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GIS and Hypsometry based Analysis on the Evolution of Sub-basins in Ataq Area-Shabwah, Yemen

Hamdi S. Aldharab[1], Syed Ahmad Ali[2], Javed Ikbal[3], Saleh Ghareb[4]
[1,2,3,4] Department of Geology, Aligarh Muslim University, Aligarh, India

Abstract: Hypsometric analysis of drainage basins reveals useful information to distinguish between the erosional landforms at different stages during their evolution; it gives ideas for understanding the geomorphic development of a basin. In this paper, we used SRTM data (30m resolution) to derive and analysed hypsometric data for the Ataq-Southeastern Yemen; the study area was divided into six sub-basin and hypsometric analysis was carried out for all of these sub-basins using digital contour map which was generated for every sub-basin with the helping of ArcGIS also hypsometric curve was prepared for every sub-basin; differences in hypsometric curve shape and hypsometric integral values are indicated to the degree of disequilibrium in the balance of erosive processes and tectonic forces. The result values of the hypsometric integral for all the sub-basins are ranges "between" 21.9% to 51.4%; according to these results, two stages were identified in the study area namely mature or equilibrium and old stages. The overall of the study for hypsometric analysis in this paper was to understand the erosional topography and tectonic activities in the area.
Keywords: Hypsometry, Sub-basin, SRTM, Remote Sensing and GIS, Yemen, Ataq

I. INTRODUCTION

The hypsometric analysis was firstly introduced by Langebein (1947) to expresses the overall slope and the forms of a drainage basin. The percentage of the hypsometric curve represents the relationship between the horizontal cross-sectional areas of a drainage basin to the relative elevation above the basin mouth (Strahler, 1952). Hurtrez, (1999) stated that the hypsometric curve is related to the volume of soil masses in the basin and the amount of the erosion that had occurred in a basin against the remaining masses. By geometric analysis of watershed site selection for soil conservation has been done (Ikbal et al., 2017). According to Strahler (1952) and Schumm (1956), a hypsometric analysis is used to distinguish between the erosional landforms at different stages during their evolution; hypsometric analysis provides useful information for understanding the geomorphic development of a basin, it may reflect the interaction between tectonics and erosion processes (Ali and Ikbal 2017). Hypsometry may be expressed quantitatively as hypsometric integral (Strahler, 1952). The hypsometric integral (HI) provides a measure of the distribution of landmasses volume remaining beneath or above a basal references plane (Sivakumar, 2011; Singh, et al., 2008). Hypsometric analysis using GIS has been used by several researchers to deal with erosional topography, like Pandey, (2004); Singh, (2008). Drainage analysis of different area with the help of remote sensing and GIS has been carried out (Ali et al., 2017; Ikbal et al., 2017). In Yemen, there is a lack of hypsometric studies for the watershed, which is attributable to the tedious nature of data acquisition and analysis is involved in estimation of hypsometric analysis. Considering the above facts and due to the advent of remote sensing data including derived digital elevation models and open sources software tools (GIS); the estimation and understand the geomorphic stages become easier than conventional methods. This study was undertaken in six sub-basins for Ataq area, Yemen to estimate and understand the geomorphic stages.

II. STUDY AREA

The study area is located in the Shabwah Province, south-eastern central of Yemen; between longitude 46º 47' – 47º 00 E and latitude 14º 20' – 14º 32' N, Fig. 1. It covers an area about 792 km^2. Geologically the study area located in the south-eastern part of Marib-Shabwah Graben; which formed part of an extensive rift system developed across much of Yemen and Somalia during the late Jurassic (Beydoun, 1964), the Graben is northwest-southeast trending; and bounded by two major normal faults. The study area covers by syntectonic granite infrastructure and the overlying Mesozoic-Cenozoic sedimentary successions (Al Wosabi et al., 2013). Most of the northern part of the area belongs to a desert plain lying at the altitude of 1100-1200m, the southern part extended by low mountainous ridge held by Precambrian rocks, (Isakin, 1990). The eastern part of the area is occupied by a plateau with altitudes of

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1550-1650m; the plateau is underlain by flatty lying Paleogene limestones and is separated from the desert by a steep scarp 150-200m high. The major Wadis on the area drain in the north-west direction and gradually vanish in the desert.

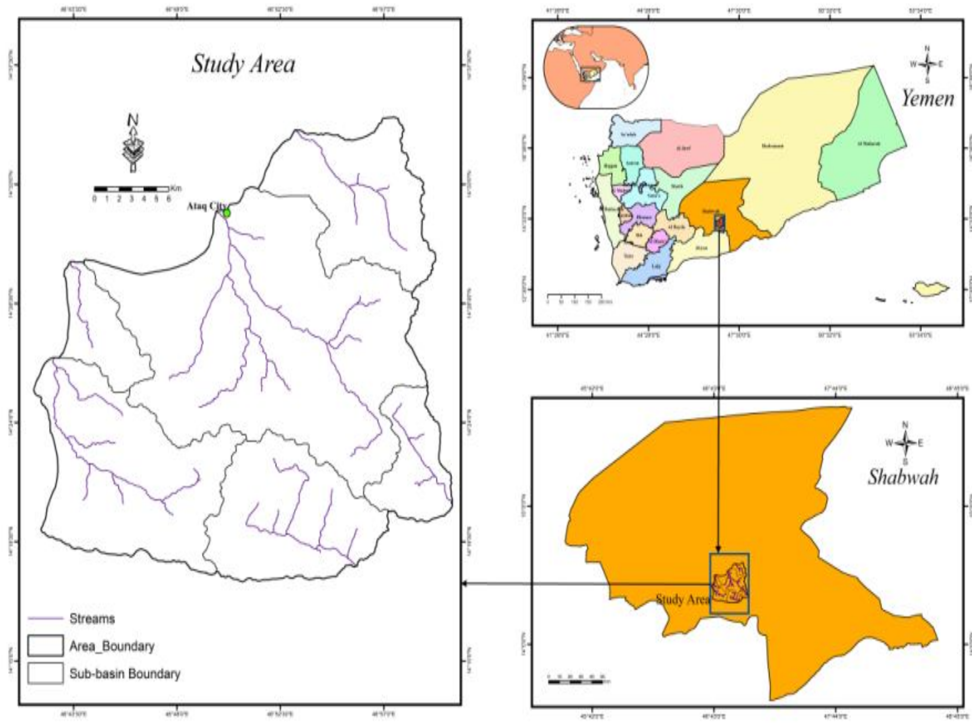

Fig. 1 Location Map of the Study Area

III. METHODOLOGY AND DATA

The hypsometric curve can be readily obtained from grid or contour representation of surface topography; digital elevation model base SRTM data with spatial resolution 30m was downloaded via internet from USGS website, and used in this study to generate elevation and slope maps Fig. 3 and 4; ArcGIS software was used to analyse and obtained the values, Excel program has been used to determine the hypsometric curve values. The study area is delineated into six distinct sub-basins, and digital contour map was carried out from SRTM data for each sub-basin using ArcGIS Fig. 5. The digital contour maps were used to generate the data required for relative area and elevation ranges.
The following procedures have been adopted for Hypsometric analysis:

A. Plotting of Hypsometric Curves (HC)

Considering the drainage basin to be bounded by vertical sides and a horizontal base plane passing through the mouth; the relative height can be obtained as the ratio of the height of a given contour (h) from the base plane of the stream mouth to total height of the basin with reference to the same base level (H), and the relative area is obtained as the ratio of the area above a particular contour (a) to the total area of the watershed encompassing the outlet (A) (Sarangi, 2001; Reitter, 2002). Strahler, (1952) interpreted the shape of the hypsometric curve and classified the basins in to three type based on hypsometric curve, these are: young (convex upward curves), mature (S-shaped curve, which concaves upwards at high elevations and convex downward at low elevations) and old age which represent the peneplain or distorted area, and it concave upward curves. The hypsometric curve was generated by plotting the relative area along the abscissa and the relative height along the ordinate, as shown in Fig. 2 (after Singh, et al. 2008). Values of Relative height and Relative area of these sub-basins are presented in the Tables (1, 2, 3, 4, 5, 6 and 7).

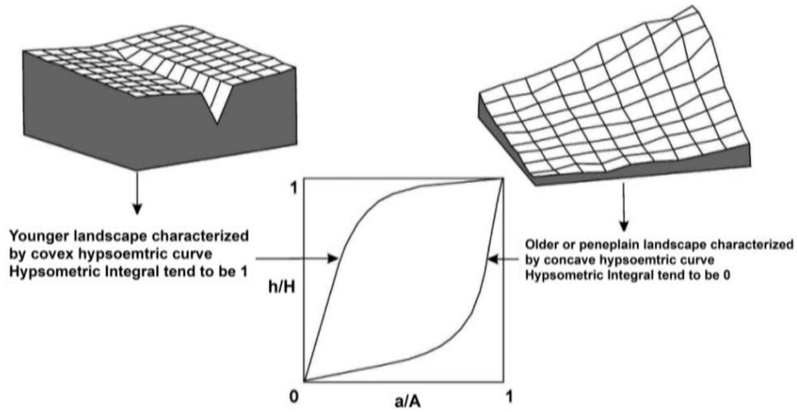

Fig. 2: Hypothetical diagram showing how watershed morphology is related to hypsometric curve and hypsometric integral (Singh, et al., 2008)

B. *Estimation of Hypsometric Integrals (HIS)*

Hypsometric integral (His) represent the area under the hypsometric curve and give an indication of the cycle of erosion (Strahler, 1952 and Garg, 1983). The hypsometric integral was calculated using the elevation relief ratio which defined as Integration of hypsometric curve; this method was approved by Pike and Wilson (1971). This relationship is expressed mathematically as:

$$E \approx His = \frac{Mean\ Elevation - Minimum\ Elevation}{Maximum\ Elevation - Minimum\ Elevation}$$

Where, E is the elevation ratio equivalent to the hypsometric integral; Elevation values were derived automatically from SRTM Dem. The hypsometric integral is expressed in percentage units and is obtained from the percentage hypsometric curve by measuring the area under the curve. This provided a measure of the distribution of landmass volume remaining beneath or above a basal reference plane (Singh, et al., 2008). The cycle of erosion is the total time which required for reduction of the land area to the base level or lower level. The entire period of cycle erosion according to Strahler, (1952) can be divided into three stages based on hypsometric integral values; these stages are: inequilibrium or youthful stage (His > 0.6) in which the river basin is highly susceptible to erosion, equilibrium or mature stage (His between 0.3 and 0.6 in which the river basin is in mature phase of basin development, and monadnock or old stage (His < 0.3) in which the river basin is fully stabilized.

Table .1 Relative height and Relative area of Ataq Sub-basin

Altitude Range Ataq Sub-Basin	Area (a) (km^2)	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1118 - 1180	45.8	6.29%	45.80	1118	1.000	62	62	1118	0.000
1180 - 1245	147.8	20.27%	193.60	1180	0.937	65	127	1180	0.095
1245 - 1310	180.2	24.72%	373.80	1245	0.734	65	192	1245	0.194
1310 - 1375	165.9	22.75%	539.70	1310	0.487	65	257	1310	0.294
1375 - 1440	75.1	10.30%	614.80	1375	0.260	65	322	1375	0.394
1440 - 1505	42.2	5.79%	657.00	1440	0.157	65	387	1440	0.493
1505 - 1570	42.8	5.87%	699.80	1505	0.099	65	452	1505	0.531
1570 - 1635	23.7	3.25%	723.50	1570	0.040	65	517	1570	0.651
1653 - 1700	5.0	0.68%	728.50	1635	0.008	65	582	1653	0.792
1700 - 1771	0.5	0.07%	729.00	1700	0.001	71	653	1700	0.891
	729.0	100.00%		1771	0.000	653		1771	1.000

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Tables .2, 3 and 4 Relative height and Relative area of the 1st, 2nd and 3rd sub basin

Altitude Range SB1	Area (a) (km^2)	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1153 – 1200	9.63	10.47%	9.36	1153	1.00	47	47.00	1153	0.00
1200 – 1248	12.01	13.05%	21.64	1200	0.90	48	95.00	1200	0.10
1248 – 1296	11.34	12.33%	32.98	1248	0.76	48	143.00	1248	0.20
1296 – 1344	4.99	5.42%	37.97	1296	0.64	48	191.00	1296	0.30
1344 – 1392	3.02	3.28%	40.99	1344	0.59	48	239.00	1344	0.39
1392 – 1440	5.69	6.18%	46.68	1392	0.55	48	287.00	1392	0.49
1440 – 1488	8.09	8.79%	54.77	1440	0.49	48	335.00	1440	0.59
1488 – 1536	6.92	7.52%	61.69	1488	0.40	48	383.00	1488	0.69
1536 – 1584	24.90	27.07%	86.59	1536	0.33	48	431.00	1536	0.79
1584 - 1637	5.41	5.88%	92.00	1584	0.06	53	484.00	1584	0.89
	92.00	100.00%		1637	0.00	484		1637	1.00

Altitude Range SB2	Area (a) ($km^{2)}$	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1139 – 1200	75.50	23.97%	75.50	1139	1.0000	61	61	1139	0.000
1200 – 1265	90.71	28.80%	166.21	1200	0.7603	65	126	1200	0.097
1265 – 1330	65.67	20.85%	231.88	1265	0.4723	65	191	1265	0.199
1330 – 1395	31.37	9.96%	263.25	1330	0.2639	65	256	1330	0.302
1395 – 1460	20.02	6.36%	283.27	1395	0.1643	65	321	1395	0.405
1460 – 1525	12.00	3.81%	295.27	1460	0.1007	65	386	1460	0.508
1525 – 1590	10.84	3.44%	306.11	1525	0.0626	65	451	1525	0.611
1590 – 1655	6.54	2.08%	312.65	1590	0.0282	65	516	1590	0.714
1655 – 1720	2.30	0.73%	314.95	1655	0.0075	65	581	1655	0.816
1720 - 1771	0.05	0.02%	315.00	1720	0.0002	51	632	1720	0.919
	315.00	100.00%		1771	0.0000	632		1771	1.000

Altitude Range SB3	Area (a) (Km^2)	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1180 – 1210	7.11	20.91%	7.11	1180	1.000	30	30	1180	0.000
1210 – 1250	7.71	22.68%	14.82	1210	0.791	40	70	1210	0.078
1250 – 1290	4.27	12.56%	19.09	1250	0.564	40	110	1250	0.181
1290 – 1330	2.89	8.50%	21.99	1290	0.439	40	150	1290	0.284
1330 – 1370	3.65	10.74%	25.64	1330	0.354	40	190	1330	0.388
1370 – 1410	4.42	13.00%	30.06	1370	0.246	40	230	1370	0.491
1410 – 1450	2.39	7.03%	32.46	1410	0.116	40	270	1410	0.594
1450 – 1490	1.07	3.15%	33.53	1450	0.046	40	310	1450	0.698
1490 – 1530	0.44	1.29%	33.96	1490	0.014	40	350	1490	0.801
1530 - 1567	0.05	0.15%	34.00	1530	0.001	37	387	1530	0.904
	34.00	100.00%		1567	0.000	387		1567	1.000

Tables .5, 6 and 7 Relative height and Relative area of the, 4th, 5th and 6th sub basin

Altitude Range SB4	Area (a) (km^2)	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1225 – 1280	32.10	21.99%	32.10	1225	1.000	55	55	1225	0.00
1280 – 1335	47.26	32.37%	79.36	1280	0.780	55	110	1280	0.10
1335 – 1390	33.65	23.05%	113.01	1335	0.456	55	165	1335	0.20
1390 – 1445	16.31	11.17%	129.32	1390	0.226	55	220	1390	0.30
1445 – 1500	8.74	5.99%	138.06	1445	0.114	55	275	1445	0.40
1500 – 1555	4.07	2.79%	142.13	1500	0.054	55	330	1500	0.51
1555 – 1610	2.25	1.54%	144.38	1555	0.027	55	385	1555	0.61
1610 – 1665	0.70	0.48%	145.08	1610	0.011	55	440	1610	0.71
1665 – 1720	0.59	0.40%	145.67	1665	0.006	55	495	1665	0.81
1720 - 1769	0.33	0.23%	146.00	1720	0.002	49	544	1720	0.91
	146.0	100.00%		1769	0.000	544		1769	1.00

Altitude Range SB5	Area (a) (km^2)	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1205 – 1250	2.90	2.82%	2.90	1205	1.000	45	45	1205	0.00
1250 – 1300	13.87	13.47%	16.77	1250	0.972	50	95	1250	0.09
1300 – 1350	50.90	49.42%	67.67	1300	0.837	50	145	1300	0.20
1350 – 1400	21.29	20.67%	88.96	1350	0.343	50	195	1350	0.30
1400 – 1450	8.39	8.15%	97.35	1400	0.136	50	245	1400	0.40
1450 – 1500	2.68	2.60%	100.03	1450	0.055	50	295	1450	0.50
1500 – 1550	1.28	1.24%	101.31	1500	0.029	50	345	1500	0.61
1550 – 1600	0.73	0.71%	102.04	1550	0.016	50	395	1550	0.71
1600 – 1650	0.70	0.68%	102.74	1600	0.009	50	445	1600	0.81
1650 - 1692	0.26	0.25%	103.00	1650	0.003	42	487	1650	0.91
	103.0	100.00%		1692	0.000	487		1692	1.00

Altitude Range SB6	Area (a) (km^2)	Area in Percept (a/A *100)	Cumulative Area	Relative Area		Height (m) (h)	Cumulative Height	Relative Height	
				Above altitude	a/A			Below altitude	h/H
1118 – 1175	0.91	2.33%	0.91	1118	1.00	57	57	1118	0.00
1175 – 1230	2.02	5.18%	2.93	1175	0.98	55	112	1175	0.10
1230 – 1285	4.94	12.67%	7.87	1230	0.92	55	167	1230	0.20
1285 – 1340	17.28	44.31%	25.15	1285	0.80	55	222	1285	0.30
1340 – 1395	6.55	16.79%	31.70	1340	0.36	55	277	1340	0.39
1395 – 1450	2.32	5.95%	34.02	1395	0.19	55	332	1395	0.49
1450 – 1505	1.60	4.10%	35.62	1450	0.13	55	387	1450	0.59
1505 – 1560	1.46	3.74%	37.08	1505	0.09	55	442	1505	0.68
1560 – 1615	1.30	3.33%	38.38	1560	0.05	55	497	1560	0.78
1615 - 1684	0.62	1.59%	39.00	1615	0.02	69	566	1615	0.88
	39.00	100.00%		1684	0.00	566		1684	1.00

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IV. RESULTS AND DISCUSSION

Differences in Hypsometric curve shape and hypsometric integral values are an indication to the degree of disequilibrium in the balance of erosive processes and tectonic forces.

A. Hypsometric Integral values

The hypsometric integral values (His) ere obtained for the six sub-basins based on Elevation relief ratio method; these values are presented in Table 8. The result values of the hypsometric integral for all the sub-basins are ranges “between” 21.9% to 51.4%, according to these results, two stages were identified in the study area namely as mature or equilibrium and old stages; this classification depending on Strahler (1952) classification. The overall of the study for hypsometric analysis in this paper was to understand the erosional topography and tectonic activities in the area.

Table .8 Hypsometric integral values of sub-basins in study

Basin name	**Area (Km^2)**	**Maximum Elevation(m)**	**Minimum Elevation(m)**	**Mean Elevation(m)**	**Hypsometric Integral value**	**Erosional Stage**
SB1	92	1637	1153	1402.0	0.514	Equilibrium
SB2	315	1771	1139	1289.8	0.239	Monadnock
SB3	34	1567	1180	1294.0	0.295	Monadnock
SB4	146	1769	1225	1344.0	0.219	Monadnock
SB5	103	1692	1205	1344.9	0.287	Monadnock
SB6	39	1684	1118	1343.0	0.398	Equilibrium
Ataq SB	729	1771	1118	1325.80	0.318	Monadnock

B. Hypsometric Curve Shapes

Hypsometric curves were obtained by plotting percentage of the relative height against the percentage of the relative area. The hypsometric curve plotted individually for the six sub-basins as well as for the Ataq sub-basin, these curves are presented in the Fig 6 and 7. Based on the shapes of the curves the sub-basins are grouped into two categories; the first and sixth sub-basins are considered to be under the mature or equilibrium stages (the first is in the early of the mature stage), while the remaining four sub-basins are considered to be under the old or monadnock stages of development. And we can see that the Ataq sub-basin is under the old stage; which means that the area is almost under the old geological erosional stage. From the curves of the four basins, it is clear that the gradual unloading of sediments is taking place.

Fig.3 Fig. Elevation distribution map of Ataq Sub-basin

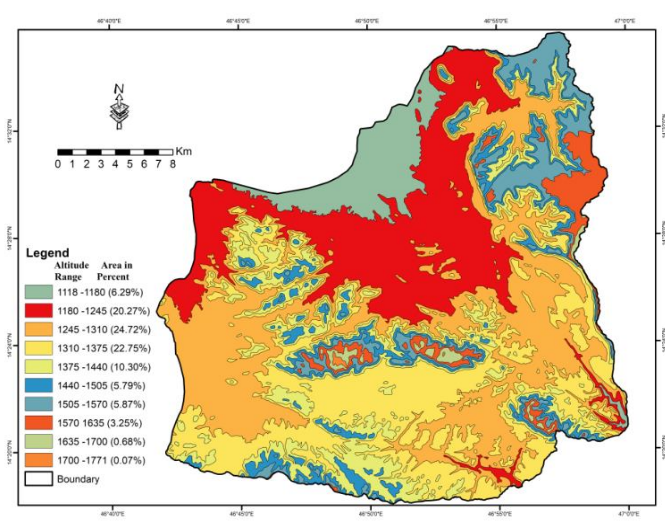
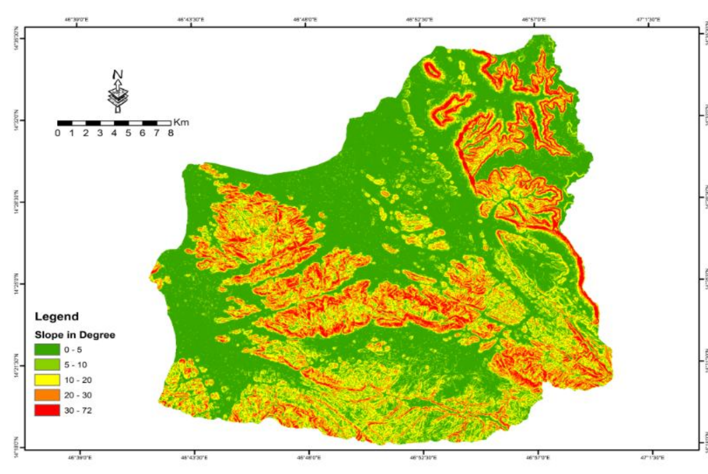


Fig.4 Slope map of study area



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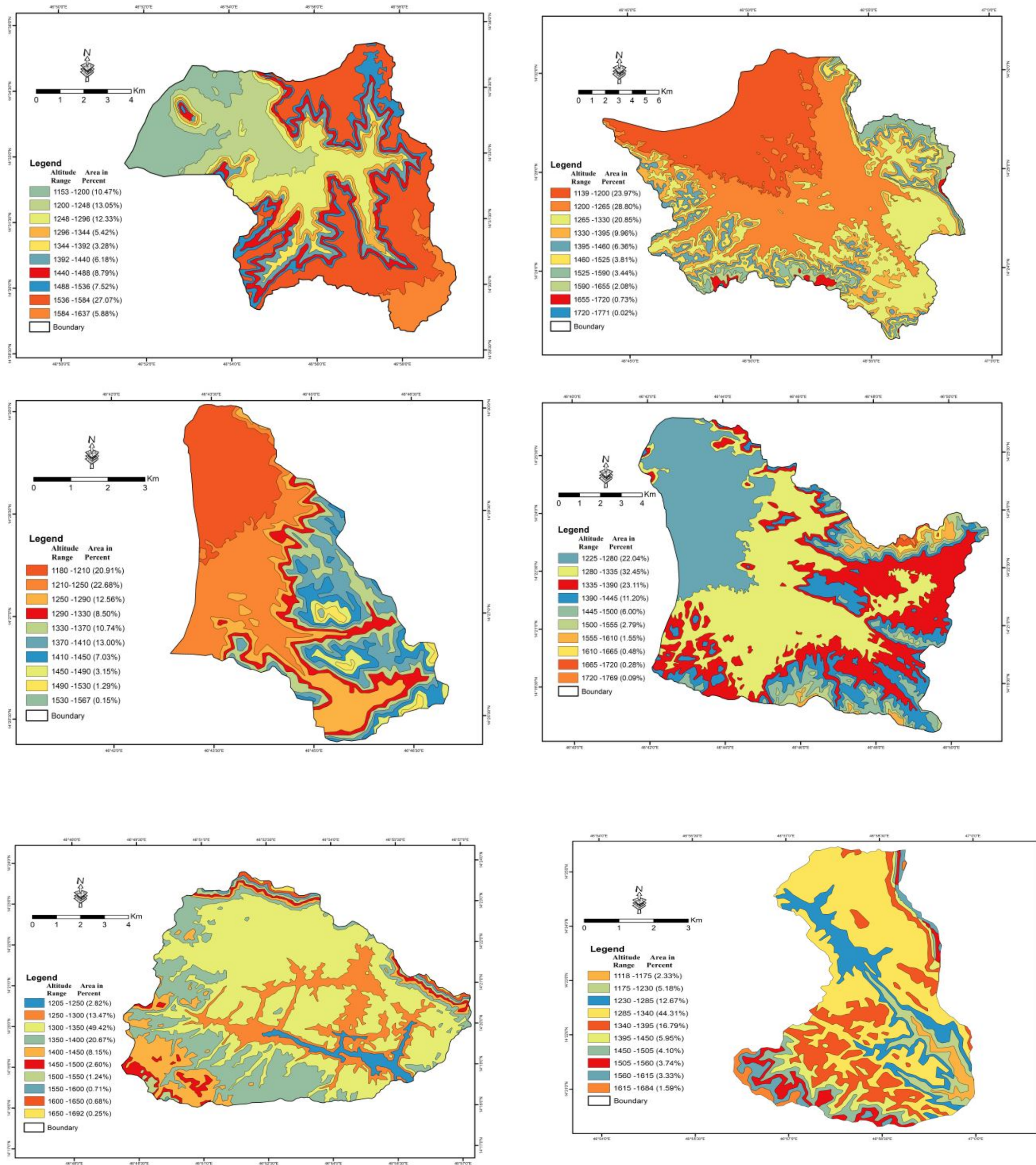
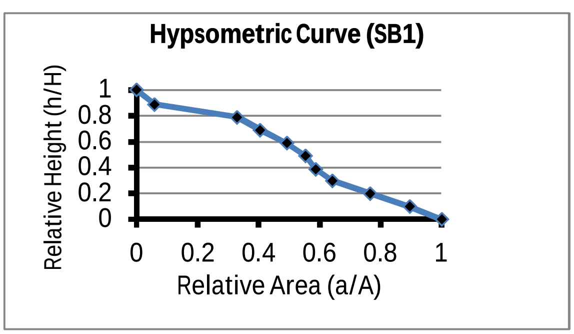
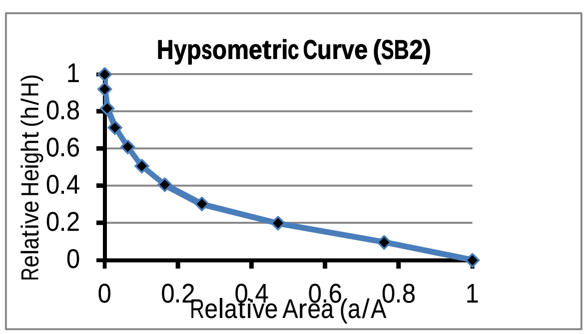


Fig.5 Elevation distribution map of six sub-basins in study area





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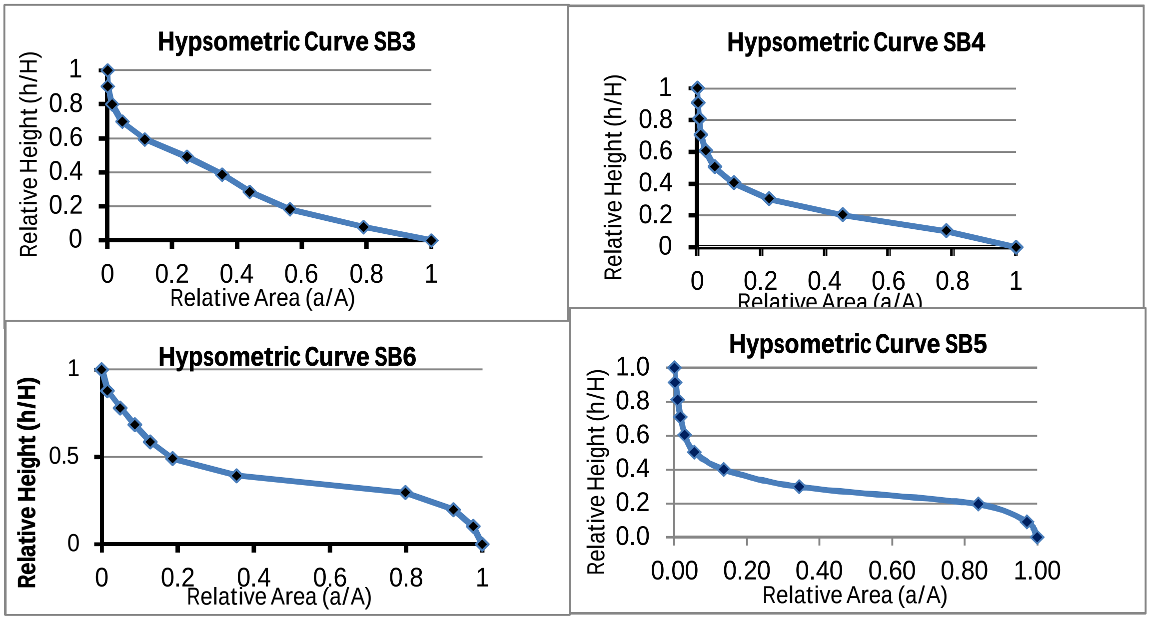

Fig.6 Hypsometric curve of six sub-basins

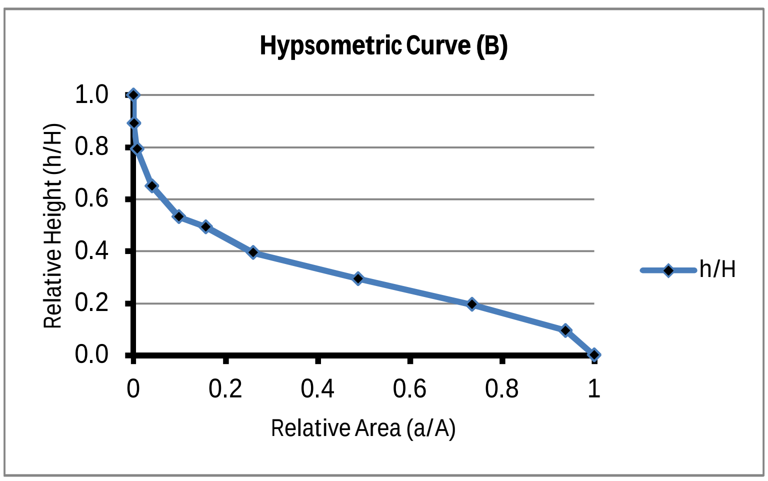

Fig.7 Hypsometric curve of Ataq Sub-basin

V. CONCLUSIONS

With remote sensing data and GIS software, it becomes less tedious to generate hypsometric integrals and curves. This study highlights the importance of hypsometric analysis to explain the geological stages of development and the degree of denudation in the study area; these give an idea about the rate of morphological changes on the area. Also hypsometric integral can assess the tectonic activity. It was observed from the hypsometric curves and the integral value of these sub-basins that the drainage system on the study area has been transformed into an old stage or monadnock stage as compared with classification of Strahler (1952) for various drainage systems. Among the six sub-basins, four sub-basins show old stage, and the other two sub-basins are show mature or equilibrium stage. So, from these values, it can be seen that the study area is passing through the old stage of development. The hypsometric curve of study area sub-basins also suggests that a larger part of the area is moderate to gently sloping as compared with slope map for the study area. The degree of slope exhibited in Ataq sub-basin are varies from 0 to 72 degrees, with a mean slope of 10.56 degree. The moderate slope found in the internal plateau of the area; while the higher slope gradient belongs to the hilly mountains in the south-western part of the area and north-eastern part of the area.

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