QUANTITATIVE ANALYSIS OF WATERSHED GEOMORPHOLOGY AND ITS HYDROLOGICAL IMPLICATIONS USING GIS: CASE STUDY OF BILLI DRAINAGE BASIN, EGYPT

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ABSTRACT

Since there is a direct relation between the geomorphological characteristics and the hydrological processes within the drainage basin, it's important to develop a morphometric database as a primary step to understand the context of landform development; its characteristics; and the pattern of its contribution to the hydrological system, especially when there is a lack in the hydrological data. Several studies cited conventional approaches of field investigation or using topographic maps to derive the necessary parameters. However, using of Digital Elevation Model integrated with GIS environment can save time, effort, and provides accurate results. The aim of this paper is to analyse numerically the geomorphological characteristics of Billi drainage basin, Egypt, and its sub-basins in details through deriving more than 80 morphometric parameters of all aspects and evaluate their hydrological implications, to develop deep understanding of the main differences and similarities with other regions in term of flow generation processes. The results refer to monadnock stage of development cycle indicating the attainment of a stable state in the processes of erosion and transportation within the drainage network and its contributing slopes, and a system of channel slopes and valley wall slopes has been developed. The range of values of the sub-basins shows moderate to high drainage density indicating gullied slopes and surface of low permeability. So, it's recommended to implement a detail hydrological study, followed by a statistical analysis to evaluate quantitively the weight of each morphometric parameters and analyse its contribution. This paper offers a morphometric database that can be used in sustainable management of water resources and future planning applications of rain water harvesting and flash flood risk assessment.

Keywords: Quantitative analysis, Geomorphology, Hydrology, GIS, Billi drainage basin, Egypt.

1 INTRODUCTION

Hydrologists and water engineers are concerned with the hydrological response of a drainage basin. Horton (1932) classified five factors controlling the hydrological processes within a drainage basin, which are: Morphologic, Soil, Geologic-structural, Vegetational & Climatic-hydrologic factors. He defined the Morphometry as "the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms".

The quantitate analysis is the most rational procedure used to express numerically the size and form of the morphometric properties that have high correlation with runoff-phenomena. The resulted information are useful to explain the history of evolution of landforms; the rates of erosion and sediment production; formulation of rational equations relating geomorphic properties; and indicating the variance in hydrological properties of a drainage basin (Strahler, 1957).

The present paper adapts various methods to measure and calculate mathematically the landform characteristics, where the drainage network analysis carried out using the methods suggested by (Horton, 1945), (Strahler, 1952), (Schumm, 1956), (Strahler, 1957), and (Chorley, et al., 1957); the basin geometry using methods of (Horton, 1932), (Smith, 1950), (Schumm, 1956), (Strahler, 1957), (Mueller, 1968), (Gregory & Walling, 1973), and (Zavoianu, 1985); the texture analysis by methods of (Horton, 1932), (Horton, 1945), (Schumm, 1956), (Faniran, 1962), (Gregory & Walling, 1968), (Zavoianu, 1985) and (Das & Mukherjee, 2005); the relief done based on (Horton, 1932), (Strahler, 1952), (Schumm, 1956), (Broscoe, 1959), (Zavoianu, 1985), (Snow & Slingerland, 1987), (Willgoose & Hancock, 1998), (Sinha-Roy, 2002) and (Pareta & Pareta, 2011). The cited formulas are presented in Table 8. Only the drainage pattern of the stream network was analyst spatially using the spatial analyst tool of Esri ArcMap 10.5 software.

The results have been discussed and evaluated at the sub-basin level, where Billi drainage basin has been re-delineated to 14 sub-basins based on the junction points of each 5^{th} and 4^{th} stream order with the main stream course of 6^{th} order, Figure 1 (right). The derived parameters where classified into four classes of drainage network, basin geometry, relief analysis and texture analysis, and presented in the form of statistical indices, graphs or maps.

2 STUDY AREA

Billi drainage basin, Figure 1 (left), locates in the Eastern Desert of Egypt, extends from Red Sea Hills at the western part to El-Gouna coastal plain in the east, and bounded by the coordinates 33° 12' 33" to 33° 40' 18" E and 26° 57' 56" to 27° 28' 20" N. Its area estimated by 878.7 km^2 and elevated from 0 to 2126 m. The basin is surrounded by Wadi Umm Masaad in the north borders, Wadi Umm Diheis at the south borders, drainage basins of the Nile river in west, and the Red Sea to the East. Five main morphological features are included in the basin, from west to east, that have specific features: high mountains, Abu Sha'ar plateau, wadi Billi, coastal ridge of Esh Al-Mellaha, and a coastal plain (Bauer, et al.).

Events of heavy rain may occur in yearly frequency, which increasing the potentiality of flash floods hazardous. Especially that the urban area located in the catchment's delta, El-Gouna town, isn't prepared with protection structures like dams or drainage canals. In the same time, it's still depending on desalination of salt groundwater to meet the local demand.

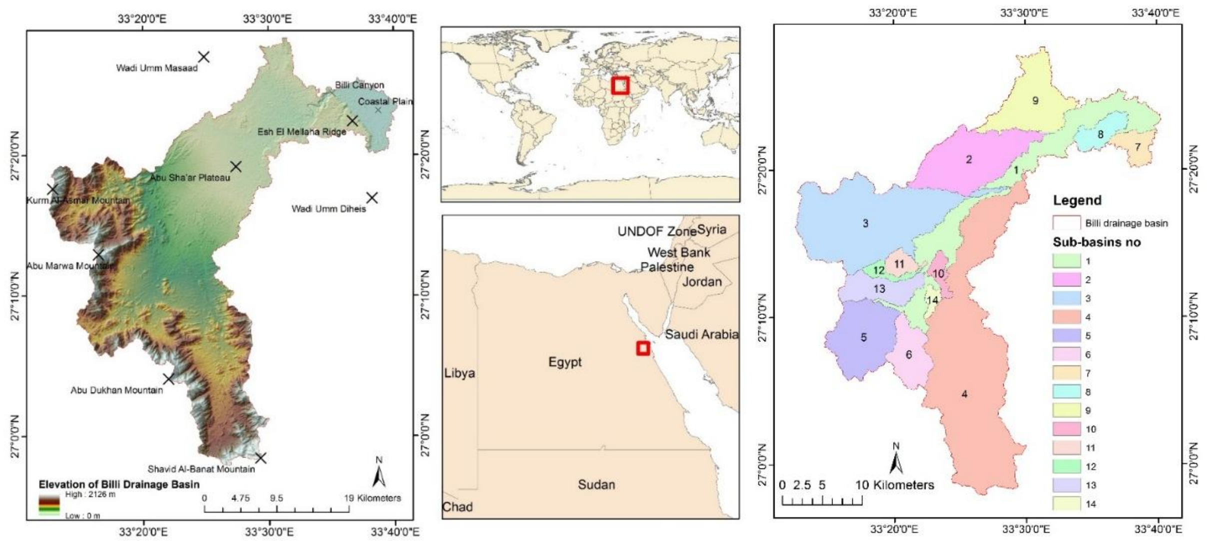

Figure 1. Location of Billi drainage basin and its sub-basin

3 METHODOLOGY AND DATA USED

This paper follows a systematically approach to the problem of objective geomorphological analysis of a highly complex surface. Starting by collecting the relevant data of literature;

Topographical Maps of NG 36-2 & NG 36-3 with scale of 1:250,000 issued by (Army Map Service, 1958); and the Digital Elevation Model (DEM) of 30 m resolution, released in November 2011 under the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) program (METI & NASA, 2011). GIS techniques used for assessing the terrain and morphometric parameters, as it provides a flexible environment and a powerful tool for manipulating and analysis the spatial information. So, Esri ArcMap 10.5 software has been used to analyse the data and generate most of morphometric parameters. Also, Microsoft Excel 2016 has been used to manage, analyse and illustrate the results statistically. Finally, the rational procedures are followed to evaluate and assess the results, and to predict the relevant hydrological process in the light of the literature.

4 RESULTS AND DISCUSSION

4.1 Drainage Network

The discharge network was delineated using geoprocessing algorithms of ArcMap 10.5 software on the basis of ASTER DEM. The composition of the drainage network of Billi basin expressed quantitatively in terms of Stream Order, Stream Number, Bifurcation Ratio, Stream Length, Stream-Length Ratio, Rho Coefficient, Channel Index and Valley Index, respectively.

Stream Ordering (Su) is the first step of the quantitative analysis for drainage basin (Pareta & Pareta, 2011). (Strahler, 1952) ordering system has been used to classify the stream system of Billi drainage basin. Figure 4 (left) shows that Billi drainage basin of sixth order, and includes only SB1 under 6^{th} order, SB2-6 under 5^{th} order and SB7-13 of 4^{th} order.

Stream number (Nu) defined as the overall of order wise stream segments (Horton, 1945). The results presented in Table 1 & Figure 2 (left) support Horton’s (1945) fundamental law of stream numbers, where it has been noticed an inverse geometric series between the stream order and its numbers over Billi basin and its sub-basins. Also, it shows close variation in the mean **Bifurcation Ratios (Rb)**, which refer to irregularities in the geological and lithological development. The high range of values for Billi drainage basin and its sub-basins indicating mountainous and well dissected areas (Horton, 1945). Only SB12 & SB14 have Rb of 2.83 and 2.43, respectively, which refer to flat, less structural disturbances, and the drainage system branched systematically. The weighted mean bifurcation ratio (Rbwm) has been calculated to mitigate the variation of the bifurcation ratio from one order to another and arrive better representative of bifurcation number.

The **Stream's lengths (Lu)** have been measured using Esri ArcMap 10.5 software, then it was summed for each order, **Error! Reference source not found.**Table 1. It has been noticed that the total length of stream segments decreases with increasing the order. The results presented in Figure 2 (right) supports Horton's (1945) fundamental law of stream lengths, where a direct geometric series between the average length of streams and its order existing within Billi basin and its sub-basins. The highest value of total length of streams of 1^{st} and 2^{nd} order found in SB1-4 and SB9 indicating vast drainage area and eroded landform. Also, it shows variation in **Stream Length Ratio (Lurm)** from one order to another during the sub-basin, which indicate different stages of landform development. So, a weighted mean length ratio is used to mitigate the variation of the stream length ratio.

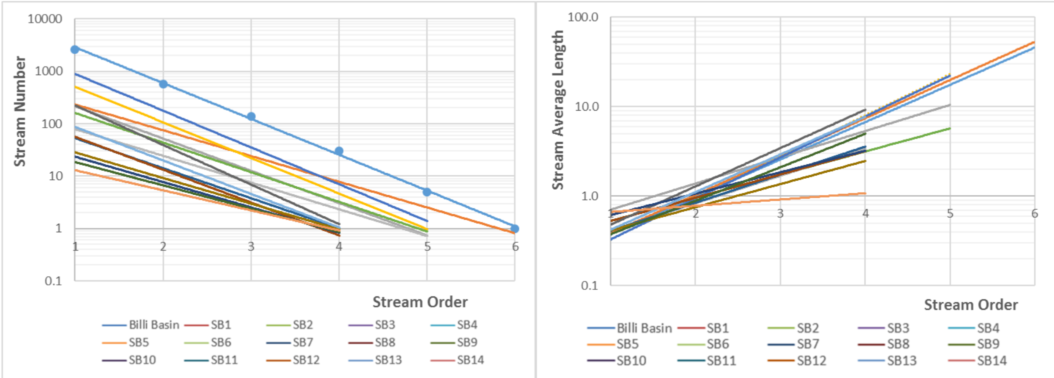

Figure 2. Relation of stream order to number of streams (left), and stream number to mean stream lengths (right) for Billi drainage basin and its sub-basins

The results of **Rho Coefficient (ρ)** illustrated in Table 1**Error! Reference source not found.** shows moderate to high values for Billi drainage basins and its sub-basins from 0.44 to 0.97 indicating moderate to high hydrologic storage during floods and minimizing the erosion resulted from elevated discharge.

The length of main channel, valley length, and the shortest air distance has been measured using Esri ArcMap 10.5 software for Billi drainage basin and its sub-basins, then calculated the **Channel Index (Ci) and Valley index (Vi)** according to (Mueller, 1968) definition, Table 2. The length of main channel is almost equal the valley length for SB7-9 indicating valleys of youthful stage of erosion. While it has low difference for SB2-6, SB10 & SB12-13 pointing to valleys in early maturity. Only Billi drainage basin, SB1 and SB14 shows channel-occupied valley in mature stage of erosion, where the channel has big lateral migration upon the embryonic floodplain.

4.2 Basin Geometry

The assessment of a basin's shape can be used to explain the unfolding of certain hydrological processes. A series of morphometric parameters and even the way in which floods are formed and move depend on basin's shape (Zavoianu, 1985). The composition of the drainage basin geometry of Billi basin expressed quantitatively in terms of Length of Basin, Basin Area, Stream order wise mean area, Basin Perimeter, Form Factor, Elongation Ratio, Circularity Ratio, Topographic Texture Ratio, and Sinuosity Index, respectively.

The (Schumm, 1956) definition cited by (Zavoianu, 1985) for the **Basin Length (Lb)** has been used as the longest dimension of a drainage basin parallel to the main drainage line. The length of Billi drainage basin measured as 51.4 km, and for its sub-basins ranged from 4.22 to 41.54 km.

The **Basin Area (A)** defined as the area in square kilometres of the outline of the watershed of a stream as projected onto the horizontal plane (Melton, 1957). The results, Table 3, show the sub-basins of high area values includes the main stream of 5^{th} order comparing with smaller sub-basins of 4^{th} order. Also, the sorting of sub-basins according the area matching with the sorting according to the summation of stream lengths or number of streams. This meet with Schumm's (1956) suggestion for a direct proportional relation between mean stream length and mean drainage basin area.

Billi drainage basin has been re-delineated to micro-basins of first order to sixth order to calculate the stream order **Wise Mean Area**, then the area ratio as a dimensionless property of drainage basin. It has been noticed that the first order micro-basin has lowest wise mean area with 0.16 km^2, and the sixth order micro-basin has the highest with 878.7 km^2. The highest area ratio is 7.08; the lowest is 3.63; and the mean area ratio (Arm) is 5.74. The Weighted Mean Area Ratio (Arwm) has been calculated to arrive a more representative mean area ratio with 5.34, Figure 3.

Table 1. Drainage network characteristics of Billi drainage basin and its sub-basins

Name	Stream Number (Nu)							Bifurcation Ratio (Rb)		Total Stream Length (Lu) [km]							Stream Length Ratio (Lur)		Rho Coefficient (ρ)
	1st	2nd	3rd	4th	5th	6th	Total	Mean	Weighted	1st	2nd	3rd	4th	5th	6th	Total	Mean	Weighted	
Billi	2638	568	140	30	5	1	3382	4.97	4.56	1159.62	620.80	324.51	126.18	92.31	59.78	2383.20	2.81	2.45	0.59
SB1	335	68	15	-	-	1	419	4.73	4.86	165.59	60.74	33.57	-	-	59.78	319.67	2.16	2.01	0.46
SB2	239	51	13	2	1	-	306	4.28	4.59	140.34	92.33	32.14	12.21	9.31	-	286.34	2.11	2.43	0.49
SB3	480	109	26	4	1	-	620	4.77	4.45	181.01	102.70	65.84	22.94	31.44	-	403.93	3.23	2.79	0.68
SB4	789	168	41	10	1	-	1009	5.72	4.62	321.11	179.94	90.51	34.67	43.85	-	670.07	4.73	3.14	0.83
SB5	192	37	11	3	1	-	244	3.80	4.79	83.34	32.55	29.52	11.51	4.07	-	160.99	1.89	2.13	0.50
SB6	105	23	5	2	1	-	136	3.42	4.44	40.42	21.17	8.45	6.63	3.63	-	80.30	1.82	2.08	0.53
SB7	55	13	4	1	-	-	73	3.83	4.03	21.27	12.34	6.61	3.56	-	-	43.79	2.12	2.19	0.55
SB8	66	13	2	1	-	-	82	4.53	5.20	22.36	18.06	6.32	1.90	-	-	48.64	2.33	3.10	0.51
SB9	199	41	9	1	-	-	250	6.14	4.94	100.45	51.69	28.00	9.97	-	-	190.11	2.72	2.59	0.44
SB10	31	8	3	1	-	-	43	3.18	3.56	12.44	6.19	4.31	2.37	-	-	25.31	1.81	1.85	0.57
SB11	27	7	2	1	-	-	37	3.12	3.67	12.93	9.62	4.73	2.51	-	-	29.79	1.88	2.20	0.60
SB12	21	6	2	1	-	-	30	2.83	3.28	7.77	4.93	5.17	4.47	-	-	22.33	2.37	2.36	0.83
SB13	87	19	5	1	-	-	112	4.46	4.46	45.29	22.91	6.65	12.71	-	-	87.55	4.33	3.21	0.97
SB14	14	5	2	1	-	-	22	2.43	2.64	6.41	5.65	2.70	0.74	-	-	15.49	1.40	1.75	0.58

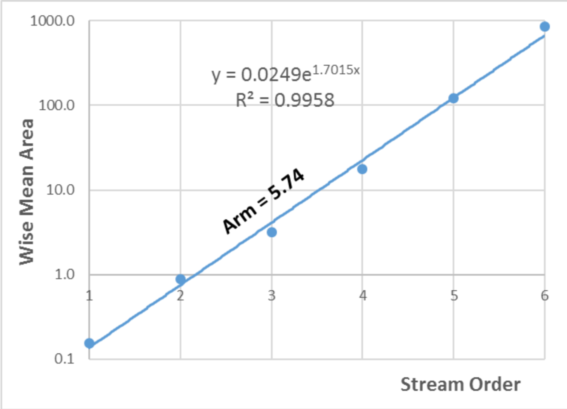

Figure 3. Relation between stream number to stream wise mean area for Billi drainage basin

The **basin perimeter (P)** of Billi drainage basin and its sub-basins measured using Esri ArcMap 10.5 software as the outer boundary projected onto the horizontal plane (Melton, 1957), Table 3.

The **Form Factor (Ff)** denotes the shape of the basin quantitively from 0 as elongated to 1 as circular, hence, denote the related hydrological processes (Zavoianu, 1985). The results presented in Table 3 shows that Billi drainage basin and SB2-4, SB6-8 and SB10-14 are slightly elongated indicating long time for raindrops concentration; comparing with the perfect circular shape of SB5 and SB9 that yield high flood peak values. Only SB1 has an extreme low value as it has long and narrow shape indicating longer duration and lowest peak flow.

The **Elongation Ratio (Re)** used by (Schumm, 1956) to indicate the shape of any drainage basin. (Zavoianu, 1985) cited conclusion of Seyhan (1975, 1976) that the elongation ratio more is correlated with rainfall and runoff than the form factor. The results presented in Table 3 shows that Billi drainage basin, SB2-3, SB6, SB8, SB10-11 & SB13-14 are elongated; SB1, SB4 & SB12 are more elongated; SB7 is less elongated; while SB5 and SB9 have an oval shape.

The **Circularity Ratio (Rc)** measuring how far a drainage basin is close to circle (Melton, 1957). It's affected by structural and lithological characteristics of landforms. According to (Zavoianu, 1985) circular basins with low bifurcation ratio indicating youth landform; low permeability and producing a sharp peak of discharge. The results illustrated in Table 3 shows that SB1 has elongated shape indicating landform of monadnock stage; high permeable and homogenous geologic materials. Billi drainage basin, SB3-4, SB9-10 & SB12 are strongly elongated indicating old to mature landform and low discharge. SB2, SB5-8, SB11 & SB13-14 are less elongated refer to mature and last youth landform; low permeable materials; and high discharge producing sharp peak.

The **Topographic Texture Ratio (T)** express the regions dissected by erosional streams. Its value dominated by lithology of landform, soil, climate, vegetation, relief (Smith, 1950). The results presented in Table 4 shows that SB1, SB7-8 & SB10-14 have coarse textured topography indicating limited number of streams; high permeable soil; low drainage density. While, SB2-6 & SB9 have medium-textured topography refer to existing of massive and resistant rocks; less permeable soil; higher drainage density. The weighted mean texture ratio for Billi drainage basin has been calculated as 5.481 to arrive more representative value of textured topography instead of 12.27 indicating medium-textured topography.

The results of presented in Table 2 shows that Billi drainage basin, SB1-2, SB4-6, SB10-12 & SB14 have higher value of **Hydraulic Sinuosity Index (HIS)** comparing with **Topographic Sinuosity Index (TSI)** indicating an old stage of development as most of the topographic sinuosity has been removed and the hydraulic factors dominating of channel behaviour, and the channel length has been increased through the lateral migration within its floodplain. While, SB3, SB7-9 & SB13 have higher value of TSI comparing with HSI indicating youth stage of erosion; the valley course remains irregular, and the floodplain is not formed yet.

Table 2. Sinuosity parameters of Billi drainage basin and its sub-basins

Name	length of Main channel	valley length	air distanc e	Channel Index	Valley Index	Hydraulic Sinuosity Index	Topographic Sinuosity Index	Standard Sinuosity Index
	CL	VL	Air	CI	VI	HIS	TSI	SSI
	km	Km	km			%	%	
Billi Basin	59.78	47.0	39.13	1.53	1.20	61.79	38.21	1.27
SB1	59.78	47.0	39.13	1.53	1.20	61.79	38.21	1.27
SB2	9.31	7.93	7.65	1.22	1.04	82.96	17.04	1.17
SB3	31.44	27.53	23.12	1.36	1.19	46.96	53.04	1.14
SB4	43.85	36.60	31.70	1.38	1.15	59.63	40.37	1.20
SB5	4.07	3.48	3.27	1.24	1.06	74.16	25.84	1.17
SB6	3.63	3.25	3.22	1.13	1.01	92.93	7.07	1.12
SB7	3.56	3.38	3.01	1.18	1.12	33.69	66.31	1.05
SB8	1.90	1.83	1.62	1.18	1.13	25.79	74.21	1.04
SB9	9.97	9.23	7.81	1.28	1.18	34.10	65.90	1.08
SB10	2.37	2.05	1.91	1.24	1.07	69.28	30.72	1.15
SB11	2.51	2.02	1.84	1.37	1.10	72.35	27.65	1.24
SB12	4.47	3.76	3.61	1.24	1.04	82.83	17.17	1.19
SB13	12.71	10.84	8.82	1.44	1.23	48.03	51.97	1.17
SB14	0.74	0.55	0.48	1.54	1.15	72.87	27.13	1.34

4.3 Drainage Texture Analysis

The composition of the drainage texture of Billi basin expressed quantitatively in terms of Stream Frequency, Drainage Density, Constant of Channel Maintenance, Infiltration Number, Drainage Pattern, and Length of Overland Flow.

The **Stream Frequency (Fs)** defined as the number of streams per unit of area (Horton, 1932). According to (Zavoianu, 1985) it reflects the hydrological behaviour of surface formations and the degree of geomorphological evolution. The number of streams has been counted using ArcMap 10.5, and the results presented in Table 5 shows low values for Billi drainage basin and its sub-basins indicating limited number of streams per unit area; well-developed channels and valleys; old stage of landform development; stable surface runoff; or high surface permeability.

The **Drainage Density (Dd)** defined by (Horton, 1932) as the length of streams per unit of drainage area. It's used as an excellent indicator to the surface permeability and the landform stage of development (Horton, 1945). (Gregory & Walling, 1968) concluded that its value varying according to the dynamics of inputs and outputs within the basin. The results illustrated in Table 5 and Figure 4 (right) shows that Billi drainage basin and its sub-basins have moderate to high values of drainage density indicating mature to old stage of landforms; including gullied slopes; surface of low permeability. Only SB2 shows very high value with 3.4 km/km2 due to its dense parallel drainage pattern.

The **Constant of Channel Maintenance (1/D)** defined as the minimum area required to develop and sustain 1 km of drainage channel. Its value influenced by relative relief, lithology, and climate (Schumm, 1956). The results illustrated in Table 5 shows that Billi drainage basin and its sub-basins have values ranged from 0.29 to 0.42 km^2/km indicating moderately low erodible surface.

Table 3. Geometry parameters (A) of Billi drainage basin and its sub-basins

Name	Basin Area	Basin Perimeter	Basin Relative Perimeter	Basin Length	Mean Basin Width	Length Area Relation	Lemniskate's	Form Factor Ratio	Elongation Ratio	Circularity Ratio
	A	**P**	**Pr = A / P**	**Lb**	**Wb**	**Lar**	**K**	**Rf**	**Re**	**Rc**
	km2	**km**	**Km**	**km**	**Km**					
Billi	878.7	275.7	3.19	51.4	17.10	81.74	2.36	0.33	0.65	0.15
SB1	111.2	185.2	0.60	41.5	2.68	23.65	12.18	0.06	0.29	0.04
SB2	84.2	57.7	1.46	20.2	4.17	20.01	3.80	0.21	0.51	0.32
SB3	163.3	84.5	1.93	27.2	6.00	29.78	3.56	0.22	0.53	0.29
SB4	257.8	133.7	1.93	39.4	6.54	39.16	4.73	0.17	0.46	0.18
SB5	64.2	38.5	1.67	11.0	5.82	17.01	1.49	0.53	0.82	0.54
SB6	33.4	30.1	1.11	9.9	3.36	11.48	2.32	0.34	0.66	0.46
SB7	16.5	24.1	0.68	6.3	2.63	7.53	1.87	0.42	0.73	0.36
SB8	18.4	25.2	0.73	7.7	2.40	8.04	2.51	0.31	0.63	0.36
SB9	64.1	55.1	1.16	10.9	5.90	16.99	1.45	0.54	0.83	0.27
SB10	9.2	20.1	0.46	6.2	1.48	5.30	3.30	0.24	0.55	0.29
SB11	10.6	17.1	0.62	5.4	1.97	5.77	2.15	0.37	0.68	0.46
SB12	7.5	20.4	0.37	7.7	0.98	4.69	6.19	0.13	0.40	0.23
SB13	30.5	32.7	0.93	11.3	2.71	10.88	3.26	0.24	0.55	0.36
SB14	5.4	14.5	0.37	4.2	1.28	3.85	2.59	0.30	0.62	0.32

Table 4. Geometry parameters (B) of Billi drainage basin and its sub-basins

Name	Topographic Texture Ratio	Compactness Coefficient	Fitness Ratio	Wandering Ratio	Shape Factor Ratio	Elipticity Index	Circularity Ration	Inverse shape form	Basin shape index	Compactness ratio
	T	Cc	Rf	Rw	Rs	Ie	Rcn	Sv	Ish	SH
Billi Basin	12.27	2.64	0.22	1.27	3.01	1.98	3.19	3.01	0.42	0.03
SB1	2.26	4.99	0.32	1.27	15.52	15.61	0.60	15.52	0.08	0.02
SB2	5.30	1.79	0.16	1.17	4.84	0.59	1.46	4.84	0.26	0.04
SB3	7.34	1.88	0.37	1.14	4.53	3.64	1.93	4.53	0.28	0.04
SB4	7.54	2.37	0.33	1.20	6.02	4.08	1.93	6.02	0.21	0.03
SB5	6.33	1.37	0.11	1.17	1.90	0.15	1.67	1.90	0.67	0.06
SB6	4.51	1.48	0.12	1.12	2.95	0.25	1.11	2.95	0.43	0.05
SB7	3.02	1.69	0.15	1.05	2.39	0.54	0.68	2.39	0.53	0.05
SB8	3.25	1.67	0.08	1.04	3.20	0.14	0.73	3.20	0.40	0.05
SB9	4.54	1.95	0.18	1.08	1.84	1.04	1.16	1.84	0.69	0.04
SB10	2.14	1.88	0.12	1.15	4.21	0.36	0.46	4.21	0.30	0.04
SB11	2.17	1.49	0.15	1.24	2.74	0.30	0.62	2.74	0.46	0.05
SB12	1.47	2.12	0.22	1.19	7.88	1.48	0.37	7.88	0.16	0.04
SB13	3.43	1.68	0.39	1.17	4.16	3.03	0.93	4.16	0.31	0.05
SB14	1.52	1.77	0.05	1.00	3.29	0.04	0.37	3.29	0.39	0.05

The **Infiltration Number (If) is** another parameter used to measure the texture of topography by multiplying drainage density with stream frequency. Its value influenced by soil, lithology, climate, vegetation and relief indicating the infiltration characteristics of a drainage basin (Das & Mukherjee, 2005). The results presented in Table 5 shows that Billi drainage basin and its sub-basins have high values refer to low infiltration capacity and thus high surface runoff.

The **Drainage Pattern (Dp)** describes the distribution form of the tributaries over a drainage basin. (Horton, 1945) relates the form to the influence of the slope and geology. Analysing the stream network of Billi drainage basin Figure 4 (left) and Table 5 shows that the dendritic type (A) is the most common, which indicates the longer time of formation and a fairly homogeneous rock without controlling the underlying geologic structure. The parallel pattern (B) emerged in the relatively flat surface of Abu Sha'ar Plateau (SB2 and parts of SB4), which explain the highest drainage density of SB2 with 3.4 [km/km^2]. Also, trellis pattern (C) exists in parts of SB4 where the tributaries meets with the parent stream in almost 90 angles and parallel to local ridges. This type indicates a folded topography as the tributaries developed in valleys resulted by synclines. The rectangular pattern (D) extends only over SB3, which may refer to a fault topography and indicates rocks that have approximately uniform resistance to erosion.

Due to the limitation of the drainage pattern in deriving the hydrologic implications of Billi drainage basin, the author used only the qualitative analysis. However, it's recommended to study the drainage pattern quantitively, and to combine the results with the available geological maps, to develop deep understanding of lithology and structure control over Billi drainage basin.

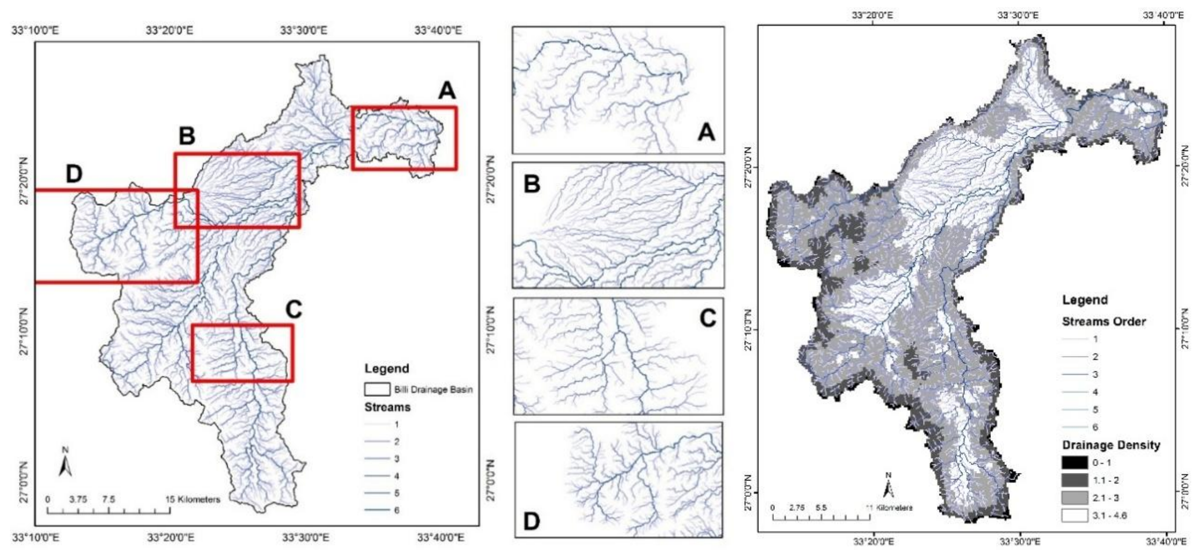

Figure 4. Stream network of Billi drainage basin and its drainage patterns (left), and drainage density (right).

The **Length of Overland Flow (Lg)** defined as the minimum length required to flow a sheet of water over the ground to produce sufficient runoff volume to initiate erosion and becomes concentrated in definite stream channel. Its value influenced by runoff intensity, infiltration-capacity, resistivity of the soil to erosion, and surface slope (Horton, 1945). The results presented in Table 5 shows that the length of overland flow for Billi drainage basin and its sub-basins vary from 0.147 to 0.208 km. It has been noted that the sub-basins of mountainous areas required higher length of overland flow in spite of it includes higher relief and steep slopes due to its higher surface resistivity to erosion. Thus, it includes less channel erosion.

Table 5. Drainage Texture parameters of Billi drainage basin and its sub-basins

Name	Drainage Density	Stream Frequency	Constant of channel maintenance	Drainage Intensity	Infiltration Number	Drainage Pattern	Length of Overland Flow
	Dd	Fs	C	Di	If		Lg
	km/km2		km2/km				km
Billi Basin	**2.71**	**3.85**	**0.37**	**1.42**	**10.44**	**Dendritic & & Parallel**	**0.184**
SB1	**2.87**	**3.77**	**0.35**	**1.31**	**10.83**	**Dendritic**	**0.174**
SB2	**3.40**	**3.63**	**0.29**	**1.07**	**12.36**	**Parallel & Dendritic**	**0.147**
SB3	**2.47**	**3.80**	**0.40**	**1.53**	**9.39**	**Rectangular & Dendritic**	**0.202**
SB4	**2.60**	**3.91**	**0.38**	**1.51**	**10.17**	**Trellised, Parallel & Dendritic**	**0.192**
SB5	**2.51**	**3.80**	**0.40**	**1.52**	**9.52**	**Dendritic**	**0.199**
SB6	**2.41**	**4.08**	**0.42**	**1.69**	**9.82**	**Dendritic**	**0.208**
SB7	**2.65**	**4.42**	**0.38**	**1.67**	**11.74**	**Dendritic**	**0.188**
SB8	**2.64**	**4.46**	**0.38**	**1.69**	**11.78**	**Dendritic**	**0.189**
SB9	**2.97**	**3.90**	**0.34**	**1.32**	**11.57**	**Dendritic**	**0.169**
SB10	**2.75**	**4.67**	**0.36**	**1.70**	**12.86**	**Dendritic**	**0.182**
SB11	**2.81**	**3.49**	**0.36**	**1.24**	**9.81**	**Dendritic**	**0.178**
SB12	**2.98**	**4.00**	**0.34**	**1.34**	**11.91**	**Parallel & Dendritic**	**0.168**
SB13	**2.87**	**3.67**	**0.35**	**1.28**	**10.54**	**Parallel & Dendritic**	**0.174**
SB14	**2.87**	**4.07**	**0.35**	**1.42**	**11.69**	**Parallel & Dendritic**	**0.174**

4.4 Relief Characteristics

Relief analysis is crucial to develop deep understanding of the spatial arrangement of landforms. The composition of relief characterizes of Billi basin expressed quantitatively in terms of Relative Relief Ratio, Relief Ratio, Ruggedness Number, Melton Ruggedness Number, Dissection Index, Slope Analysis, Hypsometric Analysis, Clinographic Analysis, Erosion Surface, Longitudinal Profiles, Channel Gradient, and Concavity Index, respectively.

The **Relative Relief Ratio (Rhp)** is the measurement of a basin general steepness from the summit to the mouth (Melton, 1957). The results illustrate in Table 6, shows high values for SB11-13 with 4.35, 4.96 and 4.08, respectively, which indicate high rate of topographic change over limited area. While the lowest value for SB9 with 0.35 that extends over the flat plateau.

The **Relief Ratio (RhI)** defined by (Schumm, 1956) as the ratio of the elevation difference of highest and lowest points of a basin to the basin length. Analysing the results of Table 6 shows that the sub-basins of high relative relief and steep slope are characterized by high values of relief ratio. This indicate a mountain area and high eroded activity. While the sub-basins of low to moderate relief and gentle slope matching with moderate values of relief ratio and indicating a flat surface with resistant basement rocks. Therefore, the relief ratio should be considered in detail in analysing the hydrological processes such as the annual sediment loss per unit area, infiltration rate, drainage pattern, and even the morphologic evolution of the area.

The **Ruggedness Number (Rn)** indicates to the landform structure complexity and combines slope steepness over the length (Melton, 1957). The results illustrated in Table 6 shows extreme high values for Billi drainage basin and many of its sub-basins (SB3-6 & SB11-13). This indicate rugged mountain areas with high potentiality of surface erosion, where they have high drainage density, high value of relief, and steep long slope surface. Comparing with the other sub-basins (SB7-10 & SB14) that have moderate values due to limited values of relief and slope. This mean the area is less likelihood for landform erosion and have a complex structure in relation to drainage density. In spite of SB2 have limited relief and gentle slope. However, it's still had very high value of ruggedness number because the very high drainage density due to its parallel drainage pattern.

Melton Ruggedness Number (MRn) is a slope index that provides specialized representation of relief ruggedness within a drainage basin (Pareta & Pareta, 2011). The results , Table 6, shows that Billi drainage basin and most of the sub-basins are only exposed to floods events. SB3-6, SB11 and SB13 have relatively higher values comparing with others as they're in mountainous areas, while others extend over flat surface or have limited relief value. Only SB12 locate in debris flood class. So, it could subject up to twice peak discharge of flood discharge and the sediments transport dominated by bedload component.

The **Dissection Index (Dis)** refers to the degree of vertical erosion and indicate the stage of landform development (Pareta & Pareta, 2011). The results illustrated in Table 6 shows maximum value of 1 for Billi drainage basin and SB1 as they're overlooking on the shoreline of the Red Sea. While SB3-4 and SB7-8 have very high values as they extend over the western mountainous area and the ridge mountain of Esh Al-Mellaha, respectively. Only SB10 and SB14 have low dissection index value, which indicate limited vertical erosion and undulating flat surface at Abu Sha'ar plateau. Even SB2 locate in the Abu Sha'ar plateau. However, its dissection index slightly high due to the dense net of parallel drainage pattern that accompanied with very high value of drainage density, hence the sub-basin includes high rate of erosional activity during young valleys. While other sub-basins have moderate to high values as they're within escarpment or hill slope.

(Zavoianu, 1985) defined the **Slope** as the tangent of the angle of inclination of a line or plane defined by a land surface. (Horton, 1932) considered the slope as one of the major factors that controlling the concentration time of rainfall and it's in direct relation to flood magnitude. The slope map of Billi drainage basin has been generated using Surface Analysis Tool in Esri ArcMap 10.5,

Figure 5. Slope distribution (left), and aspect distribution (right) of Billi drainage Basin (left). The wide variations between slope values is due to the variation of the topography and lithology distribution of the main morphometric types: western mountains, central plateau, mountain ridges, Wadi Billi & coastal plain. The average gradient of the coastal plain surface is 4.2 m/km in smooth distribution. While it's doubled for the flat plateau of Abu Sha'ar with 8.5 m/km. The average gradient is reduced for Billi canyon before penetrating ridge of Esh Al-Mellaha mountain to 3 m/km, then it's increased to 11.9 m/km for parts that penetrate the ridge mountain, while the wadi wall sides have steep slope over 35°. The moderate slope distributing on the ridge of Esh Al-Mellaha, where it's permeated by heights with slopes up to 15°, and not exceed 6° in the north part. The steepest slope distributed on mountainous areas in the western part of the basin which above 35° to exceed 72° for parts of Abu Dukhan mountain.

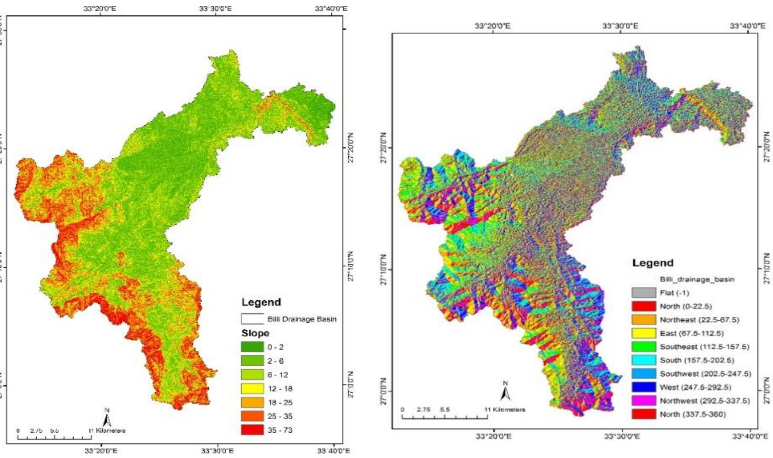

Figure 5. Slope distribution (left), and aspect distribution (right) of Billi drainage Basin

Table 6. Relief Characteristics of Billi drainage basin and its sub-basins

Billi Basin	Minimum elevation	Maximum elevation	Total Basin Relief	Absolute Relief	Relief Ratio	Relative Relief	Dissection Index	Channel Gradient	Gradient Ratio	Watershed Slope	Ruggedness Number	Melton Ruggedness Number
	z	Z	H	Ra	Rhi	Rhp	Dis	Cg	Rg	Sw	Rn	MRn
	m	m	m	m				m/km				
Billi Basin	0	2126	2126	2126	0.041	0.77	1.00	6.57	0.04	0.041	5.77	0.07
SB1	0	780	780	780	0.019	0.42	1.00	6.57	0.02	0.019	2.24	0.07
SB2	96	456	360	456	0.018	0.62	0.79	5.09	0.02	0.018	1.22	0.04
SB3	155	1650	1495	1650	0.055	1.77	0.91	12.47	0.05	0.055	3.70	0.12
SB4	133	2126	1993	2126	0.051	1.49	0.94	11.28	0.05	0.051	5.18	0.12
SB5	404	1607	1203	1607	0.109	3.12	0.75	14.06	0.11	0.109	3.02	0.15
SB6	396	1931	1535	1931	0.15	5.09	0.79	19.23	0.15	0.15	3.70	0.27
SB7	4	220	216	220	0.034	0.89	0.98	1.79	0.03	0.034	0.57	0.05
SB8	9	231	222	231	0.029	0.88	0.96	8.30	0.03	0.029	0.59	0.05
SB9	84	274	190	274	0.017	0.35	0.69	7.51	0.02	0.017	0.56	0.02
SB10	272	434	162	434	0.026	0.81	0.37	12.77	0.03	0.026	0.45	0.05
SB11	295	1037	742	1037	0.138	4.35	0.72	13.28	0.14	0.138	2.09	0.23
SB12	319	1331	1012	1331	0.132	4.96	0.76	24.10	0.13	0.132	3.01	0.37
SB13	322	1656	1334	1656	0.118	4.08	0.81	24.87	0.12	0.118	3.83	0.24
SB14	335	527	192	527	0.046	1.33	0.36	29.97	0.05	0.046	0.55	0.08

The **Hypsometric Analysis (Hs)** considering the distribution of the ground surface area with respect to elevation (Strahler, 1952). The percentage hypsometric curve used dimensionless parameters to compare drainage basins of different sizes and elevations, and by analysing its shape and the related parameters can conclude different characteristics of a drainage basin. Esri ArcMap 10.5 has been used to calculate the percentage hypsometric curve and its parameters for Billi drainage basin and its sub-basins, Figure 6 (left).

Inspecting the resulted curves shows generally S-shaped curves, and the group of SB1-6 and SB11-13 with high up-concavity in the upper part; a low convexity in the lower part; and gentle slope at the inflection point area, comparing with another group of (SB2, SB9 & SB14) that have high convexity at toe, and third group (SB7 and SB8) that shows low up-concavity at head; and low convexity at toe and steep slope at the inflection point region. Analysing the hypsometric curve of Billi drainage basin Figure 6 shows an abnormally low integral value with 23%, indicating a monadnock phase of the normal development cycle, which is an expression of the attainment of a steady state in the processes of erosion and transportation within the fluvial system and its contributing slopes, a system of channel slopes and valley wall slopes has been developed. The basin is no longer expanding in area; and it is in contact with similar basins on all sides. The SB shows the lowest hypsometric integral value with 25% and roughly equal width to length, which meets with the theory of (Willgoose & Hancock, 1998). While, the SB8 has the highest hypsometric integrals with 67%, and the highest y value of inflection point which indicate a youth stage of landform, and low degree of peneplanation.

The **Clinographic Analysis (Cga)** illustrate the ground slope distribution with respect to elevation. Inspection of Figure 6 (right) shows the steep and gentle slope parts of the hypsometric curve are coincide with belts of relatively steep and gentle slope parts of ground surface, respectively. However, the calculated average slope of ground surface is 49° compared to the slope of the percentage hypsometric curve refer to rough correspondence and only in the upper part.

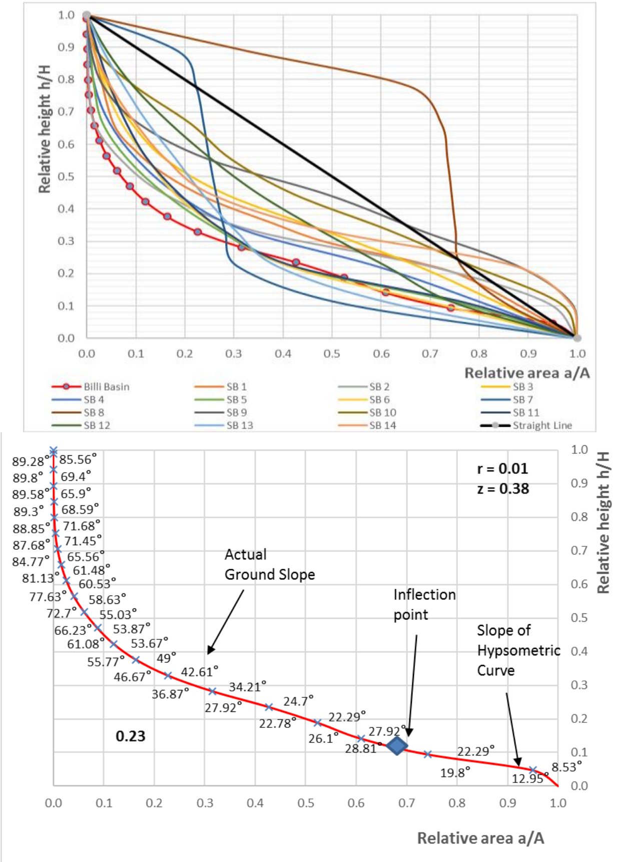

Figure 6. Percentage hypsometric curves of Billi drainage basin and its sub-basins (left, and the Clinographic curve of Billi drainage basin (right) showing the relation between slope of segments of hypsometric curve and actual mean ground slopes of corresponding segments

The superimposed profiles give a panoramic view and illustrate with precision the land form and the difference in altitude (Pareta & Pareta, 2011). It also clarifies the depth of valleys and the **Erosion Surface (Es)** of a morphological unit. The skyline profile for each of the main morphometric types of Billi drainage basin has been drawn using parallel traverse lines extends from north west to the south east boarders. The cartesian axis has been rotated and the coordinates are modified to ensure realistic representation referencing to start point of Mountain's line Figure 7. Several of erosional surfaces and valleys are noticed within Billi drainage basin. The figure illustrates the diversification of topography from high elevated and steep summits in western mountains to relatively undulating surface at Abu Sha'ar plateau, where the high outline exceeds 411 m and lower until 147 m. Also, it's easy to notice the eroded and dissected topography of Esh Al-Mellaha ridge mountain, where it's penetrated by Wadi Billi that connect the coastal plain with the rest of the basin. The depth of Wadi Billi measured as 148 m. While the coastal plain described by smooth line, with relatively no prominents.

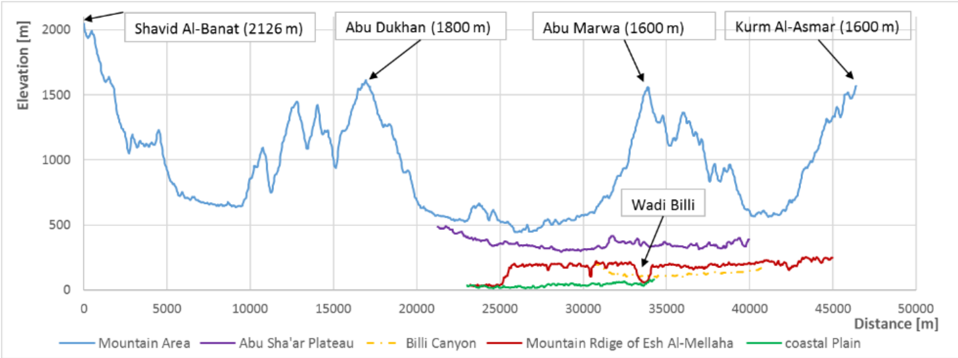

Figure 7. Superimposed Profile analysis of Billi drainage basin

The **Longitudinal Profiles (Lp)** of a stream is an erosional curve represents the geometry of valleys forms and it's a result of different morphometric processes in different intensities over a period of years (Pareta & Pareta, 2011). Inspecting of Figure 8 shows variable characteristics of the longitudinal profile of the main stream of Billi drainage basin of 6^{th} order at different flow distance from its origin point until its mouth. In general, there is two major concavities reflects the main morphological types of Billi drainage basin, where it starts with high elevation source in upstream and inclined steeply along the mountains foots area until Abu Sha'ar plateau where it's extending in moderate slope and be gently through the higher part of Billi Canyon before penetrating the mountain ridge of Esh Al-Mellaha, then it's inclined again steeply in high rate during the ridge to be more gentle and in smooth graded nature in the coast plain of El-Gouna.

It's worth to mention that the author generated the longitudinal profile based on ASTER DEM 30*30 m and using geoprocessing algorithms of Esri ArcMap 10.5. This explain the limited accuracy of the resulted profile especially of the area of low relief at Billi canyon. These barriers have been overcome by using average values for long scale distances.

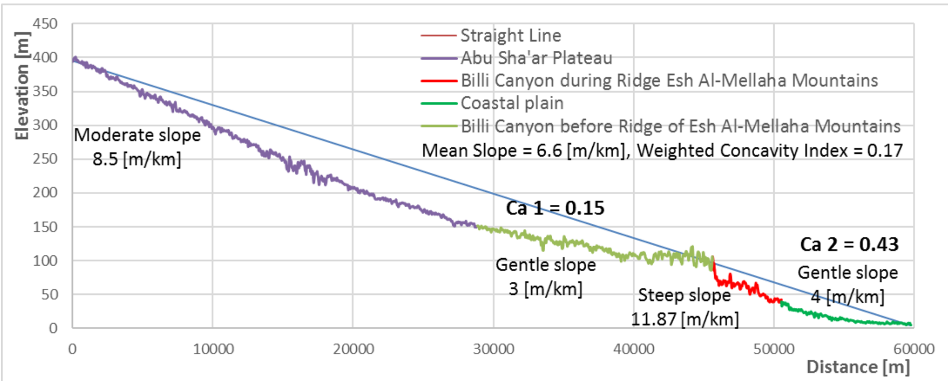

Figure 8. Longitudinal profile of the main channel (6th order stream).

(Horton, 1932) used the average slope of streams or the **Channel Gradient (Cg)** to estimate the effect of stream channel storage and the concentration time required for flood waves to traverse the stream channels. Esri ArcMap 10.5 has been used to measure the length of all streams, together with their elevations at source and mouth points, then it has been used to calculate the average slope for each order, and for the main channel of each sub-basins; and the related gradient, Table 7. It's noticed that the average mean channel slope is decreasing with increasing the order number. This meets with Horton's (1945) law for Stream Slopes, which define an inverse geometric series relationship between the slope of the streams and their orders. This meet with the (Bauer, et al.) explanation for the reasons that increase the flow velocity at the western mountains area, where the higher gradient of channels, the extreme steep slope of overland and in addition to the impermeable rock composition of the outcropping basement, comparing with Abu Sha'ar plateau, where the channels of low gradients, gentle land slope and porous sediments.

Table 7. Average Stream slope and gradient for each order in Billi drainage basin

Stream Order	1st	2nd	3rd	4th	5th	6th
Average Mean Gradient of Stream [m/km]	112.64	57.83	32.32	17.44	12.67	6.64
Average Mean slope [degree]	6.45	3.30	1.83	1.00	0.73	0.37

The **Concavity Index (Ca)** indicates the folding degree of the longitudinal profile quantitively (Pareta & Pareta, 2011). According to (Snow & Slingerland, 1987) it's significantly controlled by variables of discharge, sediment load, and sediment characteristics. Inspecting of Figure 8 illustrate tow up-concavities with weighted value of 0.17. The first one extends for long distance 45 km with small value of 0.15, and the other is much higher with 0.43 through limited distance, which indicate that the downstream is greatly affected with strong change in discharge and weak change in sediment load.

Table 8. Morphometric parameters, modified after (Masoud, et al., 2014) (Pareta and Pareta, 2011)

No	Morphometric parameters	Formula	Reference
Drainage Network			
1	Stream Order (Su)	Hierarchical Rank (Strahler system)	(Strahler, 1952)
2	1st Order Stream (Suf)	$Suf = N1$	(Strahler, 1952)
3	Stream Number (Nu)	$Nu = N_1 + N_2 + N_3 + \cdots + Nn$	(Horton, 1945)
4	Stream Length (Lu) [km]	$Lu = L_1 + L_2 + \ldots + Ln$	(Strahler, 1964)
5	Stream Length Ratio (Lur)	$L_{ur} = \overline{L_u}/\overline{L_{u-1}}$	(Strahler, 1964)
6	Mean Stream Length Ratio (Lurm)	Lurm = average of stream length ratio of all orders	(Horton, 1945)
7	Weighted Mean Stream Length Ratio (Luwm)	Luwm = multiplying the stream length ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values.	(Horton, 1945)
8	Bifurcation Ratio (Rb)	$R_b = N_u/N_{u+1}$	(Horton, 1945)
9	Mean Bifurcation Ratio (Rbm)	Rbm = average of bifurcation ratio of all orders	(Horton, 1945)
10	Weighted Mean Bifurcation Ratio (Rbwm)	Rbwm = multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values.	(Schumm, 1956)
11	Main Channel Length (Cl) [km]	The distance of channel course between the source and mouth. Measured	(Mueller, 1968)

		directly using GIS software Analysis.	
12	Valley Length (Vl) [km]	The valley length along a stream, the length of a line which is everywhere midway between the base of the valley walls. Measured directly using GIS software Analysis.	(Mueller, 1968)
13	Minimum Areal Distance (Adm) [km]	The shortest air distance between the source and mouth of the stream. Measured directly using GIS software Analysis.	(Mueller, 1968)
14	Channel Index (Ci)	$Ci = Cl / Adm$	(Mueller, 1968)
15	Valley Index (Vi)	$Vi = Vl / Adm$	(Mueller, 1968)
16	Rho Coefficient (ρ)	$\rho = L_{ur} / R_b$	(Horton, 1945)
Basin Geometry			
17	Length from Catchment's Center to its Mouth (Lcm) [km]	Measured directly using GIS software Analysis.	(Black, 1972)
18	Width of Catchment at the Center of Mass (Wcm) [km]	Measured directly using GIS software Analysis.	(Black, 1972)
19	Basin Length (Lb) [km]	The longest dimension of a drainage basin parallel to the main drainage line. Measured directly using GIS software Analysis.	(Schumm, 1956)
20	Basin Width (Wb) [km]	$W = A/L_b$	(Horton, 1932)
21	Basin Area (A) [km2]	The area in square kilometres of the outline of the watershed of a stream as projected onto the horizontal plane. Measured directly using GIS software Analysis.	(Schumm, 1956)
22	Area ratio (Ar)	$A_r = \overline{A_u}/\overline{A_{u-1}}$ $\overline{A_u}$= Am = Stream order wise mean area.	(Horton, 1945)
23	Mean Area Ratio (Arm)	The average of area ratio of all orders	(Horton, 1945)
24	Weighted Mean Area Ratio (Arwm)	Arwm = multiplying the mean area ratio for each successive pair of orders by the total number of streams involved in the ratio and taking the mean of the sum of these values.	(Pareta & Pareta, 2011)

25	Basin Perimeter (P) [km]	The length of the outer boundary of a drainage basin as projected onto the horizontal plane of the map. Measured directly using GIS software Analysis.	(Melton, 1957)
26	Basin Relative Perimeter (Pr)	$P_r = A / P$	(Schumm, 1956)
27	Length Area Relation (Lar)	$Lar = 1.4 * A^{0.6}$	(Hack, 1957)
28	Lemniscate (k)	$k = Lb^2 . \pi / 4A$	(Chorley, et al., 1957)
29	Form Factor Ratio (Rf)	$Ff = A / Lb^2$	(Horton, 1932)
30	Shape Factor Ratio (Rs)	$Sf = Lb^2 / A$	(Pandi, et al., 2017)
31	Elongation Ratio (Re)	$R_e = (2\sqrt{A/\pi}) / Lb$	(Schumm, 1956)
32	Ellipticity Index (Ie)	$Ie = \pi . Vl^2 / 4 . A$	(Pandi, et al., 2017)
33	Circularity Ratio (Rc)	$R_C = 4 . \pi . A / P^2$	(Strahler, 1964)
34	Circularity Ration (Rcn)	$Rcn = A / P$	(Pandi, et al., 2017)
35	Topographic Texture Ratio (T)	$T = Nu / P$	(Smith, 1950)
36	Compactness Coefficient (Cc)	$Cc = 0.2841 * (\frac{P}{\sqrt{A}})$	(Horton, 1932)
37	Fitness Ratio (Rf)	$Rf = Cl / P$	(Praveen Kumar Rai, et al., 2018)
38	Wandering Ratio (Rw)	$Rw = Cl / Lb$	(Smart & Surkan, 1967)
39	Watershed Eccentricity (τ)	$\tau = \frac{[\lvert Lcm^2 - Wcm^2]^{0.5}}{Wcm}$	(Black, 1972)
40	Centre of Gravity of the Watershed (Gc)	Measured directly using GIS software Analysis.	(Pareta & Pareta, 2011)
41	Hydraulic Sinuosity Index (HSI) [%]	$HSI = \left[\frac{Ci - Vi}{Ci - 1}\right] . 100$	(Mueller, 1968)
42	Topographic Sinuosity Index (TSI) [%]	$TSI = \left[\frac{Vi - 1}{Ci - 1}\right] . 100$	(Mueller, 1968)
43	Standard Sinuosity Index (SSI)	$SSI = Ci / Vi$	(Mueller, 1968)
44	Longest Dimension Parallel to the Principle Drainage Line (Clp) [km]	Measured directly using GIS software Analysis.	(Pandi, et al., 2017)
45	Basin shape index (Ish)	$Ish = 1.27 A / Lb^2$	(Khakhlari & Nandy, 2016)
46	Compactness ratio (SH)	$SH = Pr / 2\sqrt{\pi . A}$	(Horton, 1932)
Drainage Texture			
47	Stream Frequency (Fs)	$Fs = \sum_{i=1}^{K} Nu / A$	(Horton, 1932)
48	Drainage density (Dd) [km/km2]	$Dd = \sum Lu / A$	(Horton, 1932)
49	Constant of Channel Maintenance [km2/km]	$c = 1 / Dd$	(Schumm, 1956)
50	Drainage Intensity (Di)	$Di = Fs / Dd$	(Faniran, 1962)
51	Infiltration Number (FN)	$FN = Fs . Dd$	(Faniran, 1962)

52	Drainage pattern (Dp)	Analysed qualitatively using GIS software Analysis using DEM	(Horton, 1932)
53	Length of Overland Flow (Lg)	$Lg = \frac{1}{2 * Dd} = \frac{Lu}{2 * A}$	(Horton, 1945)
Relief Characterizes			
54	Maximum Elevation of the Basin (Z)	Elevation of highest summit. Measured directly using GIS software Analysis using DEM	(Strahler, 1952)
55	Minimum Elevation of the Basin (z)	Elevation of Basin Mouth. Measured directly using GIS software Analysis using DEM	(Strahler, 1952)
56	Total Basin Relief (H) [m]	$H = Z - z$	(Strahler, 1952)
57	Relief Ratio (Rhl)	$Rhl = \left(\frac{H}{Lb}\right)$	(Schumm, 1956)
58	Absolute Relief (Ra) [m]	$Ra = Z$	(Melton, 1957)
59	Relative Relief Ratio (Rhp)	$Rhp = \frac{H * 100}{P}$	(Melton, 1957)
60	Dissection Index (Dis)	$Dis = H/Ra$	(Pareta & Pareta, 2011)
61	Channel Gradient (Cg) [m/km]	$Cg = \frac{Z_{source} - Z_{mouth}}{L_u}$	(Zavoianu, 1985)
62	Watershed Slope (Sw)	$Sw = H/Lb$	(Praveen Kumar Rai, et al., 2018)
63	Ruggedness Number (Rn)	$Rn = Rf.Dd$	(Melton, 1957)
64	Melton Ruggedness Number (MRn)	$MRn = H/A^{0.5}$	(Wilford, et al., 2004)
65	Total Contour Length (Ctl) [km]	Measured directly using GIS software	(Strahler, 1952)
66	Contour Interval (Cin) [m]	Measured directly using GIS software	(Strahler, 1952)
67	Length of Two Successive Contours (L1+L2) [km]	Measured directly using GIS software	(Strahler, 1952)
68	Slope Analysis (Sa)	Generated through DEM analysis using GIS software	(Zavoianu, 1985)
69	Mean Slope of Overall Bain (Θs)	$\Theta s = \frac{\sum(\mathrm{Ctl} * \mathrm{Cin})}{A}$	(Praveen Kumar Rai, et al., 2018)
70	Hypsometric Integral (Hi) [%]	Area under the hypsometric curve	(Strahler, 1952)
71	Erosional Integrals (Ei) [%]	Area above the hypsometric curve	(Strahler, 1952)
72	Clinographic Analysis (Cga)	Tan Q = Cin/Awc	(Strahler, 1952)
73	Slope ratio	$r_g = s_g/s_c$	(Horton, 1932)
74	Tangent ratio	$r_t = \tan s_g / \tan s_{gc}$	(Horton, 1932)
75	Erosional Surface (Es) [m]	Superimposed Profiles	(Pareta & Pareta, 2011)
76	Surface Area of Relief (Rsa)	Composite Profile:	(Pareta & Pareta,

	[km2]	Area between Composite Curve and Horizontal Line	2011)
77	Composite Profile Area (Acp) [km2]	Area between Composite Curve and Horizontal Line over distance equal to the distance of projected profile	(Pareta & Pareta, 2011)
78	Minimum Elevated Profile Area as Projected Profile (App) [km2]	Area between Minimum Elevated Profile as Projected Profile and Horizontal Line	(Pareta & Pareta, 2011)
79	Erosional Affected Area (Aea) [km2]	Aea = Acp – App	(Pareta & Pareta, 2011)
80	Longitudinal Profile Curve Area (A1) [km2]	The numerically integrated area that lies between the profile curve and a straight line connecting the profile endpoints	(Snow & Slingerland, 1987)
81	Profile Triangular Area (A2) [km2]	The triangular Area created by that Straight Line and above the Horizontal Axis	(Snow & Slingerland, 1987)
82	Concavity Index (Ca)	$Ca = A_1/A_2$	(Snow & Slingerland, 1987)

5 CONCLUSION

Due to the complex topography of Billi drainage basin, two groups of parameters refer to opposite hydrological processes. The first one is the big drainage area, high relief, steep slope distribution, low surface permeability, well developed drainage system with high drainage density indicating high intensity of surface runoff and increasing the susceptibility of flash flood events. The second one, the long distance of basin length and the shape characteristics that reflects moderate to high elongation character indicating longer time for rainwater concentration and maximize the chance of groundwater recharge.

Although the quantitative results tend to overcome the effects of the first group on the hydrological response behaviour. However, it’s recommended to conduct a hydrological study for Bill drainage basin, followed by a statistical analysis to examine the correlation between the hydrologic and the morphometric parameters and determine its relative weight. Such a study may provide a useful scientific database for future planning activities like flash flood hazard management and site selection for rainwater harvesting.

It’s worth to mention that a degree of error produced during measurement, where two potential sources of such error is determined. The first one is the limited accuracy of DEM especially with low relief terrain. So, the authors used a topographic map to match the delineated basin with the map, hence, discounting this as a source of any discernible error. The second potential source of error is in the use of a numerical approximation techniques. The author used reasonable balance between accuracy and the computation time and effort.

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