	Maximum	Mean	d. deviation
log(Q)	6	0	6	1.806	2.322	2.099	0.206
log(A)	6	0	6	1.186	2.366	2.019	0.430
log(P)	6	0	6	2.696	2.887	2.812	0.064
log(S)	6	0	6	-1.431	-0.439	-0.839	0.323
log(L)	6	0	6	0.875	1.587	1.376	0.277

Correlation matrix:

	log(A)	log(P)	log(S)	log(L)	log(Q)
log(A)	1	-0.081	-0.259	0.937	-0.389
log(P)	-0.081	1	-0.851	-0.223	0.792
log(S)	-0.259	-0.851	1	-0.140	-0.442
log(L)	0.937	-0.223	-0.140	1	-0.367
log(Q)	-0.389	0.792	-0.442	-0.367	1

Regression of variable log(Q):

Goodness of fit statistics (log(Q)):

Observati	6.000
Sum of we	6.000
DF	1.000
R^2	0.99951
Adjusted I	0.998
MSE	0.000
RMSE	0.010
MAPE	0.163
DW	2.098
Cp	5.000
AIC	-55.807
SBC	-56.848
PC	0.005

`

Analysis of variance (log(Q)):

Source	DF	m of squa	ean squar	F	Pr > F
Model	4	0.212	0.053	511.740	0.033
Error	1	0.000	0.000		
Corrected	5	0.212			

Computed against model Y=Mean(Y)

Type I Sum of Squares analysis (log(Q)):

Source	DF	m of squa	ean squar	F	Pr > F
log(A)	1	0.032	0.032	309.736	0.036
log(P)	1	0.123	0.123	1193.437	0.018
log(S)	1	0.020	0.020	189.159	0.046
log(L)	1	0.037	0.037	354.628	0.034

Type III Sum of Squares analysis (log(Q)):

Source	DF	m of squa	ean squar	F	Pr > F
log(A)	1	0.035	0.035	336.188	0.035
log(P)	1	0.106	0.106	1029.026	0.020
log(S)	1	0.031	0.031	296.642	0.037
log(L)	1	0.037	0.037	354.628	0.034

Model parameters (log(Q)):

Source	Value	andard err	t	Pr > |t|	er bound (	er bound (95%)
Intercept	-13.775	0.500	-27.572	0.023	-20.123	-7.427
log(A)	-0.599	0.033	-18.335	0.035	-1.015	-0.184
log(P)	5.769	0.180	32.078	0.020	3.484	8.054
log(S)	0.604	0.035	17.223	0.037	0.158	1.049
log(L)	0.995	0.053	18.832	0.034	0.324	1.667

Equation of the model (log(Q)):

log(Q) = -13.7748362870243-0.599471849733481*log(A)+5.7689451839762*log(P)+0.603932132439755*log(S)+0.995385526616181*log(L)

Standardized coefficients (log(Q)):

Source	Value	andard err	t	Pr > |t|	er bound (	er bound (95%)
log(A)	-1.253	0.068	-18.335	0.035	-2.121	-0.385
log(P)	1.794	0.056	32.078	0.020	1.084	2.505
log(S)	0.947	0.055	17.223	0.037	0.248	1.645
log(L)	1.339	0.071	18.832	0.034	0.435	2.242

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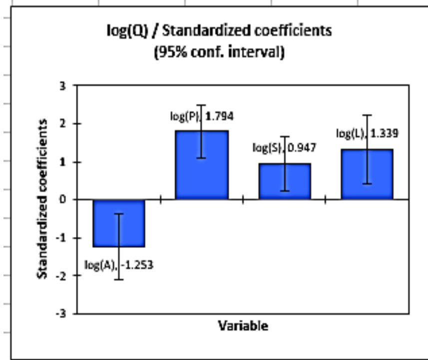

Predictions and residuals (log(Q)):

Observatio	Weight	log(Q)	red(log(Q	Residual	td. residua	ntized res	on pred.	ound 95%	ound 95%	n pred. (O	nd 95% (O	nd 95% (Observation)
Obs1	1	1.806	1.804	0.002	0.230	1.000	0.010	1.678	1.930	0.014	1.623	1.984
Obs2	1	1.881	1.883	-0.002	-0.210	-1.000	0.010	1.757	2.009	0.014	1.702	2.064
Obs3	1	2.196	2.204	-0.008	-0.811	-1.000	0.006	2.128	2.280	0.012	2.054	2.354
Obs4	1	2.215	2.211	0.004	0.415	1.000	0.009	2.093	2.328	0.014	2.036	2.385
Obs5	1	2.322	2.320	0.002	0.229	1.000	0.010	2.194	2.446	0.014	2.140	2.500
Obs6	1	2.176	2.175	0.001	0.147	1.000	0.010	2.047	2.302	0.014	1.993	2.356

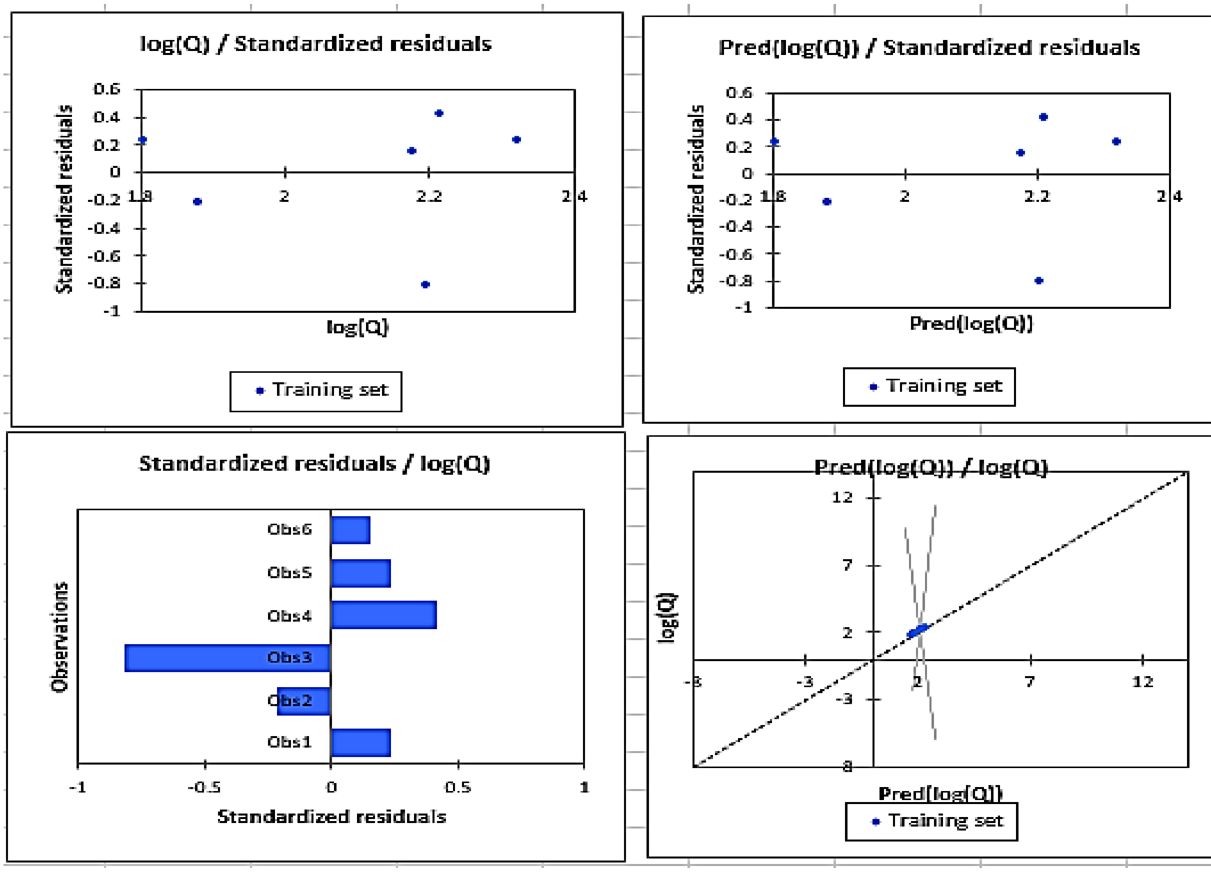

Figure (4.4): South Darfur regression result

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Table (4.1): Coefficients and regression functions For Different States

Region	Coefficients		Predicted discharge function Q (million m^3)
West	$\log b_0$	1.5799	$38.0155\ A^{2.0113} P^{-0.7437} S^{-0.008} L^{-2.2056}$
	b_1	2.0113	
	b_2	-0.7437	
	b_3	-0.008	
	b_4	-2.2056	
	$\mathbf{R^2}$	**0.9951**	
North	$\log b_0$	19.2168	$1.64732\times10^{19}\ A^{-17.6439} P^{-4.8284} S^{6.7052} L^{29.2168}$
	b_1	-17.6439	
	b_2	-4.8284	
	b_3	6.7052	
	b_4	29.2912	
	$\mathbf{R^2}$	**0.9998**	
South	$\log b_0$	-13.7748	$1.67944\times10^{-14}\ A^{-0.5995} P^{5.7689} S^{0.6039} L^{0.9954}$
	b_1	-0.5995	
	b_2	5.7689	
	b_3	0.6039	
	b_4	0.9954	
	$\mathbf{R^2}$	**0.9995**	

Where:

A=catchment area (Km^2)

P=precipitation (mm)

S=slope (m/m) %

L=longest flow path in catchment (Km)

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4. 2.Discussion

4.2.1.Discussion of West Dar fur state:

I. The prediction of the discharge is considered being the most important parameter in this study. It was revealed from the result that the difference between measured and predicted annual discharges was small (table 4.2). It lies within the range from 0.25% to 7.71 %. Furthermore, it is associated with an acceptable reasonable correlation coefficient close to one

$$(R^2 = \pm 1) \rightarrow R^2 = 0.9951$$

II. For the verification equation, the analysis is depicted in table (4.3). From table (4.3) it is clearly apparent that the verification stations located in Wadi Azum has a smaller difference, (approximately 29.2) than that located in Wadi Kaja (approximately 113.5). Wadi Azum Station has close precipitation data values and would preferably be used to developed the equation.

III. Tables (4.4) and (4.5) described simple calculation of the annual discharges for Wadi Azum and Wadi Kaja respectively by helps with sets of figures (4.5 to 4.8).

IV. Table (4.6) show that, the calculated discharge based on small catchment areas a lot of and much rain values ranged by using Kriging Method which identified the rain parameters at any point in the map were (367.923- 970.051), (258.850-615.372) for Azum and Kaja respectively. The calculated discharge quantities were less than that in the study (Yousif, 2011)and (Ali, 2014)because the latter was not considered the measurement located in a small wadi. The result gave high discharge quantity especially in Azum. also the results higher than study(Barsi, 2010) it used the a less rain parameters (546), (465) for the two wadis which are shown in table 3.10 that led to small discharge estimated value. The accuracy of the equation led to accurate water resource with sustainable development of groundwater resources.

4.2.2.Discussion of North Darfur state:

I. The result revealed difference between measured and predicted annual discharges was small (table 4.7). It lies within the range from 0.21% to 3.2 %. Furthermore, it is associated with an acceptable reasonable correlation coefficient close to one

$$(R^2 = \pm 1) \rightarrow R^2 = 0.9998$$

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II. For the verification equation, the analysis is depicted in table (4.8).
From table (4.8) all the stations located in Wadi Azum has a smaller difference than that located in Wadi Kaja and it is clearly apparent that the first two stations located in Wadi Azum belong to the state has a smaller difference, (approximately 1.67 to 2.8) than that values when applied west equation (approximately 29.2 to 34.65) so, it was recommended use the equation for specific area in North state. Wadi Beida (um kadada station) and Wadi Saleh, has less values than Wadi Azum Station because the first one lay near to south state and the second far away at west Darfur state.

V. Tables (4.9) (4.10) described calculation of the annual discharges for wadis Alku and Howar respectively by helps with sets of figures (4.9 to 4.12).

III. Table (4.11) showed the discharge quantities based on small catchment areas. It shows the same results of discharge quantity as those in the study (Yousif, 2011)and (Barsi, 2010). Referring to the accuracy of equation results lead to accurate values of water resources. In this State, it remains constant, however the precipitation data was changed.

Discussion of South Darfur state:

I. The result revealed difference between measured and predicted annual discharges was small (table 4.12). It lies within the range from 0.49% to 1.9 %. Furthermore, it is associated with an acceptable reasonable correlation coefficient close to one

$$(R^2 = \pm 1) \rightarrow R^2 = 0.9995$$

II. For the verification equation, the analysis is depicted in table (4.13).
From table (4.13) it is clearly apparent that the Wadi Beida (Um Kadada station) has a smaller difference, (approximately 96.9) than that north equation value.

III. Tables (4.14, to 4.18) described simple calculation of the annual discharges for five wadis by help the figures (4.13 to 4.17), the discharge quantities based on small catchment areas and rain parameter ranged from 496 to 770mm. They gave results greater than that of study (Barsi, 2010). the latter it was used one rain value equal (496 mm) for all wadis. Refer here to the accuracy of equation and results lead to the south state has rich surface water resource can be used to increase the amount of water and population needs.

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Table No. (4.2): West Darfur State Predicted and Measured Discharges

Wadi, station	Q Measured annual discharge (M.m^3)	Q Predicted annual discharge (M.m^3)	Difference %
Wadi Saleh, Saleh	180	180.458	0.255
Wadi Toro , Toro	45	46.317	2.926
Wadi Aribo, Aribo	58	53.530	7.706
Wadi Dodari, Dodari	40	41.823	4.558
Wadi Bari, Murnei	150	152.136	1.424
Wadi Bari, kabkabiya	70.93	70.232	0.984

Table No. (4.3): Verify West Dar Fur Equation

Years of measured	Big Wadi-small wadi -station	Q Measured annual discharge (M.m^3)	Q Predict annual discharge (M.m3)	Difference %
1977-1997	Azum -Wadi Elserief- kabkabiya	23.270	30.070	29.223
1965-1973	Kaja - Wadi Abu sunut -Ereigi	9.929	21.200	113.524
1965-1972	Kaja- Wadi Abu sunut -Tilfou	2.708	6.991	158.169
1964-1973	Kaja -Wadi Abu sunut -Abu Gidad	45.202	81.384	80.045
1978-2002	Azum -Wadi Bargu-Umm Sineina	40.790	26.654	34.656

Table No. (4.4): Calculated Wadi Azum Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	length of flow path (L) km	slope%	precipitation (mm))	Pred Q (M.cm)
162	3231.616	1373.955	923.775	150.97	0.298	367.923	84.837
170	1077.417	1111.134	923.775	78.59	0.238	375.825	38.760
172	80.09485	923.775	921.221	12.28	0.0209	402.677	12.087
174	5540.519	921.221	736.43	163.54	0.113	566.114	153.832
175	1974.184	1463.652	921.221	135.94	0.399	425.163	35.551
182	1526.142	1145.335	1105.925	91.85	0.043	446.686	49.351
186	1638.639	1821.245	1060.513	102.81	0.740	485.401	40.810
191	30.60531	1060.513	1105.925	11.33	0.401	541.809	1.633
192	1203.044	1275.332	1060.513	58.41	0.368	561.114	68.870

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193	12.60822	1105.925	1005.851	6.07	1.649	545.105	1.070
194	1589.628	897.69	735.933	97.22	0.166	672.046	34.503
197	1422.191	1302.953	1005.851	73.5	0.404	644.218	52.378
198	298.986	1005.851	897.69	29.29	0.369	513.931	20.487
199	3119.261	870.46	643.763	114.31	0.198	767.236	84.755
200	1282.083	1225.616	897.69	69.06	0.475	724.513	44.642
202	1206.129	857.661	643.763	76.69	0.279	777.284	29.864
206	3726.948	1091.976	609.183	129.15	0.374	970.051	77.405
208	1461.726	887.675	609.183	85.17	0.327	797.976	34.161
213	153.4563	609.183	581.34	22.52	0.124	805.462	6.907
214	191.551	584.703	581.34	18.3	0.018	807.683	17.276
215	9.103717	581.34	571.609	6.98	0.139	816.033	0.309
223	3186.626	799.402	584.703	115.32	0.186	911.245	76.394
225	1456.116	730.879	584.703	66.22	0.221	818.661	58.121
Sum	**35418.674**						**1024.004**

Table No. (4.5): Calculated Wadi Kaja Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	Length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
138	4363.07	966.998	884.653	183.02	0.045	275.679	127.689
139	3167.741	1236.244	900.349	131.15	0.256	258.850	144.563
140	2027.09	1108.259	900.349	127.25	0.163	300.606	56.530
143	972.4702	928.832	884.653	48.2	0.092	370.407	94.440
145	2767.195	991.137	853.652	103.94	0.132	372.372	141.103
147	1538.251	912.53	887.591	67.23	0.037	264.298	147.604
148	1769.888	1111.594	882.14	134.8	0.170	335.005	34.947
150	47.35878	882.14	887.591	12.08	0.045	354.0999	4.763
151	1418.051	892.362	853.652	66.37	0.058	402.579	93.946
152	1373.896	1010.032	882.14	92.33	0.139	350.459	46.862
156	3793.35	974.261	873.06	116.96	0.087	494.665	166.625
163	2174.417	908.099	873.06	109.26	0.032	504.160	62.831
173	1029.509	995.057	850.921	65.61	0.220	529.750	40.830
176	931.0133	873.06	850.921	56.6	0.039	575.981	44.012
177	1373.583	892.798	763.928	50.25	0.256	615.372	117.326
Sum	**28746.883**						**1324.073**

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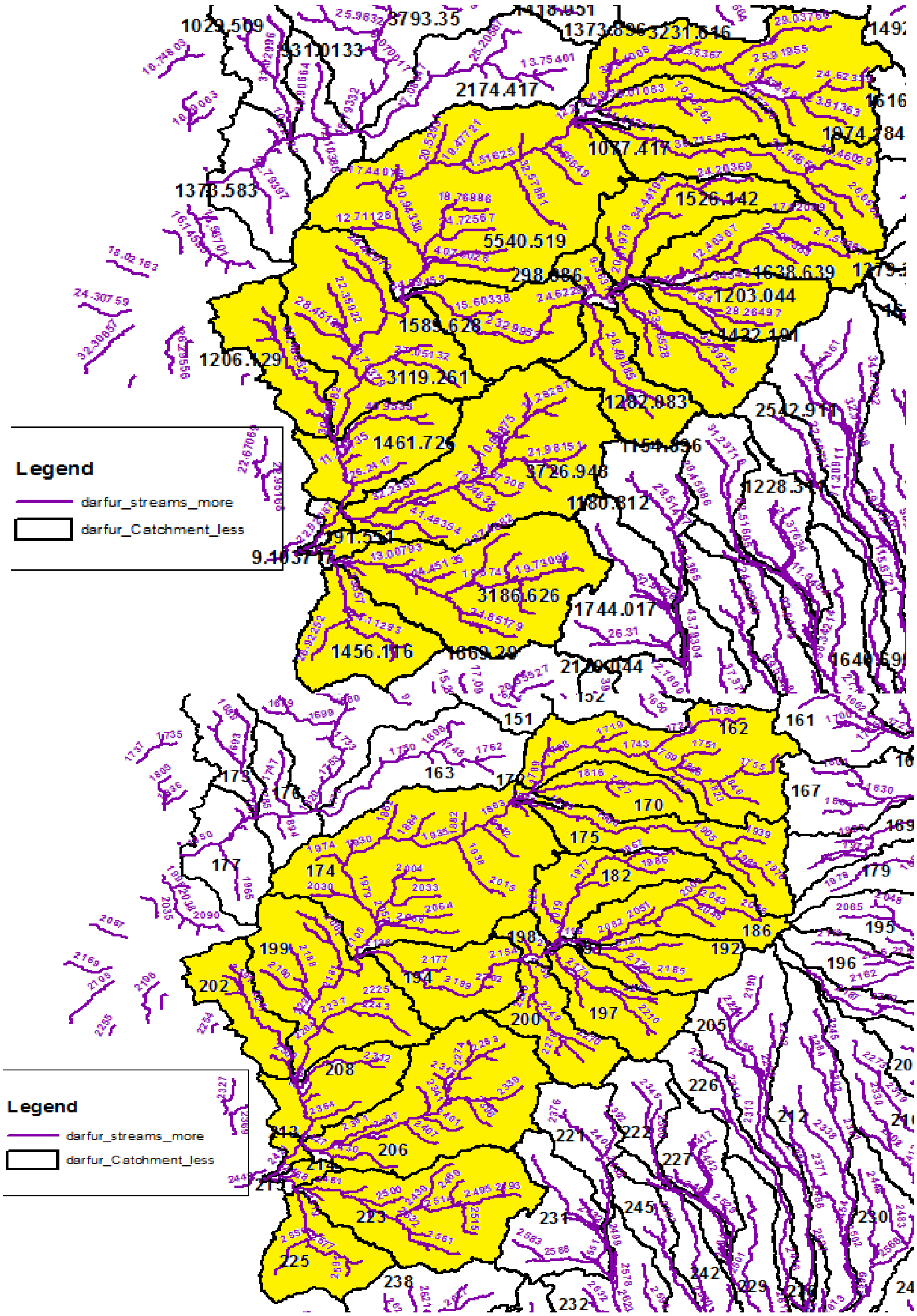

Fig.No.(4.5): Wadi Azum, (a) Grid ID catchments and streams length, ,(b) values of catchments and streams length

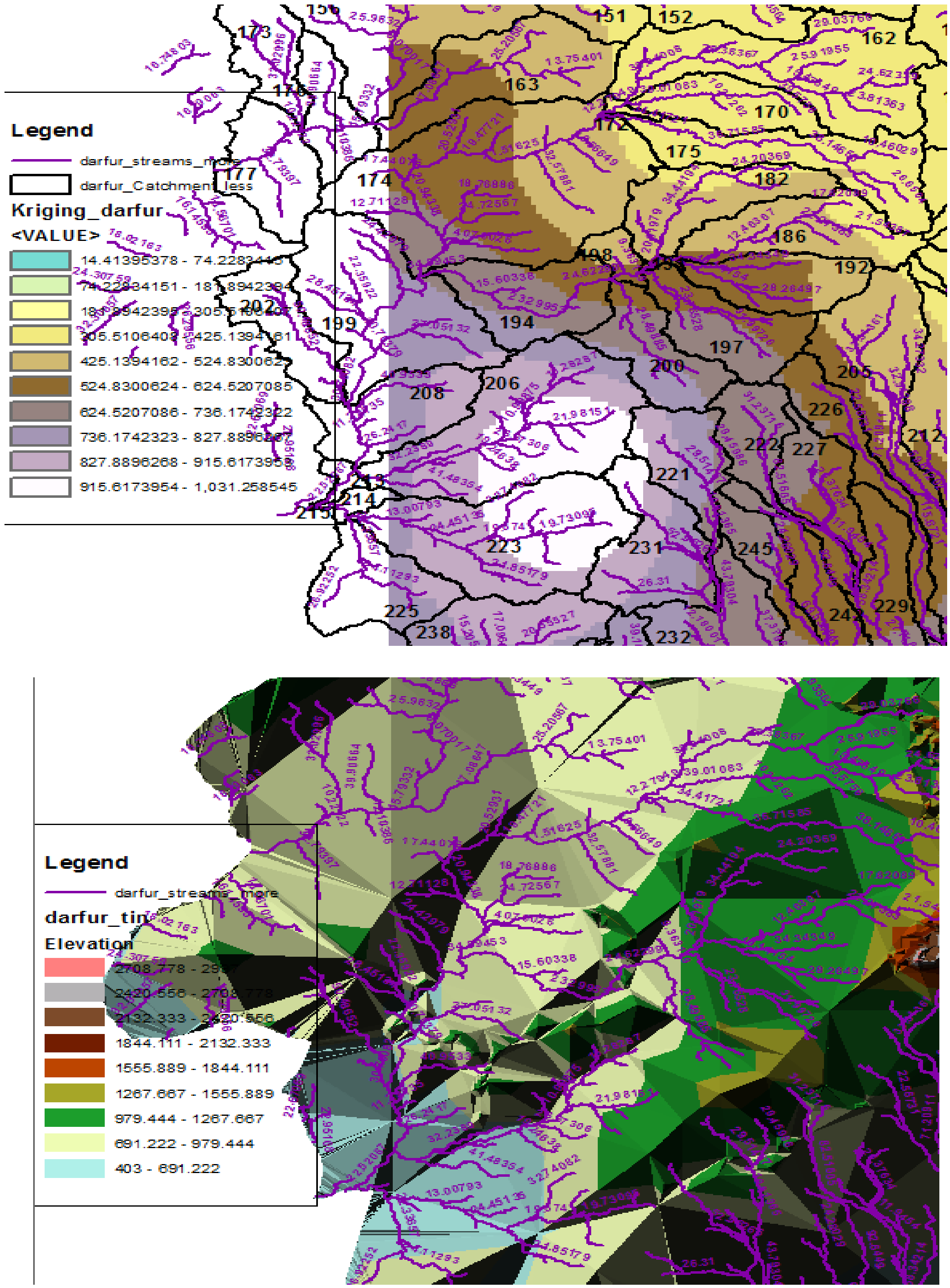

Fig.No.(4.6): Wadi Azum, (a) rain, catchment and stream length,(b) elevation

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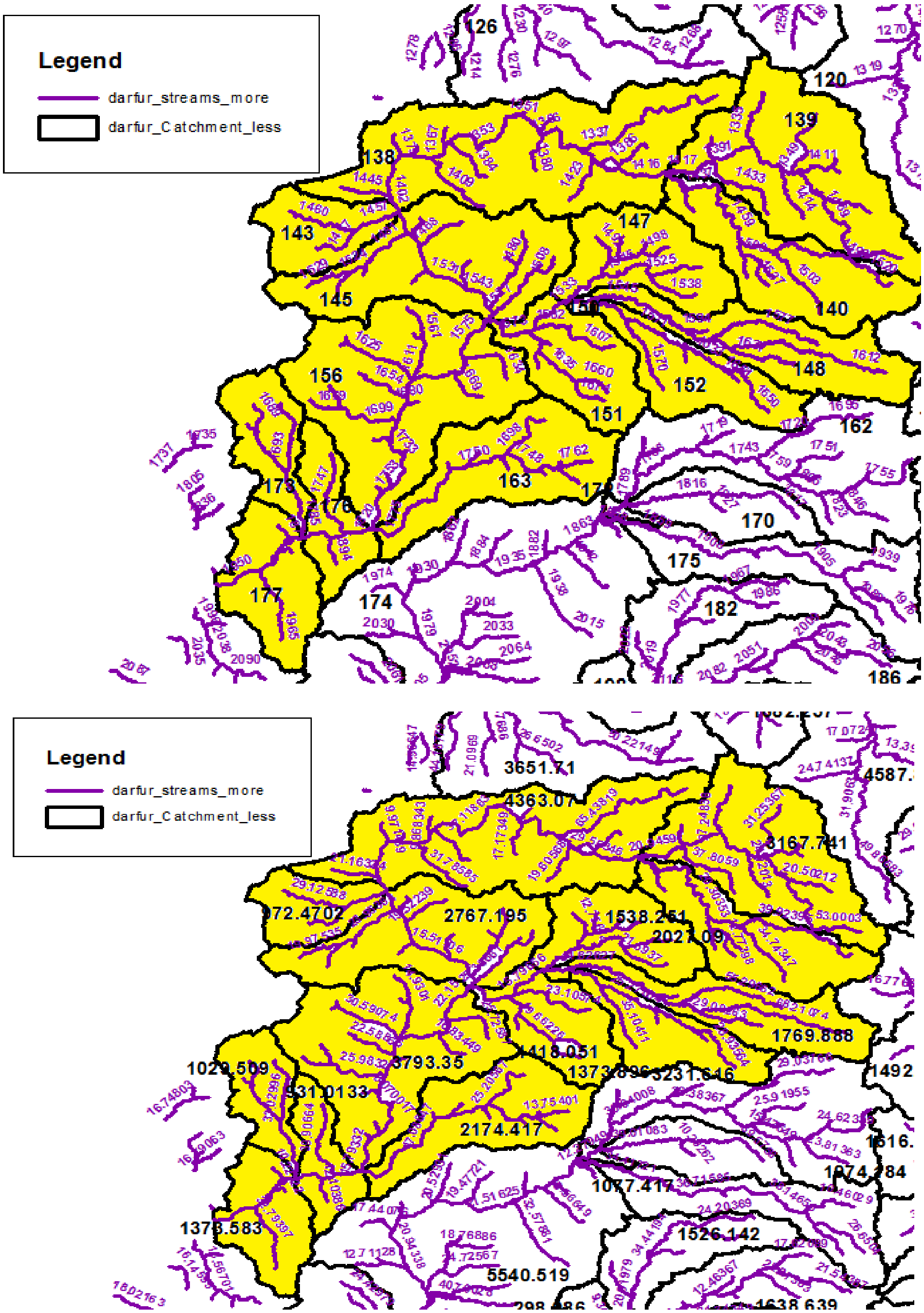

Fig.No.(4.7): Wadi Kaja, (a) Grid ID catchments and streams length, ,(b) values of catchments and streams length

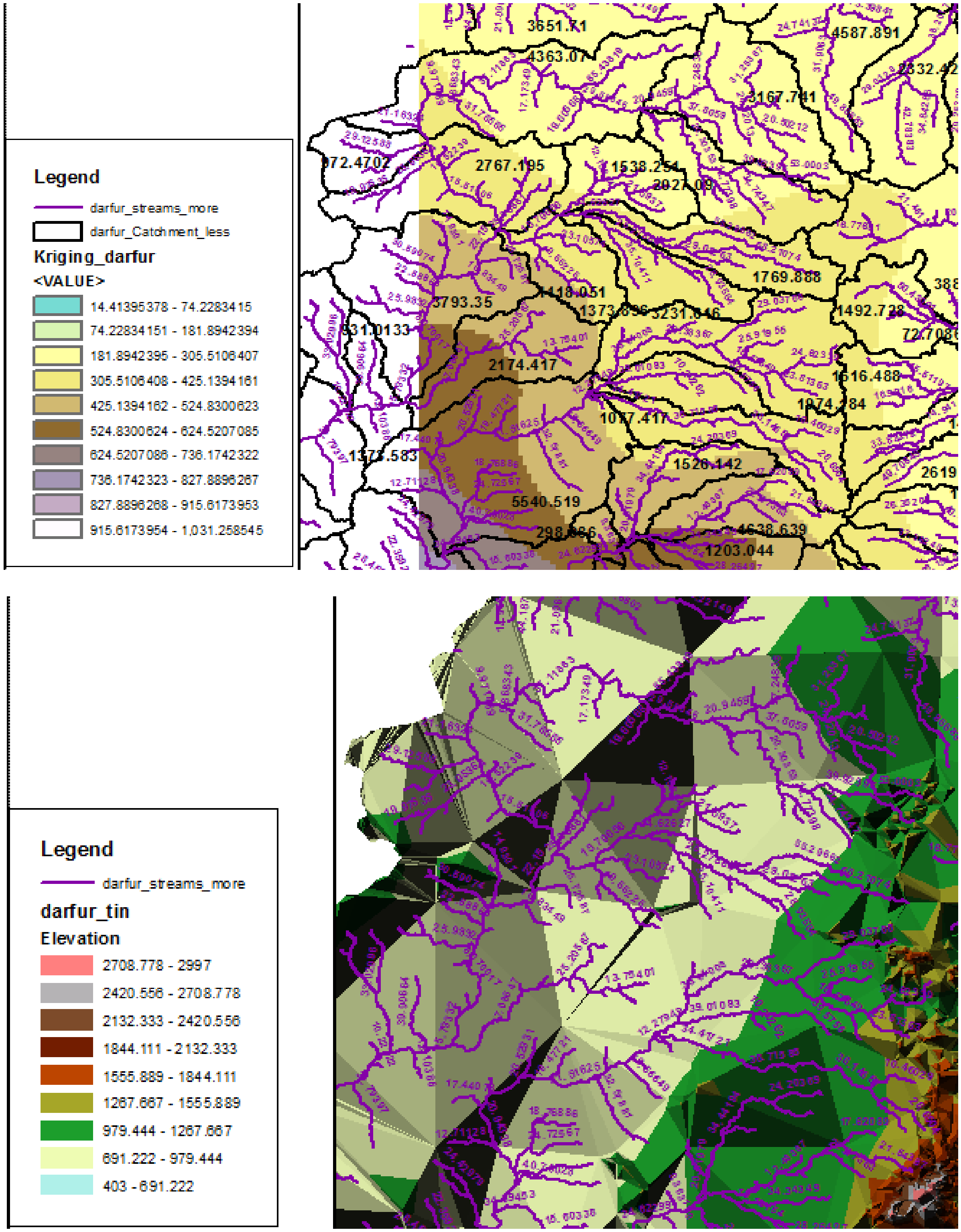

Fig.No.(4.8): Wadi Kaja, (a) rain, catchment and stream length,(b) elevation

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Table No. (4.6): Comparison Between Present and Previous Studies for West Dar Fur

NO.	Name of wadi	Catchment area (Km)	Estimated/predicted Annual Discharge (M.CM)	Estimated/predicted Total Annual Discharge (M.CM)	Reference
1	Azum	36965	-	4016	(Yousif, 2011)
	Kaja	-	-		
2	Azum	36700	601	900	(Barsi, 2010)
	Kaja	42850	299		
3	Azum	40393	2597	4016	(Ali, 2014)
	Kaja	47337	1419		
4	Azum	**35418.674**	**1024**	**2348**	Work study
	Kaja	**28746.883**	**1324**		

Table No.(1:7): North Dar Fur State Predicted and Measured Discharges

Wadi, station	Q Measured annual discharge (M.m^3)	Q Predict annual discharge (M.m^3)	Difference %
Wadi Bari, kabkabiya	70.930	72.092	1.638
Wadi Bargu, UmmSineina	40.790	39.620	2.869
Wadi Kaj, Dar elslam	0.110	0.110	0.219
Wadi Al ku ,Dar elslam	3.750	3.868	3.149
Wadi Elserief, kabkabiya	23.270	23.660	1.676
Wadi Beida, Beida	6.882	6.661	3.205

Table No. (4:8) Verify North Dar Fur Equation

Years of measured	Big Wadi-small wadi station	Q Measured annual discharge (M.m^3)	Q Predict annual discharge (M.m3)	Difference %
1977-1997	Azum -Wadi Elserief kabkabiya	23.270	23.660	1.676
1978-2002	Azum -Wadi Bargu Umm Sineina	40.790	39.645	2.808
1965-1973	Kaja - Wadi Abu sunut Ereigi	9.928	8.33E+06	83.899
1965-1972	Kaja- Wadi Abu sunut Tilfou	2.708	7.04E-09	99.999
1964-1973	Kaja -Wadi Abu sunut Abu Gidad	45.202	2.86E-07	99.999
1988-1990	Azum -Wadi Saleh, Saleh	180.00	2.29E-11	100
1988-1990	wadi Beida, um kadada	4.970	3.83E-13	100

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Table No. (4:9): Calculated Wadi Al Ku Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
153	3885.894	1279.342	821.714	106.00	0.432	278.868	8.999
161	1492.728	881.42	821.714	29.50	0.202	268.872	7.67646E-11
164	1907.928	775.908	752.002	17.30	0.138	185.385	7.65641E-20
165	72.70863	821.714	807.152	11.63	0.125	223.213	1.556
166	367.6933	784.182	752.225	33.68	0.095	202.883	4.916
167	1616.488	886.659	807.152	40.73	0.195	294.213	1.21372E-07
168	58.63076	752.002	738.621	8.04	0.166	175.180	0.030
169	1493.083	786.75	738.621	33.03	0.146	194.541	1.10378E-09
171	3912.85	739.439	647.098	107.93	0.086	232.703	0.001
178	1776.782	649.339	647.098	38.64	0.006	346.669	1.2767E-19
179	2619.79	775.361	646.204	117.82	0.110	341.861	7.969
183	1327.984	673.781	651.039	38.65	0.059	228.936	9.07087E-10
184	6.543114	647.098	646.204	4.73	0.019	350.796	5.566
185	38.34624	646.204	640.810	4.62	0.117	353.362	1.52703E-08
187	595.5386	678.861	640.810	9.56	0.398	332.703	1.30319E-16
188	648.766	668.547	651.039	76.65	0.023	353.362	30.966
189	3076.026	640.810	556.078	159.52	0.053	353.246	22.245
195	1379.268	780.658	727.193	28.26	0.189	241.153	9.46984E-11
196	1618.948	820.722	727.193	37.43	0.210	238.748	1.42796E-07
Sum	**27895.996**						**82.249**

Table No. (4.10): Calculated Wadi Howar Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	length flow path (L) km	slope%	precipitation (mm))	Pred Q (M.cm)
79	1807.655	542.585	491.873	80.66	0.063	200	0.027
81	4964.734	630.045	537.502	201.00	0.046	200	24.876
83	66.94912	542.585	540.919	12.60	0.013	18.892	2.987
91	342.3341	637.296	630.045	27.66	0.026	19.670	0.762
92	1330.43	636.557	630.045	36.80	0.018	20.850	7.002E-09
94+95	1392.538	646.667	637.296	29.17	0.032	20.161	2.2222E-10
96	984.2682	640.858	637.296	13.23	0.027	22.202	1.70253E-18
Sum	**12828.260**						**28.652**

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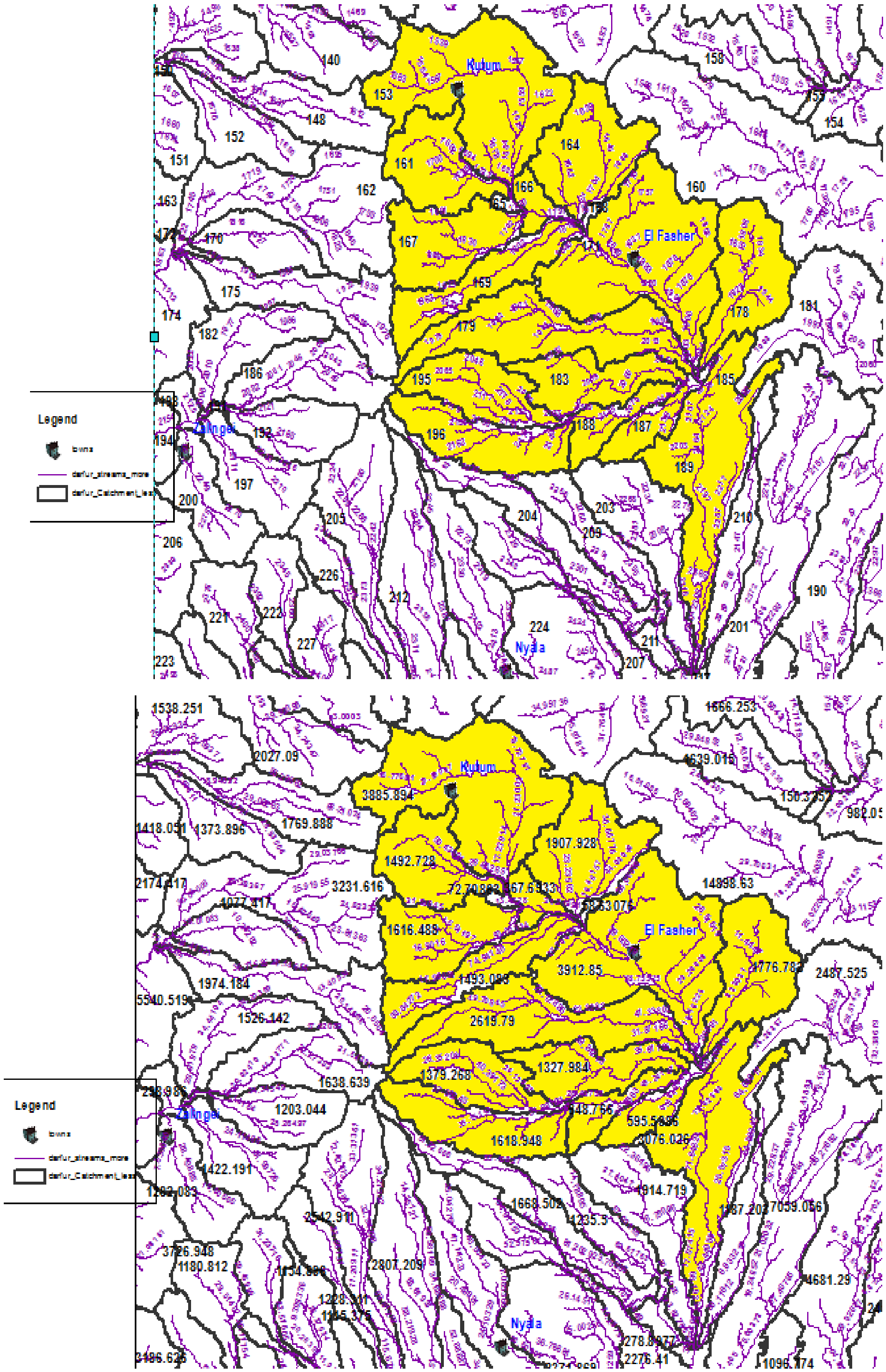

Fig.No.(4.9): Wadi Alku, (a) Grid ID catchments and streams length, (b) values of catchments and streams length

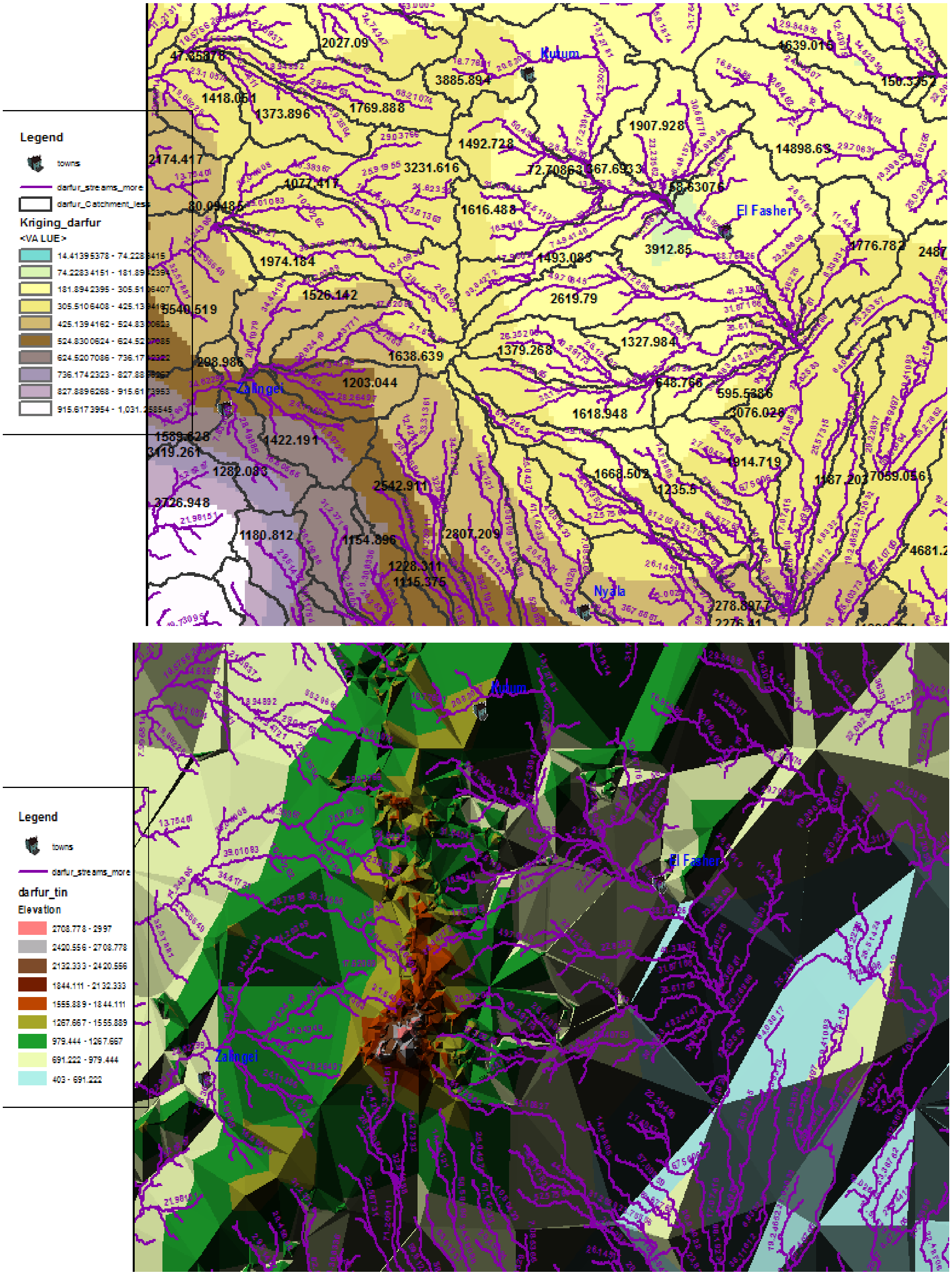

Fig.No.(4.10): Wadi Alku, (a) rain, catchment and stream length,(b) elevation

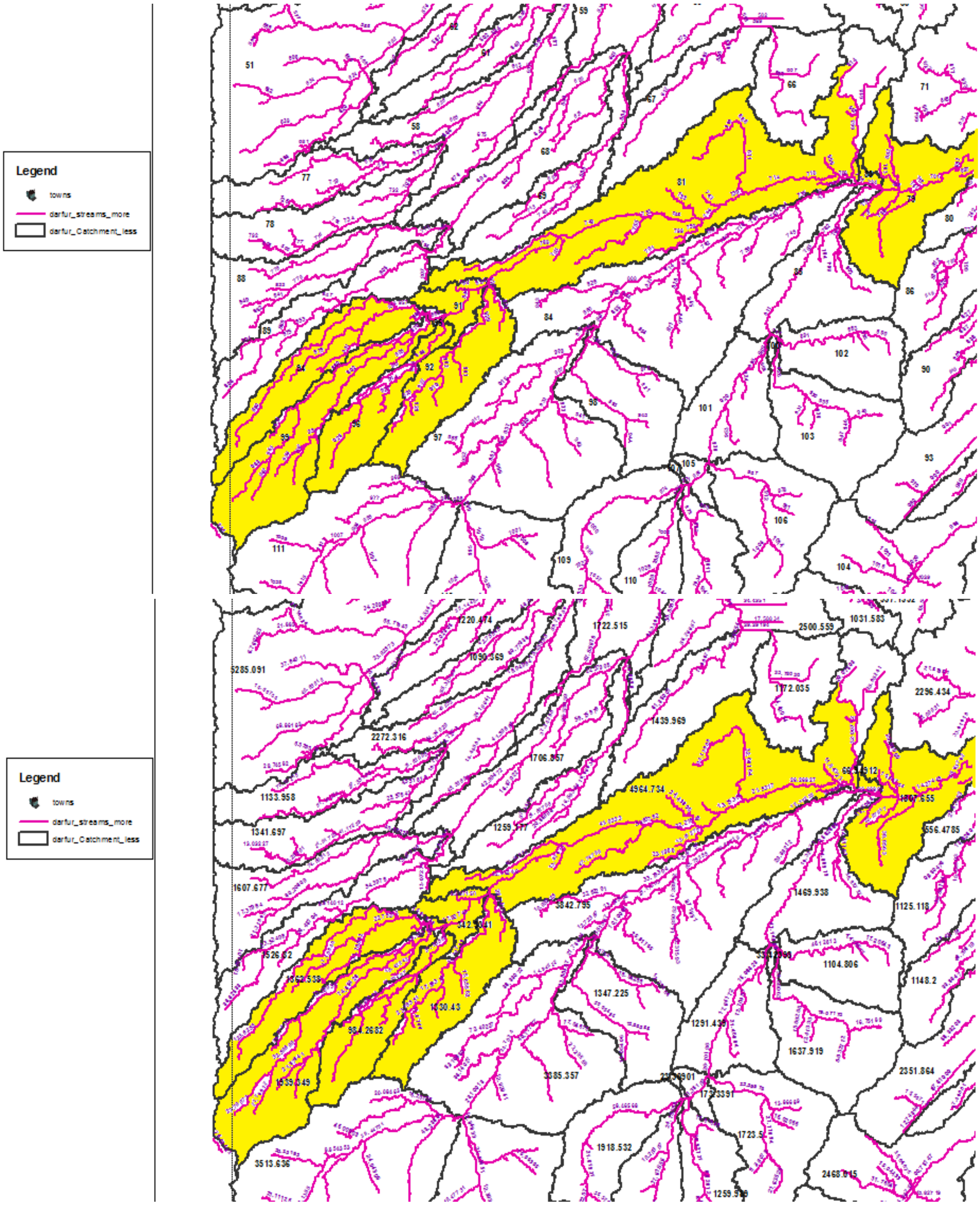

Fig.No.(4.11): Wadi Hawar, (a) Grid ID catchments and streams length ,(b) values of catchments and streams length

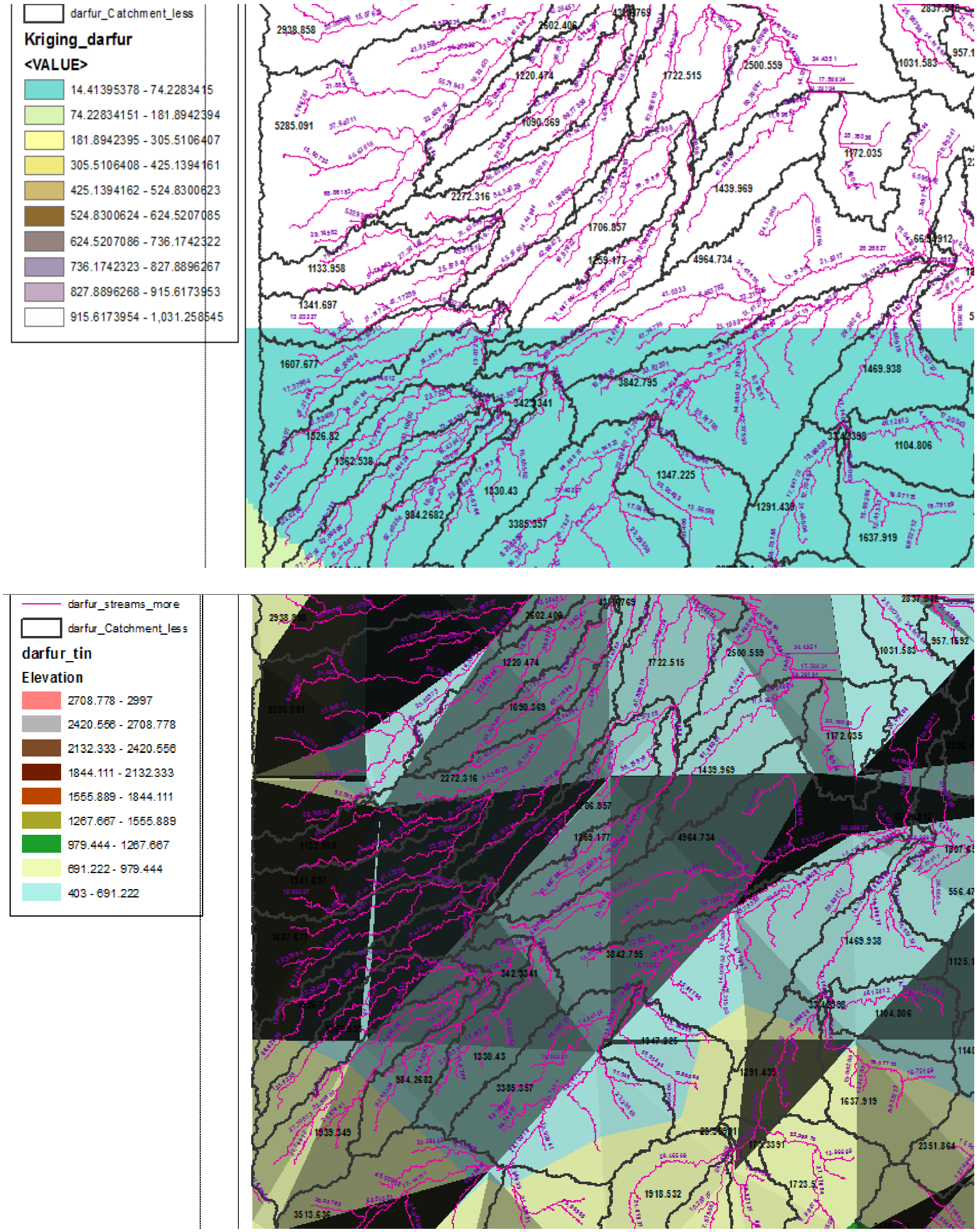

Fig.No.(4.12): Wadi Hawar, (a) rain, catchment and stream length, (b) elevation

Table No. (4.11): Comparison Between Present and Previous Studies for North Dar Fur

no	Name of Wadi	Catchment area (Km)	Estimated/predicted Annual Discharge (M.CM)	Estimated/predicted Total Annual Discharge (M.CM)	Reference %
1	Al Ku	28000	-	103	(Yousif, 2011)
	Howar	-	-		
2	Al Ku	28000	76	100	(Barsi, 2010)
	Howar	12200	24		
3	Al Ku	**27895.996**	**82.249**	**110.901**	Work study
	Howar	**12828.260**	**28.652**		

Table No. (4.12): South Dar Fur State Predicted and Measured Discharges

Wadi, station	Q Measured annual discharge ($M.m^3$)	Q Predict annual discharge ($M.m^3$)	Difference %
Wadi Nyala, Nyala	64	63.656	0.538
Wadibulubul, Timbshuo	76	76.374	0.493
Wadi kaya, EDD elfursan	157	160.010	1.917
Wadi Sindo, Um higira	164	162.415	0.967
Wadi Ebra, Nashala	210	208.878	0.534
Wadi Tawal, Abu likslik	150	149.485	0.343

Table No. (4:13): Verify South Darfur Equation

Years of measured	Big Wadi-small wadi station	Q Measured annual discharge ($M.m^3$)	Q Predict annual discharge (M.m3)	Difference %
1988-1990	Wadi beida, um kadada	4.970	0.152	96.947

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Table No. (4:14): Calculated Wadi Nyala Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
162	4153.147	1222.747	468.128	175.670	0.430	495.951	41.553
Sum	**4153.147**						**41.553**

Table No. (4.15): Calculated Wadi Kaya Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
229	1641.000	666.369	565.131	108.880	0.093	649.468	84.687
227	1115.375	721.630	666.097	26.379	0.211	599.799	26.946
222	1154.896	748.742	666.097	42.158	0.196	596.4297	39.022
Sum	**3911.271**						**150.655**

Table No. (4.16): Calculated Wadi Ebra Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	Length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
254	893.873	565.106	540.283	41.620	0.060	705.348	57.622
242	1435.024	591.176	565.106	52.470	0.050	658.710	32.976
Sum	**2328.897**						**90.597**

Table No. (2.17): Calculated Wadi Bulbul Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
212	2807.209	809.028	608.547	110.860	0.181	627.531	76.599
230	1374.854	634.033	608.547	43.290	0.059	678.346	36.669
239	390.445	608.547	599.451	19.960	0.046	681.611	31.785
Sum	**4572.508**						**145.053**

Table No. (4:18): Calculated Wadi Negida Discharge

Gird ID of catchment	Area (km^2)	Max.Elev	Min.Elev	Length of flow path (L) km	slope%	precipitation (mm)	Pred Q (M.cm)
274	3062.552	507.745	492.278	43.530	0.036	770.031	34.943
Sum	**3062.552**						**34.943**

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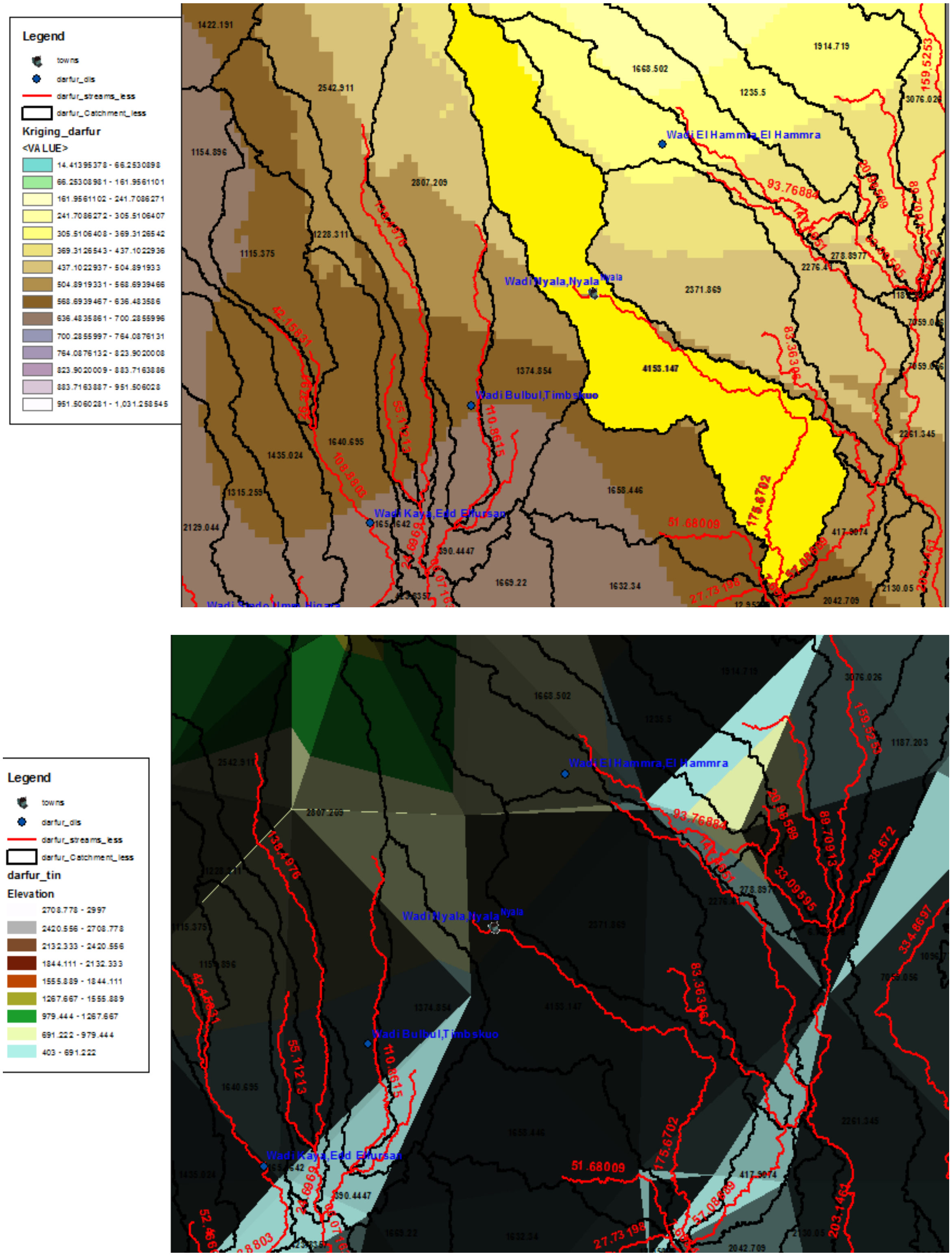

Fig.No.(4.13): Wadi Nyala, (a) rain, catchment and stream length, (b) elevation

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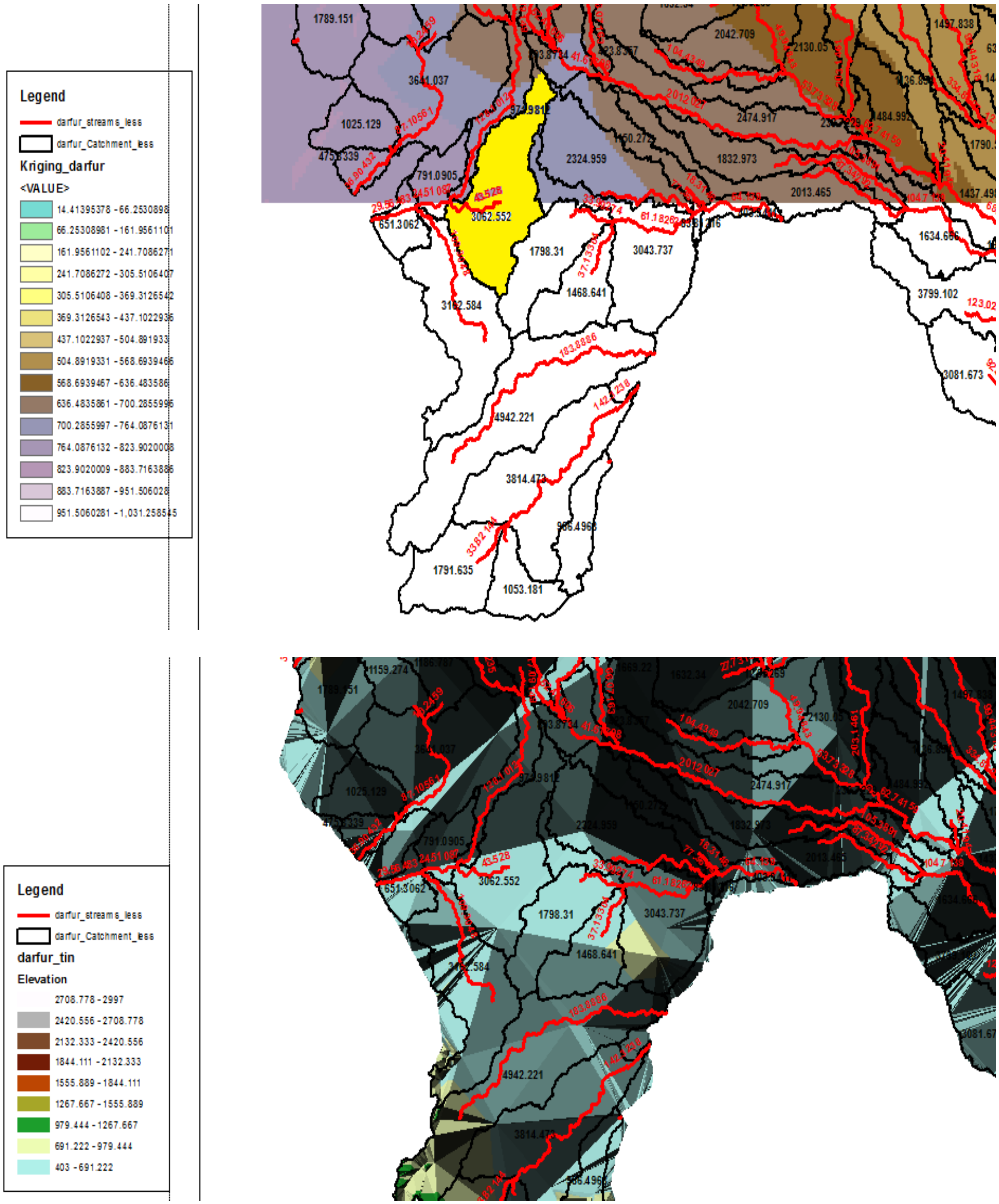

Fig.No.(4.14): Wadi Negida, (a) rain, catchment and stream length, (b) elevation

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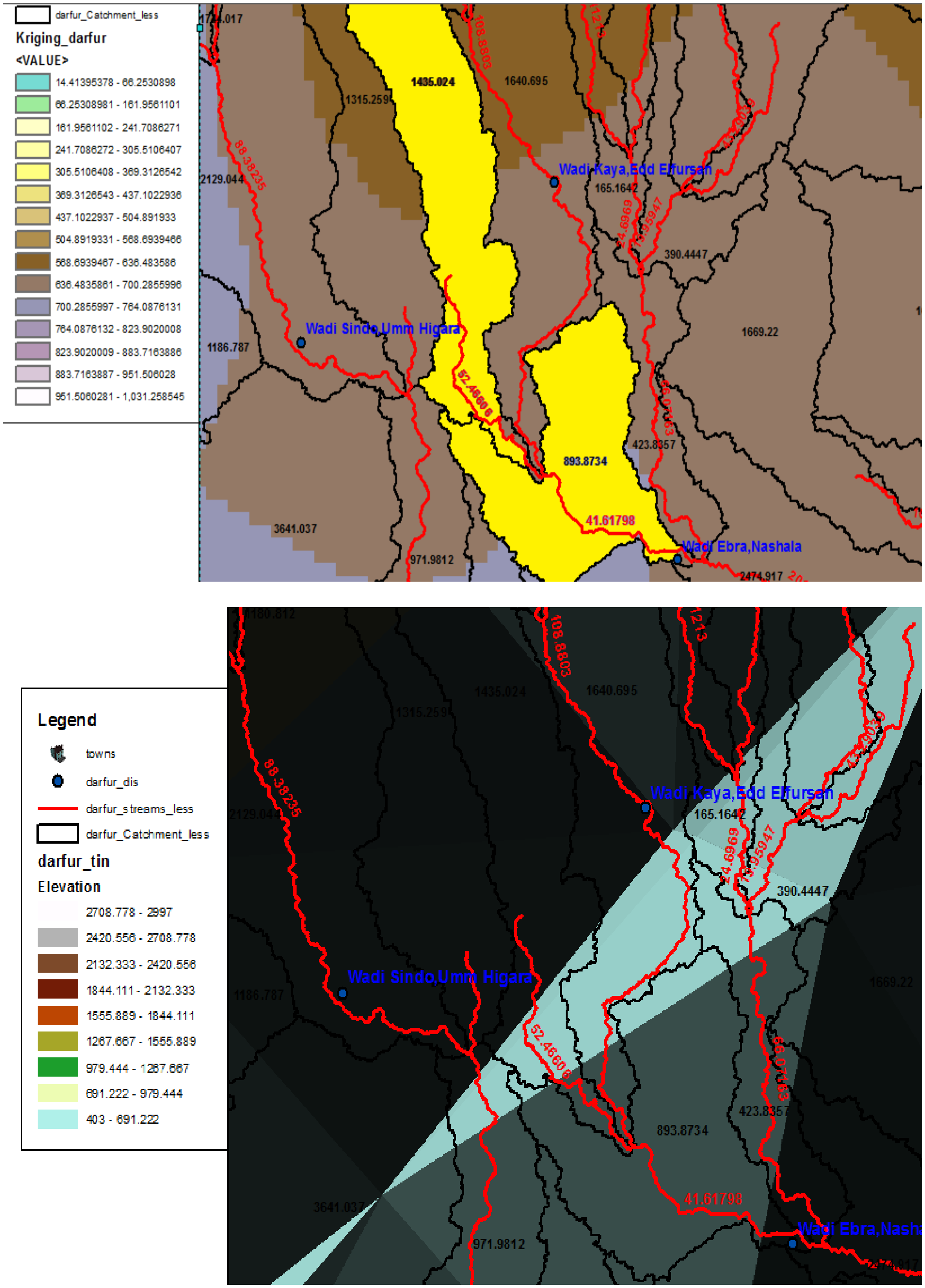

Fig.No.(4.15): Wadi Ebra, (a) rain, catchment and stream length, (b) elevation

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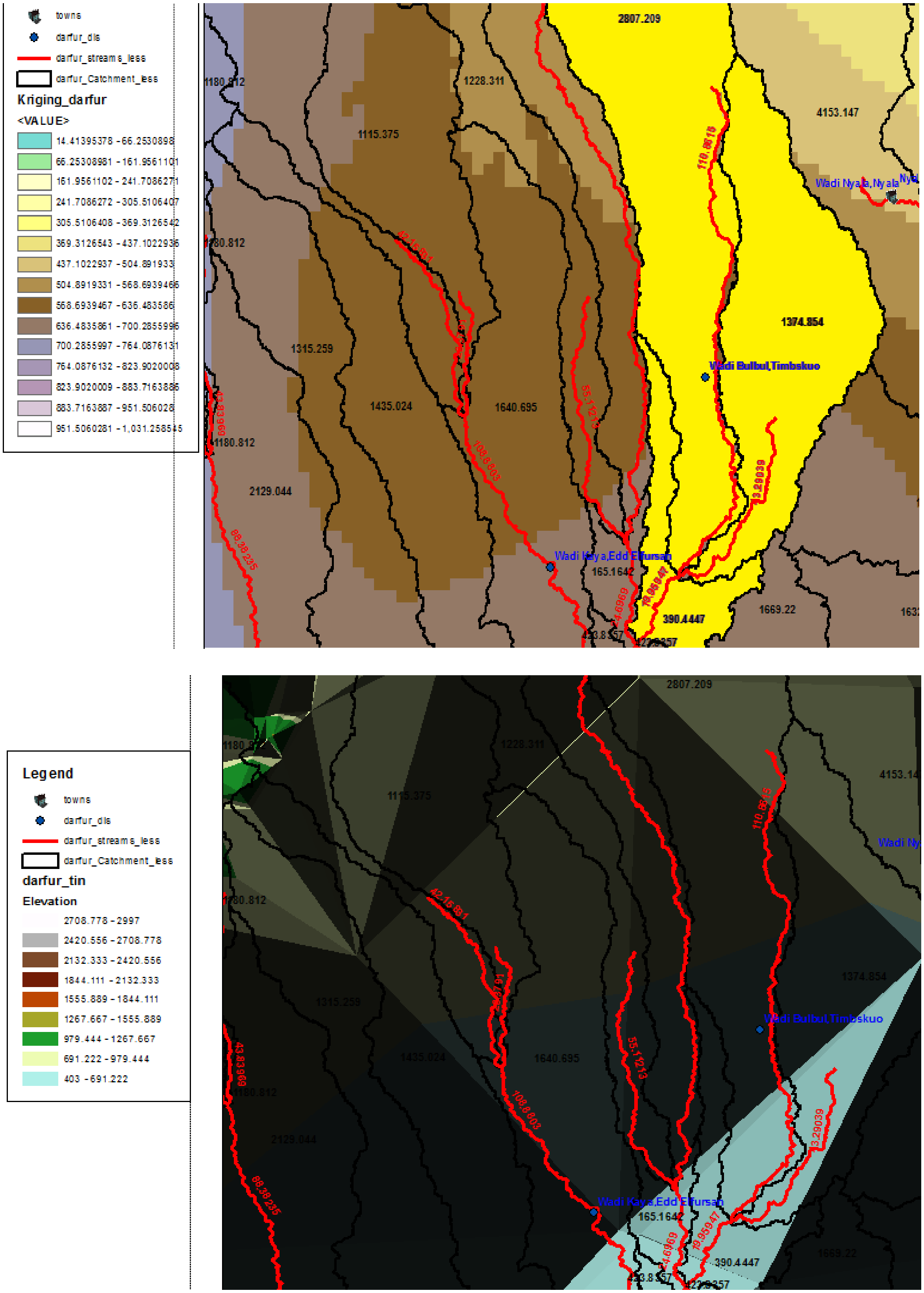

Fig.No.(4.16): Wadi bulbul, (a) rain, catchment and stream length, (b) elevation

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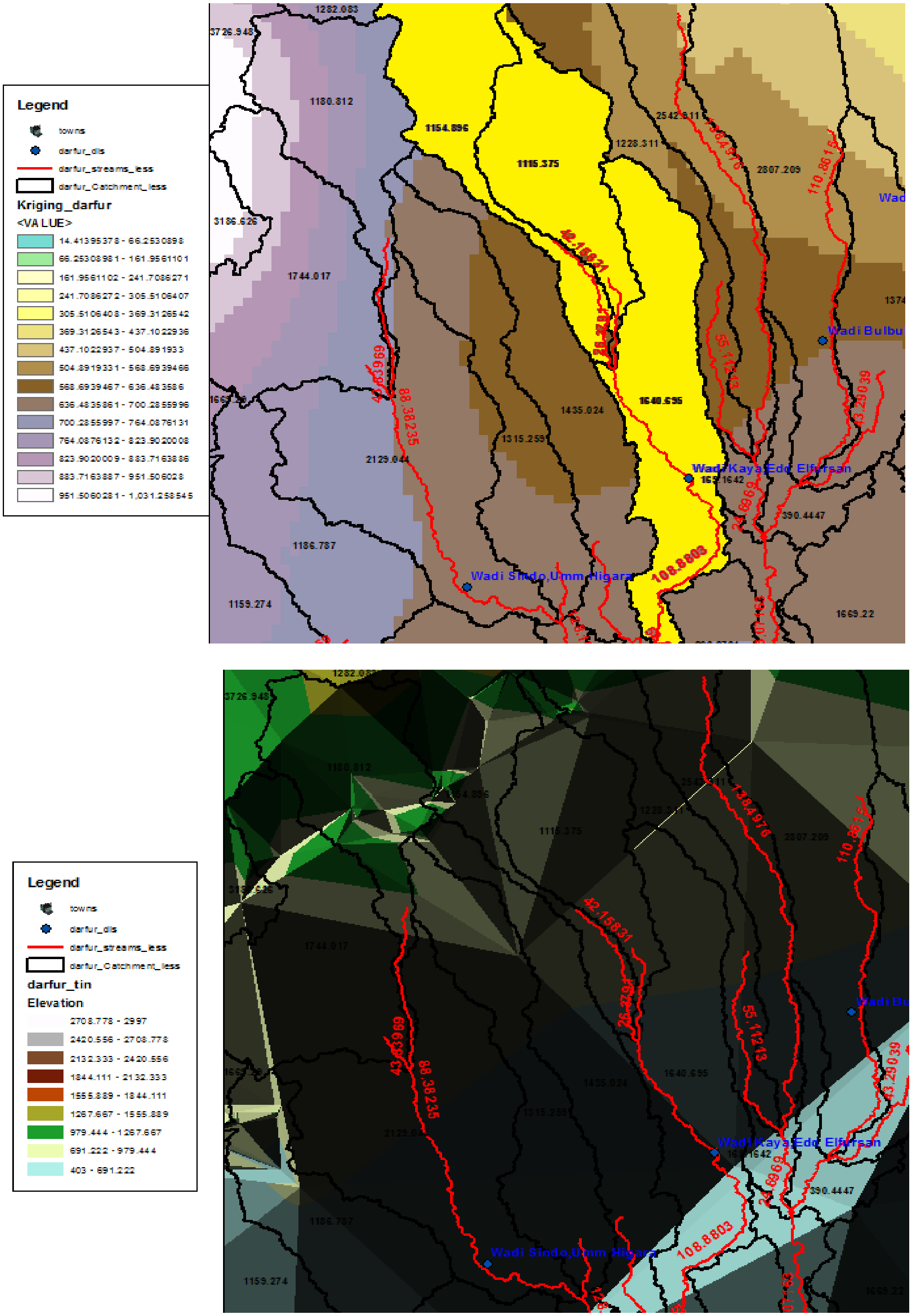

Fig.No.(4.17): Wadi Kaya, (a) rain, catchment and stream length, (b) elevation

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Table No. (4.19): Comparison Between Present and Previous Study for South Dar Fur

No	Name of wadi	Catchment area (Km)	Estimated/predicted Annual Discharge (M.CM)	Estimated/predicted Total Annual Discharge (M.CM)	Reference
1	Nyala	8389	-	823	(Yousif, 2011)
	Negeida	-	-		
	Ibra	15180	-		
	Bulbul	-	-		
	Kaya	-	-		
2	Nyala	4080	41	159	(Barsi, 2010)
	Negeida	3060	31		
	Ibra	1900	19		
	Bulbul	4600	46		
	Kaya	2200	22		
4	Nyala	4153.147	41.553	462.801	Work study
	Negeida	3062.552	34.943		
	Ibra	2328.897	90.597		
	Bulbul	4572.508	145.053		
	Kaya	3911.271	150.655		

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CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions: -

1. Integration of digital elevation models with geographic information systems resulted in generating maps on a scale that cannot be achieved by simple calculations.
2. The study found that the coefficients of regression function have high correlation. This kind of formula is practical and convenient for engineers to use. In many application, such as design of hydraulic structures.
3. The multiple regression gave satisfactory results to produced data output for the area of study has reached a considerable level of clarity and indicated a possible use of considerable amount of water.

5.2. Recommendations: -

1. Use of digital elevation models STRM (DEM 90 m) enabled to generate appropriate maps elevation, drainage lines (stream), catchments and rain using kriging method. It is highly recommended to be used all throughout catchments in the Darfur state.
2. The methodology of using Arc Hydro extension tools reduced time needed to delineate Dar Fur catchments. Using the so, called 3D TIN layer for elevation values instead of using contour lines, and kinging method to rain data. This methodology also would help scientists to understand morphology and topographic characteristics of study area.
3. It is high recommended to using XLSTAT tools in Excel to get best suitable probability distributions fit for the annual rainfall data and multiple regression method.

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4. Verification of generated hydrological maps for all Sudanese localities through measurements and collection of more new accurate data to lead more accurate results.
5. More software need to be calibrated and verified against measured runoff data for a particular region before its usage.
6. The GIS should be used for a wide range because it is more accurate and easier than other Software's.
7. High resolutions DEMs (like 30m) for small area study are required to estimation of the characteristic of catchments with higher resolution is expected to enhance the quality of the results.
8. More meteorological stations to be established in these regions and rehabilitate old stations and update discharge /rain data.
9. Other method of flow estimation in catchment should be used.
10. To improve the regression prediction equations in future studies it is recommended to use rain fall intensity rather than just the precipitation value.

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APPENDIXES

Appendix A: wadi system in Darfur:

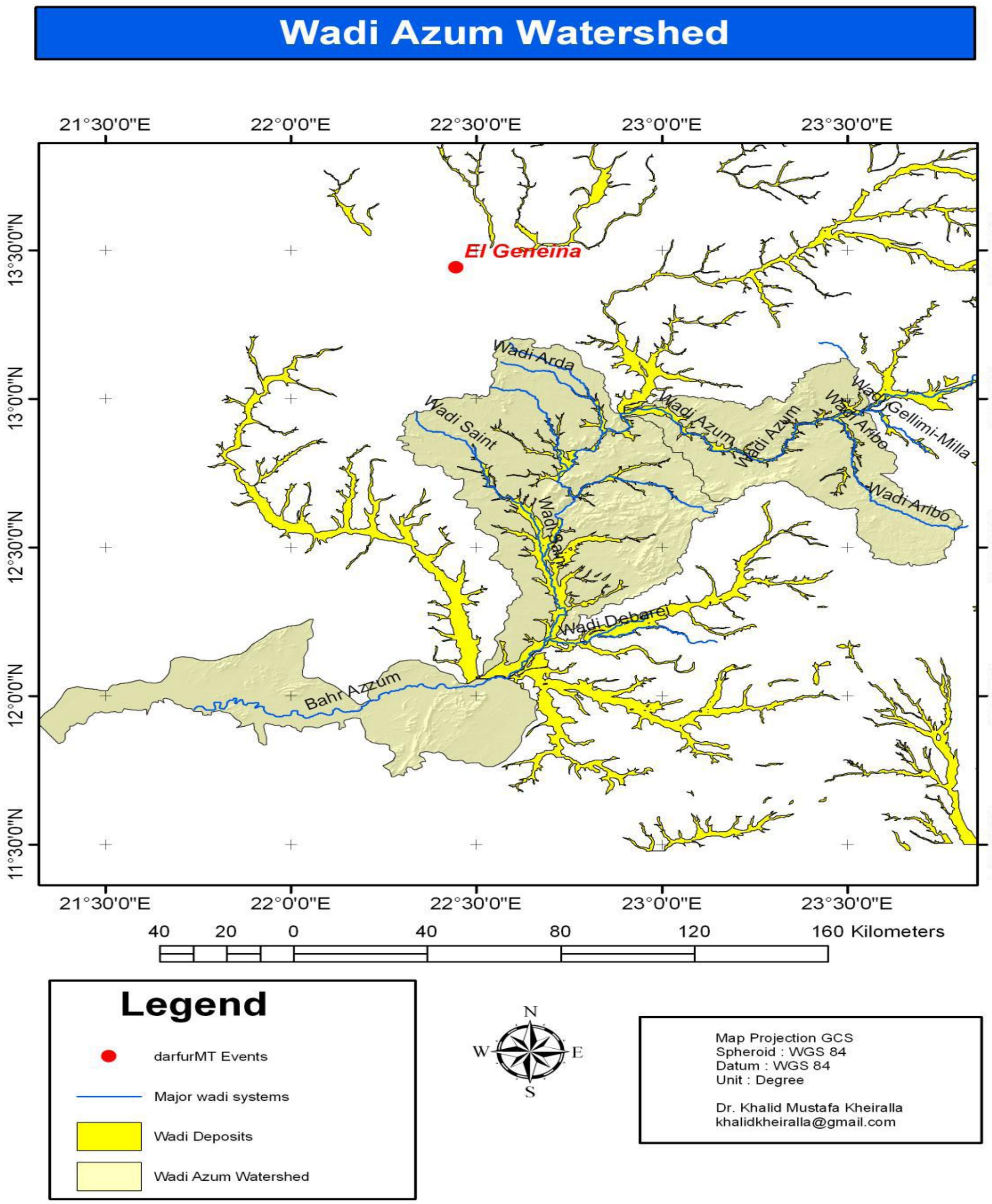

Fig.No. (A.1): wadi Azum

(Barsi, 2010)

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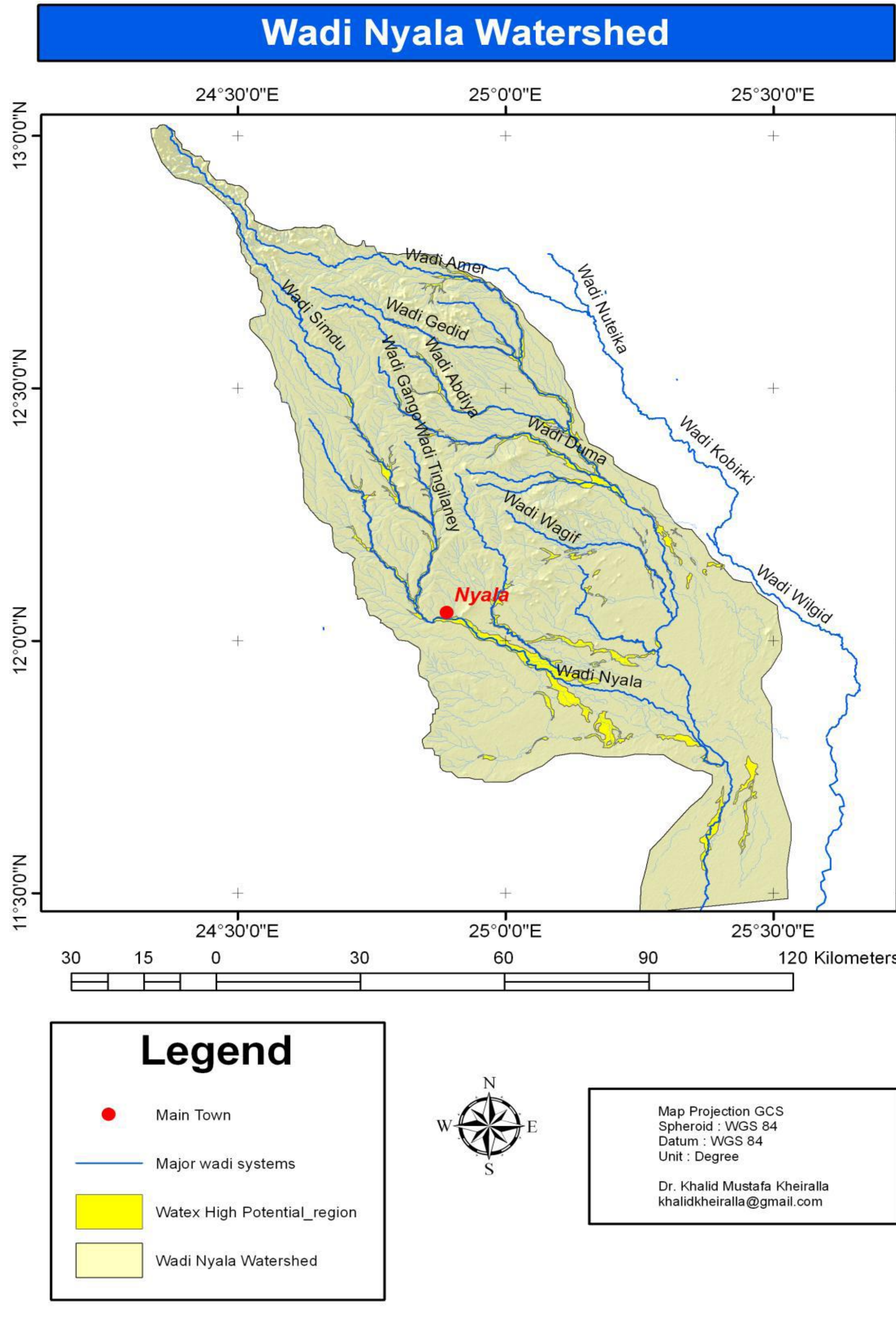

Fig.No.(A.2): wadi Nyala

(Barsi, 2010)

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Appendix B: rainfall distribution fitting with XLSATA tools:

year	p120228	p120231	p130234	p133238	p123228	p123231	p123234	p123238	p126228	p126231	p126234	p126238	p130228	p130231	p130234	p130238	p133228	p133231	p133234	p133238	p136228	p136231	p136234	p136238	p139231	p139234	p139238	p139241	p139244	p142231
1984	475.989	505.296	558.624	333.442	510.006	564.231	587.703	375.005	491.540	490.155	425.977	372.153	357.001	302.571	206.535	237.211	167.902	120.893	75.898	84.368	77.210	66.639	42.908	45.856	55.923	35.210	27.272	38.705	33.153	22.878
1985	771.520	824.829	872.605	517.702	764.136	901.278	863.889	515.912	735.684	782.173	624.386	527.543	655.266	508.369	387.844	452.734	431.270	342.205	270.540	310.556	299.147	288.893	258.138	261.060	273.445	240.347	228.953	263.587	203.566	173.633
1986	869.277	997.345	1007.620	757.796	866.750	961.653	983.553	698.447	874.067	869.439	774.144	715.108	776.919	688.915	575.518	618.447	589.965	535.943	395.784	422.368	397.969	391.496	331.261	317.842	298.398	270.368	277.634	299.361	266.021	211.416
1987	933.181	1097.024	1140.407	800.120	850.498	1049.678	1057.582	784.704	802.364	904.090	788.757	724.425	729.661	625.909	481.369	598.332	597.193	467.761	350.524	413.515	554.635	472.512	320.978	291.002	550.641	408.946	296.010	327.306	296.545	440.829
1988	1020.249	1284.264	1297.607	793.566	1066.869	1361.681	1229.403	784.246	1166.903	1159.829	924.306	838.429	1230.941	988.244	746.664	937.935	1312.189	1081.689	788.962	884.785	1420.231	1327.500	918.270	784.117	1231.697	963.505	757.955	744.092	595.466	980.624
1989	570.204	712.171	818.659	555.350	628.225	760.941	792.549	533.501	772.691	791.265	662.176	593.626	985.923	761.018	540.281	589.216	986.931	780.363	499.097	471.499	891.143	805.558	573.186	425.809	675.539	588.538	439.724	357.629	234.891	478.104
1990	712.732	760.309	766.169	476.184	643.208	775.904	851.470	561.092	649.760	699.542	685.990	608.978	602.530	553.694	497.336	530.433	561.805	464.358	343.667	341.047	531.074	445.805	310.132	225.062	398.028	299.098	222.350	191.353	142.738	282.686
1991	619.025	578.950	582.158	347.734	650.108	725.755	724.245	486.303	651.905	661.512	601.047	559.819	562.891	518.359	434.576	507.544	516.319	466.249	366.397	397.705	558.240	539.801	443.334	387.368	645.001	557.844	464.880	404.893	305.050	594.699
1992	1025.508	1131.903	1099.401	674.996	1027.070	1174.643	1059.854	631.449	918.587	960.205	761.573	621.155	758.451	630.821	455.161	527.080	614.977	508.821	384.377	457.766	628.441	562.527	457.444	472.482	578.194	537.198	512.061	524.334	433.442	458.235
1993	911.628	995.943	1071.119	777.453	887.918	1042.747	1050.878	748.912	906.340	934.479	832.282	752.024	868.855	791.107	653.697	662.888	694.374	693.508	548.478	532.348	589.771	590.613	519.187	488.721	514.034	491.535	453.977	495.716	416.331	384.883
1994	712.244	897.575	935.239	563.897	755.015	991.254	989.606	649.214	847.965	949.251	864.523	796.969	898.974	824.450	707.138	816.430	775.313	693.136	558.903	646.148	721.832	731.999	533.193	487.281	755.634	583.610	435.934	486.204	473.998	695.652
1995	953.331	1196.365	1363.116	1007.830	965.875	1225.028	1290.530	888.733	1052.986	1022.223	906.687	870.696	1067.775	863.503	663.694	796.992	1082.627	831.932	592.509	673.634	1022.284	851.813	629.897	628.374	758.528	577.896	613.745	642.699	516.742	567.484
1996	862.670	1012.697	1069.162	746.738	747.471	930.316	1022.318	725.671	766.172	799.563	789.386	778.360	767.386	669.538	540.795	660.198	611.939	494.993	372.446	458.794	489.777	433.502	307.386	313.101	453.921	358.623	311.845	349.070	353.725	436.394
1997	692.862	1009.143	1191.407	859.170	652.885	993.919	1187.892	913.881	689.498	867.961	924.114	897.389	681.642	645.782	585.575	722.410	479.196	440.140	337.656	402.728	419.031	348.532	247.099	210.856	333.771	258.252	172.386	202.604	176.622	264.238
1998	732.198	876.671	1020.535	748.161	740.661	889.515	911.729	655.764	930.103	900.633	802.830	738.403	1046.364	888.803	747.261	827.777	1058.561	929.477	770.127	841.202	1110.143	978.112	852.294	793.295	1037.453	884.054	745.866	682.581	562.319	974.865
1999	849.823	1046.547	1178.090	861.380	726.317	991.945	1095.570	800.870	753.175	862.285	799.553	803.861	823.447	716.642	561.443	683.778	942.999	775.730	568.824	567.326	1059.134	996.530	708.253	605.348	987.441	812.576	689.309	713.490	598.617	745.031
2000	578.715	580.185	565.913	437.942	540.969	548.495	544.227	406.582	536.539	461.920	399.611	380.975	496.494	367.461	240.353	269.180	375.857	264.078	161.559	141.303	269.996	208.437	133.039	89.001	155.442	127.217	74.559	56.366	35.754	82.140
2001	581.439	644.617	711.675	518.922	558.471	708.765	705.985	496.495	599.310	630.830	584.261	536.371	590.865	525.347	435.318	519.956	543.341	451.788	363.797	366.390	466.197	442.005	336.879	257.381	402.824	319.797	200.573	178.065	152.402	326.673
2002	756.618	794.602	786.938	549.668	709.170	771.300	735.572	483.202	740.152	725.769	606.893	449.903	620.315	641.298	501.270	459.891	479.546	475.616	393.122	382.086	421.684	388.826	299.368	272.626	362.269	268.878	228.026	234.827	190.708	303.103
2003	673.317	880.901	963.612	689.426	672.410	832.694	853.152	619.206	733.527	747.123	657.750	616.813	717.910	616.547	494.111	524.865	528.308	430.407	328.692	362.075	347.616	324.210	258.446	240.652	256.285	219.262	195.148	202.803	174.373	181.621
2004	957.218	1000.764	989.992	655.203	811.118	922.923	939.178	615.589	578.904	660.907	633.065	547.072	374.339	374.050	302.110	364.599	287.310	254.011	171.765	184.040	202.132	188.592	137.876	107.508	151.134	123.820	97.778	114.969	175.981	89.213
2005	715.752	824.854	894.803	626.901	620.638	788.164	866.680	629.110	719.752	832.329	715.668	653.996	754.359	709.463	555.054	630.697	648.231	554.729	419.127	455.430	523.323	489.480	337.564	315.388	393.462	312.419	276.723	313.367	276.656	291.970
2006	692.200	867.706	972.267	785.678	573.861	811.321	894.184	703.160	614.431	687.945	656.250	692.921	738.778	541.998	467.118	612.882	709.167	495.130	328.367	406.403	666.132	455.106	268.317	239.461	363.688	250.215	174.837	196.154	189.844	208.116
2007	879.909	1102.021	1187.755	874.755	943.663	1167.665	1214.256	854.661	1104.722	1131.157	1022.249	909.053	1046.549	909.924	756.839	849.967	830.498	728.151	630.984	690.535	711.483	699.496	646.509	616.931	641.051	618.007	561.209	549.497	475.774	498.211
2008	746.784	925.129	1012.490	716.263	686.877	947.677	995.604	633.131	713.345	731.432	630.275	535.044	738.309	590.695	382.860	389.555	622.092	477.077	280.705	266.470	450.890	369.192	250.019	239.111	290.285	287.026	254.128	275.523	228.903	203.114
2009	824.467	889.838	960.316	651.218	799.750	901.478	929.839	655.326	776.392	811.525	739.356	666.493	690.660	571.334	482.311	607.897	572.262	468.609	341.327	409.543	505.735	441.127	298.053	267.560	341.404	245.670	210.290	254.399	246.191	197.141
2010	1438.652	1489.805	1546.128	1110.889	1316.070	1507.681	1429.956	1084.549	1125.510	1112.504	998.202	924.601	904.199	764.702	590.292	718.516	718.579	622.633	451.482	532.361	666.723	651.134	504.569	472.651	680.368	576.193	555.777	653.535	619.799	556.616
2011	912.528	799.206	970.134	775.734	996.544	908.353	1322.804	1053.163	812.362	761.325	811.726	550.417	455.869	501.684	486.269	198.580	405.336	511.609	638.596	249.810	400.913	509.254	643.389	349.508	452.166	433.040	287.610	318.020	352.635	371.777
2012	1034.795	1158.295	1567.838	1313.326	1085.878	1216.899	2084.081	1721.075	1101.865	1176.716	1462.826	1089.253	839.816	910.705	857.787	426.733	705.300	778.253	995.782	433.251	655.458	729.956	939.130	547.006	689.897	683.997	495.071	489.904	492.601	623.375
2013	876.611	1039.097	1482.009	1124.376	925.729	1004.115	1775.385	1527.348	850.646	898.781	1171.381	924.385	581.196	681.742	642.774	408.063	510.366	572.708	733.685	298.018	492.102	500.077	671.443	364.270	448.883	495.617	370.400	386.565	328.450	327.599

year	p142238	p142241	p142244	p133253	p133256	p133259	p136253	p136256	p136259	p139253	p139256	p139259	p123250	p126250	p130250
1984	475.989	505.296	558.624	333.442	510.006	564.231	587.703	375.005	491.540	490.155	425.977	372.153	357.001	302.571	206.535
1985	771.520	824.829	872.605	517.702	764.136	901.278	863.839	515.912	735.684	782.173	624.386	527.543	655.266	508.369	387.844
1986	869.277	997.345	1007.620	757.796	866.750	961.653	983.553	698.447	874.067	869.439	774.144	715.108	776.919	688.915	575.518
1987	933.181	1097.024	1140.407	800.120	850.498	1049.678	1057.582	784.704	802.364	904.090	788.757	724.425	729.661	625.909	481.369
1988	1020.249	1284.264	1297.607	793.566	1066.869	1361.681	1229.403	784.246	1166.903	1159.829	924.306	838.429	1230.941	988.244	746.664
1989	570.204	712.171	818.659	555.350	628.225	760.941	792.549	533.501	772.691	791.265	662.176	593.626	985.923	761.018	540.281
1990	712.732	760.309	766.169	476.184	643.208	775.904	851.470	561.092	649.760	699.542	685.990	603.978	602.530	553.694	497.336
1991	619.025	578.950	582.158	347.734	650.108	725.755	724.245	486.303	651.905	661.512	601.047	559.819	562.891	518.359	434.576
1992	1025.508	1131.903	1099.401	674.996	1027.070	1174.643	1059.854	631.449	918.587	960.205	761.573	621.155	758.451	630.821	455.161
1993	911.628	995.943	1071.119	777.453	887.918	1042.747	1050.878	748.912	906.340	934.479	832.282	752.024	868.855	791.107	653.697
1994	712.244	897.575	935.239	563.897	755.015	991.254	989.606	649.214	847.965	949.251	864.523	796.969	898.974	824.450	707.138
1995	953.331	1196.365	1363.116	1007.830	965.875	1225.028	1290.530	888.733	1052.986	1022.223	906.687	870.696	1067.775	863.503	663.694
1996	862.670	1012.697	1069.162	746.738	747.471	930.316	1022.318	725.671	766.172	799.563	789.386	778.360	767.386	669.538	540.795
1997	692.862	1009.143	1191.407	859.170	652.885	993.919	1187.892	913.881	689.498	867.961	924.114	897.389	681.642	645.782	585.575
1998	732.198	876.671	1020.535	748.161	740.661	889.515	911.729	655.764	930.103	900.633	802.830	738.403	1046.364	888.803	747.261
1999	849.823	1046.547	1178.090	861.380	726.317	991.945	1095.570	800.870	753.175	862.285	799.553	803.861	823.447	716.642	561.443
2000	578.715	580.185	565.913	437.942	540.969	548.495	544.227	406.582	536.539	461.920	399.611	380.975	496.494	367.461	240.353
2001	581.439	644.617	711.675	518.922	558.471	708.765	705.985	496.495	599.310	630.830	584.261	536.371	590.865	525.347	435.318
2002	756.618	794.602	786.938	549.668	709.170	771.300	735.572	483.202	740.152	725.769	606.893	449.903	620.315	641.298	501.270
2003	673.317	880.901	963.612	689.426	672.410	832.694	853.152	619.206	733.527	747.123	657.750	616.813	717.910	616.547	494.111
2004	957.218	1000.764	989.992	655.203	811.118	922.923	939.178	615.589	578.904	660.907	633.065	547.072	374.339	374.050	302.110
2005	715.752	824.854	894.803	626.901	620.638	788.164	866.680	629.110	719.752	832.329	715.668	653.996	754.359	709.463	555.054
2006	692.200	867.706	972.267	785.678	573.861	811.321	894.184	703.160	614.431	687.945	656.250	692.921	738.778	541.998	467.118
2007	879.909	1102.021	1187.755	874.755	943.663	1167.665	1214.256	854.661	1104.722	1131.157	1022.249	909.053	1046.549	909.924	756.839
2008	746.784	925.129	1012.490	716.263	686.877	947.677	995.604	633.131	713.345	731.432	630.275	535.044	738.309	590.695	382.860
2009	824.467	889.838	960.316	651.218	799.750	901.478	929.839	655.326	776.392	811.525	739.356	666.493	690.660	571.334	482.311
2010	1438.652	1489.805	1546.128	1110.889	1316.070	1507.681	1429.956	1084.549	1125.510	1112.504	998.202	924.601	904.199	764.702	590.292
2011	912.528	799.206	970.134	775.734	996.544	908.353	1322.804	1053.163	812.362	761.325	811.726	550.417	455.869	501.684	486.269
2012	1034.795	1158.295	1567.838	1313.326	1085.878	1216.899	2084.081	1721.075	1101.865	1176.716	1462.826	1089.253	839.816	910.705	857.787
2013	876.611	1039.097	1482.009	1124.376	925.729	1004.115	1775.385	1527.348	850.646	898.781	1171.381	924.385	581.196	681.742	642.774

year	p108238	p108241	p108244	p108247	p111238	p111241	p111244	p111247	p114238	p114241	p114244	p114247	p117238	p117241	p117244	p117247
1984	237.211	167.902	120.893	75.898	84.368	77.210	66.639	42.908	45.856	55.923	35.210	27.272	38.705	33.153	22.878	20.397
1985	452.734	431.270	342.205	270.540	310.556	299.147	288.893	258.138	261.060	273.445	240.347	228.953	263.587	203.566	173.633	184.134
1986	618.447	589.965	535.943	395.784	422.368	397.969	391.496	331.261	317.842	298.398	270.368	277.634	299.361	266.021	211.416	192.937
1987	598.332	597.193	467.761	350.524	413.515	554.635	472.512	320.978	291.002	550.641	408.946	296.010	327.306	296.545	440.829	364.186
1988	937.935	1312.189	1081.689	788.962	884.785	1420.231	1327.500	918.270	784.117	1231.697	963.505	757.955	744.092	595.466	980.624	841.332
1989	589.216	986.931	780.363	499.097	471.499	891.143	805.558	573.186	425.809	675.539	588.538	439.724	357.629	234.891	478.104	442.044
1990	530.433	561.805	464.358	343.667	341.047	531.074	445.805	310.132	225.062	398.028	299.098	222.350	191.353	142.738	282.686	254.997
1991	507.544	516.319	466.249	366.397	397.705	558.240	539.801	443.334	387.368	645.001	557.844	464.880	404.893	305.050	594.699	547.669
1992	527.080	614.977	508.821	384.377	457.766	628.441	562.527	457.444	472.482	578.194	537.198	512.061	524.334	433.442	458.235	444.237
1993	662.888	694.374	693.508	548.478	532.348	589.771	590.613	519.187	488.721	514.034	491.535	453.977	495.716	416.331	384.883	387.374
1994	816.430	775.313	693.136	558.903	646.148	721.832	731.999	533.193	487.281	755.634	583.610	435.934	486.204	473.998	695.652	554.264
1995	796.992	1082.627	831.932	592.509	673.634	1022.284	851.813	629.897	628.374	758.528	577.896	613.745	642.699	516.742	567.484	470.022
1996	660.198	611.939	494.993	372.446	458.794	489.777	433.502	307.386	313.101	453.921	358.623	311.845	349.070	353.725	436.394	372.389
1997	722.410	479.196	440.140	337.656	402.728	419.031	348.532	247.099	210.856	333.771	258.252	172.386	202.604	176.622	264.238	236.796
1998	827.777	1058.561	929.477	770.127	841.202	1110.143	978.112	852.294	793.295	1037.453	884.054	745.866	682.581	562.319	974.865	864.179
1999	683.778	942.999	775.730	568.824	567.326	1059.134	996.530	708.253	605.348	987.441	812.576	689.309	713.490	598.617	745.031	716.339
2000	269.180	375.857	264.078	161.559	141.303	269.996	208.437	133.039	89.001	155.442	127.217	74.559	56.366	35.754	82.140	76.056
2001	519.956	543.341	451.788	363.797	366.390	466.197	442.005	336.879	257.381	402.824	319.797	200.573	178.065	152.402	326.673	241.062
2002	459.891	479.546	475.616	393.122	382.086	421.684	388.826	299.368	272.626	362.269	268.878	228.026	234.827	190.708	303.103	269.009
2003	524.865	528.308	430.407	328.692	362.075	347.616	324.210	258.446	240.652	256.285	219.262	195.148	202.803	174.373	181.621	170.322
2004	364.599	287.310	254.011	171.765	184.040	202.132	188.592	137.876	107.508	151.134	123.820	97.778	114.969	175.981	89.213	94.718
2005	630.697	648.231	554.729	419.127	455.430	523.323	489.480	337.564	315.388	393.462	312.419	276.723	313.367	276.656	291.970	251.329
2006	612.882	709.167	495.130	328.367	406.403	666.132	455.106	268.317	239.461	363.688	250.215	174.837	196.154	189.844	208.116	155.747
2007	849.967	830.498	728.151	630.984	690.535	711.483	699.496	646.509	616.931	641.051	618.007	561.209	549.497	475.774	498.211	451.589
2008	389.555	622.092	477.077	280.705	266.470	450.890	369.192	250.019	239.111	290.285	287.026	254.128	275.523	228.903	203.114	220.756
2009	607.897	572.262	468.609	341.327	409.543	505.735	441.127	298.053	267.560	341.404	245.670	210.290	254.399	246.191	197.141	147.246
2010	718.516	718.579	622.633	451.482	532.361	666.723	651.134	504.569	472.651	680.368	576.193	555.777	653.535	619.799	556.616	537.661
2011	198.580	405.336	511.609	638.596	249.810	400.913	509.254	643.389	349.508	452.166	433.040	287.610	318.020	352.635	371.777	320.976
2012	426.733	705.300	778.253	995.782	433.251	655.458	729.956	939.130	547.006	689.897	683.997	495.071	489.904	492.601	623.375	560.570
2013	408.063	510.366	572.708	733.685	298.018	492.102	500.077	671.443	364.270	448.883	495.617	370.400	386.565	328.450	327.599	311.487

year	p145241	p145238	p145234	p126269	p126272	p130269	p130272	p133269	p133272	p136241	p136244	p142253	p142256	p142259	p167247
1984	475.989	505.296	558.624	333.442	510.006	564.231	587.703	375.005	491.540	490.155	425.977	372.153	357.001	302.571	206.535
1985	475.989	505.296	558.624	333.442	510.006	564.231	587.703	375.005	491.540	490.155	425.977	372.153	357.001	302.571	206.535
1986	771.520	824.829	872.605	517.702	764.136	901.278	863.839	515.912	735.684	782.173	624.386	527.543	655.266	508.369	387.844
1987	869.277	997.345	1007.620	757.796	866.750	961.653	983.553	698.447	874.067	869.439	774.144	715.108	776.919	688.915	575.518
1988	933.181	1097.024	1140.303	799.787	850.498	1049.678	1057.441	784.520	802.364	904.090	788.757	724.425	729.661	625.909	481.369
1989	1020.249	1284.264	1297.607	793.566	1066.869	1361.681	1229.403	784.246	1166.903	1159.829	924.306	838.429	1230.941	988.244	746.664
1990	570.204	712.171	818.659	555.350	628.225	760.941	792.549	533.501	772.691	791.265	662.176	593.626	985.923	761.018	540.281
1991	712.732	760.309	766.169	476.184	643.208	775.904	851.470	561.092	649.760	699.542	685.990	603.978	602.530	553.694	497.336
1992	619.025	578.950	582.158	347.734	650.108	725.755	724.245	486.303	651.905	661.512	601.047	559.819	562.891	518.359	434.576
1993	1025.508	1131.903	1099.401	674.996	1027.070	1174.643	1059.854	631.449	918.587	960.205	761.573	621.155	758.451	630.821	455.161
1994	911.628	995.943	1071.119	777.453	887.918	1042.747	1050.878	748.912	906.340	934.479	832.282	752.024	868.855	791.107	653.697
1995	712.244	897.575	935.239	563.897	755.015	991.254	989.606	649.214	847.965	949.251	864.523	796.969	898.974	824.450	707.138
1996	953.331	1196.365	1363.116	1007.830	965.875	1225.028	1290.530	888.733	1052.986	1022.223	906.687	870.696	1067.775	863.503	663.694
1997	862.670	1012.697	1069.162	746.738	747.471	930.316	1022.318	725.671	766.172	799.563	789.386	778.360	767.386	669.538	540.795
1998	692.862	1009.143	1191.407	859.170	652.885	993.919	1187.892	913.881	689.498	867.961	924.114	897.389	681.642	645.782	585.575
1999	732.198	876.671	1020.535	748.161	740.661	889.515	911.729	655.764	930.103	900.633	802.830	738.403	1046.364	888.803	747.261
2000	849.823	1046.547	1178.090	861.380	726.317	991.945	1095.570	800.870	753.175	862.285	799.553	803.861	823.447	716.642	561.443
2001	578.715	580.185	565.913	437.942	540.969	548.495	544.227	406.582	536.539	461.920	399.611	380.975	496.494	367.461	240.353
2002	581.439	644.617	711.675	518.922	558.471	708.765	705.985	496.495	599.310	630.830	584.261	536.371	590.865	525.347	435.318
2003	756.618	794.602	786.938	549.668	709.170	771.300	735.572	483.202	740.152	725.769	606.893	449.903	620.315	641.298	501.270
2004	673.317	880.901	963.612	689.426	672.410	832.694	853.152	619.206	733.527	747.123	657.750	616.813	717.910	616.547	494.111
2005	957.218	1000.764	989.992	655.203	811.118	922.923	939.178	615.589	578.904	660.907	633.065	547.072	374.339	374.050	302.110
2006	715.752	824.854	894.803	626.901	620.638	788.164	866.680	629.110	719.752	832.329	715.668	653.996	754.359	709.463	555.054
2007	692.200	867.706	972.267	785.678	573.861	811.321	894.184	703.160	614.431	687.945	656.250	692.921	738.778	541.998	467.118
2008	879.909	1102.021	1187.755	874.755	943.663	1167.665	1214.256	854.661	1104.722	1131.157	1022.249	909.053	1046.549	909.924	756.839
2009	746.784	925.129	1012.490	716.263	686.877	947.677	995.604	633.131	713.345	731.432	630.275	535.044	738.309	590.695	382.860
2010	824.467	889.838	960.316	651.218	799.750	901.478	929.839	655.326	776.392	811.525	739.356	666.493	690.660	571.334	482.311
2011	1438.652	1489.805	1546.128	1110.889	1316.070	1507.681	1429.956	1084.549	1125.510	1112.504	998.202	924.601	904.199	764.702	590.292
2012	912.528	799.206	970.134	775.734	996.544	908.353	1322.804	1053.163	812.362	761.325	811.726	550.417	455.869	501.684	486.269
2013	1034.795	1158.295	1567.838	1313.326	1085.878	1216.899	2084.081	1721.075	1101.865	1176.716	1462.826	1089.253	839.816	910.705	857.787

year	p167250	p167253	p167256	p167259	p167263	p170247	p170250	p170253	p170256	p170259	p170263	p105238	p105241	p105244	p105247	p105250
1984	237.211	167.902	120.893	75.898	84.368	77.210	66.639	42.908	45.856	55.923	35.210	27.272	38.705	33.153	22.878	20.397
1985	237.211	167.902	120.893	75.898	84.368	77.210	66.639	42.908	45.856	55.923	35.210	27.272	38.705	33.153	22.878	20.397
1986	452.734	431.270	342.205	270.540	310.556	299.147	288.893	258.138	261.060	273.445	240.347	228.953	263.587	203.566	173.633	184.134
1987	618.447	589.965	535.943	395.784	422.368	397.969	391.496	331.261	317.842	298.398	270.368	277.634	299.361	266.021	211.416	192.937
1988	598.332	597.193	467.761	350.524	413.515	554.635	472.512	320.978	291.002	550.641	408.946	296.010	327.306	296.545	440.829	364.186
1989	937.935	1312.189	1081.689	788.962	884.785	1420.231	1327.500	918.270	784.117	1231.697	963.505	757.955	744.092	595.476	980.624	841.332
1990	589.216	986.931	780.363	499.097	471.499	891.143	805.558	573.186	425.809	675.539	588.538	439.724	357.629	234.891	478.104	442.044
1991	530.433	561.805	464.358	343.667	341.047	531.074	445.805	310.132	225.062	398.028	299.098	222.350	191.353	142.738	282.686	254.997
1992	507.544	516.319	466.249	366.397	397.705	558.240	539.801	443.334	387.368	645.001	557.844	464.880	404.893	305.050	594.699	547.669
1993	527.080	614.977	508.821	384.377	457.766	628.441	562.527	457.444	472.482	578.194	537.198	512.061	524.334	433.442	458.235	444.237
1994	662.888	694.374	693.508	548.478	532.348	589.771	590.613	519.187	488.721	514.034	491.535	453.977	495.716	416.331	384.883	387.374
1995	816.430	775.313	693.136	558.903	646.148	721.832	731.999	533.193	487.281	755.634	583.610	435.934	486.204	473.998	695.652	554.264
1996	796.992	1082.627	831.932	592.509	673.634	1022.284	851.813	629.897	628.374	758.528	577.896	613.745	642.699	516.742	567.484	470.022
1997	660.198	611.939	494.993	372.446	458.794	489.777	433.502	307.386	313.101	453.921	358.623	311.845	349.070	353.725	436.394	372.389
1998	722.410	479.196	440.140	337.656	402.728	419.031	348.532	247.099	210.856	333.771	258.252	172.386	202.604	176.622	264.238	236.796
1999	827.777	1058.561	929.477	770.127	841.202	1110.143	978.112	852.294	793.295	1037.453	884.054	745.866	682.581	562.319	974.865	864.179
2000	683.778	942.999	775.730	568.824	567.326	1059.134	996.530	708.253	605.348	987.441	812.576	689.309	713.490	598.617	745.031	716.339
2001	269.180	375.857	264.078	161.559	141.303	269.996	208.437	133.039	89.001	155.442	127.217	74.559	56.366	35.754	82.140	76.056
2002	519.956	543.341	451.788	363.797	366.390	466.197	442.005	336.879	257.381	402.824	319.797	200.573	178.065	152.402	326.673	241.062
2003	459.891	479.546	475.616	393.122	382.086	421.684	388.826	299.368	272.626	362.269	268.878	228.026	234.827	190.708	303.103	269.009
2004	524.865	528.308	430.407	328.692	362.075	347.616	324.210	258.446	240.652	256.285	219.262	195.148	202.803	174.373	181.621	170.322
2005	364.599	287.310	254.011	171.765	184.040	202.132	188.592	137.876	107.508	151.134	123.820	97.778	114.969	175.981	89.213	94.718
2006	630.697	648.231	554.729	419.127	455.430	523.323	489.480	337.564	315.388	393.462	312.419	276.723	313.367	276.656	291.970	251.329
2007	612.882	709.167	495.130	328.367	406.403	666.132	455.106	268.317	239.461	363.688	250.215	174.837	196.154	189.844	208.116	155.747
2008	849.967	830.498	728.151	630.984	690.535	711.483	699.496	646.509	616.931	641.051	618.007	561.209	549.497	475.774	498.211	451.589
2009	389.555	622.092	477.077	280.705	266.470	450.890	369.192	250.019	239.111	290.285	287.026	254.128	275.523	228.903	203.114	220.756
2010	607.897	572.262	468.609	341.327	409.543	505.735	441.127	298.053	267.560	341.404	245.670	210.290	254.399	246.191	197.141	147.246
2011	718.516	718.579	622.633	451.482	532.361	666.723	651.134	504.569	472.651	680.368	576.193	555.777	653.535	619.799	556.616	537.661
2012	198.580	405.336	511.609	638.596	249.810	400.913	509.254	643.389	349.508	452.166	433.040	287.610	318.020	352.635	371.777	320.976
2013	426.733	705.300	778.253	995.782	433.251	655.458	729.956	939.130	547.006	689.897	683.997	495.071	489.904	492.601	623.375	560.570

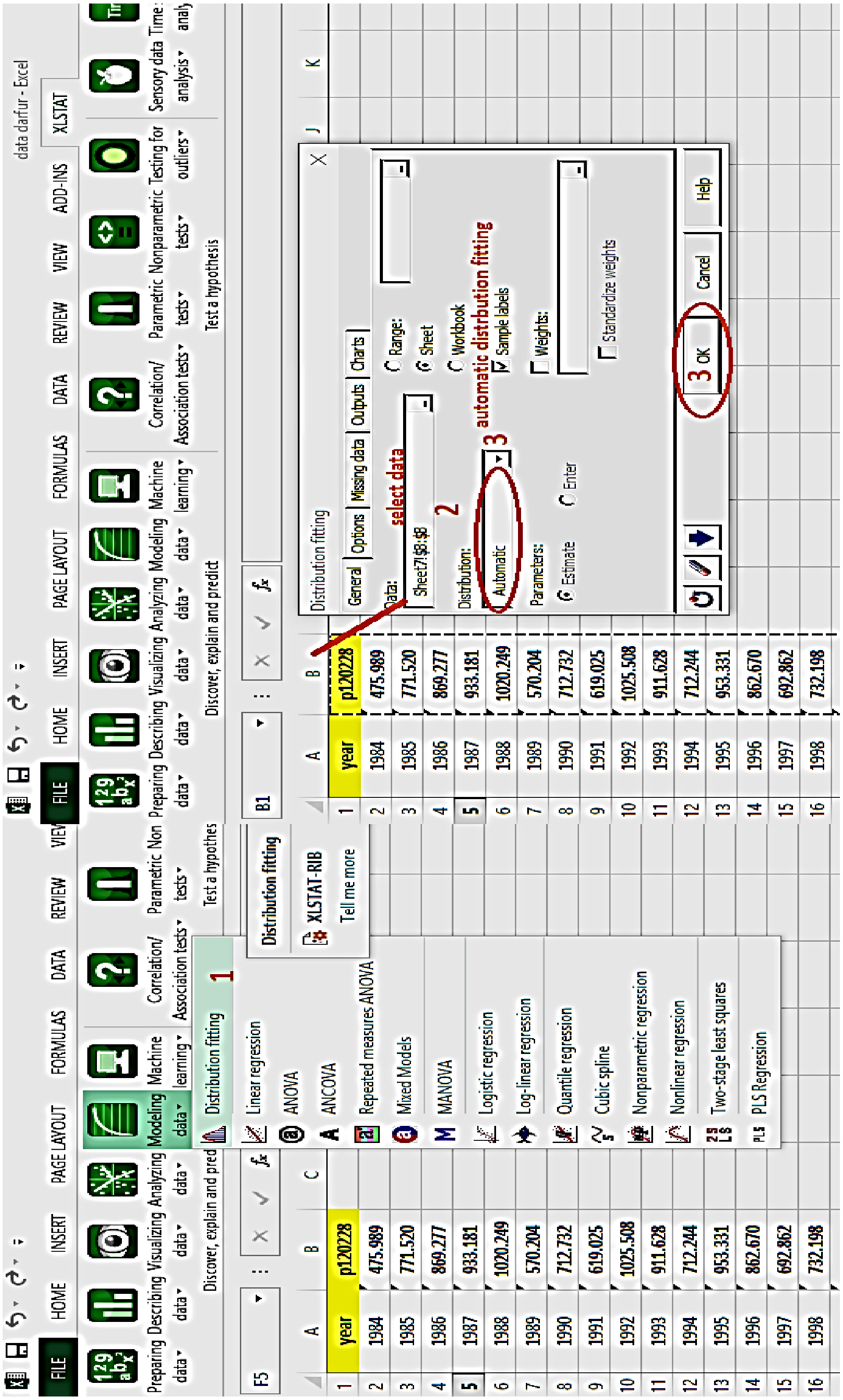


Fig.No.(B.1): Steps of distribution fitting by XLSATA tools

XLSTAT 2016.02.27444 - Distribution fitting - Start time: 8/27/2016 at 12:07:02 AM
Data: Workbook = data darfur.xlsx / Sheet = Sheet7 / Range = Sheet7!$B:$B / 30 rows and 1 column
Significance level (%): 5
Distribution: Automatic
Estimation method: Maximum likelihood

Summary statistics:

Variable	bservation	vith missin	thout miss	Minimum	Maximum	Mean	d. deviation
p120228	30	0	30	475.989	1438.652	812.715	188.609

Distributio	p-value
Beta4	0.272
Chi-square	0.000
Erlang	< 0.0001
Exponenti	< 0.0001
Fisher-Tip	< 0.0001
Fisher-Tip	0.857
Gamma (1	< 0.0001
Gamma (2	0.952
GEV	0.930
Gumbel	< 0.0001
Log-norm	0.960
Logistic	**0.980**
Normal	0.957
Normal (S	< 0.0001
Student	< 0.0001
Weibull (1	< 0.0001
Weibull (2	0.767
Weibull (3	0.918

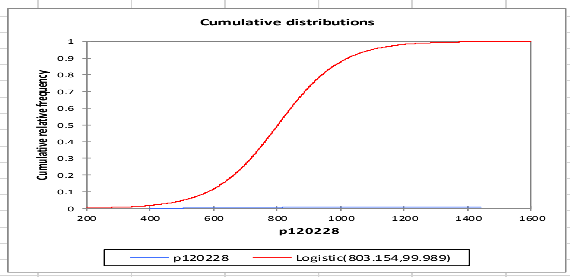
The distribution that fits best the data for the goodness of fit test is the Logistic distribution.

Estimated parameters:

Parameter	Value	andard error
μ	803.154	31.690
s	99.989	15.120

Statistics estimated on the input data and computed using the estimated parameters of the Logistic distribution:

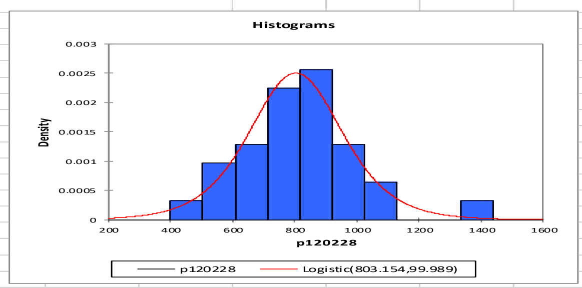
Statistic	Data	Parameters
Mean	812.715	803.154
Variance	35573.481	32891.214
Skewness	0.945	0.000
Kurtosis (I	1.896	1.200



Chi-square test:

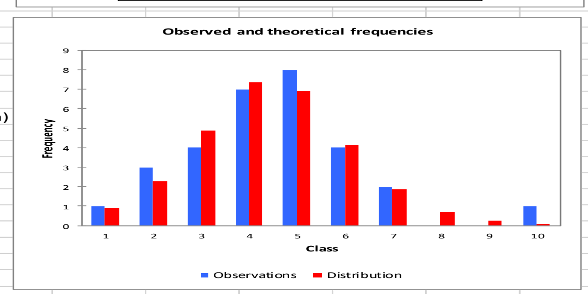
Chi-square	10.353
Chi-square	14.067
DF	7
p-value	0.169
alpha	0.05

Test interpretation:
H0: The sample follows a Logistic distribution
Ha: The sample does not follow a Logistic distribution
As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.
The risk to reject the null hypothesis H0 while it is true is 16.94%.



Comparison between the observed and theoretical frequencies:

Class	ower bound	oper bound	quency (D	ncy (Distri	Chi-square
1	400.000	504.000	1	0.911	0.009
2	504.000	608.000	3	2.297	0.215
3	608.000	712.000	4	4.869	0.155
4	712.000	816.000	7	7.362	0.018
5	816.000	920.000	8	6.924	0.167
6	920.000	1024.000	4	4.144	0.005
7	1024.000	1128.000	2	1.848	0.012
8	1128.000	1232.000	0	0.715	0.715
9	1232.000	1336.000	0	0.261	0.261
10	1336.000	1440.000	1	0.093	8.796



Descriptive statistics for the intervals :

Lower boun	pper boun	Frequency	tive freque	nsity (Dat	ty (Distribution)
400	504	1	0.033	0.000	0.030
504	608	3	0.100	0.001	0.077
608	712	4	0.133	0.001	0.162
712	816	7	0.233	0.002	0.245
816	920	8	0.267	0.003	0.231
920	1024	4	0.133	0.001	0.138
1024	1128	2	0.067	0.001	0.062
1128	1232	0	0.000	0.000	0.024
1232	1336	0	0.000	0.000	0.009
1336	1440	1	0.033	0.000	0.003

Fig.No.(B.2): The result of a best of type distribution fitting vs. measured rain fall data

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Appendix C: Dar Fur Rain Fall stations measured and the best distribution

Point station	Longitude	Latitudes	Elevation (m)	Data Annual Average rainfall (mm)	Distribution annual average Parameter (mm)	Best type of distribution fitting
p120228	22.8125	12.021	583	812.715	803.154	Logistic
p120231	23.125	12.021	679	930.802	930.694	Weibull (3)
p130234	23.4375	12.021	784	1019.459	1011.177	Logistic
p133238	23.75	12.021	822	721.727	710.610	Logistic
p123228	22.8125	12.333	612	790.805	788.151	Fisher-Tippett (2)
p123231	23.125	12.333	691	945.934	934.467	Logistic
p123234	23.4375	12.333	930	1032.987	1034.265	GEV
p123238	23.75	12.333	1075	741.210	738.986	Log-normal
p126228	22.8125	12.645	675	800.573	801.236	Log-normal
p126231	23.125	12.645	901	834.162	834.162	Gamma (2)
p126234	23.4375	12.645	1073	775.242	758.702	Logistic
p126238	23.75	12.645	1265	689.041	688.387	GEV
p130228	22.8125	12.958	734	745.456	745.456	Gamma (2)
p130231	23.125	12.958	826	656.156	655.240	Logistic
p130234	23.4375	12.958	862	532.645	532.067	Logistic
p130238	23.75	12.958	954	571.693	571.515	GEV
p133228	22.8125	13.27	832	645.325	624.380	Logistic
p133231	23.125	13.27	843	557.066	545.373	Logistic
p133234	23.4375	13.27	1106	448.773	448.586	GEV
p133238	23.75	13.27	1114	436.117	425.019	Logistic
p136228	22.8125	13.582	840	585.015	555.136	Logistic
p136231	23.125	13.582	889	540.957	545.562	Fisher-Tippett (2)
p136234	23.4375	13.582	881	439.252	429.553	Fisher-Tippett (2)
p136238	23.75	13.582	1005	370.554	370.554	Gamma (2)
p139231	23.125	13.894	873	505.894	505.894	Gamma (2)
p139234	23.4375	13.894	930	427.625	427.625	Gamma (2)
p139238	23.75	13.894	1003	354.401	353.909	Weibull (2)
p139241	24.0625	13.894	1357	364.921	364.363	Weibull (2)
p139244	24.375	13.894	1459	318.310	319.204	Weibull (3)
p142231	23.125	14.206	843	399.077	399.077	Gamma (2)
p142234	23.4375	14.206	891	356.727	356.213	Weibull (2)
p142238	23.75	14.206	945	304.531	304.681	Weibull (2)
p142241	24.0625	14.206	1050	324.134	324.001	Weibull (2)
p142244	24.375	14.206	1208	339.013	332.717	Fisher-Tippett (2)
p133253	25.3125	13.27	744	200.337	205.175	Log-normal

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p133256	25.625	13.27	662	332.716	335.840	Log-normal
p133259	25.9375	13.27	669	378.576	378.221	GEV
p136253	25.3125	13.582	738	173.093	173.093	Gamma (2)
p136256	25.625	13.582	794	276.472	280.671	Log-normal
p136259	25.9375	13.582	678	290.820	290.868	GEV
p139253	25.3125	13.894	826	197.436	197.436	Gamma (2)
p139256	25.625	13.894	927	252.312	252.312	Gamma (2)
p139259	25.9375	13.894	792	212.377	212.377	Gamma (2)
p123250	25	12.333	743	357.709	357.709	Gamma (2)
p126250	25	12.645	807	269.351	268.991	GEV
p130250	25	12.958	781	227.179	225.945	GEV
p108238	23.75	10.772	502	772.345	772.305	Logistic
p108241	24.0625	10.772	532	726.995	726.272	Weibull (3)
p108244	24.375	10.772	536	718.023	718.370	Weibull (3)
p108247	24.6875	10.772	517	685.419	679.976	Logistic
p111238	23.75	11.084	549	699.495	698.891	Logistic
p111241	24.0625	11.084	535	674.744	674.071	Logistic
p111244	24.375	11.084	522	705.735	707.587	Logistic
p111247	24.6875	11.084	500	681.225	681.225	Normal
p114238	23.75	11.396	632	724.034	726.883	Logistic
p114241	24.0625	11.396	566	643.968	643.433	Weibull (2)
p114244	24.375	11.396	568	686.625	687.217	Weibull (2)
p114247	24.6875	11.396	540	698.368	693.262	Beta4
p117238	23.75	11.709	683	712.867	711.243	Weibull (3)
p117241	24.0625	11.709	647	581.924	581.924	Normal
p117244	24.375	11.709	650	604.598	604.807	Weibull (2)
p117247	24.6875	11.709	623	671.604	672.005	Weibull (3)
p145241	23.4375	14.519	875	219.326	219.326	Gamma (2)
p145238	23.75	14.519	910	217.576	217.576	Gamma (2)
p145234	24.0625	14.519	942	254.827	254.426	GEV
p126269	26.875	12.645	539	371.947	369.296	Weibull (3)
p126272	27.1875	12.645	525	383.379	384.375	Weibull (2)
p130269	26.875	12.958	549	297.569	297.569	Normal
p130272	27.1875	12.958	530	306.144	306.795	Weibull (2)
p133269	26.875	13.27	607	281.680	282.529	Weibull (2)
p133272	27.1875	13.27	572	264.369	274.213	Beta4
p136241	24.0625	13.582	1131	448.842	448.112	Weibull (2)
p136244	24.375	13.582	1466	417.011112	415.8791241	Weibull (2)
p142253	25.3125	14.206	1214	277.110	286.796	Log-normal
p142256	25.625	14.206	1018	278.151	278.151	Gamma (2)
p142259	25.9375	14.206	945	179.840	180.310	Weibull (2)

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p167247	24.6875	16.704	654	22.310	22.310	Exponential
p167250	25	16.704	651	20.747	20.747	Gamma (2)
p167253	25.3125	16.704	655	16.779	16.779	Gamma (2)
p167256	25.625	16.704	633	14.867	14.943	Weibull (2)
p167259	25.9375	16.704	645	15.558	15.558	Exponential
p167263	26.25	16.704	649	18.438	18.506	Weibull (3)
p170247	24.6875	17.017	651	15.858	15.846	Weibull (2)
p170250	25	17.017	619	17.724	17.737	Weibull (2)
p170253	25.3125	17.017	623	16.618	16.618	Weibull (2)
p170256	25.625	17.017	594	14.654	14.654	Gamma (2)
p170259	25.9375	17.017	595	14.363	14.460	Weibull (3)
p170263	26.25	17.017	585	16.237	16.176	Weibull (3)
p105238	23.750	10.460	538.000	816.193	817.651	Weibull (2)
p105241	24.063	10.460	519.000	777.669	764.975	Beta4
p105244	24.375	10.460	509.000	748.142	748.162	Weibull (3)
p105247	24.688	10.460	501.000	717.168	717.697	Weibull (3)
p105250	25.000	10.460	478.000	678.374	679.393	Weibull (2)

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