AL-Dibdiba Formation Basin Hydrological Aspects Extraction Using GIS techniques and Quantitative Morphometric Analysis

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Abstract:

The drainage basin's hydrological aspect studying is considered to be important issue because of their influence (especially in arid to semi-arid regions) on the water management projects, agricultural management projects, and grazing ones. The importance of this study is coming from the fact that AL-Dibdiba formation basin climate is arid to semi-arid and there are human activities (habitation and agricultural) in the east part of it, so the water resources management is needed for this basin. The morphometric analysis illustrates the hydrological aspects in a quantitative form; the problem is the use of the traditional schemes in the calculation processes (such as the topographic map and the planmeter), which coast time and money and accuracy as well (the data generalization case). In this study the morphometric analysis achieved using the SRTM DEM as ancillary data and the ArcGIS 9.3 as a tool for measuring and analyzing.

Two new approaches introduced in this study, the first to overcome the No data pixels problem by using the circular focal mean with threshold pixel values, the second approach is basin borders delineation perfectly by applying the 3D analyst tools (interpolate line and create profile graph) on the corrected 30m SRTM.

AL-Dibdiba basin drainage pattern derived from DEM showed to be dendritic for the low orders and parallel for the high orders, the morphometric parameters were computed using GIS techniques, then categorized into three classes (linear, areal, and relief) aspects; for the first class there are 938 1st order streams, 428 2nd order stream, 251 3rd order streams,126 4th order streams, and 2 5th ones, the 1st order streams length is 1389520.54m, the 2nd order length is 770265.45m, the 3rd order length is 412819.23m, the 4th order length is 210484m, and the 5th one is 3776m, the 1st order bifurcation ratio is 2.191, the 2nd order bifurcation ratio is 1.705, the 3rd order bifurcation ratio is 1.992, and the 4th order bifurcation ratio is 63. The average (after excluding the anomaly 4th order one value is 1.962, for the second class the drainage density is (1.028km^{-1}), the drainage frequency is 0.64 stream /km^2, Drainage Texture is 2.999 stream / km, the elongation ratio is 0.6724, the circularity ratio is 0.34, the form factor is 0.354, the infiltration number is 0.658, and the length of the overland follow is 0.486 km, for the third one the basin relief is 148m, the relief ratio is 0.00169, the channel gradient value is 1.68 m/km, and Constant of Channel Maintenance is 0.97 km.

Keyword: GIS, Quantitative Morphometric Analysis, and 30mSRTM DEM.

استخلاص الخواص الهيدروليكية لحوض تكوين الدبدبة باستخدام تقنيات نظم المعلومات الجغرافية والتحليل المورفومتري الكمي

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الخلاصة:

إن دراسة الخصائص الهيدرولوجية لأحواض التصريف من المسائل المهمة بسبب تاثيرها (خاصة في المناطق الجافة إلى شبه الجافة) على مشاريع إدارة الموارد المائية، المشاريع الزراعية، ومشاريع الرعي. إن أهمية هذه الدراسة تتأتى من حقيقة كون المناخ لحوض تكوين الدبدبة جاف إلى شبه جاف ووجود نشاط بشري (سكني وزراعي) في الجزء الشرقي منه، لهذا إدارة الموارد المائية ضرورية في هذا الحوض.

التحليل المورفومتري يبين الخصائص الهيدرولوجية وبصيغة كمية; لكن المشكلة هي باستخدام الوسائل التقليدية في إجراء الحسابات(الخارطة الطوبوغرافية وأداة قياس المسافة و المساحة) والتي تكلف الوقت والمال والدقة كذلك (مشكلة التعميم). في هذه الدراسة، التحليل المورفومتري تم باستعمال نموذج الارتفاع الرقمي الراداريSRTM DEM كبيانات أولية وبرنامج Arc GIS 9.3 كأداة للقياس والتحليل.

تم تقديم طريقتين جديدتين في هذه الدراسة، الأولى للتغلب على مشكلة البيانات المفقودة في بعض بكسلات الصورة الرادارية باستخدام مرشح المعدل الحسابي الدائري المسبق بتحديد عتبة خاصة لقيم هذه البكسلات تتناسب و طوبوغرافية المنطقة، أما الثانية فهي لرسم حدود الحوض بدقة باستخدام أدوات تحليل البعد الثالث (interpolate line and create profile graph) على النموذج الرقمي المصحح 30mSRTM.

إن شبكة تصريف حوض الدبدبة المستخلصة من نموذج الارتفاعات الرقمية تظهر النمط الشجيري للمراتب الدنيا والمتوازي للعليا، الخصائص المورفومترية تم حسابها باستخدام تقنيات نظم المعلومات الجغرافية ثم صنفت لثلاث أنواع الخصائص(الخطية، المساحية، والتضاريسية). للصنف الأول فان عدد جداول المرتبة الأولى هو938 جدولا والثانية 428 والثالثة 251 والرابعة 126 والخامسة جدولان فقط، أما مجموع أطوال الجداول فهو للمرتبة الأولى 1389520,54 م وللثانية 770265,45 م وللثالثة 412819,23 م وللرابعة 210484 م وللخامسة 3776 م ، نسبة التفرع للمرتبة الأولى هي 2,191 وللثانية 1,705 وللثالثة 1,992 وللرابعة 63 ; المعدل (بعد استبعاد نسب التفرع الشاذة للمرتبة الرابعة) هو 1,962. للصنف الثاني فان كثافة التصريف الطوليةDd هي 1,028كلم $^{-1}$ وكثافة التصريف العدديةFs هي 0,64 جدولا للكلم²، Rtهي 2,999 جدولا\كلم، Re هي 0,6724، Rc هي 0,34، Rf هي 0,345، If هو 0,658، Lg هو 0,486 كلم، للصنف الثالث فان H هو 148م، Rh هي 0,00169، انحدار القناة هو 1,68م\كلم، وثابت البقاء للقناة هو 0,97كم.

Introduction:

Morphometry represents the topographical expression of land by way of area, slope, shape, length, etc. these parameters affect catchment stream flow pattern through their influence on concentration time [1]. The significance of these landscape parameters was earlier pointed out by [2], who observed that stream flow can be expressed as a general function of geomorphology of a watershed. The assertion still stands valid following [3], [4] and [5], who reported that the geomorphoric characteristics of a drainage basin play a key-role in controlling the basins hydrology. Morphometric analysis of basins thus provides not only an elegant description of the landscape, but also serve as a powerful means of comparing the form and process of drainage basins that may be widely separated in space and time [6].

In the early days, most basins were described as well-drained or poorly drained or they were connoted descriptively in the Davisian scheme as being youthful, mature or old [7]. The mechanics of how river channels actually form within a basin and how water gets into the channels was only understood in vague terms by both geologists and hydrologists. Measurements and quantitative expression of drainage basins began with the work of James Hotton 1775.

Subsequently, a great step forward was made by [8], when he crystallized previous works, added new measures, and proposed general methods for the description of drainage basins characteristics [7]. Since then mathematical analysis of drainage basin has been a subject of considerable analysis, both the temperate region or in the humid tropics [9] and [5].

However, morphometric characteristics of drainage basin exhibit spatio-temporal variation, hence the need for detail investigation of basin characteristics, not only from one area to another, but also from time to time. This is because, the form of a basin in terms of its morphometric characteristics determine the processes operating in such a basin. This form-process relationship according to [7] produced a temporary dilemma in geomorphological investigation either in the study of form or process..

The study area

The study area is AL-Dibdiba formation basin, which falls in the middle part of Iraq, it comprises of districts from five administratives (Karbala, Najaf, Babil, Anbar, and Al-Qadisiyah). Its borders identified by applying the 3D analyst tools in Arc GIS 9.3 (interpolate line and create profile graph) on the corrected 30m SRTM elevation model to recognize the recharging and discharging zones, which is a sink zone for the present area of the basin. The basin extends between the north latitudes 31º 54´ and 32º 42´and east longitudes 43º 38´ and 44º 33´and covers an area of 2706.876 km². The region is arid to semiarid with rare rain storms around the year; the surface water is absent, therefore, rainfall recharged groundwater is very important for the drinking and agricultural purposes.

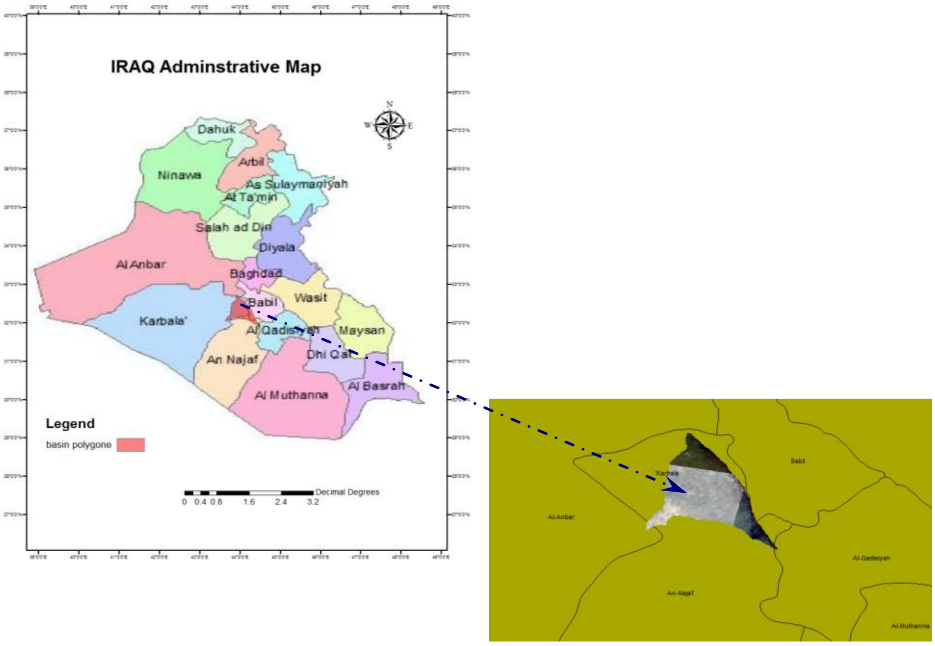


Figure 1- Iraq administratives map illustrating the study region positioning

Methodology

The demanded steps to extract the hydrological (Linear, Areal, and Relief) aspects illustrated in the following chart:

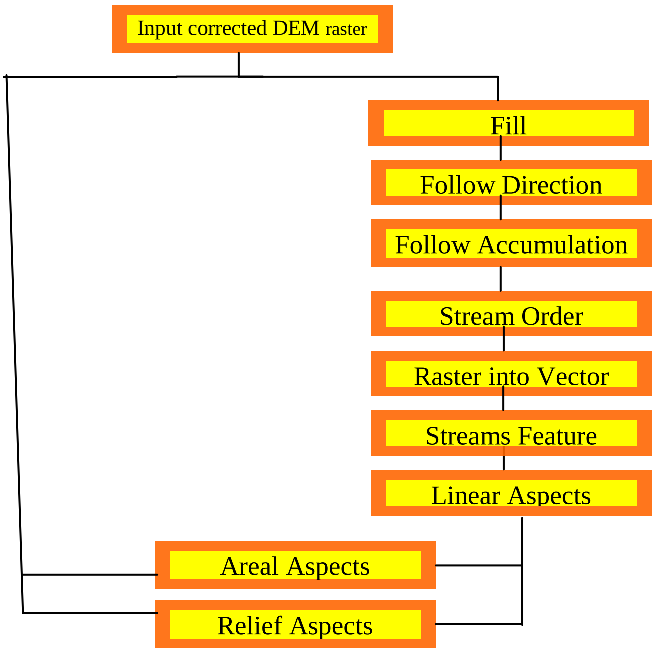


Figure 2- the search methodology steps.

The pre-processing step involves correcting the DEM image, the correction processes involves:

- The background value removal.
- Filling the "No data" pixels using the conditioned SRTM and circular focal mean.

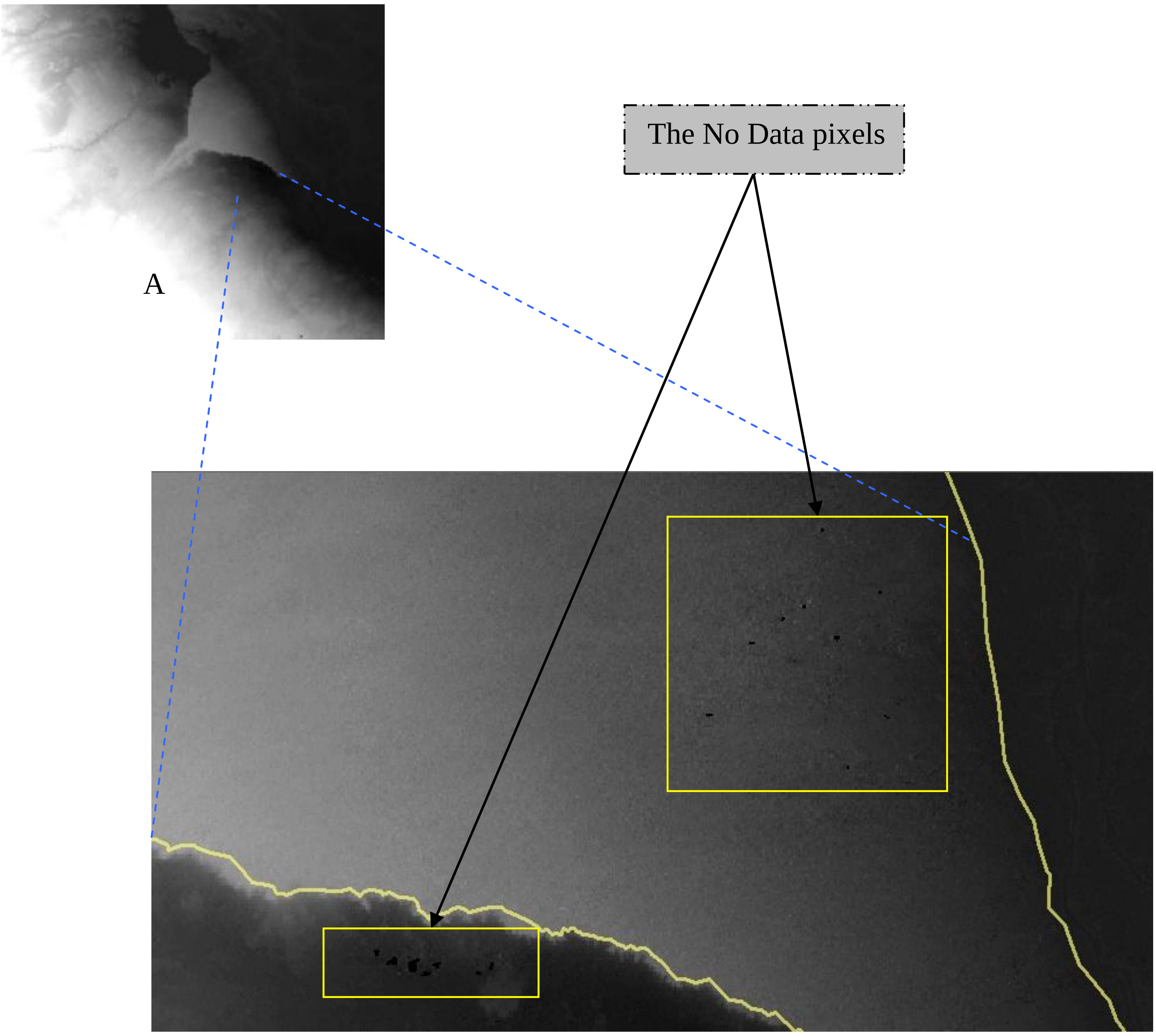
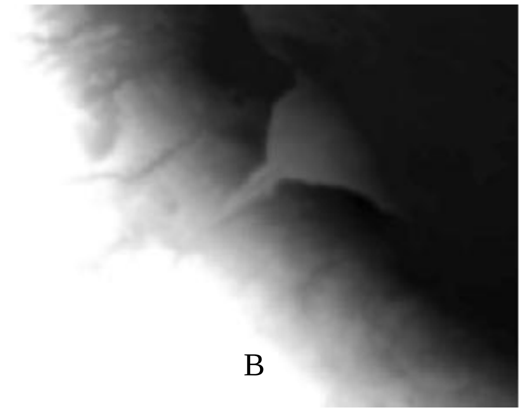
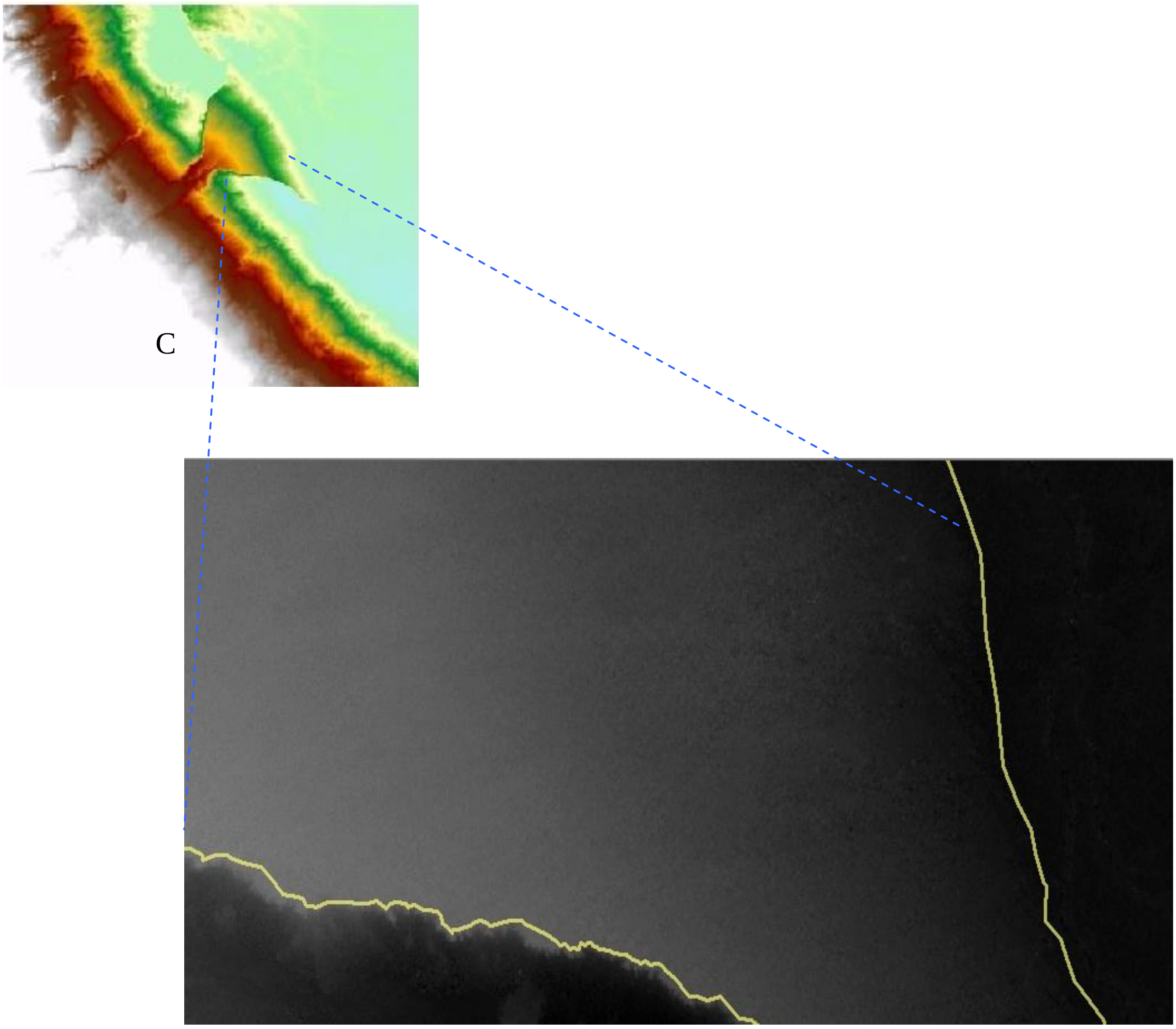


Figure 3- A) the original 30m SRTM Digital Elevation Model mosaic image with its No Data pixels image illustrated bellow.



B) The circular focal mean image with 10 pixels radius.



C) The corrected 30m Digital Elevation Model image.

The next step is study area extraction, as mentioned earlier in (the study area section).

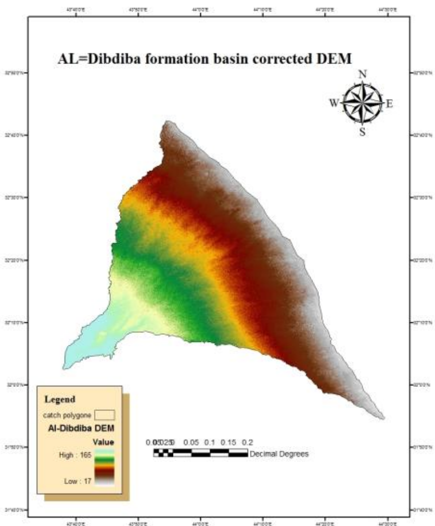


Figure 4- AL-Dibdiba formation basin corrected DEM image.

Next after, the basin drainage network delineation phases, the stream orders, and the converting of raster drainage network into vector one is achieved utilizing the (hydrology tool) of the spatial analyst tools in ArcGIS 9.3, as follow:

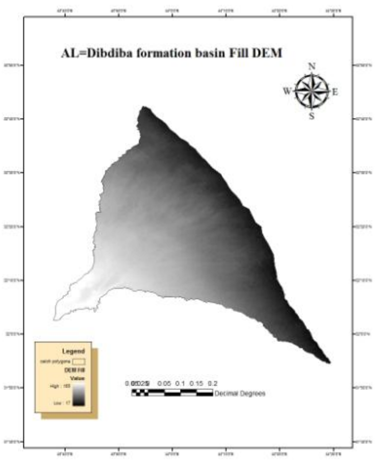


Figure 5- Filled DEM

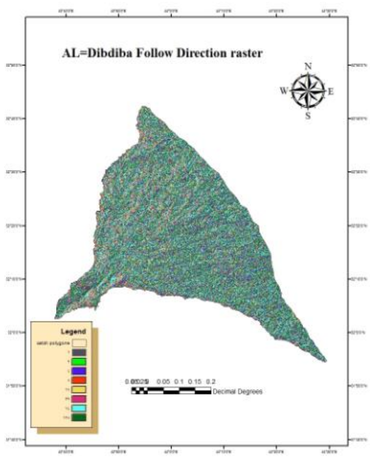


Figure 6- Follow Direction

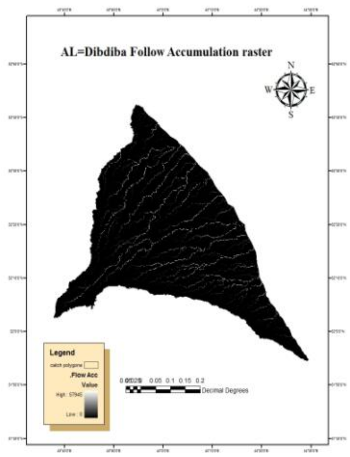


Figure 7- Follow Accumulation

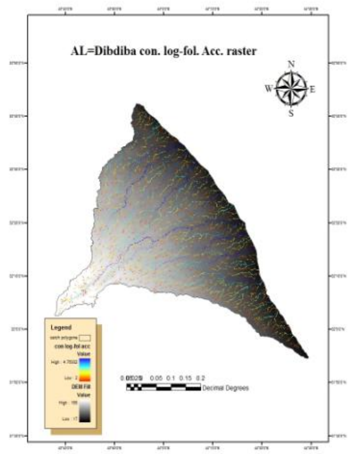


Figure 8- conditioned log-F.A.

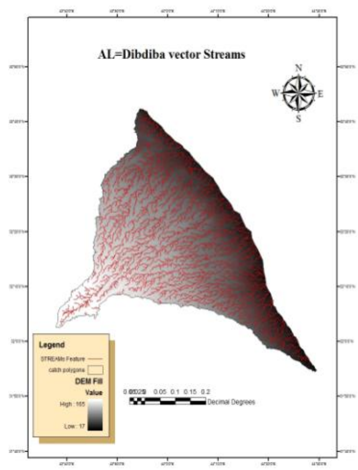


Figure 9- Vector Streams

Linear aspect:

The drainage network transport water and sediments of any basin through a single outlet, which is marked as the maximum order of the basin, conventionally the highest order stream available in the basin considered as the basin order. The size of rivers and basins varies greatly with the order of it. Ordering of streams is the first stage of basin analysis [10].

Stream Order (U):

There are five different systems of ordering streams that are available; Gravelius (1914), Horton (1945), Strahler (1952), Shiver (1960), and Schideggar (1970). Strahler's system, which is slightly modified of Horton's one has been followed because of its clarity and simplicity. Where the smallest, unbranched fingertip streams are designated as 1^{st} order, the confluence of two or more 1^{st} order channels give a channel segment of 2^{nd} one, two or more 2^{nd} order streams join to form a segment of 3^{rd} order and so on. When two channels of different order join then the higher order is maintained. The trunk stream is the one of the highest order [12].

The drainage network of Al-Dibdiba formation basin is delineated using ArcGIS 9.3 hydrology Arc tools utilizing 30m SRTM as ancillary data, AL-Dibdiba is found to be a five order basin.

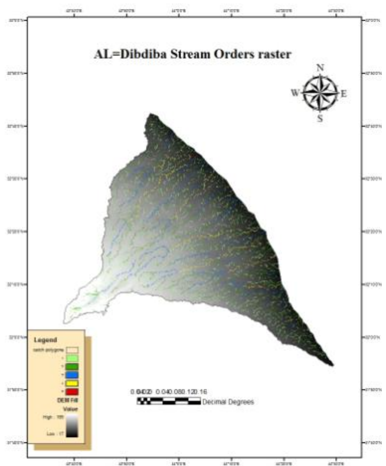


Figure 10-Stream Orders raster

Stream Number (Nu):

The total number of stream segments present in each order is the stream number (Nu) [10]. In the present study area there are (938 1st order streams, 428 2nd order streams, 251 3rd order streams, 126 4th order streams, and 2 5th ones).

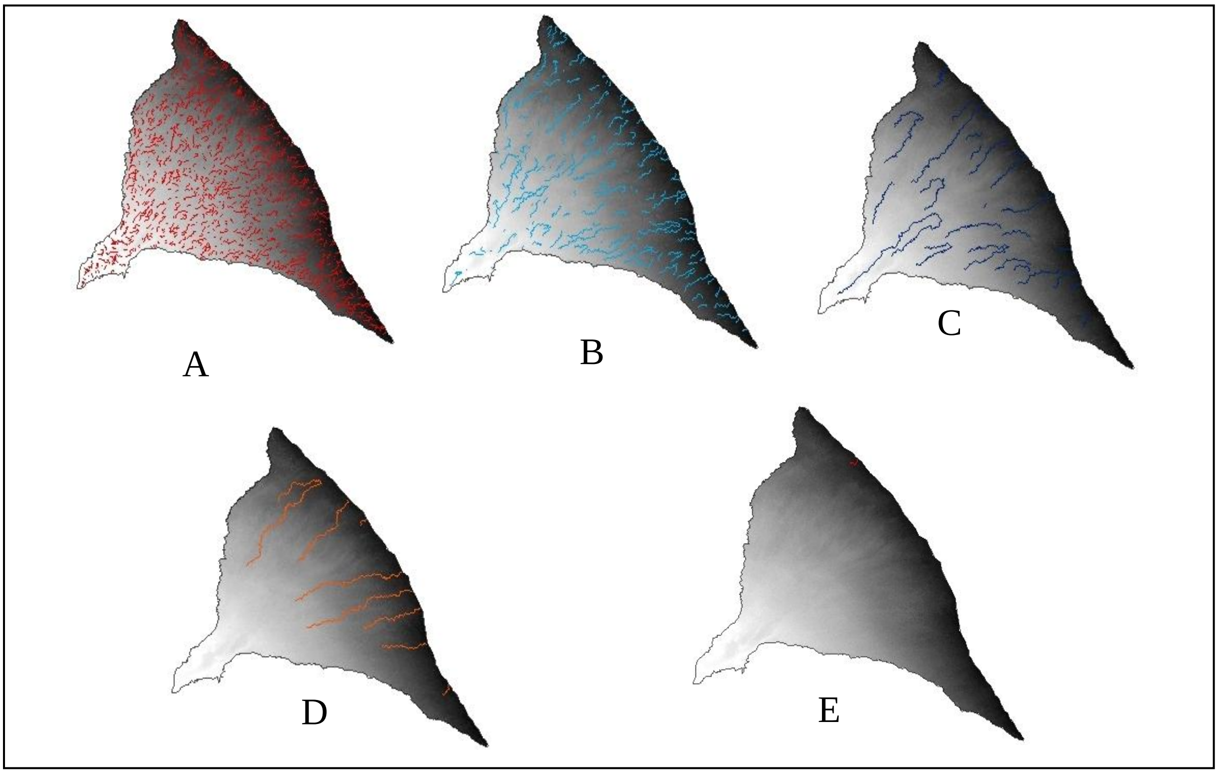


Figure 11- (A) 1st order streams, (B) 2nd order streams, (C) 3rd order streams, (D) 4th order streams, and (E) 5th order streams

Stream Length (Lu):

The total length in (m) of individual stream segments of each order is the stream length of that order (Lu) [10]. In AL-Dibdiba the (1st order Lu is1389520.54, 2nd order Lu is 770265.45, 3rd order Lu is 412819.23, 4th order Lu is 210484, and 5th order Lu is 3776).

Bifurcation Ratio (Rb):

The bifurcation ratio is the ratio between the number of streams in one order and others in the next. It is calculated by dividing the number of streams in the lower by the number in the higher of the two orders; the bifurcation ration of large basins is generally the average of the bifurcation rations of the stream orders within it [10]. Rb is considered as an important measurement as its influence on the discharge rate (i.e. the lower the Rb value, the higher the flood hazard in the discharge area) [3]. For AL-Dibdiba formation basin the 1st order Rb is 2.191, 2nd order Rb is 1.705, 3rd order Rb is 1.992, and 4th order Rb is 63. The average (after excluding the anomaly 4th order Rb value is 1.962 , which means that the flood hazard is absent, this is because the soil of the study area is sandy (high permeability one), yielding that the runoff is few.

Areal Aspect:

Drainage density (Dd):

Drainage density has long been recognized as topographic characteristic of fundamental significance. This arise from the fact that drainage density is sensitive parameter which in many ways provides the link between the form attributes of the basin and the processes operating on the stream course [7]. It reflects the landuse and affects the infiltration and the basin response time between precipitation and discharge. It is also of geomorphological interest particularly for the slopes development. Drainage basin with high valued Dd indicates that a large proportion of the precipitation runs off. On the other hand, low valued Dd indicates that most rainfall infiltrates the ground and few channels are required to carry the runoff [11]. It expresses as the ratio of the total sum of all channel segments length within a basin to the basin area [8].

Dd can be categorized into three classes according to Strahler classification; as follow:

Table 1- the Drainage density classes beyond Strahler classification.

Dd (km/km^2)	description
3-4	Low
4-12	Medium
>12	High

AL-Dibdiba drainage basin Dd is very low ($1.028 km^{-1}$), which reflects that not only soil is high permeable but also rainfall rate is very low in this basin.

Drainage (Stream) frequency (Fs):

Drainage Frequency may be directly related to the lithological characteristics. The number of streams per unit area is termed Stream Frequency or Channel Frequency. Alluvial basins usually referred as low valued Fs, structure hills on the contrary reflect high Fs values [8]. The Fs and Dd values reflect a highly direct correlation for any basin, for the present study area Fs is 0.64 stream /km^2 indicating that the population of streams increases with respect of drainage density increasing.

Drainage Texture (Rt):

Drainage Texture is the total number of stream segments of the 1st order in the basin per perimeter of the basin [1]. It is affected by the climate, vegetation cover, permeability, and relief and considered as an important parameter since infiltration capacity and underlying lithology Marjory depend on it. Smith (1950) classified Drainage Texture into five different textures (i.e. very coarse <2, coarse 2-4, moderate 4-6, fine 6-8, and very fine >8). AL-Dibdiba drainage basin Rt is 2.999 stream / km, which reflects a coarse Drainage Texture yielding a high permeable basin generally, since texture varies from zone to another in the basin.

Elongation ratio Re:

Schumm's 1956 used an elongation ratio (Re) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The value of Re varies from 0 (in highly elongated shape) to unity (in the circular shape). Thus higher the value of elongation ratio more circular shape of the basin and vice-versa. The basins with Re ranging from 0.6-1.0 had a significant differences in their geological structures solidity [10]. These values can be grouped as:

Table 2- the elongation ratio values and their corresponding basin shape

Elongation ratio	Basin Shape
<0.7	Elongated
0.7-0.8	Less Elongated
0.8-0.9	Oval
>0.9	Circular

Al-Dibdiba formation basin Re is 0.6724 (i.e. it has an elongated shape with a significant differences in their geological structures solidity).

Circularity ratio Rc:

The circularity ratio is a similar measure as elongation ratio, originally defined by Miller (1953) [7], as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. The value of the circularity ratio varies from 0 (in line) to unity (in circle), higher the value represents more circularity in the shape of the basin and vice-versa, usually the structural control on the drainage development is responsible for the low values of the circularity ratio [8]. Al-Dibdiba formation basin Rc is 0.34(i.e. it is far away from the circular shape and its drainage pattern is controlled by the lineaments and the fracture traces).

Form factor Rf:

Form factor is the numerical index [8] commonly used to represent different basin shapes. The value of Rf is in between 0.1 to 0.8. Smaller the value of form factor, more elongated will be the basin. The basins with high Rf ~ 0.8, have high peak flows of shorter duration, whereas, elongated drainage basins with low Rf have lower peak flow of longer duration. The alluvial ones showed low Rf since the elongated shape of them. Al-Dibdiba formation basin Rf is 0.354 (i.e. it has an elongated shape with low peak flow and long duration).

Infiltration Number If:

The infiltration number is defined as the product of Drainage Density and Drainage Frequency [4]. The higher the infiltration number, the lower will be the infiltration and consequently, higher will be runoff (i.e. drainage density development) and basin impermeable lithology and higher relief.

Al-Dibdiba formation basin If is 0.658 (i.e. its high valued permeability and infiltration; low valued run off and relief).

Length of Overland Flow (Lg):

The term length of overland flow is used to describe the length of flow of water over the ground before it becomes concentrated in definite channels. Horton (1945) expressed it as equal to half of the reciprocal of Drainage Density [5]. It affects greatly on the quantity of water required to exceed a certain threshold of erosion. Smaller the value of Lg the quicker surface runoff will enter the streams represent well developed drainage network with higher slope. In a relatively homogeneous area, therefore less rain fall is required to contribute a significant volume of surface runoff to stream discharge when the value of overland flow is small than when it is large. Al-Dibdiba formation basin Lg is 0.486 km (i.e. high valued erosion threshold with very slow surface runoff entering the streams that represent well drainage pattern).

Relief Aspect:

Basin Relief (H):

Basin relief is the elevation difference of the highest and lowest point of the valley floor. Al-Dibdiba formation basin H is 148m (i.e. low valued relief basin generally).

Relief ratio (Rh):

This is a dimensionless height-length ratio commonly called (Relative Relief), which can be defined as the ratio between the total relief of the basin (H) and the longest dimension of the basin parallel to the principal drainage line, its dimensionless allows the measuring of Rh for any basin regardless of difference in scale or topography. It is the tangent of the slope angle of the hypotenuse with respect to horizontal, thus an indicator of the erosion process acting on the slope of the basin, since it control the rate of conversion of potential to kinetic energy of water draining through the basin. Higher the value of Rh, higher the steepness and relief of the basin (i.e. higher erosion power, sediment yield, and flood peak in the catchment area). Al-Dibdiba formation basin Rh is 0.00169 (i.e. low valued Relative Relief with lower erosion power, sediment yield, and flood peak in the catchment area).

Channel Gradient:

Channel Gradient is the total drop in elevation from the source to the mouth of the trunk channels in the drainage basin; it describes the basin overall steepness. In the present study area the channel gradient value is 1.68 m/km indicating that the ground steepness is low.

The Constant of Channel Maintenance:

This parameter indicates the requirement of units of watershed surface to bear one unit of channel length. Schumn [2] has used the inverse of the Dd having the dimension of length as a property termed C, higher value of C reveals strong control of lithology with a surface of high permeability. Alluvial basin of plain and piedmont zone shows highest values. Al-Dibdiba Constant of Channel Maintenance is 0.97 km (i.e. an alluvial basin with strong lithology control).

Hypsometric analysis:

Hypsometric analysis is the study of the distribution of topographic surface area with respect to altitude. Two competing factors, namely, tectonic uplift and down wasting due to erosion control landscape form and its evolution, The hypsometric curves express not only the stage of the "geomorphic cycle" but also the complexity of denudation processes and the rate of the geomorphological changes in drainage basin. Such ones take a place through subsequent stages of dynamic equilibrium between tectonic uplift and denudation [12]. Landscape evolution can be formulated as a continuity equation relating uplift, elevation and erosion for sediment transport. Hypsometric Factor reflects the development stages for water basin as time scale factor, which is calculated as follow [12]:

Hypsometric Factor = relative height/ relative area = (h/H)/ (a/A)

In the present study area, the sub- areas (zones) calculated using isopleths height map from (90m SRTM DEM). The hypsometric curves identify quantitatively the stages of the division geomorphic cycle; Strahler [10] identified three types of landform, namely, young, mature, and monadnock on the basis of hypsometric curve shape.

Table 3- AL-Dibdiba formation basin geomorphic zones in corresponding to their hypsometric factors and geomorphic stages.

zone	**Height (m)**		**Relative area%**	**Relative height%**	**Hypsometric factor**	**Geomorphic stage**
	from	to				
A	40	160	86.959	24.242	0.278	Monadnock
B	60	160	66.789	36.363	0.544	Monadnock
C	80	160	47.137	48.484	1.028	Mature
D	100	160	29.959	60.606	2.022	Mature
E	120	160	13.151	72.727	5.530	Young
F	140	160	4.063	84.848	20.883	Young

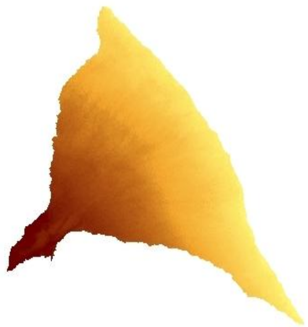


Figure (12): Original basin DEM

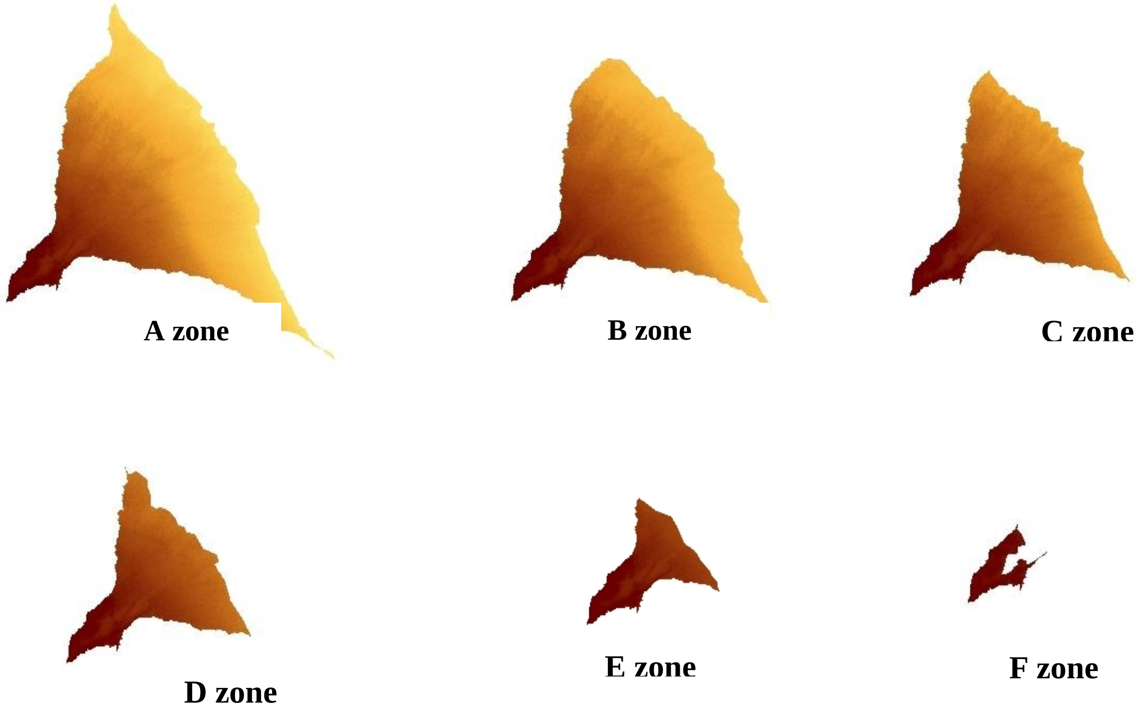


Figure 13- the basin's zones according to their heights

The stages of AL-Dibdiba formation basin geomorphic cycle can be illustrated in the bellow hypsometric curve.

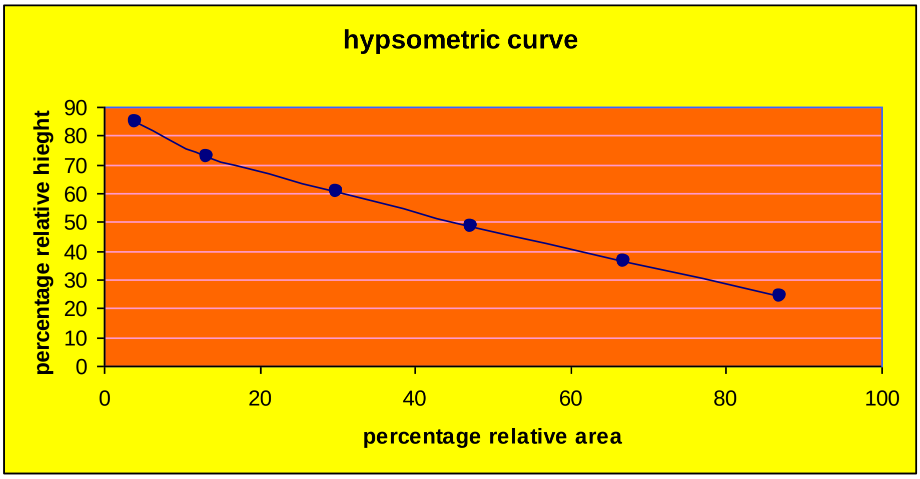


Figure 14- AL-Dibdiba basin hypsometric curve

As it obvious from the hypsometric curve the Monadnock zones can be recognized by having a high percentage relative area with low percentage relative height, while the Young ones are on the opposite and the Mature zones with medium values for both percentage relative (area and height)

Conclusions:

AL-Dibdiba formation basin is found to be a five orders one (938 1^{st} order streams, 428 2^{nd} order streams, 251 3^{rd} order streams, 126 4^{th} order streams, and 2 5^{th} ones). The average Rb value is 1.962, which means that the flood hazard is absent because the soil of the study area is sandy (high permeability one) yielding that the runoff is few. Dd is very low (1.028km^{-1}) reflecting that not only soil is high permeable but also rainfall rate is very low in this basin. The coarse Drainage Texture yielding a high permeable basin" generally", since texture varies from zone to another in the basin. The basin has an elongated shape with significant differences in their geological structures solidity and low peak flow and long duration. The ground steepness and relief is low with lower (erosion power, sediment yield, and flood peak) in the catchment area.

References:

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