RESEARCH ARTICLE

Morphometric analysis of watersheds in *Kelani* river basin for soil and water conservation

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Abstract: Geomorphic behaviour of watersheds influences the soil erosion characteristics in river basins and is used to prioritise the watersheds for soil and water conservation. There is evidence of higher rates of soil erosion occurring in the *Kelani* river basin. Thus, soil conservation in this basin is crucial at present. This study was carried out to identify the priority within the *Kelani* river basin for soil and water conservation using GIS spatial environment. *Kelani* river basin was first delineated on the digital elevation model (DEM) of 15 × 15 m resolution. It was further sub divided into 20 watersheds (KB1 to KB20) using spatial analysis techniques in GIS. Morphometric parameters such as areal, linear and relief were calculated for the 20 watersheds and ranked considering the susceptibility to erosion. Final priority was assessed based on the compound value. Hypsometric integral was also calculated for the 20 watersheds, and the watersheds were classed as young, mature and old. The results showed that upstream sub watersheds KB18 and KB20 fell under very high priority for soil and water conservation and they were further sub divided (KB18.1 to KB18.6 and KB 20.1 to KB 20.8, respectively) to investigate the most prioritised areas for soil and water conservation. The results showed that KB18.5 and KB18.6, and KB20.1, KB20.2 and KB20.3 are the most susceptible areas for soil erosion in KB18 and KB20 watersheds, respectively. Significant higher correlation (- 0.529 at significant level 0.01) between the compound value and observed turbidity data validated the morphometric base priority for soil and water conservation in *Kelani* river basin. Results of the study can be utilised in watershed prioritisation for soil and water conservation in *Kelani* river basin in Sri Lanka.

Keywords: GIS, *Kelani* river, morphometric analysis, soil and water conservation, soil erosion.

INTRODUCTION

The importance of morphometric analysis of a drainage basin is pivotal to understand the geological and geomorphic behaviour of a drainage basin, which influences the soil erosion characteristics in the basin (Panhalkar *et al.*, 2012). Quantitative analysis of morphometric parameters is of immense utility in river basin evolution and watershed prioritisation for soil and water conservation at micro-level watersheds (Kanth & Hassan, 2012). Morphometric analysis could be used for prioritisation of micro-watersheds by studying different linear and aerial parameters of the watershed, even without the availability of soil maps (Sidhu *et al.*, 1998; Biswas *et al.*, 1999). Geographical information system (GIS) techniques are currently being used for assessing various terrain and morphometric parameters of the basin as they provide a flexible and powerful tool for manipulation and analysis of spatial information (Pareta & Pareta, 2011).

A wide body of literature is available on morphometric assessment of watersheds for soil and water conservation at different scales for different parts of the world. However, there are only a few published studies on the prioritisation of watersheds for soil and water conservation in Sri Lanka. Kadupitiya *et al.* (2006) reported the prioritisation of sub watersheds in the Victoria catchment for soil conservation using remote sensing and GIS. They divided the Victoria catchment into 78 sub watersheds and soil erosion of

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each sub watershed was assessed based on land use, slope, soil erodibility and rainfall erosivity factors. These assessments identified high priority sub watersheds for soil conservation planning in the Victoria catchment. Similarly, a study was carried out to conserve the *Kothmala oya* and apply proper catchment management practices using catchment characteristics derived from GIS (Senadeera *et al.*, 2001). Pawar-Patil and Mali (2013) showed the importance of morphometric parameters obtained using GIS for the prioritisation of land reclamation and soil erosion prevention in the *Tulasi* sub watershed. In their assessment, appropriate weightages were assigned to different morphometric parameters and priority sub watersheds were determined on the compound value. A morphometric analysis was carried out to prioritise the watersheds for soil and water conservation in *Biswa* and *Kedar* sub basins of the *Purna* river basin using remote sensing and GIS (Manjare *et al.*, 2014). Moreover, Nooka *et al.* (2013) used remote sensing and GIS techniques in the morphometric analysis of sub watersheds of *Sarada* river basin. The analysis of various linear and areal aspects have revealed that the topographical configuration and geomorphic setting of the basin have set a dendritic to sub-dendritic drainage pattern with 7th order drainage. Omar (2015) conducted a morphometric analysis of the *Kshipra* river basin located in the Madhya Pradesh of Central India and found that five sub watersheds out of the 43 sub watersheds in the basin were erosion susceptible. These studies prove that the geomatic techniques are effective tools to understand and compute various terrain parameters, and for the analysis of a basin for prioritisation of soil conservation.

The *Kelani* river drains an area about 2,300 km² and the basin is rich with biodiversity and natural resources. It is the primary source of drinking water for millions of people in the greater Colombo area. Over 10,000 industries and businesses, providing a vast number of employment opportunities, are located within the *Kelani* river basin. The ecosystem of the *Kelani* river basin supports socioeconomic activities such as agriculture, mining, urban development, industrial development, tourism, and power generation, among other things. The basin contains some of the most picturesque landscapes in Sri Lanka, offering a high potential to be developed as tourist destinations (Gordon, 2014; Red Dot Tours, 2015), probably giving an alternative to the present industrial based economy. A five year (2010 – 2015) estimate of the mass of sediments in the *Kelani* river has revealed that, on average about 2,300 metric tons of sediments pass through the Hanwella bridge, annually (Mallawatantri *et al.*, 2016). Thus, soil and water conservation in the *Kelani* river basin is crucial to sustain the use of water for different users. Therefore, the present study was aimed at

prioritising sub watersheds in the *Kelani* river basin for soil and water conservation based on geo-morphometric analysis and hypsometric integral.

METHODOLOGY

Description of the study area

The *Kelani* river, which is 145 km in length, is the fourth longest river and the second largest watershed in Sri Lanka. It is located in between northern latitudes 6° 47' to 7° 05' and eastern longitudes 79° 52' to 80° 13'. The *Kelani* river starts near the Adams Peak and Kirigalpotta areas in the central hills of Sri Lanka and drains *via* Kithulgala, Avissawella and ending with the Colombo outfall into the Indian Ocean (Goonetilleke *et al.*, 2005). The minimum and maximum elevations in the basin range from 0 to 2345 m above mean sea level (Figure 1). The upper basin is mountainous and the lower basin, which is below Hanwella, has plain features. The basin receives an average annual rainfall of about 2400 mm and carries a peak flow of about 800 – 1500 m³/s during the monsoon season to the Indian Ocean (De Silva *et al.*, 2012). Main agricultural land uses in the area are tea, rubber, grass and forest in the upper catchment and the lower catchment is highly urbanised.

Materials

This study used digital elevation model (DEM) (15 m × 15 m resolution) from the Survey Department of Sri Lanka as the base map for the generation of morphometric parameters (Figure 1). Turbidity data collected from the National Water Supply and Drainage Board were also used in verification of morphometric analysis. The software used for the analysis was ArcGIS (ver.10.2), as an interface to derive the morphometric parameters from DEM.

Methods

The susceptibility to soil erosion was evaluated based on the morphometric analysis. Hypsometric integral was separately calculated as an individual entity to evaluate soil erosion. DEM was used as a base map to develop the fill and flow direction raster map using ArcGIS hydrology tool. A perfect flow direction was assumed to contain 8 values (D-8 method). It represents the direction, in which water would flow. From the flow direction map, flow accumulation raster map was developed. The flow accumulation operation performs a cumulative count of the number of pixels that naturally drains into outlets and finds the drainage pattern of the terrain. The prepared flow accumulation map was used as the basic map to develop

the drainage network extraction raster map. The drainage networks ordering operations examine all drainage lines in the drainage network map, and find the nodes where two or more streams meet. The final methods of DEM processing were watershed delineation and stream network generation. The entire *Kelani* basin was divided into 20 sub watersheds and the boundaries of the sub-watersheds were derived by defining pour point as per the guidelines provided by the Survey Department of Sri Lanka (Figure 2). The 20 sub watersheds were named KB1 to KB20. The most prioritised watersheds (KB18 and KB20) were further divided into micro watersheds.

Stream order in this study was developed according to the Strahler (1964) method. The stream lengths and basin areas were measured with ArcGIS 10.2 software. Table 1 indicates the morphometric parameters used in the study with the calculation method and the relevant references. Singh *et al.* (2008) showed the importance of hypsometric analysis (area-elevation analysis) for the prioritisation of watersheds for soil and water conservation. Hence, this study used hypsometric integral (HI) as a separate parameter in prioritisation

of watersheds for soil conservation in the *Kelani* river basin.

The linear morphometric parameters such as bifurcation ratio (Rb), compactness coefficient (Cc), elongation ratio (Re), drainage density (Dd), stream frequency (Fs), foam factor (Ff) and drainage texture (Dt) have a direct relationship with erodibility (Biswas, 1999). These parameters are also termed as erosion risk assessment parameters. Hence, the values of linear parameters were ranked from the highest to the lowest for prioritisation of watersheds. In contrast, areal parameters such as compactness coefficient (Cc), elongation ratio (Re), foam factor (Ff) and circularity ratio (Rc) have an inverse relationship with erodibility. Therefore, the lowest value of areal parameters was rated as rank 1, the next lower value as rank 2, and the highest value was rated last in rank as described by Nooka *et al.* (2005). Slope of the watershed is one of the important erosion risk assessment parameters, which can be used to prioritise the watersheds (Burrough, 1986). It also has a direct relationship with erodibility. Therefore, slope was also ranked as a linear parameter. After the ranking was

Figure 1: Location of *Kelani* river basin in Sri Lanka and variation of its elevation derived from DEM 15×15 m (DEM source - Survey Department of Sri Lanka)

Figure 2: Delineated 20 sub watersheds KB1 to KB20 in *Kelani* river basin

done based on every single parameter, the ranking values for all the linear, areal and relief parameters of each watershed were added up to arrive at compound value (Cp). Based on the average value of these parameters, the watershed having the least rating value was assigned the highest priority and the next higher value was assigned the second priority and so on. The watershed, which

got the highest Cp value was assigned the last priority as described by Turner *et al.* (1990). Watersheds in the *Kelani* river basin were prioritised following the above methods.

Watersheds in the *Kelani* river basin were also categorised and prioritised based on HI values of each

Table 1: Morphometric parameters, their formulas and relevant references

No.	Morphometric parameters	Formula	Reference
01	Stream order (U)	Hierarchical rank	Strahler (1964)
02	Stream length (Lu)	Length of the stream	Horton (1945)
03	Bifurcation ratio (Rb)	$Rb = Nu/Nu + 1$ where Nu = total no. of stream segments of order 'u'; Nu + 1 = number of segments of the next higher order	Schumm (1956)
04	Drainage density (Dd)	$Dd = Lu / A$ where Lu = total stream length of all orders; A = area of the basin (km ²)	Horton (1945)
05	Stream frequency (Fs)	$Fs = Nu/A$ where Nu = total number of streams of streams of all orders; A = area of the basin (km ²)	Horton (1945)
06	Circularity ratio (Rc)	$Rc = 4 * \pi * A/P^2$ where $\pi = \pi$ value, i.e., 3.141; A = area of the basin (km ²); P ² = square of the perimeter (km)	Miller (1953)
07	Elongation ratio (Re)	$Re = 1.128 \sqrt{A/Lb}$ where A = area of the basin, km ² Lb = basin length	Schumm (1956)
08	Form factor (Ff)	$Ff = A/Lb^2$ where, A = area of the basin (km ²); Lb = basin length	Schumm (1956)
09	Hypsometric integral (HI)	$HI = (H-h)/(H_{max}-h)$ where, H = the weighted mean elevation; H _{max} = maximum elevation; h = minimum elevation	Hurtrez (1999)
10	Drainage texture (T)	$T = Nu/P$ where Nu = total no. of streams of all orders; P = basin perimeter (km);	Horton (1945)
11	Compactness coefficient (Cc)	$Cc = 0.2821 P/A^{0.5}$ where A = Area of the basin (km ²); P = basin perimeter (km)	Horton (1945)

watershed as described by Strahler (1964) and Sarangi *et al.* (2001). For validation of the results of the study, turbidity data of a few stations of the river were collected from the National Water Supply and Drainage Board (Table 2). Again the *Kelani* river basin was divided into 5 sub basins taking these turbidity measuring stations as the watershed outlets, and Cp values were calculated as stated above. Subsequently, correlations between turbidity and calculated Cp values were tested by using non-parametric Spearman's rho correlation coefficient (ρ) using statistical package for the social sciences (SPSS).

Table 2: Turbidity recording stations and periods of records

Stations	Longitude	Latitude	Periods of records
Sithawaka Thotupala	80.20322	6.97677	2004-2015
Wak Oya	80.09828	6.91758	2004-2015
Pussali Oya	80.06573	6.91009	2004-2015
Rakgahawatta Ela	79.96922	6.93927	2014-2015
Kananthalla Bridge	80.12335	6.97348	2014-2015

RESULTS AND DISCUSSION

Figure 2 shows the delineated sub watersheds from the DEM using ArcGIS Hydro-tool. KB1 to KB20 indicate different sub watersheds in the basin.

Morphometric analysis of linear parameters

This study assessed linear morphometric parameters such as stream order (U), stream number (Nu), stream length (Lu), stream length ratio (RL), bifurcation ratio (Rb) and length of overland flow (Lof). The stream ordering is a measure of stream branching in a watershed: a first order stream is an unbranched tributary; a second order stream is a tributary formed by two or more first order streams; a third order stream is a tributary formed by two or more second order tributaries. In general, an N^{th} order stream is a tributary formed by two or more streams of order (N-1) and streams of lower order (Strahler, 1957). Lower the order, higher the number of streams is implied throughout the catchment. Areas with larger slopes and finer textures are characterised by streams of relatively smaller lengths. Flatter gradients are generally represented by longer length of streams. Figure 3 shows stream orders of all

Figure 3: Stream order of Kelani river basin

Table 3: Stream numbers in different orders in different sub watersheds in Kelani river basin in Sri Lanka

Basin no.	Stream numbers in different orders								Total no. of streams
	1 st	2 nd	3 rd	4 th	5 th	6 th	7 th	8 th	
KB1	985	506	257	121	51	41	—	—	1961
KB2	433	191	116	63	35	26	—	—	864
KB3	470	213	103	49	98	—	—	—	933
KB4	693	359	154	86	15	7	67	—	1381
KB5	329	156	86	24	10	—	—	54	659
KB6	226	124	52	28	18	—	—	—	448
KB7	1126	577	283	126	23	12	41	74	2262
KB8	260	140	66	33	20	—	—	—	519
KB9	796	407	178	101	35	3	—	78	1598
KB10	347	179	94	51	20	—	—	—	691
KB11	409	197	94	67	5	48	—	—	820
KB12	92	49	28	7	4	—	—	—	180
KB13	202	108	37	36	20	—	—	—	403
KB14	326	171	50	57	31	10	—	—	645
KB15	609	238	197	126	42	—	—	—	1212
KB16	293	137	92	18	43	—	—	—	583
KB17	152	88	30	18	15	—	—	—	303
KB18	1147	518	247	131	103	138	—	—	2284
KB19	439	216	115	62	23	19	—	—	874
KB20	1068	491	261	99	70	137	—	—	2126
Kelani	10402	5065	2540	1303	681	441	108	206	20746

orders of the entire *Kelani* river basin. Stream length of first order streams constitute 48.48 % of the total stream length and that of the 8th order is 1.15 %. However, the total stream length of 8th order (73.13 km) is more than the length of 7th order (38.78 km). This change may occur due to the flowing of streams from high altitude and steep slopes. Table 3 indicates the stream numbers in different orders in different sub watersheds in the *Kelani* basin along with the entire basin. There are 20746 streams linked with all the 8 orders of streams over an area of 2338.59 km². The highest number of stream segments is found in sub watershed KB18 (2284), while the lowest number of stream segments is found in sub watershed KB17 (313). The percentage of streams by different stream orders to the total number of streams is 50.14 in 1st order and 0.99 in 8th order for the whole *Kelani* river basin. Generally the total length of stream segments decreases as the stream order increases (Manjare *et al.*, 2014).

Table 4 shows the variation in linear morphometric parameters of different sub watersheds in the *Kelani* river basin. The total drainage area of the *Kelani* river basin is 2338.59 km² and the sub watershed KB7 has the largest areal extent (298.94 km²). The larger basins record large average discharges (Kale & Gupta, 2001).

Bifurcation ratio is a dimensional parameter that expresses the ratio of the number of streams of any given order (Nu) to the number of streams in the next lower orders (Nu+1) (Horton, 1945). In general, lower values of Rb are characteristic of a watershed of which the drainage pattern has not been distorted by structural disturbances and show less structural disturbances (Nag & Chakraborty, 2003). Higher mean Rb values are characteristic of structurally more disturbed watersheds with prominent distortion in drainage pattern (Nag, 1998). Mean bifurcation ratio of different sub watersheds in the *Kelani* basin varies from 1.64 (KB18) to 4.11 (KB9). The highest value (KB9) suggests that it has a structurally controlled drainage pattern, whereas the value of the sub basin KB18 implies smaller amount of structural disturbance (Table 4).

Stream frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932). Fs has been related to permeability, infiltration capacity and relief of watersheds (Montgomery & Dietrich, 1989), and it generally decreases with the increase in stream number. Sub basins, which have higher Fs, take a long time to obtain peaks because of low runoff rates caused by lesser number of streams (Ghoneim *et al.*, 2002). The

Table 4: Variation of linear parameters [area, perimeter, mean bifurcation ratio (Rb), drainage texture (Dt), drainage density (Dd) and stream frequency (Fs)] of different sub watersheds in *Kelani* river basin

Sub basin no.	Area (Km ²)	Perimeter (Km)	Mean Rb	Linear parameters		
				Dt	Fs	Dd (Km ⁻¹)
KB1	235.68	128.51	1.93(12)	15.26(4)	8.32(14)	2.67(11)
KB2	91.46	96.97	1.78(17)	8.91(15)	9.45(7)	2.44(18)
KB3	91.58	86.08	1.72(19)	10.84(9)	10.19(4)	2.59(14)
KB4	137.11	87.21	2.34(5)	15.84(3)	10.07(5)	2.76(9)
KB5	131.51	105.70	2.48(3)	6.23(18)	5.01(20)	1.82(20)
KB6	48.76	59.11	1.90(14)	7.58(17)	9.19(8)	3.21(1)
KB7	298.95	202.28	2.07(9)	11.18(8)	7.57(18)	2.74(10)
KB8	60.96	57.09	1.91(13)	9.09(13)	8.51(13)	2.78(8)
KB9	187.44	130.70	2.06(1)	10.12(6)	8.52(11)	2.97(2)
KB10	81.12	68.31	4.11(10)	12.23(11)	8.53(12)	3.09(5)
KB11	99.46	102.49	3.82(2)	8.00(16)	8.24(15)	2.41(19)
KB12	23.59	35.28	2.34(4)	5.10(19)	7.63(17)	3.07(3)
KB13	42.45	40.78	1.90(15)	9.88(12)	9.49(6)	2.51(16)
KB14	73.77	59.57	2.23(7)	10.83(10)	8.74(9)	2.65(12)
KB15	111.43	72.28	2.08(8)	16.77(2)	10.88(1)	2.45(17)
KB16	70.86	64.91	2.29(6)	8.98(14)	8.23(16)	2.62(13)
KB17	41.64	62.03	1.88(16)	4.88(20)	7.28(19)	2.53(15)
KB18	212.02	154.06	1.64(20)	14.83(5)	10.77(2)	2.99(4)
KB19	101.10	73.66	1.93(11)	11.87(7)	8.64(10)	2.80(7)
KB20	197.72	121.40	1.72(18)	17.51(1)	10.75(3)	2.85(6)

analysis showed that the F_s is maximum in sub watershed KB15 (10.88/Km²) and minimum in sub watershed KB5 (5.01/Km²) (Table 4). KB15 may require comparatively more bank stabilisation than KB5.

Drainage density (Dd) is defined as the length of streams per unit area (Horton, 1932). Factors affecting the Dd are, resistance to weathering, permeability of rock formation, climate and vegetation. It also influences the travel time of water within a watershed (Gardiner & Park, 1978). The low and moderate Dd of the basins revealed that they are composed of permeable sub surface material and good vegetation cover, which result in more infiltration capacity (Harlin & Wijeyawickrama, 1985). Sub watershed KB5 has the lowest (below 2/km) Dd while sub basins KB2 and KB11 have moderate (2 – 2.5/km) Dd, which indicate that these watersheds may comprise permeable materials with good vegetation. However, sub watersheds KB6, KB10, and KB12 contain higher Dd values (Table 4). Thus, off-farm conservation measures may be a high priority to these sub watersheds.

Morphometric analysis of areal parameters

Areal morphometric parameters, which were assessed by this study are compactness coefficient (Cc), elongation ratio (Re), foam factor (Ff) and circularity ratio (Rc) (Table 5).

The maximum length of the watershed and sub-watersheds measured in parallel to the main drainage line of the watershed is called basin length. The highest basin length, 65.87 km was recorded in the sub watershed KB18, whereas the lowest was recorded in KB12. The observations in this study showed that the watersheds KB13 (0.23) and KB10 (0.21) are less elongated while KB11 (0.07), KB18 (0.05) and KB20 (0.08) watersheds are highly elongated (Table 5). This revealed that the *Kelani* river basin comprises high relief and steep valley sides. The compactness coefficient (Cc) of different sub watersheds in the *Kelani* river basin vary from 0.31 (KB1) to 0.84 (KB12, KB17).

Table 5: Variation of areal parameters [foam factor (Ff), circularity ratio (Rc), compactness coefficient (Cc) and elongation ratio (Re)] of different sub watersheds in *Kelani* river basin

Basin number	Basin length (Km)	Areal parameters			
		Ff	Rc	Cc	Re
KB1	50.95	0.09(4)	0.18(11)	0.31(1)	0.34(4)
KB2	28.36	0.11(9)	0.12(4)	0.60(17)	0.38(9)
KB3	30.20	0.10(6)	0.16(8)	0.53(13)	0.36(6)
KB4	30.27	0.15(13)	0.23(14)	0.36(3)	0.44(13)
KB5	25.92	0.20(16)	0.15(7)	0.45 (9)	0.50(16)
KB6	15.40	0.21(17)	0.18(10)	0.68(18)	0.51(17)
KB7	55.70	0.10(5)	0.09(1)	0.38(5)	0.35(5)
KB8	16.93	0.21(18)	0.24(16)	0.53(12)	0.52(18)
KB9	19.45	0.13(10)	0.14(6)	0.39(6)	0.41(10)
KB10	37.98	0.21(19)	0.22(13)	0.48(11)	0.52(19)
KB11	36.62	0.07(2)	0.12(3)	0.58(15)	0.31(2)
KB12	12.85	0.14(12)	0.24(17)	0.84(20)	0.43(12)
KB13	13.61	0.23(20)	0.32(20)	0.54(14)	0.54(20)
KB14	23.37	0.14(11)	0.26(18)	0.46(10)	0.41(11)
KB15	26.25	0.16(14)	0.27(19)	0.37(4)	0.45(14)
KB16	25.18	0.11(8)	0.21(12)	0.52(12)	0.38(8)
KB17	20.02	0.10(7)	0.14(5)	0.84(19)	0.36(7)
KB18	65.87	0.05(1)	0.11(2)	0.41(7)	0.25(1)
KB19	23.40	0.18(15)	0.23(15)	0.41(8)	0.48(15)
KB20	50.76	0.08(3)	0.17(9)	0.35(2)	0.31(3)

Circularity ratio (R_c) is the circumference of a circle of the same area as that of the watershed to the perimeter of the watershed; both measured in consistent units (Miller, 1953). The circularity ratio is used as a quantitative measure for visualising the shape of the basin (Christopher *et al.*, 2010). Important watershed characteristics that influence the R_c are the length, frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. Higher values of R_c indicate that the area is characterised by high relief, elongated and permeable surface resulting in greater basin lag times, while lower values indicate a lower relief and impermeable surface resulting in lower basin lag times. R_c of the *Kelani* river basin varies from 0.09 (KB7) to 0.32 (KB13) (Table 5). This indicates that KB13 shows delayed time to peak flow, while KB7 shows shorter time to peak flow.

Foam factor (F_f) is defined as the ratio of the basin area to the square of basin length (Horton, 1932). For a perfectly circular basin the values of F_f would always be less than 0.7854. The F_f for all basins vary from 0.05 to 0.16 (Table 5). The value of F_f also indicates watershed shape. Smaller the value, the watershed will be more elongated. The basins with high F_f have high peak flow of shorter duration (Kochel, 1988) that may influence on the erodibility of soil. The values of F_f for the *Kelani* river basin indicate that the whole basin is elongated, suggesting flat hydrograph peak for longer duration (Table 5). Flood flows of such elongated watersheds are easier to manage than those of the circular watersheds (Nautiyal, 1994).

Compactness coefficient (C_c) is the ratio between the perimeter of the watershed and circumferences of the circular area (Gravelius, 1914). C_c is independent of the size of the watershed and depends on the slope. It is used to express the relationship of a hydrologic basin with that of a circular watershed having the same area, as the hydrologic watershed will yield the shortest time of concentration before peak flow occurs in the watershed. Thus, a circular watershed is identified as the most hazardous from a drainage stand point. C_c values showed a wide variation (0.31 – 0.84) among different sub watersheds (Table 5) in the *Kelani* river basin.

Elongation ratio (R_e) is the ratio between the diameter of a circle with the same area as that of the watershed to the maximum length of the watershed, both expressed in the same units. The R_e generally varies from 0.6 to 1.0 associated with a wide variety of climate and geology (Javed *et al.*, 2009). Values close to 1.0 are typical of regions of very low relief and indicate a perfectly circular watershed, whereas that from 0.6 to 0.8 are associated

with high relief and steep ground slope (Dar *et al.*, 2013). These values can be grouped into three categories as circular (> 0.9), oval ($0.9 - 0.7$) and elongated (< 0.7). In this study, R_e values of the sub watersheds vary from 0.25 to 0.54 suggesting that almost all watersheds are elongated in nature (Table 5).

Watersheds prioritisation

Prioritisation based on compound value (C_p)

The ranking of 20 sub watersheds has been determined by assigning the highest rank based on the highest values in case of linear parameters, and the lowest values in case of shape parameters. Subsequently, ranking values of all the parameters for each of the sub watershed was added up and the C_p values for each of the 20 sub watersheds were determined. On the basis of C_p values of each sub watershed, they were categorised into five categories as very high (< 7.57), high (7.57 – 8.99), medium (9.00 – 11.21), low (11.22 – 13.50) and very low (> 13.51) priority for soil conservation (Figure 4). Hence, KB4, KB9, KB18 and KB20 fall under very high priority class; KB1, KB7, KB11 and KB15 under high priority class; KB3 and KB16 under medium priority class; KB2, KB6, KB10, KB14, KB17 and KB19 under low priority class; and the others fall under the very low priority class.

Prioritisation based on hypsometric integral (HI)

The hypsometric integral is the area beneath the curve, which relates the percentage of total relief to the cumulative percentage of area (Singh *et al.*, 2008). Shape of the hypsometric curve indicates the age of the catchment. Hypsometric integrals and curves can be interpreted in terms of the degree of basin dissection and relative landform age: convex-up curves with high integrals are typical for youthful stage, undissected landscapes; smooth, s-shaped curves crossing the centre of the diagram characterise mature (equilibrium stage) landscapes; and concave-up with low integrals typify old and deeply dissected landscapes (Strahler, 1952). If the resulted HI value is greater than or equal to 0.6 it indicates that the watershed is in equilibrium or at young stage indicating the susceptibility of the watershed to erosion. If the value is between 0.35 and 0.6 it indicates a naturedly dissected (mature) landform. If the resulted value is equal or less than 0.35 it indicates old or monadnock stage of the watershed, in which the watershed is stabilised and no further erosion is expected (Strahler, 1952; Sarangi *et al.*, 2001). Based on these guidelines, sub watersheds in the *Kelani* river basin were also categorised using the calculated HI values of the different sub watersheds (Figure 5). Sub watersheds

KB3, KB6, KB15, KB16, KB18 and KB20 fall under the mature stage and conservation practices should be applied immediately. Other sub watersheds fall to the old stage in which watersheds are stabilised and there is no further erosion. However, there were no young stage watersheds in the *Kelani* river basin.

Concerning the two prioritisation methods, Cp and HI, sub watersheds KB18 and KB20 fall under very high priority class and these two sub watersheds were further divided into 6 sub watersheds (micro watersheds) to investigate the most prioritised areas for soil and water conservation. Following the same analysis and prioritisation methods, we found that micro watersheds KB18.5, KB18.6, KB20.1, KB20.2 and KB20.3 are the most susceptible areas for soil erosion, and high priority areas for soil and water conservation (Figure 6).

Figure 4: Priority of sub watersheds in *Kelani* river basin based on compound value

Figure 5: Prioritisation of sub watersheds in *Kelani* river basin based on the hypsometric integral

Figure 6: Final priority for sub watersheds KB18 and KB20 (18.1 to 18.6 are micro watersheds in KB18, and 20.1 to 20.8 are micro watersheds in KB20)

Table 6: Variation of areal [mean bifurcation ratio (Rb), drainage texture (Dt), drainage density (Dd), stream frequency (Fs)], linear [foam factor (Ff), circularity ratio (Rc), compactness coefficient (Cc) and elongation ratio (Re)], relief parameters and compound values for A, B, C, D, E sub basins and the entire basin F

No.	Areal aspects				Linear aspects				Relief	Slope	Cp
	Rb	Dt	Fs	Dd	Ff	Cc	Rc	Re			
A	2.35	38.9	9.3	2.7	0.16	0.14	0.15	0.45	2334	26.3	4.4
B	2.01	40.1	9.2	2.7	0.11	0.13	0.13	0.38	2342	23.6	3.3
C	2.01	38.7	9.3	2.7	0.12	0.14	0.13	0.38	2341	24.2	4.2
D	2.01	39.6	9.1	2.8	0.09	0.13	0.10	0.34	2345	20.1	2.9
E	2.01	40.2	9.1	2.7	0.08	0.13	0.12	0.33	2344	21.8	2.3
F	2.05	39.3	9.3	2.7	0.13	0.13	0.14	0.40	2340	25.3	3.9

Figure 7: Delineated sub basins Seethawaka-Thotupala, Kananatalla, Rakgahawatta, Pusseli oya, and Wak oya in Kelani river basin for the verification study

Validation of the results with observed turbidity data

Researchers such as Altaf *et al.* (2014) and Chen *et al.* (2011) have used this morphometric analysis approach even without validation for the assessment of soil erosion. Since we could obtain turbidity data of a few stations in the *Kelani* river, an attempt was made to validate the morphometric analysis results with the observed turbidity data. For the validation of the results, sub basins were delineated using the latitude and longitude of the turbidity measuring stations as the outlet, and they were named as A, B, C, D and E for Seethawaka-Thotupala, Pusseli Oya, Wak Oya, Rakgahawatta Ela and Kananatalla, respectively (Figure 7). Cp values were calculated for each of the sub basin and are shown in Table 6. Then the correlation between the Cp values of each sub basin and the respective turbidity data was tested. First, the collected turbidity data were tested for normal distribution using descriptive analysis and found that the data were not normally distributed. Therefore, non-parametric Spearman rank correlation was used to find the association between Cp values and observed turbidity. When there were number of turbidity values for the same watershed, the same Cp values were assigned. It was found that there was a significant correlation between the Cp value and observed turbidity and it was -0.529 at $p < 0.01$. This result confirms that the highest priority needs should be given to the lowest Cp values.

Soil erosion may be enhanced further in the future in many parts of the world due to climate change towards a more vigorous hydrological cycle (Amore *et al.*, 2004, Pandey *et al.*, 2006). A similar situation could arise in the very important *Kelani* river basin. However, the implementation of a watershed management programme for the entire *Kelani* river basin is constrained by the availability of resources. In addition, assessment of *in-situ* soil erosion is also a time taking activity and needs more resources. Therefore, the ranking of critical soil erosion prone areas by morphometric analysis is vital for prioritising watersheds in the *Kelani* river basin.

CONCLUSION

Watershed prioritisation is considered as one of the most important aspects of planning and development of soil and water conservation measures. The result of prioritisation on the basis of compound value revealed that sub watersheds KB4, KB9, KB18 and KB20 are the most susceptible for soil erosion in the *Kelani* river basin. Based on hypsometric integral, watersheds KB3, KB6, KB15, KB16, KB18 and KB20 are the most susceptible sub watersheds for soil erosion in the *Kelani* river basin. KB18.5, KB18.6 and KB20.1, KB20.2 and KB20.3 are

the most susceptible areas/ micro watersheds for soil erosion in KB18 and KB20 sub watersheds, respectively. Morphometric analysis can be used to prioritise sub watersheds in the *Kelani* river basin as there was a significant correlation (-0.53) between the Cp value and observed turbidity data. The study demonstrates the utility of morphometric analysis in prioritisation of watersheds, which may be helpful for planners and decision makers for planning a river basin management plan for the *Kelani* river basin.

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