European Journal of Geography Volume 6, Number 4: 88 – 106, December 2015
©Association of European Geographers

MORPHOMETRIC ANALYSIS OF HYDROLOGICAL BEHAVIOR OF NORTH FARS WATERSHED, IRAN.

Marzieh MOKARRAM
Department of Range and Watershed Management, College of Agriculture and Natural Resources of Darab, Shiraz University, Iran,
m.mokarram.313@gmail.com

Dinesh SATHYAMOORTHY
Science & Technology Research Institute for Defence (STRIDE), Ministry of Defence, Malaysia
dinesh.sathyamoorthy@stride.gov.my

Abstract

The North Fars watershed is one of the major sources of irrigation and drinking water supplies for the Fars province in Iran. The major sources of water for this watershed are rain and snow. Morphometric analysis of the study area, consisting of 14 subwatersheds (W1 to W14), was carried out. It is found that that the entire watershed has uniform lithology and is structurally permeable. The results show that the maximum mean bifurcation ratio (R_{bm}) is seen for W5 (388.10) and thus, it will show early hydrograph peak (shorter watershed lag times), which also indicates strong structural control on the drainage development for this subwatershed. All the subwatersheds have low values of drainage density (D), indicating that they are composed of permeable subsurface material, good vegetation cover and low relief. Shape factor (R_s) is found to be minimum for W7, indicating that it has longest watershed lag time. The ruggedness number (R_n) is minimum for W14 (0.16) and maximum for W5 (0.98). Low values of constant channel maintenance (C) for W11 and W9 show that among all the subwatersheds, these two are associated with the weakest or very low-resistance soils, sparse vegetation, and mountainous terrain. The maximum values of relief ratio (R_h) for W6, W10, W12, W13 and W14 indicate that intense erosion processes are taking place. The watersheds also have lower form factor, indicating elongated shape and suggesting a flat hydrograph peak for longer duration. Flood flows of such elongated subwatersheds are easier to manage than those of circular subwatersheds. Low values of length of overland flow (L_g) for W2, W3 and W11 indicate steep slopes and shorter flow paths, while high values of L_g for the other subwatersheds indicate gentle slopes and longer flow paths. Using multiple linear regression (MLR), it is shown that there are positive and highly significant correlations between stream length, and S_w and R_t (0.933 and 0.926 respectively). The correlation between stream length and R_f (-0.910) is found to be negatively significant.

Keywords: *North Fars watershed; hydrological processes; morphometric analysis; watershed lag time; multiple linear regression (MLR)*

1. INTRODUCTION

The study of the geomorphic and hydrologic processes that happen within watersheds reveals information regarding the formation and development of land surface processes (Singh 1992; Dar et al. 2013). To this end, the development of quantitative physiographic methods to investigate the evolution and behavior of surface drainage networks has become a major emphasis in geomorphology in the past decades (Horton, 1945; Leopold and Maddock, 1953; Abrahams, 1984; Pidwirny, 2006; Melelli et al., 2014). Among these methods include morphometry, which is the mathematical analysis of the form of the earth's surface and dimensions of its landforms (Agarwal 1998). Morphometric analysis requires measurement of linear features, gradient of channel network and contributing ground slopes of the watershed (Nag and Chakraborty, 2003).

Watershed morphologies show different geological and geomorphological processes over time, as indicated by various morphometric studies (Horton 1945; Strahler 1957, 1964). With the availability of terrain data in digital format, traditional methods have been replaced by automated approaches (Kuchay and Bhat, 2013), with advantages of process reliability and cost-effectiveness (Akram et al, 2012).

Geographical information system (GIS) based evaluation using satellite image data, such as Shuttle Radar Topographic Mission (SRTM), and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), has allowed for fast and precise analysis of hydrological systems (Grohmann 2004). The processed digital elevation models (DEMs) are used for generating stream networks (Mesa 2006; Magesh et al. 2011), which are then used to deduce morphometric parameters such as stream order, stream length, stream bifurcation ratio, mean bifurcation ratio, relief ratio, drainage density, stream frequency, drainage texture, form factor, elongation ratio, length of overland flow, constant channel maintenance, ruggedness number and shape factor (Altaf et al., 2013).

The present study is aimed at using remote sensing and GIS technologies to analyze different parameters of morphometric characteristics of the 14 subwatersheds in the North Fars watershed, which is one of the major sources of irrigation and drinking water supplies for the Fars province in Iran. The computed morphometric characteristics are used to predict characteristics such as geomorphology, topography and existing vegetation conditions in order to improve watershed management. In addition, multiple regression models (MLR) is used to determine the correlation between all the morphometric parameters

2. MATERIAL AND METHODS

2.1 MATERIAL

The study area consists of 14 subwatersheds (W1 to W14) (Figure 1), which are shown in Table 1. The data used for the case study was a SRTM DEM with resolution of 30 m (Figure 2). The major land use categories of the watershed are agriculture, range land and forests. The altitude of the study area ranges from its lowest of 1,530 m to the highest of 3,851 m.

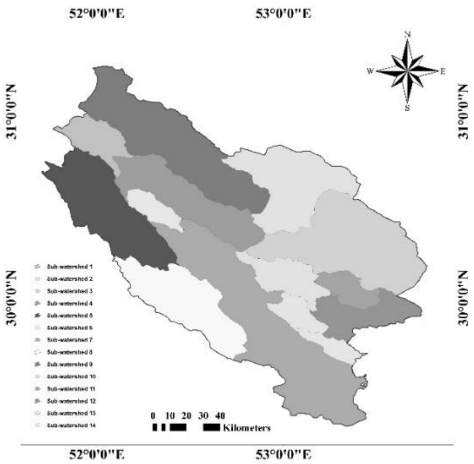


Figure 1. Location of the study area.

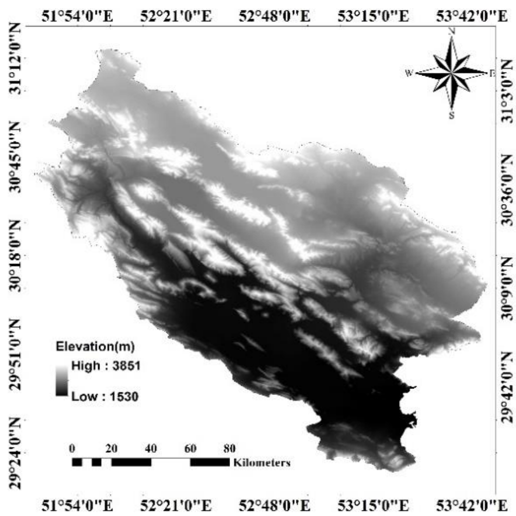


Figure 2. The SRTM DEM of the study area

Table 1. Characteristics of the subwatersheds in the study area

Subwatershed	Lot	Long	Area (km^2)
W1	30° 38′ 24″ to 30° 59′ 24″ N	51° 45′ 36″ to 52° 12′ 00″ E	625
W2	30° 48′ 36″ to 30° 19′ 42″ N	52° 39′ 36″ to 53° 24′ 36″ E	1,890
W3	30° 34′ 48″ to 30° 01′ 00″ N	52° 47′ 24″ to 53° 45′ 36″ E	2908
W4	30° 46′ 12″ to 30° 14′ 24″ N	52° 04′ 00″ to 52° 36′ 00″ E	1,623
W5	30° 42′ 00″ to 30° 08′ 04″ N	51° 42′ 00″ to 52° 25′ 42″ E	2,094
W6	30° 34′ 42″ to 30° 21′ 00″ N	52° 09′ 00″ to 52° 27′ 36″ E	344
W7	29° 18′ 36″ to 30° 25′ 12″ N	52° 16′ 12″ to 53° 26′ 24″ E	3,941
W8	29° 36′ 36″ to 30° 13′ 12″ N	52° 04′ 48″ to 52° 42′ 00″ E	1,738
W9	30° 26′ 24″ to 31° 14′ 24″ N	51° 54′ 00″ to 52° 55′ 12″ E	2,803
W10	29° 55′ 12″ to 30° 15′ 00″ N	52° 44′ 24″ to 53° 15′ 00″ E	723
W11	29° 55′ 48″ to 30° 08′ 24″ N	53° 09′ 36″ to 53° 31′ 48″ E	446
W12	29° 45′ 36″ to 30° 03′ 00″ N	53° 07′ 42″ to 53° 44′ 24″ E	879
W13	29° 48′ 00″ to 30° 01′ 48″ N	52° 54′ 00″ to 48° 14′ 24″ E	369
W14	29° 37′ 48″ to 29° 49′ 48″ N	53° 03′ 00″ to 53° 26′ 24″ E	275

2.2. Methodology

The study was carried out in two phases;

1.Extraction of drainage networks from the DEM using the flow direction method, which consists of the following steps (O'Callaghan and Mark, 1984) :

i. Fill Sinks: A sink is an uncompleted value lower than the values of its neighborhood. To ensure proper drainage mapping, these sinks were filled by increasing elevations of sink points to their lowest outflow point.

ii. Calculate Flow Direction: Using the filled DEM produced in the Step 1, the flow directions were calculated using the eight-direction flow model, which assigns flow from each grid cell to one of its eight adjacent cells in the direction with the steepest downward slope.

iii. Calculate Flow Accumulation: Using the output flow direction raster created in Step 2, the number of upslope cells flowing to a location was computed.

iv. Define Stream Network: The next step is to determine a critical support area that defines the minimum drainage area that is required to initiate a channel using a threshold value.

v. Stream Segmentation: After the extraction of drainage networks, a unique value was given for each section of the network associated with a flow direction.

2.Morphometric Analysis using Strahler's classification method (Strahler, 1964):

Strahler's system of stream analysis is probably the simplest and most used system, and hence, was used for this study. According to this method, each finger-tip drainage network is designated as a segment of the first order. At the connection of any two first-order segments, a network of the second order is produced, which extends down to the point where it joins another second order river, where upon a segment of the third order results. The different morphometric parameters were computed using the methods and formula defined in Table 2.

Table 2. The morphometric parameters computed in this study

No.	Morphometric parameters	Formula	Description	Reference
1	Stream order (U)	Hierarchical ank	-	Strahler (1964)
2	Stream length (L_u)	Length of the stream	-	Horton (1945)
3	Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$	N_u =Total number of stream segments of order u	Strahler (1964)
4	Stream length ratio (R_L)	$R_L=L_u/L_{(u-1)}$	$L_{(u-1)}$=Total stream length of the next lower order	Horton (1945)
5	Bifurcation ratio (R_b)	$R_b=N_u/N_{(u+1)}$	$N_{(u+1)}$=Number of segments of next higher order	Schumms (1956)
6	Mean bifurcation ratio (R_{bm})	R_{bm} =Average R_b of all orders		Strahler (1957)
7	Relief ratio (R_h)	$R_h = H/L$	H = Total relief (relative relief) of the watershed in km; L_b =Watershed length	Schumms (1956)
8	Drainage density (D)	D= L_u /A	A=Watershed area (km^2)	Horton (1932)
9	Stream frequency (F_s)	$F_s = N_u/A$		Horton (1932)
10	Drainage texture (R_t)	$R_t = N_u/P$	P= Watershed perimeter (km)	Horton (1945)
11	Form factor (R_f)	$R_f=A/L_b^2$		Horton (1932)
12	Circularity ratio (R_c)	$R_C=4\pi*A/P^2$		Miller (1953)
13	Elongation ratio (R_e)	$R_e=(2/L_b)*(A/\pi)^{0.5}$	π=Pi	Schumms (1956)

14	Length of overland flow (L_g)	$L_g = 1/D*2$		Horton (1945)
15	Constant channel maintenance (C)	$C=1/D$		Schumms (1956)
16	Shape index (S_w)	$S_w = L_b/A$		Horton (1945)
17	Ruggedness number (R_n)	$R_n = B_h*D$	B_h = Watershed relief; D = Drainage density	Pareta and Pareta (2011)
18	Shape factor (R_s)	$R_s = P_u/P_c$	Where P_u = Perimeter of circle of watershed area; P_c = Perimeter of watershed	Sameena et al. (2009)
19	Compactness coefficient (C_c)	$Cc= 0.2821P/A^{0.5}$		Suresh et al. (2004)

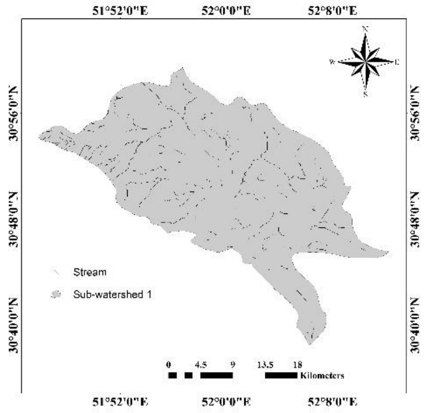
Finally, MLR was used to determine the correlation between the morphometric parameters. The general purpose of multiple regressions is to learn more about the relationship between several independent or predictor variables, and a dependent or criterion variable. The general form of the regression equations is:

$$Y=A_0 + A_1X_1 + A_2X_2 + \cdots + b_nX_n \quad (1)$$

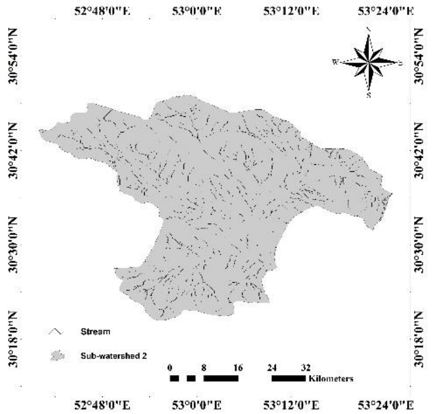
where Y is the dependent variable, A_0 is the intercept, A_1 and bn are regression coefficients, and X_1– X_n are independent variables referring to basic soil properties.

3. RESULTS

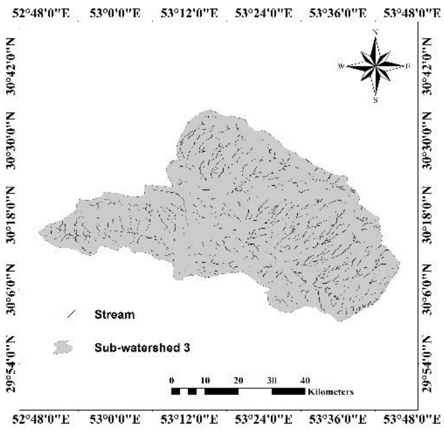
The extracted drainage networks for the subwatersheds are shown in Figure 3. Minimum elevation, maximum elevation, relative relief, and subwatershed area (A), perimeter (P) and length, which are important parameters in quantitative morphology, were computed for each subwatershed (Table 3). Subwatershed area is hydrologically important because it directly affects the size of the magnitudes of peak and mean runoff, whereby the maximum flood discharge per unit area is inversely related to size (Chorley et al., 1957).



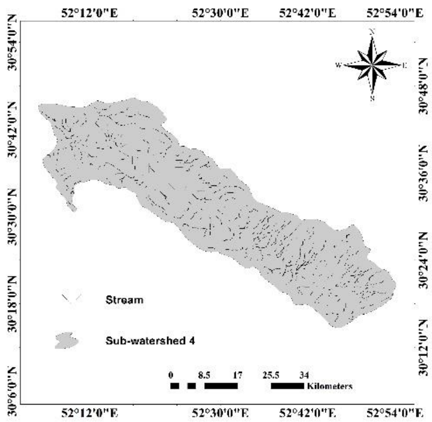
(1)



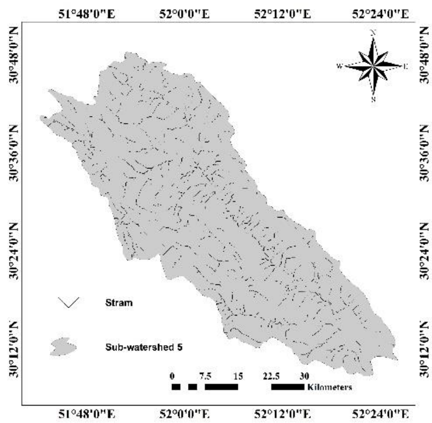
(2)


Stream
Sub-watershed 3
0 10 20 30 40 Kilometers

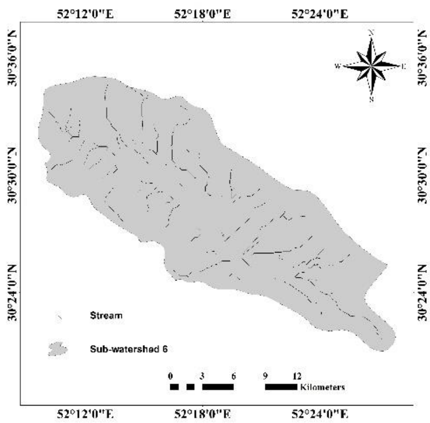
(3)


Stream
Sub-watershed 4
0 8.5 17 25.5 34 Kilometers

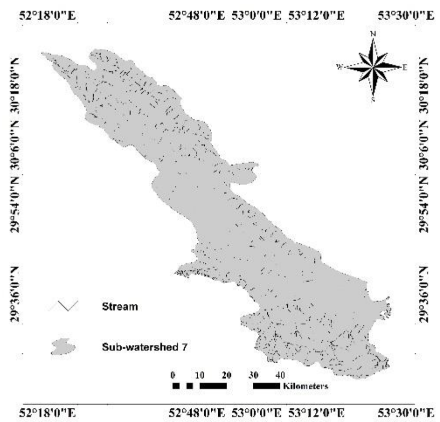
(4)


Stram
Sub-watershed 5
0 7.5 15 22.5 30 Kilometers

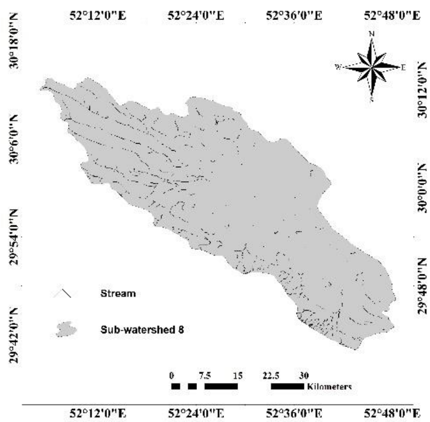
(5)


Stream
Sub-watershed 6
0 3 6 9 12 Kilometers

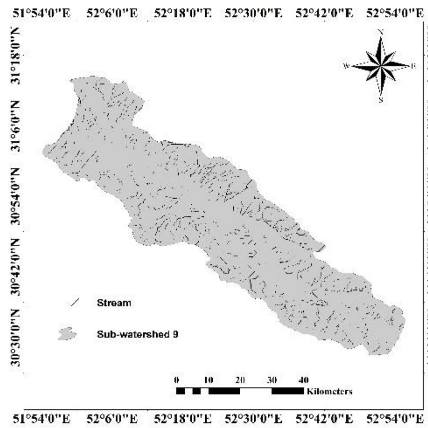
(6)


Stream
Sub-watershed 7
0 10 20 30 40 Kilometers

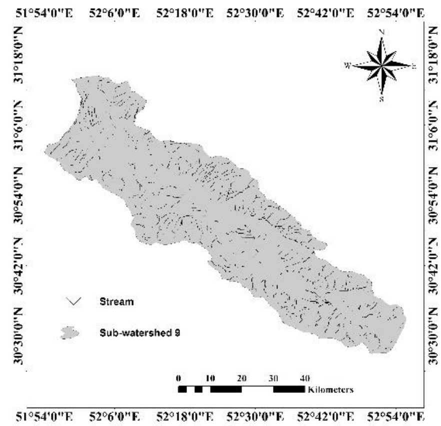
(7)


Stream
Sub-watershed 8
0 7.5 15 22.5 30 Kilometers

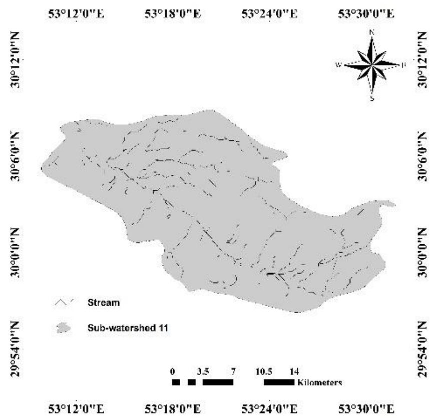
(8)



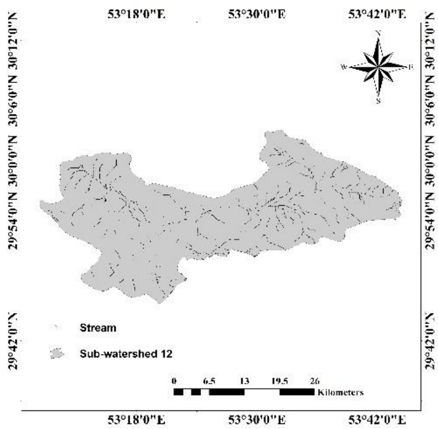
(9)



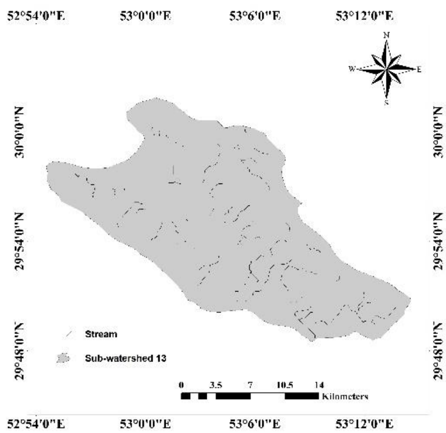
(10)



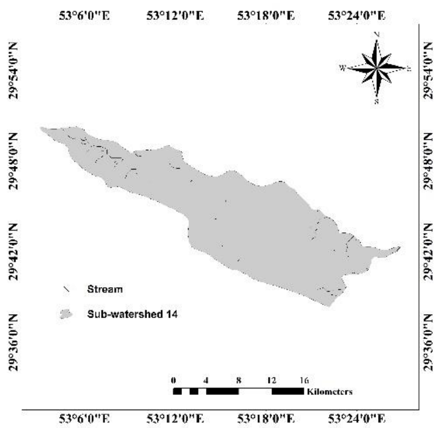
(11)



(12)



(13)



(14)

Figure 3. The extracted drainage networks for the subwatersheds. (1): Subwatershed 1, (2): Subwatershed 2, (3): Subwatershed 3, (4): Subwatershed 4, (5): Subwatershed 5, (6): Subwatershed 6, (7): Subwatershed 7, (8): Subwatershed 8, (9): Subwatershed 9, (10): Subwatershed 10, (11): Subwatershed 11, (12): Subwatershed 12, (13): Subwatershed 13, (14): Subwatershed 14

Table 3. Basic characteristics of the subwatersheds.

Subwatershed	Minimum elevation (km)	Maximum elevation	Relative relief	Area (km^2)	Perimeter (km)	Length (km)
W1	2.06	3.17	1.11	624.65	141.40	50.80
W2	2.09	3.92	1.83	1,890.00	240.65	95.27
W3	1.82	3.39	1.57	2,907.72	273.88	121.68

W4	2.06	3.50	1.44	1,623.08	240.56	87.38
W5	1.63	3.71	2.08	2,094.42	255.73	100.99
W6	2.15	3.13	0.98	343.67	90.08	36.18
W7	1.54	3.10	1.56	3941.44	475.14	144.63
W8	1.57	2.89	1.32	1,737.63	229.99	90.83
W9	2.29	3.48	1.19	2,803.31	318.82	119.18
W10	1.66	3.13	1.47	723.30	152.48	55.21
W11	1.80	2.56	0.76	446.31	104.08	41.97
W12	1.57	3.25	1.68	878.72	178.33	61.67
W13	1.60	2.83	1.23	369.19	93.80	37.68
W14	1.53	2.52	0.99	275.21	100.08	31.89

The highest stream order among the 14 subwatersheds is 4, which is shown by seven subwatersheds; W2, W5, W7, W8, W9, W11 and W12. The lowest stream order is 3, which is shown by the remaining subwatersheds; W1, W3, W4, W6, W10, W13 and W14. A perusal of Table 4 indicates that the 14 subwatersheds drain into the north of the Fars province, contributing surface runoff and sediment loads due to variations in their physical characteristics. Higher stream order is associated with greater discharge and higher velocity (Costa, 1987). The west of the study area clearly contributes more discharge and since higher velocity enhances erosion rates, this side also contributes higher sediment loads into the study area.

Furthermore, the total number of stream segments decrease with stream order. This is referred to as Horton's law of stream numbers. Any deviation indicates that the terrain is typified with high relief and/or moderately steep slopes, underlain by varying lithology and probable uplift across the watershed (Singh and Singh, 1997). In practice, when logarithms of the number of streams of a given order are plotted against the order, the points lie on a straight line (Horton, 1945). A similar geometric relationship was also found between stream order and stream numbers for all the subwatersheds (Figure 4). This indicates that the whole area has uniform underlying lithology, and geologically, there has been no probable uplift in the watershed.

Table 4. Stream order, stream number and stream length of the subwatersheds.

Sub-watershed	**Stream order**	**Stream number**				**Stream length (km)**			
		I	**II**	**III**	**IV**	**I**	**II**	**III**	**IV**
W1	3	184	78	9	-	195.53	72.14	6.27	-
W2	4	518	207	63	3	715.24	202.380	47.04	0.996
W3	3	643	277	80	-	1000.42	411.13	98.693	-
W4	3	395	145	28	-	584.93	174.196	34.173	-
W5	4	457	250	49	13	696.37	234.82	45.565	9.230
W6	3	92	28	1	-	140.599	30.865	0.040	-
W7	4	986	363	81	9	770.733	249.243	60.176	11.972
W8	4	442	178	61	13	316.91	181.067	82.672	6.271
W9	4	704	277	67	6	827.25	326.92	58.35	5.973
W10	3	170	57	12	-	209.108	54.840	7.874	-
W11	4	99	51	8	10	157.231	63.56	9.373	5.672
W12	4	238	93	20	5	317.47	97.727	14.245	2.114
W13	3	85	27	3	-	98.011	23.191	2.414	-
W14	3	90	16	1	-	33.836	9.231	2.251	-

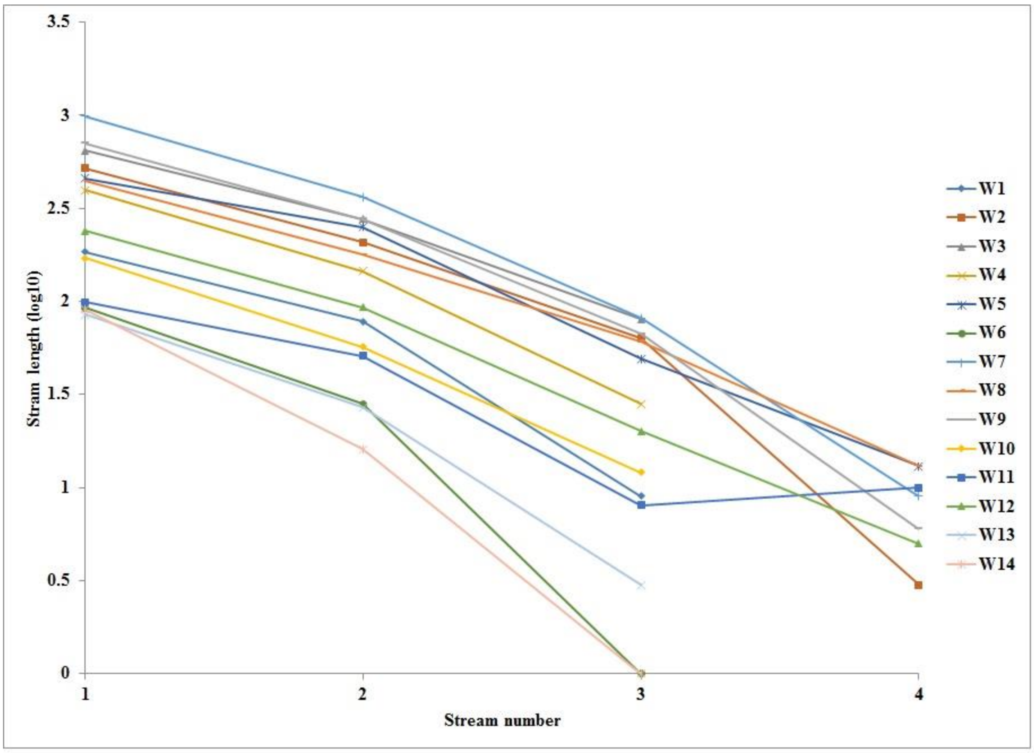


Figure 4. The relationship between stream order and stream number for the subwatersheds

Analysis of the results of stream length and mean stream length are shown in Tables 4 and 5. The total length of stream segments is the maximum in the case of first order streams. This decreases with decreasing stream order. The results reiterate that the area is underlain with uniform lithology with no probable watershed upliftment and movement of water area depends only on the drainage characteristics. In addition, there are more number of watersheds in the West of the study as compared to the East, indicating the watersheds are very active with longer travel times (Luo and Harlin, 2003). From this observation, it is deduced that during a storm event of uniform intensity over whole of the study area (Harlin, 1980), the drainage networks in the East will gave shorter watershed lag times as compared to the West under similar soil moisture and vegetation cover (Harlin, 1984; Romshoo et al., 2002; Romshoo, 2004). Lag time is defined as the time difference from the centroid of the net rainfall to the peak discharge at the watershed outlet, which affects erosion, soil moisture and vegetation (McEnroe et al., 1999).

Table 5 shows that the mean stream length (L_{sm}) of the subwatersheds range from a maximum of 2.25 km for stream order 3 of W14 to a minimum of 0.04 km for stream order 3 of W6. The mean stream length of any given order is greater than that of lower order (Horton, 1945). This geometric relationship can be seen in Figure 5.

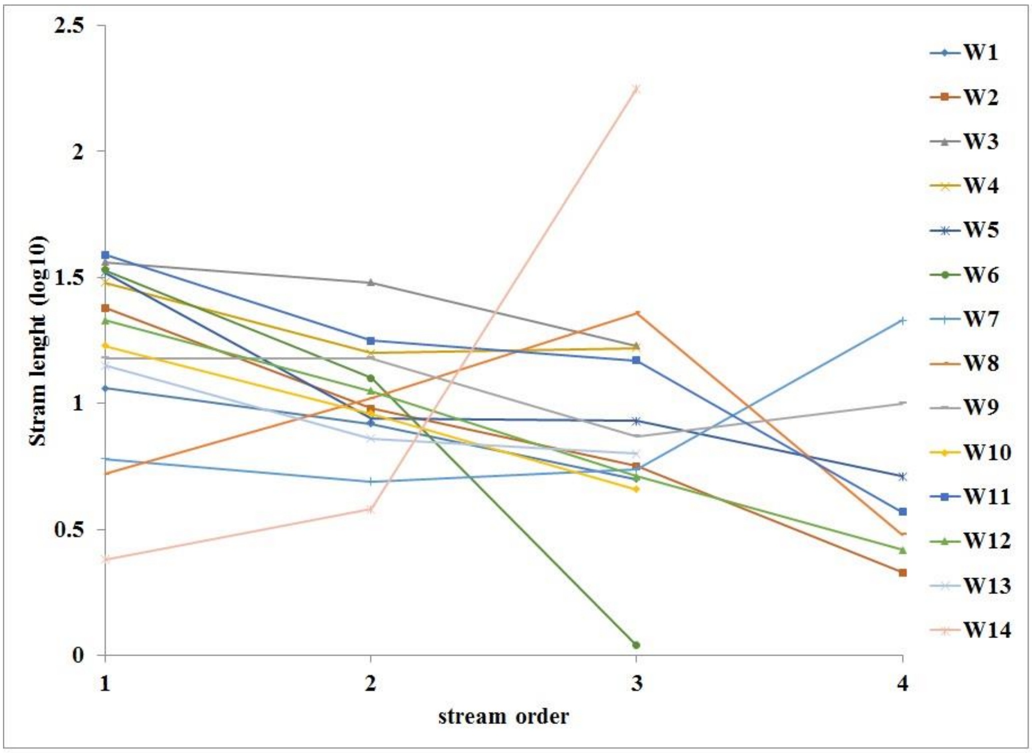


Figure 5. The relationship between stream order and stream length for the subwatersheds

Table 5. Mean stream length and stream length ratio for the subwatersheds

Subwatershed	Mean stream length (L_{sm}) (km)				Stream length ratio		
	I	II	III	IV	II/1	III/II	IV/III
W1	1.06	0.92	0.70	-	0.37	0.09	-
W2	1.38	0.98	0.75	0.33	0.28	0.23	0.02
W3	1.56	1.48	1.23	-	0.41	0.24	-
W4	1.48	1.20	1.22	-	0.30	0.20	-
W5	1.52	0.94	0.93	0.71	0.34	0.19	0.20
W6	1.53	1.10	0.04	-	0.22	0.00	-
W7	0.78	0.69	0.74	1.33	0.32	0.24	0.20
W8	0.72	1.02	1.36	0.48	0.57	0.46	0.08
W9	1.18	1.18	0.87	1.00	0.40	0.18	0.10
W10	1.23	0.96	0.66	-	0.26	0.14	-
W11	1.59	1.25	1.17	0.57	0.40	0.15	0.61
W12	1.33	1.05	0.71	0.42	0.31	0.15	0.15
W13	1.15	0.86	0.80	-	0.24	0.10	-
W14	0.38	0.58	2.25	-	0.27	0.24	-

Bifurcation ratio (R_b) is used to express the ratio of the number of streams of any given order to the number of streams in next order (Schumn, 1956). Analysis of the results of R_b are shown in Table 6. High mean bifurcation ratio (R_{bm}) shows early hydrograph peak with a potential for flash flooding during storm events (Howard, 1990; Rakesh, et al., 2000). The minimum R_{bm} is seen for W2 (3.30), indicating delayed hydrograph peak. The maximum R_{bm} is seen for W5 (388.10), and thus it will show early hydrograph peak (smaller watershed lag time), which also indicates strong structural control on the drainage development for this watershed.

Table 6. Bifurcation ratio, drainage density and stream frequency of the subwatersheds

Subwatershed	Bifurcation ratio (R_b)			Mean bifurcation ratio (R_{bm})	Drainage density (D)	Stream frequency (F_s)
	I/II	II/III	III/IV			
W1	2.71	11.51	-	7.11	0.44	0.43
W2	3.53	4.30	47.23	18.35	0.51	0.42
W3	2.43	4.17	-	3.30	0.52	0.34
W4	3.36	5.10	-	4.23	0.49	0.35
W5	2.97	5.15	4.94	4.35	0.47	0.37
W6	4.56	771.63	-	388.10	0.50	0.35
W7	3.09	4.14	5.03	4.09	0.28	0.37
W8	1.75	2.19	13.18	5.71	0.34	0.40
W9	2.53	5.60	9.77	5.97	0.43	0.38
W10	3.81	6.96	-	5.39	0.38	0.33
W11	2.47	6.78	1.65	3.63	0.53	0.38
W12	3.25	6.86	6.74	5.62	0.49	0.41
W13	4.23	9.61	-	6.92	0.33	0.31
W14	3.67	4.10	-	3.89	0.16	0.39

The travel time by water within the watershed is controlled by drainage density (*D*) (Gardiner and Park, 1978; Dodov and Foufoula-Georgiou, 2006). Generally, *D* varies between 0.55 and 2.09 km/km2. High values of *D* are observed in regions of weak and impermeable subsurface material, sparse vegetation, and mountainous relief. On the other hand, regions with low values of *D* are underlain with highly resistant permeable material with dense vegetative cover and low relief. Table 6 indicates that all the watersheds have low values of *D* (below 2.0 km/km2). This indicates that they are composed of permeable subsurface material, good vegetation cover and low relief, which results in more infiltration capacity and are good sites for ground water recharge as compared to watersheds with high values of high *D*.

Stream frequency (F_s) is the total number of streams of all orders per unit area. The low values of F_s for all the subwatersheds indicate that the study area is comparably covered with a good amount of vegetation and has very good infiltration capacity. Overall, the discharge from all the subwatersheds takes long time to peak because of low runoff rates due to lesser number of streams (Patton and Baker, 1976; Montgomery and Dietrich, 1989; Montgomery and Dietrich, 1992; Ghoneim et al., 2002).

Drainage texture (R_t) is influenced by infiltration capacity (Horton, 1945). There are five different texture classes: very coarse (<2), coarse (2–4), moderate (4–6), fine (6–8), and very fine (>8) (Smith, 1950). According to this classification, W1, W6, W10, W11, W13 and W14 have very coarse drainage texture, while W2, W3, W4, W5, W7, W8, W9 and W12 have coarse drainage texture (Table 7). Hydrologically, very coarse texture subwatersheds have large watershed lag time periods (Esper Angillieri, 2008) followed by coarse, fine, and very fine texture classes. This indicates that W1, W6, W10, W11, W13 and W14 (R_t <2) have longer durations to peak flow, while the other subwatersheds ($2<R_t<4$) have shorter durations to peak flow.

Table 7. Drainage texture, constant channel maintenance, shape index, ruggedness number and shape factor of the subwatersheds

Subwatershed	Drainage texture (R_t)	Constant channel maintenance (C)	Compactness coefficient (C_c)	Shape index (S_w)	Ruggedness number (R_n)	Shape factor (R_s)
W1	1.92	2.27	1.60	4.13	0.49	0.18
W2	3.29	1.96	1.56	4.80	0.93	0.18
W3	3.65	1.92	1.43	5.09	0.82	0.20
W4	2.36	2.04	1.68	4.70	0.71	0.17
W5	3.01	2.13	1.58	4.87	0.98	0.18
W6	1.34	2.00	1.37	3.81	0.49	0.21
W7	3.03	3.57	2.13	5.31	0.44	0.13
W8	3.02	2.94	1.56	4.75	0.45	0.18
W9	3.31	2.33	1.70	5.07	0.51	0.17
W10	1.57	2.63	1.60	4.21	0.56	0.18
W11	1.61	1.89	1.39	3.95	0.40	0.20
W12	2.00	2.04	1.70	4.33	0.82	0.17
W13	1.23	3.03	1.38	3.85	0.41	0.20
W14	1.07	6.25	1.70	3.70	0.16	0.17

The minimum and maximum shape factors (R_s) are for W7 and W6 respectively, as shown in Table 7. This parameter is similar in interpretation to circularity ratio, elongation ratio and form factor (Tucker and Bras, 1998). It gives an idea about the circular character of the subwatershed. The greater the circular character of the subwatershed, the greater is the rapid response of the subwatershed after a storm event (Tucker and Bras, 1998). Therefore, in terms of only R_s, W7 has the longest watershed lag time.

The ruggedness number (R_n) shows the structural complexity of the terrain in association with relief and drainage density. High values of R_n imply that the area is susceptible to soil erosion (Rashid et al., 2011; Zaz and Romshoo, 2012). In the present study, R_n is minimum in case of W14 (0.16) and maximum for W5 (0.98), as seen in Table 7.

Shape index (S_w) shows the rate of water and sediment yield along the length and relief of the subwatersheds. The shape index values for the subwatersheds of the study area range from 3.70 for W14 to 5.31 for W7 as shown in Table 7. In terms of only Sw, WS7 will have the shortest watershed lag time, while WS14 will have the longest watershed lag time.

The relationship of a subwatershed with that of a circular subwatershed having the same area is shown by the compactness coefficient (C_c). A circular subwatershed yields the shortest time of concentration before peak flow occurs in the subwatersed. Cc = 1 indicates that the subwatershed completely behaves as a circular subwatershed. Cc > 1 indicates more deviation from the circular nature of the subwatershed. The values for all the subwatersheds range from 1.37 for W6 to 2.13 for W7, as seen in Table 7. Consequently, WS6 has the greatest deviation from the circular nature, and on the basis of this parameter alone, it will have the longest time of concentration before peak flow occurs as compared to the other subwatersheds (Potter and Faulkner, 1987; Tucker and Bras, 1998).

Constant channel maintenance (C) varies from 1.89 for W11 to 6.25 for W14 as is shown in Table 7. Low values of □ for W11 and W9 show that among the 14 subwatersheds, these two are associated with the weakest or very low-resistance soils, sparse vegetation and mountainous terrain, while watershed W14 is associated with high-resistance soils, vegetation and comparably plain terrain (Shulits, 1968).

Relief ratio (R_h) is an indicator of the intensity of erosion processes operating on the subwatershed slopes (Dodov and Foufoula-Georgiou, 2005). R_h normally increases with decreasing drainage area and size of a given subwatershed (Gottschalk, 1964). In the study area, according to in Table 8, R_h ranges from a minimum of 0.01, for W3, W7, W8 and W9, to a maximum of 0.03, for W6, W10, W12, W13 and W14. Higher values of *Rh* indicate that intense erosion processes are taking place.

Table 8: Relief ratio, circularity ratio, form factor and length of overland flow of the subwatersheds

Subwatershed	Relief ratio (R_h)	Circularity ratio (R_c)	Form factor (R_f)	Length of overland flow (L_g)
W1	0.02	0.39	0.24	1.14
W2	0.02	0.41	0.21	0.98
W3	0.01	0.49	0.20	0.96
W4	0.02	0.35	0.21	1.02
W5	0.02	0.40	0.21	1.06
W6	0.03	0.53	0.26	1.00
W7	0.01	0.22	0.19	1.79
W8	0.01	0.41	0.21	1.47
W9	0.01	0.35	0.20	1.16
W10	0.03	0.39	0.24	1.32
W11	0.02	0.52	0.25	0.94
W12	0.03	0.35	0.23	1.02
W13	0.03	0.53	0.26	1.52
W14	0.03	0.35	0.27	3.13

Circulatory ratio (R_c) is the ratio of the area of the watershed to the area of circle having the same circumference as the perimeter of the watershed (Miller, 1953). In this study, R_c for W8, W2, W6 and W13 is in the range from 0.53 to 0.62 (Table 8), indicating that the area is characterized by high relief and permeable surface, resulting in greater watershed lag times. W1, W2, W3, W4, W5, W7, W8, W9, W10, W11, W12 and W14 have lower circularity ratios, indicating low relief and impermeable surface, resulting in lower watershed lag times. This indicates that W8, W2, W6 and W13 will have delayed time to peak flow, while the other subwatersheds will have shorter time to peak (Ward and Robinson, 2000).

Subwatersheds with high form factor (R_f) have high peak flows of shorter duration, whereas elongated subwatersheds with low form factor have lower peak flow of longer duration (Kochel, 1988; Youssef, 2011). In this study, all of the subwatersheds have low form factor (Table 8), indicating elongated shape and suggesting a flat hydrograph peak of longer duration. Flood flows of such elongated subwatersheds are easier to manage than those of circular subwatersheds (Tucker and Bras, 1998)

Length of overland flow (L_g) is one of the most important independent variables affecting both hydrologic and hydrographic development of watersheds (Horton, 1932). Low values of L_g for W2, W3 and W11 indicate steep slopes and shorter flow paths, while high values of L_g for the other subwatershed indicate gentle slopes and longer flow paths.

Finally, the relationship between all the parameters was investigated. The calculated simple linear correlation coefficients (r) between stream length (L) (as the simplest morphometric parameter in terms of measurement) and the other morphometric parameters as independent variables are summarized in Table 9. It was found that there is a positive and highly significant correlation between stream length, and shape index (S_w) and drainage texture (R_t) (0.933 and 0.926 respectively) content. It is also observed that correlation between stream length and form factor (*R*f) (-0.910) was negatively significant. Positive correlation implies that as stream length decreases, S_w and R_t also decrease and vice versa. On the other hand, negative correlation implies that as stream length decreases, as the R_f increases.

Table 9. Simple linear coefficient correlations (r) hydrological parametric

Parameter	L	D	R_r	A	P	R_b	F_s	R_t	C	C_c	S_w	R_n	R_s	R_h	R_c	R_f	L_g
L	1	.329	.616*	.909**	.830**	-.259	-.001	.926**	-.352	.332	.933**	.616*	-.329	-.740**	-.331	-.910**	-.353
D	.329	1	.203	.030	-.050	.222	.064	.303	-.932**	-.461	.177	.690**	.467	-.111	.424	-.245	-.932**
R_r	.616*	.203	1	.516	.521	-.302	.046	.601*	-.269	.290	.631*	.838**	-.330	-.170	-.352	-.626*	-.268
A	.909**	.030	.516	1	.973**	-.284	.011	.878**	-.136	.586*	.962**	.347	-.573*	-.829**	-.531	-.926**	-.137
P	.830**	-.050	.521	.973**	1	-.312	.079	.802**	-.081	.737**	.936**	.296	-.729**	-.767**	-.683**	-.911**	-.081
R_b	-.259	.222	-.302	-.284	-.312	1	-.179	-.309	-.168	-.341	-.351	-.102	.442	.325	.411	.358	-.168
F_s	-.001	.064	.046	.011	.079	-.179	1	.211	.026	.260	.090	.091	-.303	-.195	-.357	-.139	.025
R_t	.926**	.303	.601*	.878**	.802**	-.309	.211	1	-.366	.280	.947**	.587*	-.305	-.850**	-.306	-.943**	-.367
C	-.352	-.932**	-.269	-.136	-.081	-.168	.026	-.366	1	.370	-.290	-.668**	-.368	.205	-.352	.361	1.000**
C_c	.332	-.461	.290	.586*	.737**	-.341	.260	.280	.370	1	.509	-.085	-.989**	-.318	-.969**	-.489	.370
S_w	.933**	.177	.631*	.962**	.936**	-.351	.090	.947**	-.290	.509	1	.517	-.522	-.829**	-.508	-.991**	-.291
R_n	.616*	.690**	.838**	.347	.296	-.102	.091	.587*	-.668**	-.085	.517	1	.055	-.144	.001	-.550*	-.668**
R_s	-.329	.467	-.330	-.573*	-.729**	.442	-.303	-.305	-.368	-.989**	-.522	.055	1	.331	.978**	.510	-.369
R_h	-.740**	-.111	-.170	-.829**	-.767**	.325	-.195	-.850**	.205	-.318	-.829**	-.144	.331	1	.292	.827**	.206
R_c	-.331	.424	-.352	-.531	-.683**	.411	-.357	-.306	-.352	-.969**	-.508	.001	.978**	.292	1	.502	-.353
R_f	-.910**	-.245	-.626*	-.926**	-.911**	.358	-.139	-.943**	.361	-.489	-.991**	-.550*	.510	.827**	.502	1	.362
L_g	-.353	-.932**	-.268	-.137	-.081	-.168	.025	-.367	1.000**	.370	-.291	-.668**	-.369	.206	-.353	.362	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

The prediction of shape index (S_w) and drainage texture (R_t) was done using MLR. The scatter plots of the measured against predicted values of shape index (S_w) and drainage texture (R_t) obtained from the MLR model are shown in Figures 6 and 7 respectively. The regression equations for S_w and R_t are as follows:

$$S_w = 0.0015 * L + 3.79 \quad (2)$$

$$R_t = 0.0025 * L + 1.20 \quad (3)$$

These equations can be used to predict the value of S_w and R_t using stream length

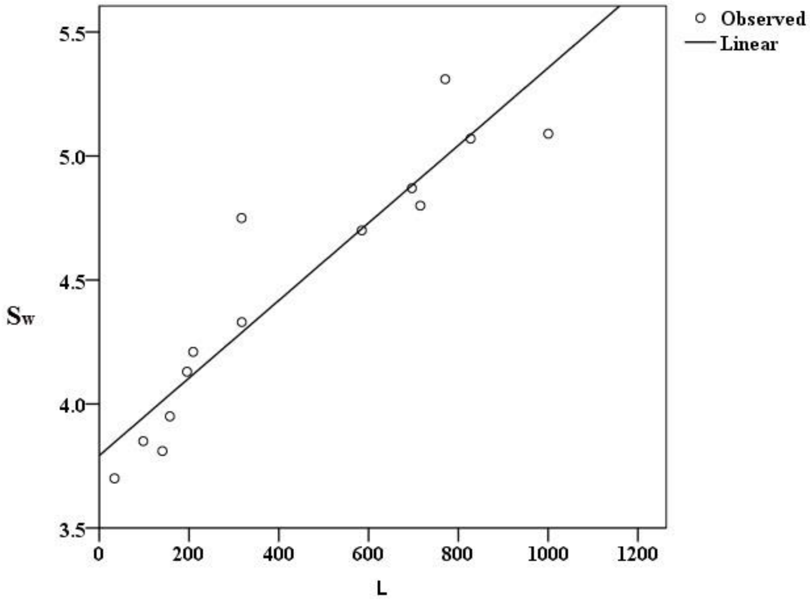


Figure 6. The scatter plot of the measured versus predicted S_w using MLR

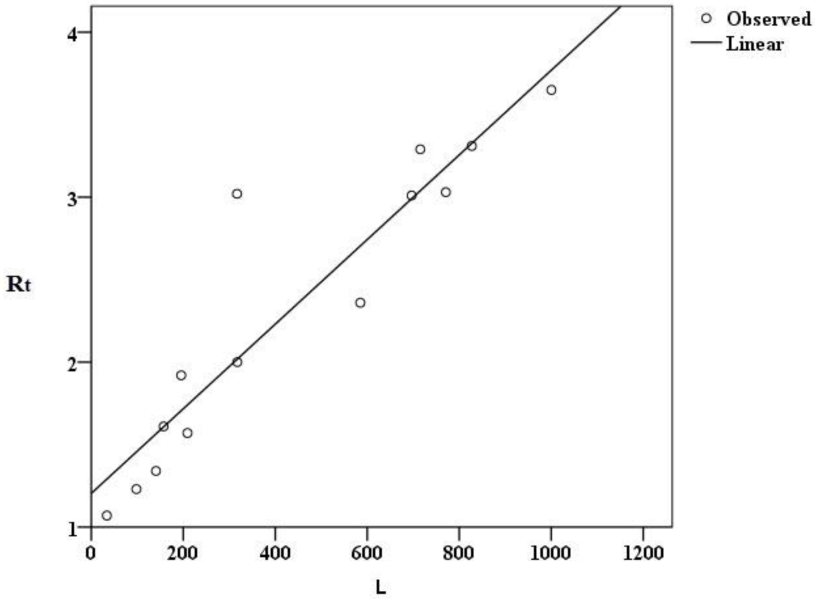


Figure 7. The scatter plot of the measured versus predicted R_t using MLR

4. CONCLUSION

The results obtained show that the 14 subwatersheds in study area have uniform underlying lithology, making the hydrological response in these subwatersheds a direct function of only the geomorphology, topography and existing vegetation conditions. The spatial variability of the morphometric parameters analyzed in this study is quite significant. Since, the hydrology of the subwatersheds changes significantly due to the spatial variations of the morphometric parameters, and therefore, the subwatersheds also exhibit different hydrological behaviors.

Overall, the results indicated that the highest stream order among the 14 subwatersheds is 4. L_{sm} for the subwatersheds range from a maximum of 1.59 km for stream order 1 of W11 to a minimum of 0.04 km for stream order 3 of WS6. The maximum R_{bm} is seen for W5 (388.10), and thus, it will show early hydrograph peak (smaller water lag time), which also indicates strong structural control on the drainage development for this subwatershed. All the subwatersheds have low value of D, indicating that they are composed of permeable subsurface material, good vegetation cover and low relief.

In addition, for all the subwatershed, the low values of F_s show that the study area is comparably covered with a good amount of vegetation and has very good infiltration capacity. W1, W6, W10, W11, W13 and W14 (R_t <2) have longer duration to peak flow, while the other subwatersheds ($2<R_t<4$) have shorter duration to peak flow. R_s is found to be maximum for all the subwatersheds, indicating that none of these subwatershed have long water lag times. R_n is minimum for W14 (0.16) and maximum for W5 (0.98).

The values of S_w for the subwatersheds range from 3.70 for W14 to 5.31 for W7. In terms of only S_w, W7 will have the shorter watershed lag time, while W14 will have longer watershed lag time. C varies from 1.89 for W11 to 6.25 for W14. Low values of C for W11 and WS9 show that among all the subwatersheds, these two are associated with the weakest or very low-resistance soils, sparse vegetation, and mountainous terrain; while W14 is associated with high-resistance soils, dense vegetation and comparably plain terrain. High values of R_h in WS6, WS10, WS12, WS13 and WS14 indicate that intense erosion processes are taking place. R_c for WS8, WS2, WS6 and WS13 is in the range from 0.53 to 0.62, indicating that the area is characterized by high relief and permeable surface, resulting in longer water lag times.

WS1, WS2, WS3, WS4, WS5, WS7, WS8, WS 9, WS10, WS11, WS12 and WS14 have lower R_c, indicating low relief and impermeable surface, resulting in lower watershed lag times. All the subwatersheds have low R_f, indicating elongated shape and suggesting a flat hydrograph peak of longer duration. Flood flows of such elongated subwatersheds are easier to manage than those of circular watersheds. Low values of L_g for W2, W3 and W11 indicate steep slopes and shorter flow paths, while high values of L_g for the other subwatersheds indicate gentle slopes and longer flow paths. Using MLR, it was shown that there are positive and highly significant correlations between stream length, and S_w and R_t (0.933 and 0.926 respectively). The correlation between stream length and R_f (-0.910) was found to be negatively significant. The information collected on the subwatersheds can be used for planning and decision-making for flood disaster risk reduction.

REFERENCES

Abrahams, A.D., 1984, *Channel networks: a geomorphological perspective*, Water Resources Research, vol. 20, no. 2, pp. 161–168, 1984.

Agarwal, C.S., 1998, Study of drainage pattern through aerial data in Naugarh area of Varanasi district, U.P., *Journal of the Indian Society of Remote Sensing*, vol. 26, no. 4, pp. 169–175.

Akram F., Rasul M.G, Khan M., Amir, M., 2012, *Automatic Delineation of Drainage Networks and Catchments using DEM data and GIS Capabilities: A case study*, 18th Australian Fluid Mechanics Conference, Launceston, Australia.

Altaf, F., Meraj, G., Romshoo, S.A., 2013, *Morphometric Analysis to Infer Hydrological Behaviour of Lidder Watershed*, Western Himalaya, India. Hindawi Publishing Corporation Geography Journal Volume 2013, Article ID 178021, 14 pages

Chorley R.J., Malm D.E.G., Pogorzelki H.A., 1957, *A new standard for estimating drainage basin shape*. Am. J. Sci., 255: 138–141.

Costa, J.E., 1987, Hydraulics and basin morphometry of the largest flash floods in the conterminous United States, *Journal of Hydrology*, vol. 93, no. 3-4, pp. 313–338.

Dar, R.A., Chandra, R., Romshoo, S.A., 2013, Morphotectonic and lithostratigraphic analysis of intermontane Karewa basin of Kashmir Himalayas, India, *Journal of Mountain Science*, vol. 10, no. 1, pp. 731–741.

Dodov B.A., Foufoula-Georgiou, E., 2006, *Floodplain morphom- etry extraction from a high-resolution digital elevation model: a simple algorithm for regional analysis studies*, IEEE Geoscience and Remote Sensing Letters, vol. 3, no. 3, pp. 410–413.

Dodov, B., Foufoula-Georgiou, E., 2005, *Fluvial processes and streamflow variability: interplay in the scale-frequency contin- uum and implications for scaling*, Water Resources Research, vol. 41, no. 5, pp. 1–18.

Esper Angillieri, M.Y., 2008, *Morphometric analysis of Colangu¨ il river basin and flash flood hazard*, San Juan, Argentina, Environmental Geology, vol. 55, no. 1, pp. 107–111.

Gardiner, V., Park, C. C., 1978, *Drainage basin morphometry,Progress in Physical Geography*, vol. 2, no. 1, pp. 1–35.

Gardiner, V., Park, C. C., 1978, *Drainage basin morphometry*,Progress in Physical Geography, vol. 2, no. 1, pp. 1–35.

Gottschalk, L.C., 1964, *Reservoir sedimentation, in Handbook of Applied Hydrology*, Chow, V.T. Ed., section 7-1, McGraw-Hill, New York, NY, USA.

Grohmann, C.H. 2004, *Morphometric analysis in Geographic Information Systems: applications of free software* ,GRASS and R. Computers & Geosciences, 30 (9-10):1055-1067.

Harlin, J.M., 1980, The effect of precipitation variability on drainage basin morphometry, *American Journal of Science*, vol. 280, no. 8, pp. 812–825.

Harlin, J.M., 1984, Watershed morphometry and time to hydrograph peak, *Journal of Hydrology*, vol. 67, no. 1-4, pp. 141–154.

Horton, R.E., 1932, *Drainage basin characteristics*, Transactions American Geophysical Union, vol. 13, pp. 350–361.

Horton, R.E., 1945, *Erosional development of streams and their drainage basins: hydrophysical approach to quantitative mor- phology*, Geological Society of America Bulletin, vol. 56, pp. 275–370.

Howard, A. D., 1990, *Role of hypsometry and planform in basin hydrologic response*, Hydrological Processes, vol. 4, no. 4, pp. 373–385.

Kochel, R. C., 1988, *Geomorphic impact of large floods: review and new perspectives on magnitude and frequency,* in Flood Geomorphology, pp. 169–187, John Wiley & Sons, New York, NY, USA.

Leopold, L.B., Maddock, T., 1953, The hydraulic geometry of stream channels and some physiographic implications, *USGS Professional Paper*, vol. 252, pp. 1–57.

Luo, W., Harlin, J.M., 2003, A theoretical travel time based on watershed hypsometry, Journal *of the American Water Resources Association*, vol. 39, no. 4, pp. 785–792.

Magesh, N.S., Chandrasekar, N., Soundranayagam J.P., 2011, *Morphometric evaluation of Papanasam and Manimuthar watersheds, parts of Western Ghats, Tirunelveli district, Tamil Nadu, India: a GIS approach.* Environ Earth Sci 64:373–381

McEnroe, B.M., Zhao, H., 1999, *Lag times and peak coefficients for rural watersheds in kansas.* University of Kansas, Lawrence, Kansas. Report No. K-TRAN: KU-98-1.

Melelli, L., Liucci, L., Vergari, F., Ciccacci, S., Monte, M.D., 2014, *Fluvial drainage networks: the fractal approach as an improvement of quantitative geomorphic analyses.* Geophysical Research Abstracts. Vol. 16, EGU2014-12452.

Mesa, L.M., 2006, *Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina).* Environ Geol 50(8):1235–1242

Miller, V.C., 1953, A *Quantitative geomorphic study of drainage basin characteristics in the Clinch Mountain area, Virginia and Tennessee,* Tech. Rep. 3 NR 389-402, Columbia University, Department of Geology, ONR, New York, NY, USA, 1953.

Montgomery, D.R., Dietrich, W.E., 1989, *Source areas, drainage density, and channel initiation*, Water Resources Research, vol.25, no. 8, pp. 1907–1918.

Montgomery, D.R., Dietrich, W.E., 1992, *Channel initiation and the problem of landscape scale*, Science, vol. 255, no. 5046, pp. 826–830.

Nag, S.K., and Chakraborty, S., 2003, *Influence of rock types and structures in the development of drainage network in hard rock area*. J Indian Soc Remote Sens 31(1):25–35

Nissar, A., Kuchay, M., Sultan, B., 2013, Automated drainage characterization of dudganga watershed in western Himalayas. *European Scientific Journal* December 2013 edition vol.9, No.35 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

O'Callaghan, J. F., Mark, D.M., 1984, *The extraction of drainage networks from digital elevation data*, Computer Vision, Graph- ics, and Image Processing, vol. 28, pp. 323–344.

Pareta, K., Pareta, U., 2011, Quantitative morphometric analysis of a watershed of Yamuna basin, India using ASTER (DEM) data and GIS, *International Journal of Geomatics and Geosciences*, vol. 2, no. 1.

Patton, P.C., Baker, V. R., 1976, *Morphometry and floods in small drainage basins subject to diverse hydrogeomorphic controls,* Water Resources Research, vol. 12, no. 5, pp. 941–952.

Pidwirny, M., 2006, The Drainage Basin Concept. Fundamentals of Physical Geography, 2nd Edition.

Potter, K.W., Faulkner, E.B., 1987, Catchment response time as a predictor of flood quantiles, *Journal of the American Water Resources Association*, vol. 23, no. 5, pp. 857–861.

Rakesh, K., Lohani, A.K., Sanjay, K., Chatterjee, C., Nema, R.K., 2000, GIS based morphometric analysis of Ajay river basin upto Srarath gauging site of South Bihar, *Journal of Applied Hydrology*, vol. 14, no. 4, pp. 45–54.

Rashid, M., Lone, M.A., Romshoo, S.A., 2011, Geospatial tools for assessing land degradation in Budgam district, Kashmir Himalaya, India, *Journal of Earth System Science*, vol. 120, no. 3, pp. 423–433.

Romshoo, S.A., 2004, *Geostatistical analysis of soil moisture mea- surements and remotely sensed data at different spatial scales*, Environmental Geology, vol. 45, no. 3, pp. 339–349, 2004.

Sameena, M., Krishnamurthy, J., Jayaraman, V., Ranganna, G., 2009, *Evaluation of drainage networks developed in hard rock terrain*, Geocarto International, vol. 24, no. 5, pp. 397–420.

Schumms, S.A., 1956, *Evolution of drainage systems and slopes in Badlands at Perth Amboy, New Jersey*, Bulletin of the Geological Society of America, vol. 67, pp. 597–646.

Shulits, S., 1968, *Quantitative formulation of stream and watershed morphology*, Bulletin of the International Association of Scien- tific Hydrology, vol. 3, pp. 201–207.

Singh, S., 1992, *Quantitative geomorphology of the drainage basin, in Readings on Remote Sensing Applications*, T. S. Chouhan and K. N. Joshi, Eds., Scientific Publishers, Jodhpur, India.

Singh, S., Singh, M.C., 1997, Morphometric analysis of Kanhar river basin, *The National Geographical Journal of India*, vol. 43, no. 1, pp. 31–43, 1997.

Strahler, A., 1957, *Quantitative analysis of watershed geomorphol- ogy*, Transactions American Geophysical Union, vol. 38, pp. 913–920.

Strahler, A.N., 1964, *Quantitative geomorphology of drainage basins and channel networks, in Handbook of Applied Hydrology*, V. T. Chow, Ed., section 4–11, McGraw-Hill, New York, NY, USA,1964.

Suresh, M., Sudhakara, S., Tiwari, K.N., Chowdary, V.M., 2004, Prioritization of watersheds using morphometric parameters and assessment of surface water potential using remote sens- ing, *Journal of the Indian Society of Remote Sensing*, vol. 32, no.3.

Tucker, G.E., Bras, R.L. 1998, *Hillslope processes, drainage density, and landscape morphology*, Water Resources Research, vol. 34, no. 10, pp. 2751–2764, 1998.

Ward, R.C., Robinson, M., 2000, *Principles of Hydrology*, McGraw- Hill, Maidenhead, UK, 4th edition, 2000.

Youssef, A.M., Pradhan, B., Hassan, A.M., 2011, *Flash flood risk estimation along the St. Katherine road, southern Sinai, Egypt using GIS based morphometry and satellite imagery*, Environmental Earth Sciences, vol. 62, no. 3, pp. 611–623, 2011.

Zaz , S., Romshoo, S. A., 2012, *Assessing the geoindicators of land degradation in the Kashmir Himalayan Region, India*, Natural Hazards, vol. 64, no. 2, pp. 1219–1245.

.