Geomorphological hazard analysis using dem along the Eastern coast between Marsa Alam and Ras Gharib, Egypt.

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Abstract

Flash floods are considered as catastrophic phenomena possessing major hazardous threat to the coastal cities, towns, villages and infrastructures. This study deals with the evaluation of flash flood hazard in the basins in Eastern coast between Marsa Alam and Ras Gharib depending on detailed morphometric parameters. For the detailed study, ASTER data were used for preparing digital elevation model (DEM) was used in the evaluation of linear, areal and relief aspects of morphometric parameters. The major parameters such as watershed boundary, basin slope, length and stream ordering are prepared using WMS and Arc map software. Forty-eight morphometric parameters were measured, calculated and interlinked to produce fifteen effective parameters by using the statistical analysis, using Pearson correlation for evaluation of the flash flood hazard degree of the study area. Based on the morphometric parameters which affect the hydrologic behavior of the basins, by influence on time of concentration which has a direct influence on flooding prone area. The flash flood hazard of the basins was identified and classified into five groups (high, moderate high, medium, moderate low and low hazard degree). The study provides details on the flash flood-prone area and the mitigation measures. This study also helps to plan rainwater harvesting and watershed management in the flash flood alert zones.

Keywords: Flash Flood hazard - Pearson correlation – time of concentration - flash flood-prone area.

Introduction

Morphometric parameters can be used as an indicator for predicting possible hydrological processes within the drainage basin. According to Strahler (1957), quantitative analysis is the most rational procedure used to numerically express the size and shape of morphometric properties that have a high relation to runoff phenomena.

Thus, this is a powerful incentive for simulating the process of rain runoff based on the theoretical correlation between the geomorphological characteristics of the watershed and its hydrological response. Many researchers studied this area or the methodology and determined their flash flood hazard degree as the following:

The research project of O.ALMASALMEH (2019) offered a morphometric database and a hydrological study for the Billi drainage basin that can be used for sustainable management and future planning of water and land resources, such as rainwater harvesting and flood protection applications (O.ALMASALMEH, 2019).

In the study of Karem Moubark (2019), Topographic data was utilized and processed using Geographic Information System approaches to compute the hydro-morphometric parameters of Wadi Qena. The morphometric analysis of the studied Wadi Qena basin and sub-basins revealed valuable information about the hydrologic characteristics of the basin. The results revealed that the basin can be classified into twenty-four sub-basins. The computed parameters that present information about the basin relief, geometry and texture were statistically analyzed and integrated to reveal the most hazardous areas for flash floods (Karem Moubark, 2019).

In the study of Yahya Farhan (2018), GIS-based morphometric analysis was employed to prioritize the W. Mujib- Wala watershed in southern Jordan. Seventy-six fourth-order sub-watersheds were prioritized using morphometric analysis often linear and shape parameters. Each sub-watershed is prioritized by designated ranks based on the calculated compound parameter (Cp). The total score for each sub-basin is assigned as per erosion threat (Yahya Farhan, 2018).

The methodology of this paper is based on the study of the morphometric parameters of the drainage basins in Eastern coast between Marsa Alam and Ras Gharib. By using Pearson correlation, classified the morphometric parameters according to their hydrological contribution to the flash flood event and showed that morphometric parameters which have a strong correlation with the storm flow generation, are changed according to the conditions of the region and it helps to determine the most Hazardous basin.

Study Area

Study area is located in the Eastern Coast covering an area of about 52.6 Km2. between Marsa Alam and Ras Gharib. It is located between latitudes (25^{O} N) and (30^{O} N), as shown in Figure 1. The Eastern coast is one of Egypt's main drainage basin systems, with the majority of the basins discharging their water to the Eastern coast. Flash floods occur once or twice a year in this area. The frequency of flash floods has increased in recent years, causing significant damage to the infrastructure and other facilities in this area. The Eastern coast contains residential areas, commercial and industrial zones, tourist villages, quarries, roads, railways, and so on. All of these objects are vulnerable to flash floods. Heavy floods occur sporadically in the area and are typically characterized by sharp peak discharges of short duration. The coastal road, which runs nearly parallel to the shoreline, is one of the catchment areas.

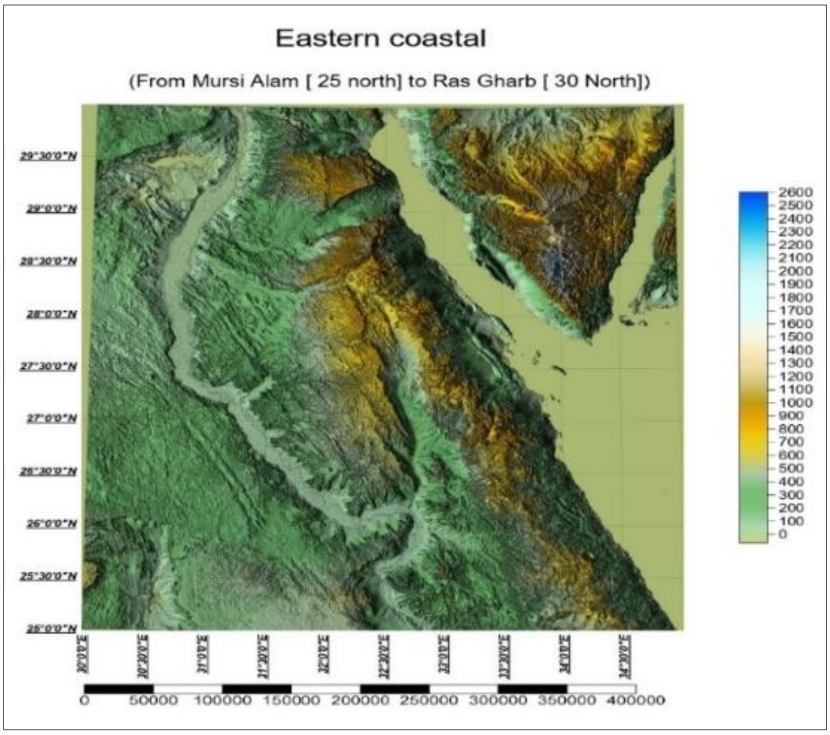

Figure 1: The study area in Eastern Coast.

Methodology of study

Figure 2 depicts a system overview with a flowchart diagram. The system begins with the input of the Dem file and then uses WMS and ARC MAP software to perform basic tasks such as determining morphological parameters. Following that, the Pearson Correlation equation and the Davis equation are used to identify the most hazardous basin (Ahmed Serwa, 2021).

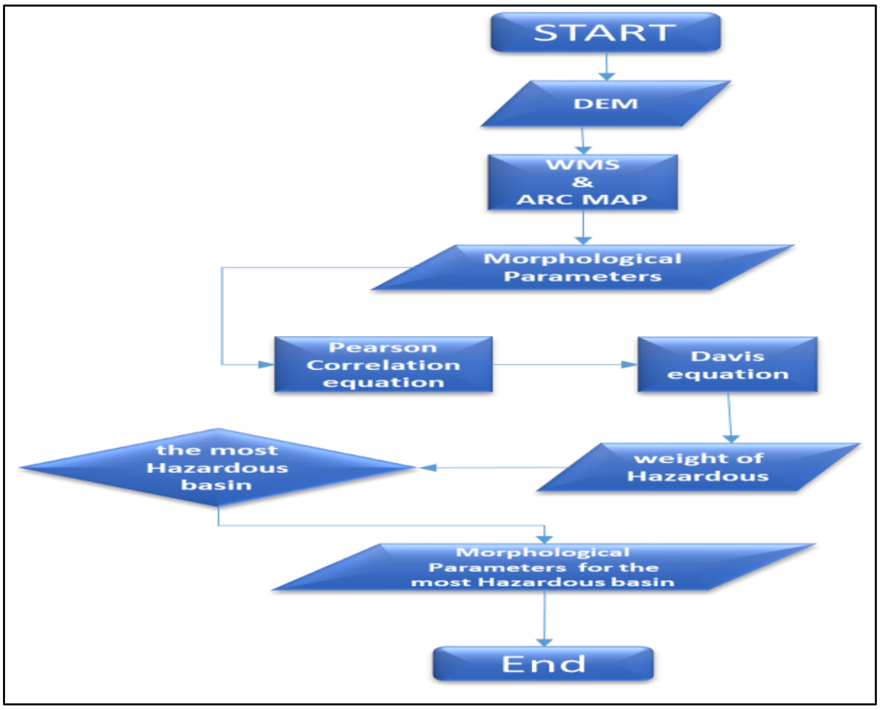

Figure 2: Block diagram of the research work.

- **Morphological Parameters**

Morphometric parameters for all basins with areas greater than 500 Km^2 must be studied to determine the Hazard degree of danger for each basin and the most hazardous basin in study area.

Remote sensing is an important tool to capture spatial information to get useful information (Ahmed Serwa, 2021). Delineation of watershed boundaries and their features were determined using the Digital Elevation Model (DEM resolution 30m) (SRTM(CGIAR), 2020) and the Topographic Parameterization Program Technique (TOPAZ) by applying in Watershed modelling system (WMS).

Various definitions and methods are adopted. The derived parameters were classified into four categories: basin geometry, drainage network, relief analysis, and drainage texture analysis (P. Dinagara Pandi, 2017).

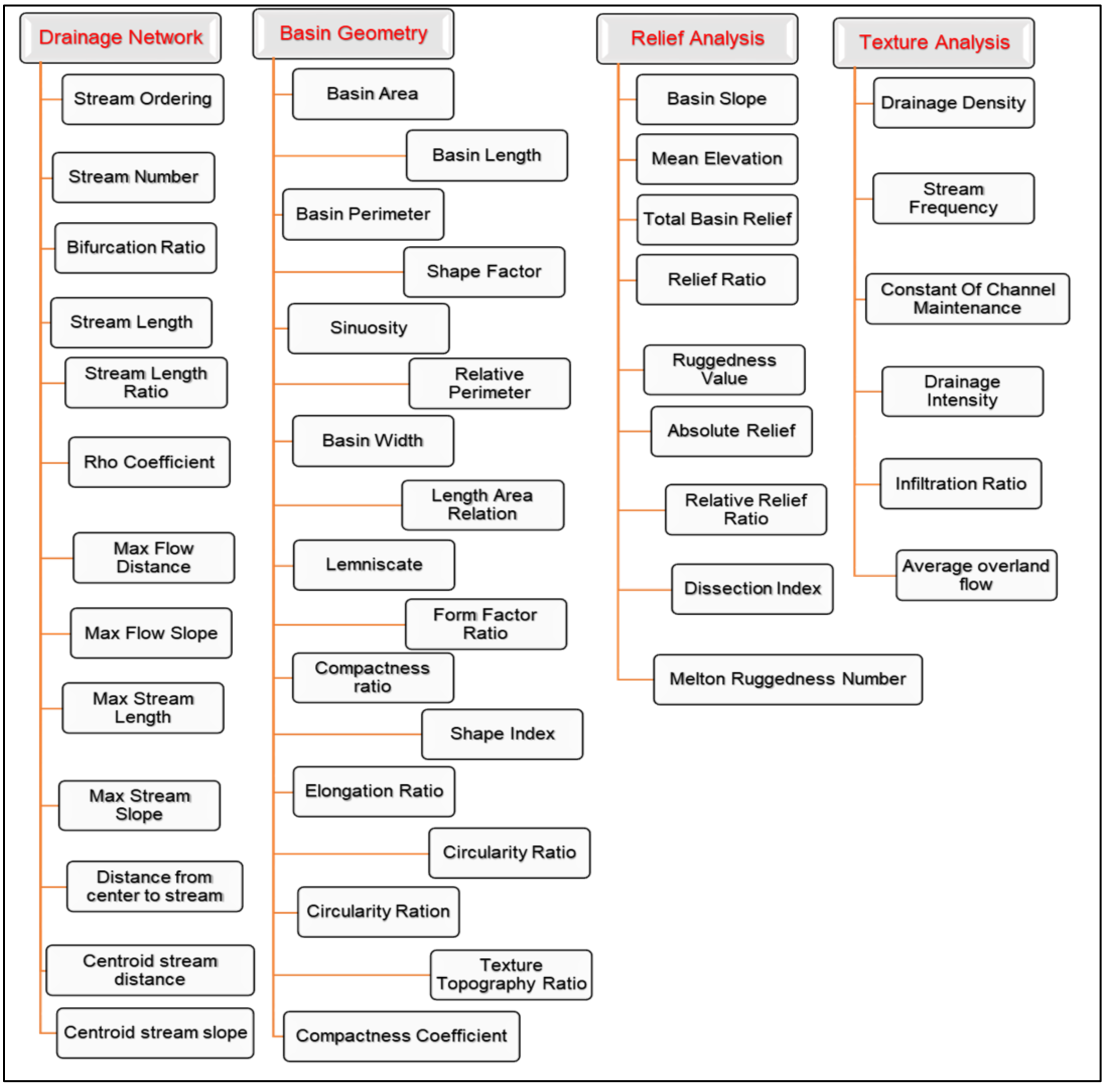

Figure 3: Morphological Parameters of basins (P. Dinagara Pandi, 2017).

The results have been analyzed and discussed at basins levels, where the 14 drainage basin has been delineated based on the junction points. The derived parameters presented in the form of statistical indices or maps as shown in Figure 4.

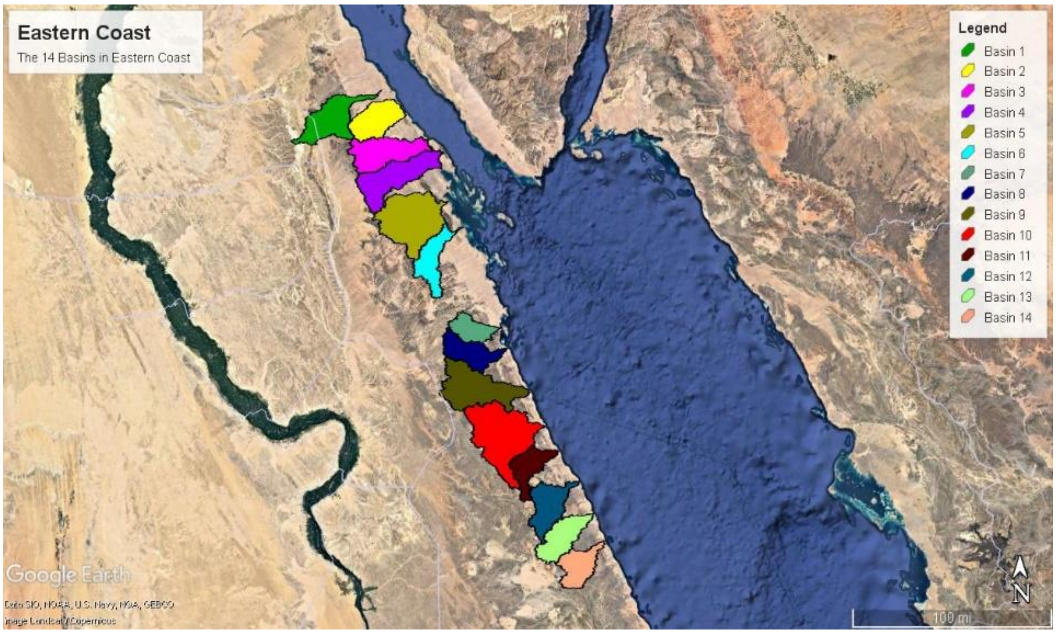

Figure 4: Basin Parameters from WMS in Eastern Coast.

➢ Morphometric analysis using WMS software

SRTM data (SRTM(CGIAR), 2020) gave the elevations about the mean sea level in the center of a grid of 30m x 30m spacing. Moreover, SRTM data are used to trace and convert the drainage network and basin boundaries to lines and polygons by WMS drainage coverage as shown in Table 1.

❖ Basin Area

It is a dimensional property explained as the area in square kilometers of the outline of the basins as expected onto the horizontal plane. It is used to calculate the total amount of water entering the basin during rainfall and to determine the total runoff and the sediment yield (SCHUMM, 1956). The values vary from 1942.7 to 507.8 Km^2 respectively as shown in Table 1.

❖ Basin Length

It is the distance between the basin's origin and the basin's outlet. Using the average basin length sets the correlation with the elongation ratio (SCHUMM, 1956). The values are ranged from 40.62 to 79.52 km as shown in Table 1.

❖ Basin Perimeter

It is defined as the length of the outer boundary of a drainage basin as is expected onto the horizontal plane of the map (Melton, 1957). The values are ranged from 161236.25 to 370955.1 m as shown in Table 1.

❖ Basin Slope

It is defined as the tangent of the angle of inclination of a line or plane defined by a land surface. It is considered as one of the major factors that controls the concentration time of rainfall, where it controls the potential and kinetic energy of a raindrop, hence, the intensity of surface runoff, erosion and transport processes (Praveen Kumar Rai, 2018). The values vary from 0.056 to 0.166 m/m as shown in Table 1.

❖ Average Overland Flow

It is the average 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. It refers to the hydrologic and physiographic development within a drainage basin, where its value is influenced by runoff intensity, infiltration-capacity, resistivity of the soil to erosion, and surface slope (HORTON, 1945). The results showed that the values vary from 252.4 to 315.21 m as shown in Table 1.

❖ Sinuosity

It is concluded that all streams are sinuous and some of them are meandering, but there is no straight stream because the land surface is irregular (MUELLER, 1968). The values vary from 1.27 to 1.61 m as shown in Table 1.

Table 1: Parameters of basins in Eastern Coast from WMS software.

Basin	A_b	BS	AOFD	NF	SF	L_b	P	SHAPE	SIN
1	1061.23	0.0563	291.74	0.57	0.43	79526.24	294727.86	5.96	1.27
2	861.86	0.0893	315.21	0.66	0.34	44284.57	175531.61	2.28	1.43
3	1103.54	0.0976	294.15	0.57	0.43	63300.72	270954.21	3.63	1.32
4	1262.26	0.0852	282.63	0.55	0.45	67140.54	314858.54	3.57	1.61
5	1736.75	0.1075	297.36	0.6	0.4	60005.77	299622.84	2.07	1.38
6	745.7	0.1431	299.64	0.62	0.38	57599.58	265886.56	4.45	1.33
7	507.8	0.1663	260.92	0.49	0.51	40622.32	161236.25	3.25	1.33
8	728.39	0.1173	256.4	0.52	0.48	49982.42	220450.57	3.43	1.44
9	1445.48	0.126	261.99	0.52	0.48	68759.65	339814.31	3.27	1.35
10	1942.7	0.1102	264.32	0.55	0.45	63471.51	370955.1	2.07	1.45
11	652.27	0.1163	268.59	0.58	0.42	46656.12	216030.11	3.34	1.48
12	864.08	0.1153	264.68	0.55	0.45	54362.68	251672.05	3.42	1.3
13	821.47	0.1133	259.08	0.53	0.47	53903.46	216314.2	3.54	1.5
14	705.02	0.1037	252.4	0.58	0.42	47486.07	203945.61	3.2	1.43

Basin	AVEL	MFD	MFS	MSL	MSS	CORSTR	CSD	CSS
1	636.02	101351.14	0.0081	100789.3	0.0079	254.56	53134.34	0.0098
2	381.2	63841.3	0.0149	63279.46	0.0143	180	26537.44	0.0089
3	436.12	84277.08	0.0123	83842.52	0.0122	254.56	46247.92	0.0091
4	367.64	108629.26	0.0091	107977.42	0.0083	284.6	64215.39	0.0058
5	399.03	83038.59	0.0115	82604.03	0.0102	450	34523.56	0.008
6	476.85	77660.67	0.0248	76589.72	0.0194	284.6	40810.56	0.0081
7	488.51	54696.18	0.018	54118.9	0.0162	254.56	30790.17	0.0155
8	479.45	72241.9	0.0119	71732.78	0.0116	318.2	38620.86	0.0108
9	460.8	93197.76	0.0082	92673.2	0.0082	90	52844.04	0.01
10	409.07	92828.78	0.0102	92304.22	0.0082	90	61528.87	0.0059
11	376.45	69744.82	0.0104	69257.54	0.0098	0	32054.92	0.0104
12	450.98	71119.28	0.0099	70684.72	0.0098	127.28	35880.12	0.0121
13	431.32	81577.93	0.0089	80873.37	0.0087	360	37499.57	0.0126
14	405.02	68239.29	0.0094	67804.74	0.0092	63.64	37671.41	0.0093

➢ Morphometric analysis using ArcMap software

Through this program, the flow direction of basin and the flow accumulation of basin files are exported from the WMS program to ArcMap 10.8 to determine the order and the length of branches in the basin.

❖ Stream order

Stream ordering is the first step of the quantitative analysis for drainage basin. This method leads to form only one stream having the highest order number, and the number increasing is related to the drainage area size (STRAHLER, 1952). The results presented in Table 2 show that B1-B5, B9, B10, B14 have 7th order. B6-B8, B11-B13 have 6th order.

❖ Stream Length

It is defined as the measurement of stream course length between the source point and the mouth point (STRAHLER, 1952). As shown in Table 3, it has been observed that the total length of stream segments decreases as the system increases.

Table 2: Stream order for basins in Eastern Coast.

Basin	Rank	N_1	N_2	N_3	N_4	N_5	N_6	N_7	$\sum N_u$
1	7	2838	1321	703	264	203	60	121	5510
2	7	2377	1104	558	265	215	96	1	4616
3	7	2867	1329	697	309	243	77	69	5591
4	7	3209	1448	839	399	124	13	193	6225
5	7	4524	2044	1074	532	415	164	39	8792
6	6	1969	875	511	230	147	88	0	3820
7	6	1160	530	254	105	120	71	0	2240
8	6	1587	746	361	207	72	108	0	3081
9	7	3293	1562	714	384	165	83	147	6348
10	7	4658	2107	1070	539	292	228	109	9003
11	6	1550	726	374	151	134	66	0	3001
12	6	1997	877	435	283	189	89	0	3870
13	6	1938	825	477	176	226	97	0	3739
14	7	1549	681	365	189	104	67	43	2998

Table 3: Stream length for basins in Eastern Coast.

Basin	L_1	L_2	L_3	L_4	L_5	L_6	L_7	$\sum L_u$
1	1421576.6	601462.5	321649.3	114808.4	80974.3	18963.7	47788.9	2607223.7
2	1450830.7	538002.3	252036.8	116342.0	111164.6	46383.0	466.8	2515226.3
3	1465158.4	602634.4	314626.1	141762.0	109229.9	32649.0	32112.9	2698172.7
4	1695896.4	696351.1	407737.8	131534.6	48211.4	10839.7	80621.5	3071192.4
5	2314524.1	807036.7	494502.8	246318.1	194314.7	68291.0	15729.9	4140717.4
6	1052957.9	419964.4	248397.4	97381.7	60860.9	49805.3	0.0	1929367.6
7	510890.9	243431.3	121289.4	52227.0	42599.7	27945.6	0.0	998383.8
8	523992.6	250386.6	132857.1	75914.0	17217.7	44043.3	0.0	1044411.4
9	1376013.6	718275.5	337882.7	160788.9	72005.1	33983.0	55168.5	2754117.3
10	781599.0	935938.1	458266.8	229588.7	116667.8	90073.7	39210.7	2651344.8
11	706650.7	335664.2	170024.0	70187.7	48864.2	24841.2	0.0	1356232.0
12	699075.4	298000.1	156461.1	82244.3	68046.6	39638.3	0.0	1343465.8
13	662644.9	291997.2	175202.9	53510.3	68529.9	33336.0	0.0	1285221.2
14	672443.9	303305.9	178341.8	79861.7	44264.4	28184.1	16458.7	1322860.5

➢ Morphometric analysis using Mathematical equations

✓ Basin Geometry

A series of morphometric parameters and even the way in which floods are formed and move depend on the basin's shape. The composition of the drainage basin geometry is expressed quantitatively in terms of parameters as shown in Table 4.

Table 4: Formulas of the morphometric Basin Geometry parameters.

Basin Geometry			
S.no.	Parameters	Formula	Reference
1	Basin Width	$W_b = A_b / L_b$	(HORTON, 1932)
2	Basin Relative Perimeter	$P_r = A_b/P$	(SCHUMM, 1956)
3	Length Area Relation	$L_{ar} = 1.4 * A_b^{0.6}$	(J.T.HACK, 1957)
4	Lemniscate	$K = L_b^2 * \pi/4A_b$	(R.J.CHORLEY, 1957)
5	Form Factor Ratio	$F_f = A_b / L_b^2$	(HORTON, 1932)
6	Elongation Ratio	$R_e = 2 * (A_b/\pi)^{0.5} / L_b$	(SCHUMM, 1956)
7	Circularity Ratio	$R_c = 4 * \pi * A_b/P^2$	(STRAHLER, 1964)
8	Circularity Ration	$R_{cn} = A_b/P$	(P. Dinagara Pandi, 2017)
9	Topographic Texture Ratio	$T = N_u/P$	(SMITH, 1950)
10	Compactness Coefficient	$C_c = 0.2841 * P/\sqrt{A_b}$	(HORTON, 1932)
11	Basin shape index	$I_{sh} = 1.27 * A_b/L_b^2$	(Gupta, 1995)
12	Compactness ratio	$SH = P_r/2 * (A_b/\pi)^{0.5}$	(HORTON, 1932)

❖ Form Factor

It is the ratio of the width to the length of the drainage basin. It indicates the shape of the basin quantitatively from 0 as elongated to 1 as circular, hence, indicates the related hydrological processes (HORTON, 1932). Table 5 shows that B1, B3, B4, B6-B9 and B11-B14 are slightly elongated indicating a long time for raindrops concentration. Comparing with the circular shape of B2, B5, and B10 that yield high flood peak values within short time.

❖ Elongation ratio

It is used to indicate the shape of any drainage basin, where it is defined that it is as the diameter of a circle that has the same area of the drainage basin to the maximum basin length. The elongation ratio is more correlated with rainfall and runoff than the form factor (SCHUMM, 1956). Table 5 shows that for B3, B4, B6-B9 and B11-B14 are elongated. B1 is more elongated; B2, B5 and B10 is less elongated.

❖ Circularity ratio

It is a dimensionless property measuring how close a drainage basin to a circle, and is defined as the ratio of a drainage basin area to the area of a circle with an equal perimeter to that of the basin. It is affected by the structural and lithological characteristics of landforms (STRAHLER, 1964). Table 5 shows that B1, B3-B14 are strongly elongated indicating old to mature landform and low discharge. B2 is less elongated referring to mature and last youth landform; low permeable materials; and high discharge which produces sharp peaks.

❖ Topographic Texture ratio

It is the ratio of number of streams to the drainage basin perimeter, and it expresses the regions dissected by erosional streams. Its value dominated by the lithology of landform, soil, climate, vegetation, and relief. It indicates the hydrological properties of the soil such as the permeability and the capacity to retain or lose water (SMITH, 1950). Table 5 shows that all basins have coarse textured topography indicating limited number of streams; high permeable soil; low drainage density.

Table 5: Basin Geometry Parameters of basins in Eastern Coast.

Ba	P_r	W_b	L_{ar}	K	F_f	SH	I_{sh}	R_e	R_c	R_{cn}	T	C_c
1	3600.7	13344.4	364429.6	4.678	0.167	0.0311	0.213	0.462	0.153	0.0122	0.0187	2.570
2	4909.9	19461.8	321654.8	1.786	0.439	0.0471	0.558	0.748	0.351	0.0279	0.0263	1.698
3	4072.7	17433.2	373079.0	2.850	0.275	0.0345	0.349	0.592	0.188	0.0150	0.0206	2.317
4	4008.9	18800.2	404405.7	2.803	0.280	0.0318	0.355	0.597	0.160	0.0127	0.0197	2.517
5	5796.4	28943.0	489745.4	1.627	0.482	0.0392	0.612	0.783	0.243	0.0193	0.0293	2.042
6	2804.5	12946.2	294894.3	3.492	0.224	0.0289	0.285	0.535	0.132	0.0105	0.0143	2.766
7	3149.4	12500.5	234176.6	2.550	0.307	0.0394	0.390	0.626	0.245	0.0195	0.0138	2.032
8	3304.0	14572.9	290767.8	2.692	0.291	0.0345	0.370	0.609	0.188	0.0149	0.0139	2.320
9	4253.7	21022.2	438667.3	2.567	0.305	0.0315	0.388	0.624	0.157	0.0125	0.0186	2.539
10	5237.0	30607.4	523807.2	1.627	0.482	0.0335	0.612	0.783	0.177	0.0141	0.0242	2.391
11	3019.3	13980.3	272135.0	2.619	0.299	0.0333	0.380	0.617	0.175	0.0139	0.0138	2.403
12	3433.3	15894.7	322151.6	2.684	0.292	0.0329	0.371	0.610	0.171	0.0136	0.0153	2.432
13	3797.5	15239.6	312523.7	2.776	0.282	0.0373	0.359	0.600	0.220	0.0175	0.0172	2.144
14	3456.9	14846.8	285133.9	2.510	0.312	0.0367	0.397	0.631	0.213	0.0169	0.0147	2.182

✓ Drainage Network

The composition of the drainage network of a drainage basin is expressed quantitatively in terms as shown in Table 6.

Table 6: Formulas of the morphometric Drainage Network parameters.

Drainage Network			
S.no.	Parameters	Formula	Reference
1	Stream number	$N_u = N_1 + N_2 + \cdots \ N_n$	(HORTON, 1945)
2	Stream Length	$L_u = L_1 + L_2 + \cdots \ L_n$	(STRAHLER, 1952)
3	Stream Length ratio	$L_{ur} = L_u / L_{u-1}$	(STRAHLER, 1952)
4	Bifurcation Ratio	$R_b = N_u / N_{u+1}$	(HORTON, 1945)
5	Rho Coefficient	$\rho = L_{ur} / R_b$	(HORTON, 1945)

❖ Bifurcation Ratio

It is a dimensionless property defined as the ratio of number of streams of a given order to the number of streams in the next higher order (HORTON, 1945). The high range of value for B2 is indicating mountainous and well dissected areas. But the others, which have low values, refer to flat, less structural disturbances, and the drainage system branched systematically as shown in Table 7.

❖ Stream-Length ratio

It is defined as the ratio of the average stream length of an order to average stream length of the next lower order. It tends to be constant throughout the successive orders of a basin (STRAHLER, 1952). The values vary (1.13-13.72) as shown in Table 7.

❖ Rho Coefficient

It refers to the maximum degree of drainage development, as its values determined by hydrological, physiographical, cultural, and geological factors (HORTON, 1945). Table 7 shows moderate to high values for the basins from 0.77 to 1.11 indicating moderate to high hydrologic storage during floods and minimizing the erosion resulted from elevated discharge.

Table 7: Drainage Network Parameters of basins in Eastern Coast.

Basin	L_{ur}	R_b	ρ
1	1.639963229	1.48375432	1.105279497
2	13.72553804	13.21367202	1.038737606
3	1.528269488	1.482882355	1.030607373
4	1.819189744	2.358542778	0.771319376
5	1.870253048	1.769101711	1.057176666
6	1.19634476	1.177429251	1.016065092
7	1.147307899	1.157435235	0.991250192
8	1.315932802	1.184931982	1.11055556
9	1.388849894	1.379386885	1.006860301
10	1.304222327	1.422922252	0.916580175
11	1.238163946	1.213769074	1.020098446
12	1.134781013	1.181403174	0.960536622
13	1.255841656	1.237191987	1.015074192
14	1.404755053	1.374906571	1.021709462

✓ Relief Characteristics

Relief analysis is crucial to develop a deep understanding of the spatial arrangement of landforms. The composition of relief characterizes of a drainage basin is expressed quantitatively in terms of Relative Relief Ratio, Relief Ratio, Ruggedness Number, Melton Ruggedness Number and Dissection Index as shown in Table 8.

Table 8: Formulas of the morphometric Relief Characterizes parameters.

Relief Characterizes			
S.no.	Parameters	Formula	Reference
1	Max Elevation (Z) Min Elevation (z)	Elevation of summit measured directly using WMS software	(STRAHLER, 1952)
2	Total Basin Relief	$H = Z - z$	(STRAHLER, 1952)
3	Relief Ratio	$R_{hl} = H/\ L_b$	(SCHUMM, 1956)
4	Absolute Relief	$R_a = \ Z$	(Melton, 1957)
5	Relative Relief Ratio	$R_{hp} = \ H * 1000/P$	(Melton, 1957)
6	Dissection Index	$D_{is} = H/R_a$	(Kuldeep Pareta, 2011)
7	Ruggedness Number	$R_n = D_d * H/1000$	(Melton, 1957)
8	Melton Ruggedness Number	$MR_n = H/\sqrt{A_b}$	(D.Wilford, 2004)

❖ Relative Relief ratio

Relative relief is the measurement of a basin's general steepness from the summit to the mouth. It is related to the characteristics of the drainage network and topography (Melton, 1957). Table 9 shows moderate values for B2, B6, B7 and B11 which indicate a moderate rate of topographic change over limited area. While the lowest value is for B1, B3-B5, B8-B10 and B12-B14 that extends over the flat plateau.

❖ Relief ratio

It is defined as the ratio of the elevation difference of highest and lowest points of a basin to the basin length. The relief ratio is used as an expression of relative relief to compare different sizes and forms of topography as it is a dimensionless ratio (SCHUMM, 1956). Table 9 shows that the basins of low to moderate relief and gentle slope have moderate values of relief ratio and indicate a flat surface.

❖ Ruggedness Number

It is a dimensionless number that's produced from the drainage density and the total relief of a basin. It indicates the landform structure complexity and combines slope steepness over the length (Melton, 1957). The values vary from 0.00147 to 0.00541as shown in Table 9.

❖ Melton Ruggedness Number

It is a slope index that provides specialized representation of relief ruggedness within a drainage basin. It is used in combination with the basin length to differentiate between drainage basins exposed to debris flows and debris floods (D.Wilford, 2004). Table 9 shows that all basins extend over flat surfaces or have limited relief value.

Table 9: Relief Characteristics Parameters of basins in Eastern Coast.

Ba	Z	z	H	R_{hl}	R_n	R_a	R_{hp}	D_{is}	MR_n
1	1046.50	58.50	988.0	0.0124	0.00242	1046.5	0.33522	0.94409	0.03032
2	1855.50	-1.50	1857.0	0.0419	0.00541	1855.5	1.05792	1.00080	0.06325
3	1303.50	-65.00	1368.5	0.0216	0.00334	1303.5	0.50506	1.04986	0.04119
4	1197.50	-64.50	1262.0	0.0187	0.00307	1197.5	0.40081	1.05386	0.03552
5	1633.50	1.50	1632.0	0.0271	0.00389	1633.5	0.54468	0.99908	0.03916
6	2072.50	0.50	2072.0	0.0359	0.00536	2072.5	0.77927	0.99975	0.07587
7	1393.50	-65.00	1458.5	0.0359	0.00286	1393.5	0.90457	1.04664	0.06472
8	990.50	5.50	985.0	0.0197	0.00141	990.5	0.44681	0.99444	0.03649
9	1030.50	-64.50	1095.0	0.0159	0.00208	1030.5	0.32223	1.06259	0.02880
10	1082.50	2.50	1080.0	0.017	0.00147	1082.5	0.29114	0.99769	0.02450
11	1424.50	5.50	1419.0	0.0304	0.00295	1424.5	0.65685	0.99613	0.05556
12	1324.50	-65.00	1389.5	0.0255	0.00216	1324.5	0.55210	1.04907	0.04726
13	981.50	-65.00	1046.5	0.0194	0.00163	981.5	0.48378	1.06622	0.03651
14	930.50	0.50	930.0	0.0195	0.00174	930.5	0.45600	0.99946	0.03502

✓ Drainage Texture Analysis

The composition of the drainage texture is expressed quantitatively in terms of Stream Frequency, Drainage Density, Constant of Channel Maintenance and Infiltration Number as shown in Table 10.

Table 10: Formulas of the morphometric Drainage Texture parameters.

Drainage Texture			
S.no.	Parameters	Formula	Reference
1	Stream Frequency	$F_s = N_u * A_b$	(HORTON, 1932)
2	Drainage density	$D_d = L_u/A_b$	(HORTON, 1932)
3	Constant of Channel Maintenance	$C = 1/D_d$	(SCHUMM, 1956)
4	Drainage Intensity	$D_i = F_s/D_d$	(Faniran, 1962)
5	Infiltration Number	$I_f = F_s * D_d$	(Faniran, 1962)

❖ Stream Frequency

It is defined as the number of streams per unit of area. It is related to the geological characteristics of surface formations, so it reflects the hydrological behavior of surface formations and the degree of geomorphological evolution (HORTON, 1932). Table 11 shows low values for the basins indicating a limited number of streams per unit area; well-developed channels and valleys; old stage of landform development; stable surface runoff; or high surface permeability.

❖ Drainage Density

The drainage density is defined as the length of streams per unit of drainage area. It is used to describe the degree of drainage development over the basin as an excellent indicator to the surface permeability and the landform stage of development. Its value varies according to the dynamics of inputs and outputs within the basin, three main factors controlling its value: the physiographic characteristics such as the relief ratio, rock type and basin shape; the inputs and outputs; and the past and future conditions (HORTON, 1932). Table 11 shows that all basins have moderate to high values of drainage density indicating mature to old stage of landforms; include gullied slopes; and have a surface of low permeability.

❖ Constant of Channel Maintenance

It is defined as the minimum area required to develop and sustain 1 km of drainage channel. It is influenced by relative relief, lithology, and climate. It is used to measure the texture (SCHUMM, 1956). Table 11 shows that all basins have values ranging from 342 to 792 m^2/m indicating a moderately low erodible surface.

❖ Infiltration Number

It is used to measure texture of topography through multiplying drainage density by stream frequency. Its value is influenced by soil, lithology, climate, vegetation and relief indicating the infiltration characteristics of a drainage basin (Faniran, 1962). Table 11 shows that all basins have high values, which refer to low infiltration capacity and thus high surface runoff.

Table 11: Drainage Texture Analysis Parameters of basins in Eastern Coast.

Basin	D_d	F_s	C	D_i	I_f
1	0.00245	5.192E-06	407.0345	0.002113	1.275E-08
2	0.00291	5.355E-06	342.6570	0.001835	1.563E-08
3	0.00244	5.066E-06	408.9953	0.002072	1.238E-08
4	0.00243	4.931E-06	410.9999	0.002026	1.199E-08
5	0.00238	5.062E-06	419.4321	0.002123	1.206E-08
6	0.00258	5.122E-06	386.4997	0.001979	1.325E-08
7	0.00196	4.411E-06	508.6220	0.002243	8.672E-09
8	0.00143	4.229E-06	697.4167	0.002949	6.065E-09
9	0.00190	4.391E-06	524.8433	0.002304	8.367E-09
10	0.00136	4.634E-06	732.7225	0.003395	6.324E-09
11	0.00207	4.600E-06	480.9427	0.002212	9.566E-09
12	0.00155	4.478E-06	643.1722	0.002880	6.963E-09
13	0.00156	4.551E-06	639.1662	0.002909	7.121E-09
14	0.00187	4.252E-06	532.9511	0.002266	7.978E-09

- **Hazard degree**

Multi-Criteria Analysis (MCA) refers to any structured approach used to determine overall preferences among alternative options, where the options achieve one or more goals. MCA specifies desirable objectives and identifies corresponding attributes or indicators. The actual measurement of indicators need not be in monetary terms but are often based on the quantitative analysis (through scoring, ranking and weighting) of a wide range of qualitative impact categories and criteria (M.Baptista, 2007). MCA provides techniques for comparing and ranking different outcomes, even though a variety of indicators are used. The morphological parameters obtained for each basin are expressed in a variety of units. As a result, using standard statistical methods to compare the different basins is difficult. As a result, a weighted factor will be used to analyze these dimensionless parameters, a process known as standardization.

➢ Pearson Correlation equation

Statistical analysis was performed using the Pearson Correlation equation to calculate the linear correlations between the morphometric parameters of each basin and the hydrological parameters (peak and volume of water and time of concentration calculated for each basin with the same curve number and precipitation) of the flash flood to determine the most effective parameters and other significant correlations, and it is expressed mathematically as in equation (1). Galton invented it in 1877, and Karl Pearson expanded on it (J.L.Rodgers, 1988). As a result, the morphometric parameters are classified based on their hydrological effect.

$$r = \frac{\sum(X_i-\bar{X})(Y_i-\bar{Y})}{\sqrt{[\sum(X_i-\bar{X})^2 * \sum(Y_i-\bar{Y})^2]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Eq\ 1$$

Where:

X_i : is the value of the morphometric parameters to be assessed for the hazard degree.

Y_i : is the value of the hydrological parameters to be assessed for the hazard degree.

$\bar{X}$: is the mean value of the morphometric parameters to be assessed.

$\bar{Y}$: is the mean value of the hydrological parameters to be assessed.

The coefficient will always be a number between -1 and 1, with a positive value indicating a positive correlation and a negative value a negative correlation. A correlation of r = 1 for a data set indicates a perfect positive linear correlation, and a correlation of r = -1 for a data set indicates a perfect negative linear correlation, while r =0 would indicate no linear correlation. The closer the value of r is to ±1, the stronger the correlation, the closer the value of r is to zero, the weaker the correlation. So it is necessary to divide the values into 4 intervals:

- High positive effect in which the correlation will be greater than 0.5 to 1.
- Low positive effect in which the correlation will be less than 0.5 to 0.
- High negative effect in which the correlation will be greater than -0.5 to 0.
- Low negative effect in which the correlation will be less than -0.5 to -1.

The results confirm the hydrological implications of the morphometric parameters for basins in Eastern coast Table 12 shows the correlation values for morphometric parameters according to their hydrological significance. Only the parameters which have a strong linear correlation are recommended to be studied further. The results are useful to optimize the accuracy of the hydrological models that are based on morphometric characteristics to predict the flood hydrograph such as: Basin Area, Basin Length, Basin perimeter, Centroid stream slope and Relative relief ratio.

Table 12: Pearson Correlation results in Eastern Coast.

Hydrological Parameters	A_b	BS	AOFD	L_b	P	SHAPE	SIN	AVEL
Peak (m3/sec)	0.925	-0.102	0.310	0.372	0.694	-0.556	-0.021	-0.258
Runoff Volume (m3)	1.000	-0.297	0.166	0.618	0.869	-0.377	0.087	-0.164
Time of Concentration (hr.)	0.592	-0.655	-0.091	0.838	0.737	0.264	0.245	0.147
Mean	0.839	-0.351	0.128	0.609	0.767	-0.223	0.104	-0.091
Hydrological Parameters	MFD	MFS	MSL	MSS	CORSTR	CSD	CSS	N_u
Peak (m3/sec)	0.377	-0.071	0.379	-0.170	0.163	0.353	-0.605	0.931
Runoff Volume (m3)	0.658	-0.360	0.661	-0.473	0.099	0.621	-0.661	0.985
Time of Concentration (hr.)	0.916	-0.760	0.919	-0.833	-0.005	0.804	-0.454	0.567
Mean	0.651	-0.397	0.653	-0.492	0.086	0.592	-0.573	0.828
Hydrological Parameters	L_u	L_{ur}	R_b	ρ	P_r	W_b	L_{ar}	
	0.786	0.081	0.087	-0.165	0.878	0.959	0.911	
Runoff Volume (m3)	0.812	-0.076	-0.062	-0.284	0.830	0.926	0.997	
Time of Concentration (hr.)	0.486	-0.280	-0.260	-0.319	0.299	0.323	0.625	
Mean	0.695	-0.092	-0.079	-0.256	0.669	0.736	0.845	
Hydrological Parameters	K	F_f	SH	I_{sh}	R_e	R_c	R_{cn}	
	-0.554	0.744	0.079	0.744	0.708	0.080	0.080	
Runoff Volume (m3)	-0.375	0.567	-0.128	0.567	0.528	-0.132	-0.132	
Time of Concentration (hr.)	0.265	-0.149	-0.455	-0.149	-0.177	-0.461	-0.461	
Mean	-0.222	0.387	-0.168	0.387	0.353	-0.171	-0.171	
Hydrological Parameters	T	C_c	D_d	F_s	C	D_i	I_f	
	0.829	-0.075	0.037	0.309	0.035	0.173	0.106	
Runoff Volume (m3)	0.755	0.114	-0.060	0.226	0.107	0.240	0.005	
Time of Concentration (hr.)	0.249	0.424	-0.109	0.063	0.087	0.154	-0.079	
Mean	0.611	0.155	-0.044	0.199	0.076	0.189	0.011	
Hydrological Parameters	H	R_{hl}	R_n	R_a	R_{hp}	D_{is}	MR_n	
	0.157	-0.106	0.127	0.166	-0.246	-0.071	-0.330	
Runoff Volume (m3)	-0.132	-0.430	-0.110	-0.124	-0.545	-0.029	-0.606	
Time of Concentration (hr.)	-0.602	-0.848	-0.447	-0.596	-0.837	0.023	-0.824	
Mean	-0.193	-0.461	-0.143	-0.185	-0.543	-0.026	-0.587	

➢ Davis equation

An empirical relation between the relative hazard degrees of basins with respect to flash floods was applied on the chosen hydro-morphological parameter, the equal spacing or simple linear interpolation between data points procedure was chosen. Assuming that a straight linear relation exists between sample points, intermediate values can be calculated from the geometric relationship (J.C.Davis, 1975). A hazard scale number starting with 1 (lowest) to 5 (highest) has been assigned to all parameters as shown in Table 13.

Table 13: Hazard scale number.

Total SRF	Class of the Hazard degree	Symbol of class
R1	Low	L
R2	Moderately Low	ML
R3	Moderate	M
R4	Moderately High	MH
R5	High	H

For determining the Hazard degree for each basin, it is necessary to calculate the weight of morphometric parameters of each basin using the Davis equation and must consider multiplying it in the Pearson correlation coefficient to determine the real effect of the hydrological parameters (J.C.Davis, 1975).

$$\textbf{Weight of Parameter} = \left(\frac{\mathbf{4(X_i - X_{min})}}{\mathbf{(X_{max} - X_{min})}} + \mathbf{1}\right) * \mathbf{r} \quad \text{.................... Eq 2}$$

Where: X_i : is the value of the morphometric parameters to be assessed for each basin.

X_{min} & X_{max} : are the min and max values of the morphometric parameters.

r: Pearson correlation coefficient of each morphometric parameter.

According to the result of Pearson Correlation values as shown in Table 12 for each parameters for basins in Eastern coast area, it was concluded that there are 15 morphometric parameters have the high effect on the hazard degree value, the following presents the weight of the parameters as shown in tables from Table 14 to Table 18

Table 14: Weight of Parameters from WMS software of basins in Eastern Coast.

Basin	W.A_b	W.BS	W. AOFD	W.L_b	W.P	W.SHAPE	W.SIN
1	2.294	1.00	1.321	3.437	2.952	0.108	1.00
2	1.828	0.578	1.513	1.229	1.209	0.951	1.194
3	2.393	0.472	1.341	2.421	2.604	0.642	1.060
4	2.764	0.630	1.247	2.661	3.246	0.656	1.414
5	3.874	0.345	1.367	2.214	3.023	1.00	1.134
6	1.556	-0.10	1.386	2.063	2.530	0.454	1.073
7	1.00	-0.40	1.069	1.000	1.00	0.729	1.073
8	1.515	0.220	1.032	1.586	1.865	0.688	1.207
9	3.193	0.109	1.078	2.763	3.611	0.724	1.097
10	4.356	0.311	1.097	2.431	4.066	1.00	1.219
11	1.337	0.233	1.132	1.378	1.801	0.708	1.255
12	1.833	0.246	1.100	1.861	2.322	0.690	1.036
13	1.733	0.271	1.054	1.832	1.805	0.662	1.28
14	1.461	0.394	1.00	1.430	1.624	0.740	1.194

Basin	W.AVEL	W.MFD	W.MFS	W.MSL	W.MSS	W.CORSTR	W.CSD	W.CSS
1	0.634	3.251	1.00	3.264	1.00	1.193	2.672	0.054
2	0.981	1.441	0.353	1.444	-0.09	1.136	1.00	0.267
3	0.906	2.427	0.600	2.442	0.263	1.193	2.239	0.219
4	1.00	3.602	0.904	3.613	0.931	1.216	3.369	1.00
5	0.957	2.367	0.676	2.382	0.606	1.342	1.502	0.479
6	0.851	2.108	-0.58	2.090	-0.96	1.216	1.897	0.456
7	0.835	1.00	0.058	1.00	-0.42	1.193	1.267	-1.29
8	0.847	1.846	0.638	1.854	0.366	1.241	1.759	-0.18
9	0.873	2.857	0.99	2.871	0.948	1.068	2.654	0.007
10	0.943	2.840	0.800	2.853	0.948	1.068	3.200	0.976
11	0.988	1.726	0.781	1.734	0.674	1.00	1.347	-0.08
12	0.886	1.792	0.828	1.803	0.674	1.096	1.587	-0.48
13	0.913	2.297	0.923	2.298	0.863	1.273	1.689	-0.60
14	0.949	1.653	0.876	1.664	0.777	1.048	1.700	0.172

Table 15: Weight of Basin Geometry Parameters of basins in Eastern Coast.

Basin	$W.P_r$	$W.W_b$	$W.L_{ar}$	$W.K$	$W.F_f$	$W.SH$
1	1.71206	1.13723	2.51921	0.11344	1	0.91844
2	2.88310	2.13207	2.02030	0.95386	2.33871	0.32744
3	2.13429	1.80218	2.62009	0.64463	1.53024	0.79265
4	2.07722	2.02448	2.98547	0.65826	1.55295	0.89439
5	3.67595	3.67394	3.98084	1	2.54993	0.62086
6	1	1.07249	1.70818	0.45800	1.28070	1
7	1.30842	1	1	0.73163	1.68950	0.61387
8	1.44677	1.33702	1.66005	0.69053	1.60985	0.79450
9	2.29613	2.38582	3.38509	0.72680	1.67970	0.90435
10	3.17559	3.94461	4.37812	0.99988	2.54937	0.83209
11	1.19209	1.24065	1.44273	0.71164	1.64970	0.83829
12	1.56238	1.55197	2.02610	0.69273	1.61390	0.85311
13	1.88814	1.44544	1.91380	0.66606	1.56629	0.68953
14	1.58344	1.38157	1.59434	0.74332	1.71381	0.71356

Basin	$W.I_{sh}$	$W.R_e$	$W.R_c$	$W.R_{cn}$	$W.T$	$W.C_c$
1	1	1	0.93437	0.93437	1.75962	1.50476
2	2.33871	2.25557	0.31484	0.31484	2.96177	1
3	1.53024	1.57083	0.82370	0.82370	2.06628	1.35821
4	1.55295	1.59250	0.91409	0.91409	1.92970	1.47431
5	2.54993	2.41210	0.65405	0.65405	3.44349	1.19915
6	1.28070	1.31952	1	1	1.07518	1.61819
7	1.68950	1.71924	0.64669	0.64669	1.00017	1.19347
8	1.60985	1.64604	0.82541	0.82541	1.01333	1.36015
9	1.67970	1.71033	0.92254	0.92254	1.75734	1.48677
10	2.54937	2.41169	0.85963	0.85963	2.64115	1.40095
11	1.64970	1.68290	0.86518	0.86518	1	1.40792
12	1.61390	1.64981	0.87833	0.87833	1.23492	1.42487
13	1.56629	1.60515	0.72443	0.72443	1.53662	1.25798
14	1.71381	1.74119	0.74825	0.74825	1.12783	1.27997

Table 16: Weight of Drainage Network Parameters of basins in Eastern Coast.

Basin	$W.N_u$	$W.L_u$	$W.L_{ur}$	$W.R_b$	$W.\rho$
1	2.60114	2.42258	0.98527	0.99149	-0.00862
2	2.16339	2.34123	0.63295	0.68573	0.19234
3	2.64080	2.50300	0.98852	0.99151	0.21690
4	2.95123	2.83284	0.98004	0.96869	1
5	4.20816	3.77854	0.97855	0.98405	0.13665
6	1.77364	1.82320	0.99820	0.99947	0.26082
7	1	1	0.99963	1	0.33576
8	1.41179	1.04069	0.99471	0.99928	-0.02455
9	3.01146	2.55247	0.99259	0.99421	0.28862
10	4.31147	2.46159	0.99506	0.99307	0.56128
11	1.37262	1.31642	0.99698	0.99853	0.24864
12	1.79812	1.30513	1	0.99937	0.42852
13	1.73397	1.25363	0.99647	0.99792	0.26381
14	1.37115	1.28691	0.99212	0.99433	0.24377

Table 17: Weight of Relief Characterizes Parameters of basins in Eastern Coast.

Basin	$W.H$	$W.R_{hl}$	$W.R_n$	$W.R_a$	$W.R_{hp}$	$W.D_{is}$	$W.MR_n$
1	0.96087	1	0.85476	0.92498	0.87521	1	0.73394
2	0.37472	-0.84452	0.42660	0.40184	-1.17055	0.95216	-0.76979
3	0.70422	0.42523	0.72330	0.75879	0.39443	0.91077	0.23765
4	0.77606	0.60166	0.76271	0.82734	0.68954	0.90740	0.49681
5	0.52649	0.07655	0.64532	0.54539	0.28229	0.95361	0.33058
6	0.22971	-0.47193	0.43497	0.26151	-0.38177	0.95304	-1.34622
7	0.64352	-0.46765	0.79176	0.70059	-0.73644	0.91349	-0.83685
8	0.96290	0.54474	1	0.96120	0.55933	0.95752	0.45224
9	0.88870	0.78113	0.90355	0.93533	0.91198	0.90004	0.80371
10	0.89882	0.71297	0.99118	0.90170	1	0.95479	1
11	0.67016	-0.12450	0.77990	0.68055	-0.03522	0.95609	-0.41840
12	0.69006	0.17891	0.89296	0.74521	0.26127	0.91144	-0.03974
13	0.92141	0.56303	0.96781	0.96702	0.45467	0.89697	0.45152
14	1	0.55239	0.95240	1	0.53332	0.95329	0.51944

Table 18: Weight of Drainage Texture Parameters of basins in Eastern Coast.

Basin	$W.D_d$	$W.F_s$	$W.C$	$W.D_i$	$W.I_f$
1	0.87651	1.68080	1.05035	1.13486	1.03004
2	0.82432	1.79667	1	1	1.04294
3	0.87784	1.59188	1.05188	1.11487	1.02838
4	0.87919	1.49651	1.05345	1.09294	1.02664
5	0.88472	1.58899	1.06004	1.13968	1.02695
6	0.86175	1.63170	1.03429	1.07016	1.03227
7	0.93200	1.12828	1.12981	1.19802	1.01170
8	0.99218	1	1.27747	1.54053	1
9	0.93887	1.11444	1.14249	1.22774	1.01033
10	1	1.28612	1.30509	1.75662	1.00116
11	0.91920	1.26248	1.10816	1.18305	1.01572
12	0.97851	1.17608	1.23504	1.50689	1.00403
13	0.97741	1.22762	1.23191	1.52077	1.00474
14	0.94215	1.01590	1.14883	1.20902	1.00859

➢ The hazard degree of each basin

To calculate the Hazard value, it is necessary to sum the weight of all the morphological parameters of each basin separately by using equation (3) and to determine the Hazard degree of each basin, the basins must be divided into 5 intervals as shown in Table 13 and calculate the range of each interval and end of each interval by using equations (4) and (5), then specify the Hazard degree by determining in what interval each basin is located (J.C.Davis, 1975).

$$\textbf{Hazard Degree} = \sum \textbf{Weight of morphometric Parameter} \ldots\ldots \quad \textit{Eq 3}$$

$$\mathbf{R_n} = \mathbf{R_{n-1}} + \textbf{Range} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Eq 4}$$

$$\textbf{Range} = (\mathbf{R_5} - \mathbf{R_1})/\mathbf{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \textit{Eq 5}$$

Where: $R_1 =$ min total weight & $R_5 =$ max total weight & $n =$ no. of classes

The Morphometric Hazard Degree assessment method was employed to perform the required morphometric analysis, to estimate the flash flood hazard and the degree of risk for the basins on the Eastern coast. Table 19 displays the results of this method for all watersheds, as expressed by ranking score for the different morphometric parameters based on the relation with hazard whether proportional or inverse. The summation of hazard degree values for the basins was grouped into five categories of susceptibility for flash floods as shown in Figure 5.

Table 19: Value of Hazard degree for all basins in Eastern Coast.

BASIN	TOTAL WEIGHT	DEGREE
1	58.83351	M
2	45.92579	ML
3	56.08731	M
4	66.17384	MH
5	68.83614	H
6	40.99630	L
7	33.09014	L
8	46.98025	ML
9	64.10437	MH
10	76.84774	H
11	43.48856	ML
12	48.32419	ML
13	50.30727	ML
14	47.50106	ML
MIN WEIGHT	33.09014	
MAX WEIGHT	76.84774	
RANGE	8.751520752	
R1	33.09014	
L		
R2	41.84166	
ML		
R3	50.59318	
M		
R4	59.34470	
MH		
R5	68.09622	
H		
R6	76.84774	

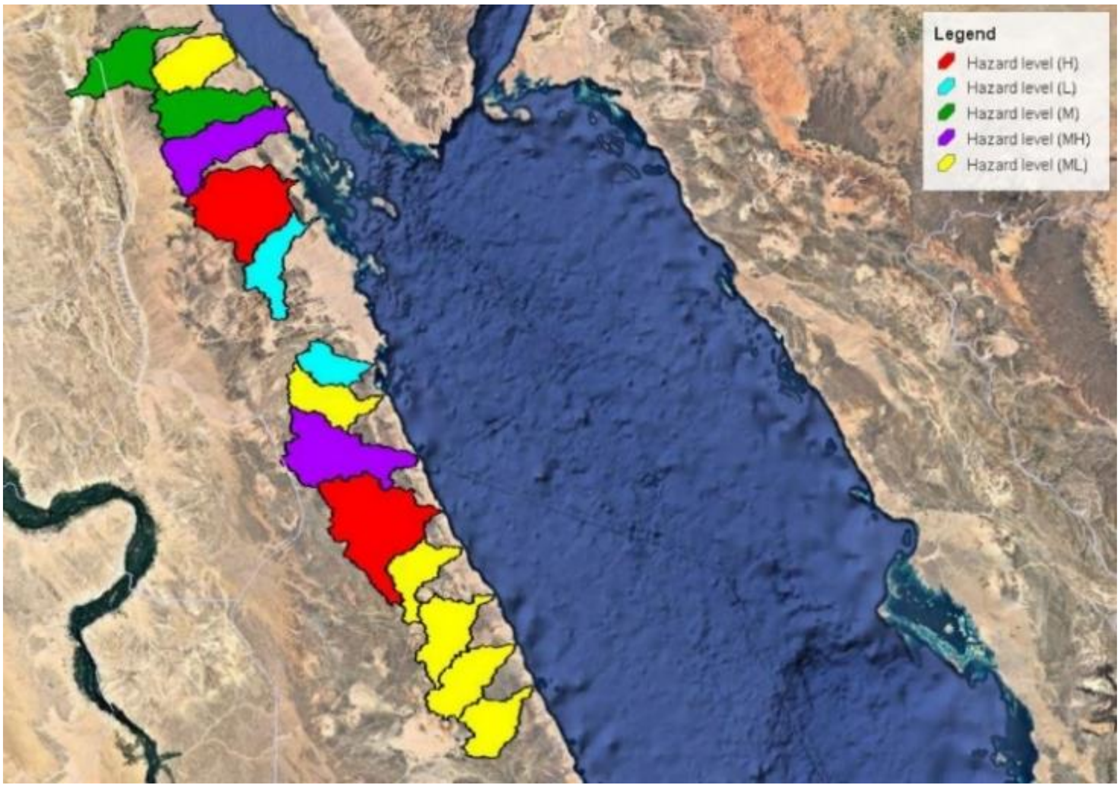

Figure 5: Hazard degree of basins in Eastern Coast.

Conclusion

In this study of Eastern coast. With the introduction of SRTM DEM maps (resolution 30*30) on WMS 11.0, basins with an area exceeding 500km^2 were deduced and 45 morphometric properties were deduced for each basin divided into four groups: Basin geometry, Drainage Network, Relief characteristics and Drainage texture analysis.

The statistical analysis, using Pearson correlation, classified the morphometric parameters according to their hydrological contribution to the flash flood event and showed that morphometric parameters which have a strong correlation with the storm flow generation, are changed according to the conditions of the region and it helps to determine the most Hazardous basin. The result was that: wadi Quseir in Figure 6 is the most dangerous of all basins in the study area of the Eastern coast.

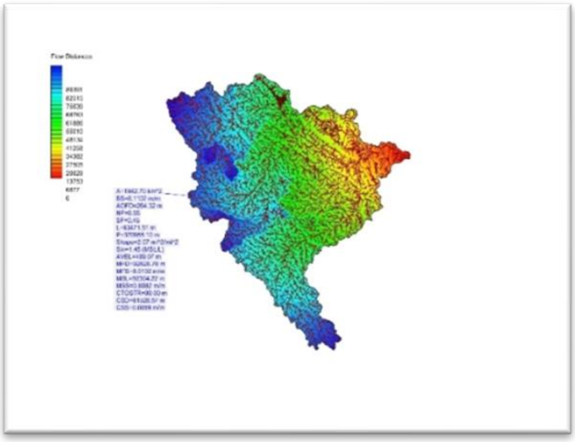

Figure 6: Wadi Quseir in Eastern Coast.

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