Journal of Geospatial Surveying (2023) 3:1
DOI: http://doi.org/10.4038/jgs.v3i1.48

ORIGINAL ARTICLE

Watershed Management Prioritization in Paddy Land Uses: A Case Study in Hungamala Ela Sub-watershed of Mahaweli River Basin of Sri Lanka

Withanage N.S. *[a], Abeysekara G.D.J.M. [b]

[a] *Department of Export Agriculture, Faculty of Animal Science and Export Agriculture, Uva Wellassa University of Sri Lanka*

[b] *Independent Researcher*

ARTICLE INFO

Article history:
Received 31 January 2023
Received in revised form 4 April 2023
Accepted 6 April 2023
Available online 21 April 2023

Keywords:
Geographical Information System
Morphometric analysis
Paddy land uses
Spatial data
Watershed prioritization

ABSTRACT

Prioritization of watersheds is important for proper planning and management of soil and water resources for sustainable development. Morphometric analysis has been commonly used to for prioritization of watersheds for management. Hence, Hungamala Ela sub-watershed of Mahaweli Basin where paddy is grown extensively was selected for this study to identify and prioritize soil and water conservation in the sensitive areas via morphometric analysis and GIS based approach. Stream network, stream order and micro-watersheds were extracted from the DEM derived from the 20 m contour interval in the Arc GIS environment. The spatial data required for morphometric analysis were derived from Arc GIS tools. Watershed prioritization was completed following the methods proposed in published literature. Paddy land use analysis was carried out for 2003, 2012 and 2020. The results of the study revealed that 14 micro-watersheds, HE1 to HE14, could be identified within the Hungamala Ela sub-watershed area and its stream network extends up to the 7th order showing a dendritic drainage pattern. The results of watershed prioritization revealed that HE6, HE7, HE9 and HE11 fall under the high priority category for soil erosion susceptibility. Moreover, paddy landuses have increased drastically, by 83% from 2003 to 2020, even in the identified sensitive micro-watersheds. Therefore, the Hungamala Ela sub-watershed management should be prioritized by introducing proper soil conservation measures especially within the identified highly sensitive areas for sustainable paddy cultivation.

1 Introduction

A drainage or river basin is an essential component of the landscape that deals with the collection and distribution of water and debris. Each basin is separated from its neighbor by a divide or interfluve. Thus, a river basin may be seen as a geomorphic system or unit (Garde, 2006). In the Sri Lankan context, Mahaweli river is the longest river and the largest riven basin among 103 major river basins, and it has many sub-river basins or sub-watersheds owing to its rich stream network with many tributaries of which many originate from the central highlands of the country (SD-SL, 2007). Hungamala Ela is a branch of Mahaweli river and thus a sub-watershed of Mahaweli basin. It spreads within Ampara and Polonnaruwa districts, where paddy is grown extensively.

A method for maximizing the benefits that can be gained from watershed resources, while preserving ecological sustainability, is watershed management. It attempts to establish a balance of healthy ecological, economic, and cultural/social conditions within a watershed by using adaptive, comprehensive, and integrated multi-resource management planning methodologies (Farhan and Anaba, 2016; Javed et al., 2011). Geomorphology, drainage, physiography, climate, soil, topography, watershed boundaries, land use/land cover, and many other factors are significant in planning watershed management (Biswas et al., 1999). In this context, identifying and prioritizing sensitive areas of a watershed is very important and thus studies on watershed management prioritization using morphometric analysis of watershed parameters have become very popular in every corner of the world (Biswas et al., 1999; Farhan and Anaba, 2016; Javed et al., 2011; Nag, 1998; Nooka Ratnam et al., 2005; Uniyal and Gupta, 2013).

* Corresponding author: N.S. Withanage, Department of Export Agriculture, Faculty of Animal Science and Export Agriculture, Uva Wellassa University of Sri Lanka, Sri Lanka.

E-mail address: nisansala@uwu.ac.lk (N.S. Withanage).

Morphometry is defined as the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms (Clarke, 1966) and is the most common technique in basin analysis. It produces an ideal areal unit for the analysis and interpretation of fluvially originated landforms where they exhibit an example of open systems of operation. Furthermore, morphometry includes the quantitative study of the area, altitude, volume and slope profiles of the land surface and the drainage characteristics of the particular watershed of interest. Morphological characteristics of river basins are about the form of the streams and adjacent areas that are related to erosion, transportation and deposition of sediment from runoff water (Garde, 2006). As explained by Strahler (1957), systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear aspects of the drainage network, areal aspects of the drainage basin and relief (gradient) aspects of the channel network, and contributing ground slopes.

The linear aspects of morphometric parameters are stream order, stream number, stream length, drainage density, drainage intensity, drainage texture, bifurcation ratio, length of overland flow, and so on (Uniyal and Gupta, 2013; Withanage et al., 2015). The shape or areal aspects are basin area, perimeter, basin length, elongation ratio, circularity ratio, form factor,, and the relief aspects are relief, relief ratio, relative relief. (Chorley et al., 1957; Clarke, 1966; Garde, 2006; Horton, 1945; Strahler, 1957). As reported in scientific literature, linear morphometric parameters have a direct relationship with erodibility; higher the value of the linear parameters, greater the erodibility, while areal morphometric parameters have an inverse relationship with erodibility; lower the value of the areal parameters, higher the erodibility (Biswas et al., 1999; Farhan and Anaba, 2016; Nooka Ratnam et al., 2005; Uniyal and Gupta, 2013).

Based on that fact, each watershed is ranked from highest to lowest for linear aspects and lowest to highest for areal aspects. Then the compound values are estimated by averaging those ranks at sub-watershed or micro-watershed level to identify and prioritize as high, medium, and low priority in accordance with the sequence in which they must be addressed for the soil conservation. Finally, a sub-watershed with the largest compound value is considered to be of low priority, whereas a watershed with the lowest compound value is considered to be of high priority (Biswas et al., 1999; Farhan and Anaba, 2016). In this line of investigations done for the watershed development and management, Geographic Information Systems (GIS) and Remote Sensing (RS) have become more popular as they provide a flexible environment for spatial data acquisition and analysis (Farhan and Anaba, 2016; Javed et al., 2011; Montgomery and Dietrich, 1989).

Despite the fact that many studies have been conducted in this field globally, as well as a few in Sri Lanka, none have been conducted for the largest Mahaweli basin yet. Therefore, this study done using models attempts to identify and prioritize the sensitive areas for soil and water conservation of Hungamala Ela sub-watershed by morphometric and land use analysis as considerable environmental degradation has been observed in the area in the recent years.

2 Materials and Methods

2.1 Study Area

Hungamala Ela sub-watershed area is within 7° 37' 0" - 7° 49' 30" N and 80° 59' 30" - 81° 08' 30" E and at 42 m (138 feet) above Mean Sea Level (mapcarta, 2022). This area falls within the Agro-ecological Region Low Country Dry Zone (DL1c) (Fig. 1) and receives less than 1,750 mm of annual average rainfall. The main soil types are sandy soil, alluvial soil and reddish brown soil, and the paddy cultivation is the dominant land use (Gov-SL, 2011). The Hungamala Ela sub-watershed receives a lot of rain throughout the Maha season (October to February), which is particularly beneficial for the rain-fed paddy cultivation. Irrigated paddy farming generally occurs throughout the Yala season during March to August (Nissanka et al., 2011).

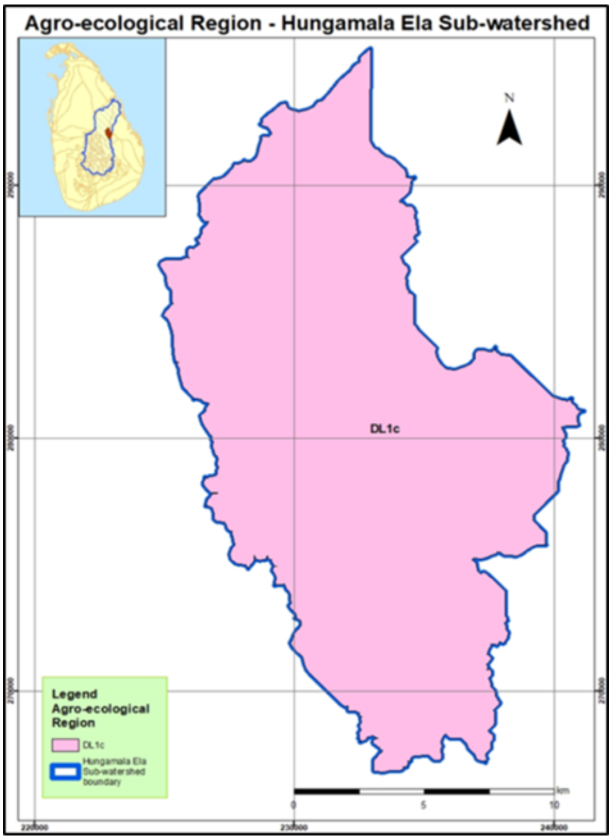

Fig. 1: Agro-ecological Region Map of Hungamala Ela Sub-watershed [Data Source: Mahaweli Authority of Sri Lanka].

Twenty meter contour interval maps were used for this study. Topographic map sheets (49 - Pallegama and 43 - Elahara) in 1:50,000 scale were collected from the Survey Department of Sri Lanka. The software used were ArcGIS 10.4.1 and Google Earth Pro. The Kandawala Coordinate System was used for all digital layers and to prepare all maps in this study.

The Digital Elevation Model (DEM) was derived using 20 m contour interval data obtained from the Survey Department of Sri Lanka. Using the DEM, stream network was developed using the Hydrology toolset in ArcMap. The spatial data on paddy land uses of this sub-watershed during 2003, 2012 and 2020 were gathered from topographic map sheets and Google Earth Pro software.

3 Theory and Calculation

The entire Hungamala Ela sub-watershed could be divided into 14 micro-watersheds (as shown in Fig. 2), named HE1 to HE14 and the subsequent boundaries were derived by defining pour points. The stream orders were obtained using Strahler (1957) method. Linear (Table 1) and areal aspects (Table 2) of morphometric parameters were assessed using ArcGIS analysis tools and different models developed and published in the available scientific literature.

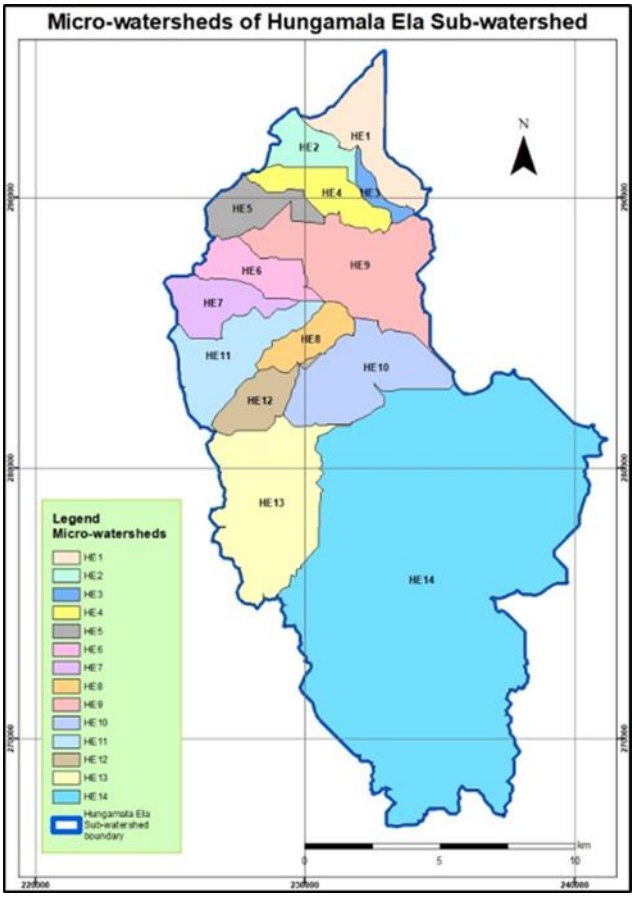

Fig. 2: Delineated Micro-watersheds, HE1 to HE14, in Hungamala Ela Sub-watershed

As reported by Biswas et al. (1999), linear parameters such as drainage density, drainage texture, drainage intensity, length of overland flow, bifurcation ratio and infiltration number show a direct relationship with soil erodibility. Hence, when prioritizing the 14 micro-watersheds, the highest value of linear parameters was ranked as 1, the second highest value as 2 and so on and so forth, and the least value was ranked last. Areal parameters such as form factor, circulatory ratio, and elongation ratio have an inverse relationship with soil erodibility (Uniyal and Gupta, 2013), meaning that lower the value, higher the soil erodibility. Thus, the lowest value of shape parameters was ranked as 1, the next lower value as 2 and so on, and the highest value was ranked last.

Table 1: Linear Aspects of Morphometric Parameters.

Morphometric Parameter	Method	Reference
Stream order (U)	Hierarchical rank	Strahler (1957)
Stream number (Nu)	$Nu = N1+N2+....Nn$	Horton (1945)
Stream length (Lu)	$Lu = L1+L2 ....+ Ln$	Horton (1945)
Mean stream length (Lum)	$Lum = Lu/Nu$	Strahler (1957)
Stream length ratio (RL)	$Rl = Lu/Lu - 1$	Horton (1945)
Stream frequency (Fs)	$Fs = Nu/A$	Horton (1932)
Drainage density (Dd)	$Dd = Lu/A$	Horton (1932)
Drainage texture (DT)	$DT = Nu/P$	Horton (1932)
Drainage intensity (Id)	$Id = Fs/Dd$	Faniran (1968)
Bifurcation ratio (Rb)	$Rb = Nu/Nu + 1$	Schumm (1956)

Table 2: Areal Aspects of Morphometric Parameters.

Morphometric Parameter	Method	Reference
Area in km^2 (A)	Arc GIS tools for area calculation	Schumm (1956)
Perimeter in km (P)	Arc GIS tools for perimeter calculation	Schumm (1956)
Length of the basin in km (Lb)	Arc GIS tools for length calculation	Schumm (1956)
Circulatory ratio (Rc)	$Rc = 4 * \pi * A/P2$	Miller(1953)
Elongation ratio (Re)	$Re = (4*A/\pi)$ 0.5/Lb	Schumm (1956)
Form factor (Ff)	$Ff = A/Lb2$	Horton (1932)

Then the compound values (Cp) were estimated averaging those ranks of each micro-watershed. A micro-watershed with the largest compound value was considered to be of low priority, whereas a watershed with the lowest compound value was considered to be of high priority as explained by Farhan and Anaba (2016). Similarly, all 14 micro-watersheds were broadly classified into three priority zones according to their compound value - High (Cp < 8), Medium (8 ≤ Cp ≤ 10), and Low (Cp > 10).

Paddy land use analysis was carried out using the spatial data gathered by digitizing paddy land uses in topographic map sheets (for 2003) and Google Earth Pro software (for 2012 and 2020) via visual image interpretation techniques such as texture, tone, shape, pattern, size, association, and so on. The accuracy of those data were further cross-checked using Google Street View. Finally, paddy land use changes that occurred during the last three decades were compared with the micro-watershed prioritization results in order to identify and prioritize the sequence in which they must be addressed for soil conservation.

4 Results and Discussion

4.1 Linear Aspects of Morphometric Parameters

4.1.1 Stream Order (U), Number (Nu) and Length (Lu)

The most crucial variables for drainage basin analysis are the number and order of streams (Garde, 2006; Horton, 1945). The identified 14 micro-watersheds of Hungamala Ela sub-watershed is depicted in Fig. 2. Strahler's (1957) classification of streams revealed that the stream network of the Hungamala Ela sub-watershed extends up to the 7th order with a dendritic drainage pattern (Fig. 3).

In the study area, there are 4,088 streams in total, of which 2,818 are of the 1st order, 903 are of the 2nd order, 271 are of the 3rd order, 61 are of the 4th order, 17 are of the 5th, and 5 and 1 are of the 6th and 7th orders, respectively (Table 3). The calculations showed that HE14 has the highest (1928) number of streams while HE3 has the lowest (29). It is also noted that the 1st order streams are most numerous in all micro watersheds, whereas highest order has the fewest. Further, Horton's (1945) and Strahler's (1957) findings were confirmed by the decreasing Nu with the increasing U in the studied 14 micro-watershed. Gregory and Walling (1973) have found that the increasing order of network is associated with greater stream flow values.

The stream length (Lu) is one of the important features of the basin, as it reveals surface runoff characteristics. As reported by Horton (1945), streams of relatively smaller lengths indicate that the area is comprised of high slopes and longer lengths are indicative of flatter gradients. Generally, the total lengths of stream segments are higher in the 1st order streams, and it decreases as the stream order increases (Horton, 1945) and most of the studied micro-watersheds in the study area also show similar patterns (Table 3). The drainage network components and its associated basin surfaces are related to the mean stream length of each order (Lum). Generally, Lum values increase with increasing order (Strahler, 1957) and the studied river network also follows a similar pattern (Table 3).

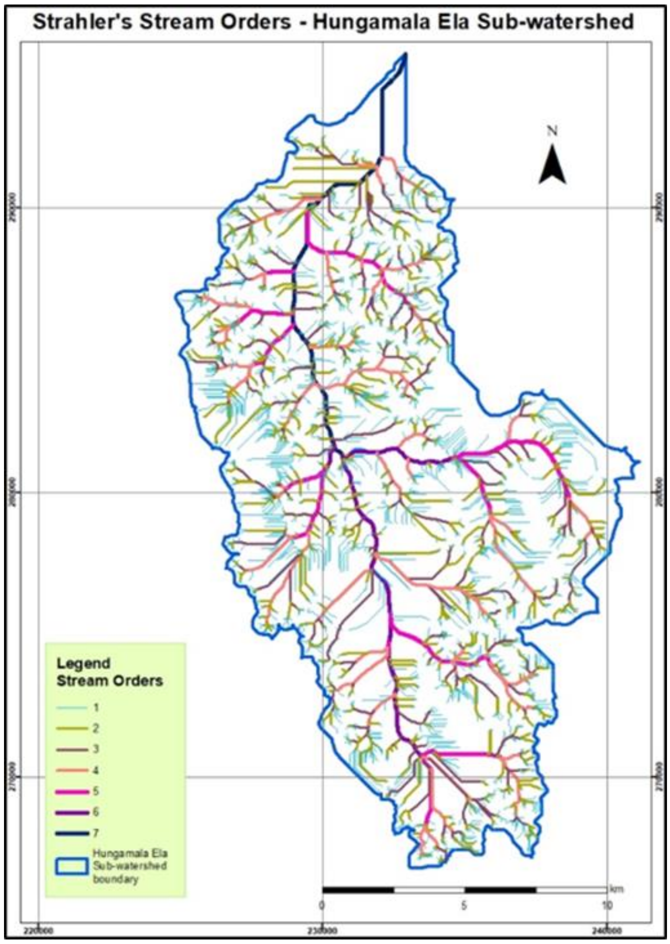

Fig. 3: Strahler's Stream Orders of Hungamala Ela Sub-watershed [Data Source: DEM derived from 20 m contour layer from Survey Department of Sri Lanka].

4.1.2 Bifurcation Ratio (Rb)

The number of streams in any given order (Nu) divided by the number of streams in the subsequent lower orders (Nu+1) is expressed as the bifurcation ratio, a dimensional quantity and generally ranges from 3.0 to 5.0 (Horton, 1945). Typically, smaller values of Rb are indicative of a watershed with fewer structural disturbances and a drainage pattern that has not been altered by structural disturbances (Nag and Chakraborty, 2003). Higher Rb basins have longer and lower peak flows, which reduces the risk of floods inside the basins (Chorley et al., 1957). As revealed by Table 4, the mean Rb value in this study ranges from 1.75 (HE3) to 4.65. (HE11). Higher mean Rb values indicate structurally damaged watersheds with pronounced drainage pattern distortion (Nag, 1998).

4.1.3 Stream Frequency (Fs)

Stream frequency (Fs) is the total number of stream segments of all orders per unit area (Horton, 1932). Fs is related to permeability, infiltration capacity and relief of watersheds (Montgomery and Dietrich, 1989), where high stream frequency are indicative of high relief and low infiltration capacity of the bedrock, pointing towards the increase in stream population with respect to an increase in drainage density. The watersheds having a large area under dense forest have low stream frequency and the area having more agricultural lands have high stream frequency (Uniyal and Gupta, 2013). The higher values of Fs produce more runoff compared to others. In this study area, Fs is maximum in micro-watershed HE6 (27.13 km/km^2) and minimum in HE1 (7.90 km/km^2) (Table 4). HE6 may require comparatively more bank stabilization than HE1.

4.1.4 Drainage Density (Dd)

Drainage density (Dd) is the total length of streams in a unit area of the watershed (Horton, 1932). As shown in Table 4, the highest Dd value was noted in HE12 (6.44 km/km^2) and the lowest in HE1 (2.43 km/km^2).

Table 3: Order-wise Stream Number (Nu) and Stream Length (Lu).

Micro-watershed	U	1st Order	2nd Order	3rd Order	4th Order	5th Order	6th Order	7th Order	Total Nu	Total Lu (km)
HE1	Nu	46	14	3	2	-	-	1	66	-
	Lu (km)	10.12	2.19	1.92	2.1	-	-	3.95	-	20.28
HE2	Nu	25	8	2	1	-	-	1	37	-
	Lu (km)	3.7	7.11	1.86	0.67	-	-	0.47	-	13.81
HE3	Nu	18	6	2	2	-	-	1	29	-
	Lu (km)	3.43	0.42	1.75	0.76	-	-	0.36	-	6.72
HE4	Nu	71	23	6	1	-	-	1	102	
	Lu (km)	10.99	11.26	5.64	0.61	-	-	1.97	-	30.47
HE5	Nu	83	24	5	1	-	-	1	114	-
	Lu (km)	15.13	7.99	3.31	2.73	-	-	0.74	-	29.9
HE6	Nu	113	34	8	3	1	-	1	160	-
	Lu (km)	17.34	4.77	2.39	3.37	2.48	-	0.4	-	30.75
HE7	Nu	113	34	8	3	1	-	1	160	-
	Lu (km)	17.34	4.77	2.39	3.37	2.48	-	0.4	-	30.75
HE8	Nu	81	24	5	1	-	-	1	112	-
	Lu (km)	16.13	4.85	1.56	1.74	-	-	1.26	-	25.54
HE9	Nu	347	91	30	7	2	-	1	478	-
	Lu (km)	50.79	19.04	12.85	6.1	6	-	2.26	-	97.04
HE10	Nu	202	62	15	5	-	-	1	285	-
	Lu (km)	31.59	13.92	7.89	5.06	-	-	2.35	-	60.81
HE11	Nu	126	43	26	2	1	1	1	200	-
	Lu (km)	36.72	10.98	5.14	3.06	2.07	0.01	0.98	-	58.96
HE12	Nu	66	21	3	1	-	-	1	92	-
	Lu (km)	21.8	5.92	2.04	2.06	-	-	0.11	-	31.93
HE13	Nu	220	75	20	6	2	1	1	325	-
	Lu (km)	65.92	20.67	11.5	6.71	4.47	1.01	0.5	-	110.78
HE14	Nu	1307	444	138	26	10	3	-	1928	-
	Lu (km)	308.98	112.19	70.78	41.52	18.92	16.07	-	-	568.46

Table 4: Estimated Linear Aspects of Morphometric Parameters of the Study Area.

Micro-watershed	Stream Frequency (Fs)	Drainage Density (Dd)	Drainage Texture (D_T)	Drainage Intensity (Id)	Length of Overland Flow (Lo)	Mean Bifurcation Ratio (Rb)
HE1	7.90	2.43	3.63	3.25	0.21	2.36
HE2	8.20	3.06	3.01	2.68	0.16	2.28
HE3	18.47	4.28	3.43	4.32	0.12	1.75
HE4	16.78	5.01	7.10	3.35	0.10	3.23
HE5	21.07	5.53	9.00	3.81	0.09	3.31
HE6	27.13	4.61	12.00	5.88	0.11	3.74
HE7	25.68	4.94	12.15	5.20	0.10	2.81
HE8	25.45	5.80	10.87	4.39	0.09	3.29
HE9	25.37	5.15	17.45	4.93	0.10	3.28
HE10	20.07	4.28	15.18	4.69	0.12	2.6
HE11	18.80	5.54	10.48	3.39	0.09	4.65
HE12	18.55	6.44	7.77	2.88	0.08	3.29
HE13	15.26	5.20	13.01	2.93	0.10	3
HE14	15.40	4.54	3.39	3.39	0.11	3.82

Uniyal and Gupta (2013) have noted that regions with highly permeable subsurface materials under dense vegetative cover and low relief are associated with low Dd, while regions with weak or impermeable subsurface materials, sparse vegetation, and mountainous relief are associated with high Dd. Dd also depends on the rock type, run-off intensity, soil type, infiltration capacity, and proportion of rocky lands in the watershed.

4.1.5 Drainage Texture (D_T)

Drainage texture (D_T) is defined as the total number of stream segments of all orders divided by the perimeter of the watershed. D_T is one of the important concepts of geomorphology which represents the relative spacing of drainage lines (Horton, 1932). This parameter depends upon various natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and maturity stage of topography. Hence soft or weak rocks not covered by vegetation result a fine texture, whereas massive and resistant rocks result a coarse texture (Smith, 1950). Sparse vegetation of arid climate affects finer textures than the rocks developed in a humid climate. Smith (1950) has also classified the drainage texture into five different textures i.e., very coarse ($D_T < 2$), coarse ($2 < D_T < 4$), moderate ($4 < D_T < 6$), fine ($6 < D_T < 8$) and very fine ($D_T > 8$). According to this classification, HE1, HE2, HE3 and HE14 are categorized as 'coarse' D_T, HE4 and HE12 as 'fine' D_T, and other micro watersheds as 'extremely fine' D_T (Table 4).

4.1.6 Length of Overland Flow (Lo)

One of the most significant independent variables influencing the hydrologic and physiographic development of drainage basins is the length of overland flow (Lo). The average Lo is roughly equal to the reciprocal of drainage density since it is half the average distance between stream channels (Horton, 1945). Lo is higher in semi-arid regions with less vegetation cover, leading to the generation of higher surface flows (Kale and Gupta, 2001). According to Table 4, Lo values of this study range from 0.08 for HE12 to 0.21 for HE1. Low Lo values indicate the presence of vegetation in these micro-watersheds as reported by Withanage et al. (2015).

4.2 Areal Aspects of Morphometric Parameters

The results of the estimated areal aspects, such as form factor (Ff), circularity ratio (Rc) and elongation ratio (Re), are given in Table 5.

Table 5: Estimated Areal Aspects of Morphometric Parameters of the Study Area.

Micro-watershed	Form Factor (Ff)	Circulatory Ratio (Rc)	Elongation Ratio (Re)
HE1	0.34	0.32	0.65
HE2	0.41	0.37	0.72
HE3	0.35	0.28	0.67

HE4	0.42	0.37	0.73
HE5	0.37	0.42	0.69
HE6	0.23	0.43	0.54
HE7	0.28	0.45	0.60
HE8	0.28	0.52	0.59
HE9	0.51	0.32	0.80
HE10	0.72	0.51	0.96
HE11	0.27	0.37	0.58
HE12	0.32	0.44	0.64
HE13	0.42	0.43	0.73
HE14	0.52	0.00	0.81

4.2.1 Form Factor (Ff)

Form factor (Ff) is a dimensionless ratio of basin area (A) to the square of basin length (Lb) (Horton, 1932). The highest Ff value is for HE10 (0.72) and the lowest for HE6 (0.23) in this study area. A higher Ff value implies that the basin is circular, whereas a low value indicates that the basin is extended and that its peak flow would be flatter for a longer period of time. Flood flows of this type of elongated basins are simpler to control than those of circular basins (Withanage et al., 2015).

4.2.2 Circulatory ratio (Rc)

Miller (1953) reported that the circularity ratio (Rc) range from 0.4 to 0.5, designating strongly elongated basins with permeable homogenous geologic materials. When the Rc value is higher, the basin shape is more circular and vice-versa. The Rc is closely related to the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. According to Miller (1953), the elongated basins result a lower discharge of runoff and highly permeable soil conditions. The Rc is useful for determining the risk of flooding, as flooding is more likely to occur at the outlet point during peak hours with a higher value. In the research area, Rc was determined to be between 0 - 0.52 (Table 5), and the mature stage of topography is indicated by the high value.

4.2.3 Elongation ratio (Re)

It is the ratio of the drainage basin's greatest length to the diameter of a circle with the same area. It is a very important parameter in basin shape analysis that provides insight into the hydrological setup of a drainage basin (Uniyal and Gupta, 2013). The range of 0.54 - 0.96 for the Re in the research area denotes significant relief and a steep ground slope. Strahler (1957) states that Re would be between 0.6 and 1.0 over a wide variety of climatic and geologic types and has further classified the basins with the help of the Re as circular (0.9 < Re < 0.10), oval (0.8 < Re < 0.9), less elongated (0.7 < Re < 0.8), elongated (0.5 < Re < 0.7), and more elongated (Re <0.5). The micro-watersheds within the study area are also in the range of 0.54-0.96 (Table 5) and thus, the findings of this study satisfy Strahler's (1957) findings.

4.3 Results of Watershed Prioritization for Management

The calculated Cp values of all 14 micro watersheds of Hungamala Ela watershed and the prioritization rating are shown in Table 6. Watersheds with the highest Cps imply lower priority while those with the lowest Cps imply high priority (Uniyal and Gupta, 2013). Watersheds resulting high priority are under very severe susceptibility to erosion. Thus, they need immediate attention to take up mechanical soil conservation measures, gully control structures and grass waterways to protect the topsoil loss (Biswas et al., 1999). Watersheds resulting low priority have a very low susceptibility to erosion and agronomical measures will be sufficient to protect the sheet and rill erosion (Uniyal and Gupta, 2013).

In this study, micro-watersheds HE5, HE6, HE7, HE8, HE9 and HE11 could be identified as the high priority level (Table 6) and they need immediate mechanical soil conservation measures. Other micro-watersheds, except HE2, fall under medium category and they need agronomic soil conservation measures. Fig. 4 shows the prioritized micro-watershed map of Hungamala Ela sub-watershed.

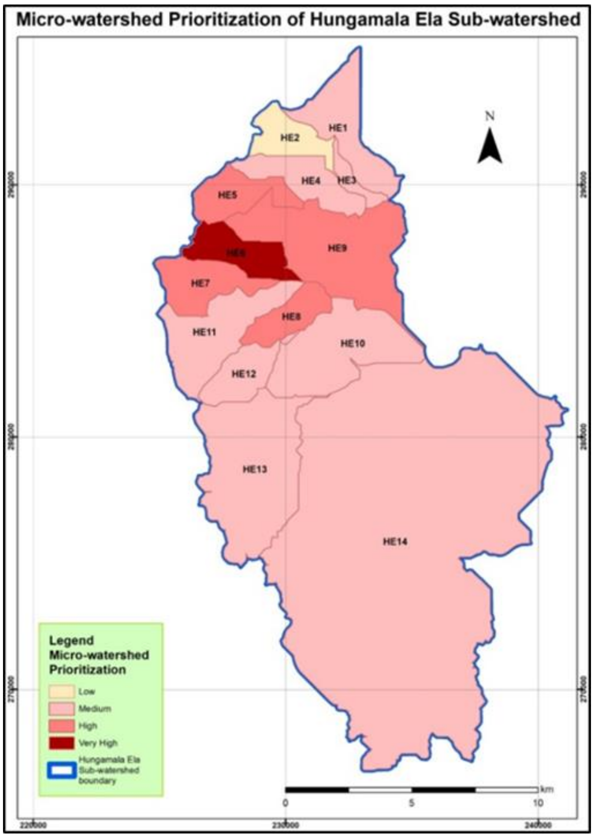

Fig. 4: Micro-watershed Prioritization Map of Hungamala Ela Sub-watershed.

Table 6: Results of Micro-watershed Prioritization from Morphometric Analysis.

Micro-watershed	Fs	D_T	Dd	Id	Lo	Rb	Ff	Rc	Re	Cp	Final Priority
HE1	14	11	14	11	1	12	6	4	6	8.78	Medium
HE2	13	14	13	14	2	13	9	7	9	10.44	Low
HE3	9	12	12	6	3	14	7	2	7	8.00	Medium
HE4	10	10	7	10	8	8	10	6	10	8.78	Medium
HE5	5	8	4	7	11	4	8	8	8	7.00	**High**
HE6	1	5	9	1	6	3	1	9	1	4.00	**High**
HE7	2	4	8	2	7	10	4	12	4	5.89	**High**
HE8	3	6	2	5	13	5	3	14	3	6.00	**High**
HE9	4	1	6	3	9	7	12	3	12	6.33	**High**
HE10	6	2	11	4	4	11	14	13	14	8.78	Medium
HE11	7	7	3	8	12	1	2	5	2	5.22	**High**
HE12	8	9	1	13	14	6	5	11	5	8.00	Medium
HE13	12	3	5	12	10	9	11	10	11	9.22	Medium
HE14	11	13	10	9	5	2	13	1	13	8.56	Medium

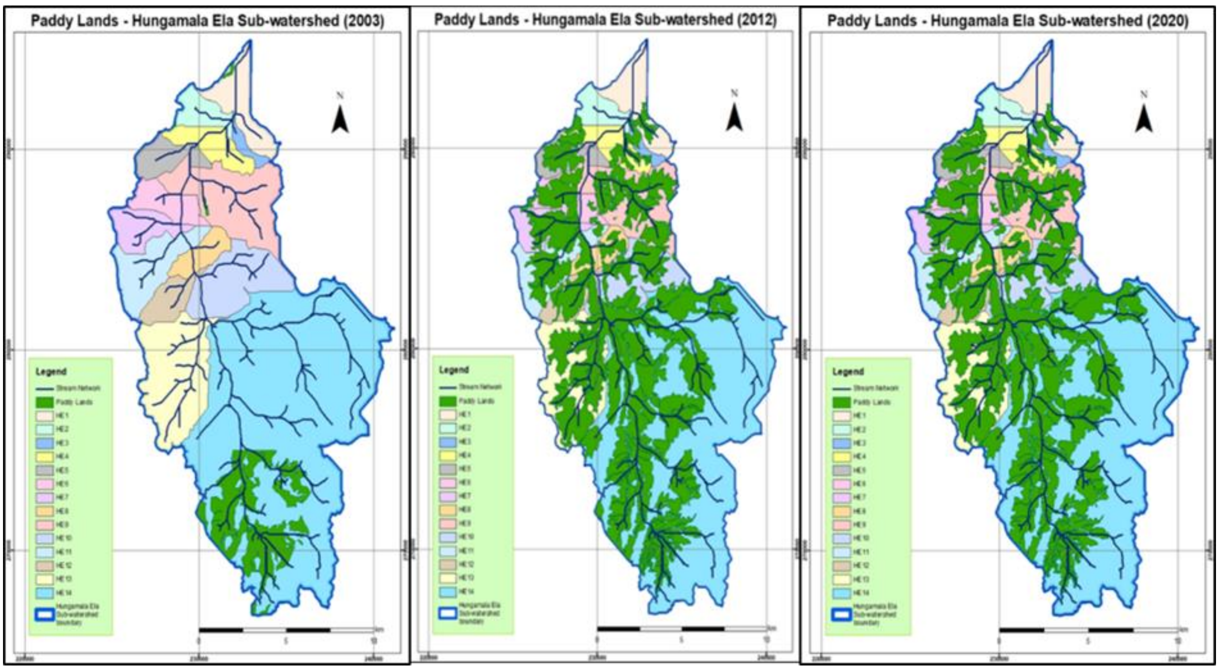

Fig. 5: Paddy land use changes within Hungamala Ela Sub-watershed during 2003-2020.

4.4 Results of Land Use Analysis

Fig. 5 and Table 7 show the results of the paddy land use analysis and it is obvious that during 2003, paddy lands have spread only within HE 1, HE2, HE9 and HE14 micro-watersheds. However, the entire sub-watershed of Hungamala Ela was occupied by paddy cultivations in 2012. There is a significant increase (83%) in paddy land use from 2003 to 2012. This indicates that the natural environment and vegetation cover of Hungamala Ela sub-watershed has been exploited and it may have already further increased the susceptibility to soil erosion in this area during the last three decades. Therefore, authors would like to suggest that a comprehensive field analysis of soil erosion in this sub-watershed area would be helpful to confirm this finding.

Table 7: Land Use Analysis Results of the Study Area.

Micro-watershed	2003	2012	2020	% increase from 2003-2012	% increase from 2012-2020
HE1	0.16	0.94	0.94	83%	0%
HE2	0.02	0.26	0.26	93%	0%
HE3	-	0.47	0.47	100%	0%
HE4	-	2.06	2.06	100%	0%
HE5	-	2.59	2.59	100%	0%
HE6	-	3.15	3.15	100%	0%
HE7	-	3.36	3.36	100%	0%
HE8	-	2.16	2.16	100%	0%
HE9	0.13	10.61	10.61	99%	0%
HE10	-	7.97	7.97	100%	0%
HE11	-	5.58	5.58	100%	0%
HE12	-	3.06	3.06	100%	0%
HE13	-	12.96	12.96	100%	0%
HE14	17.84	49.89	50.14	64%	0%
Total LU Area	18.15	105.06	105.30	83%	0.23%

Moreover, as per the watershed prioritization results (Fig. 4 and Table 6), HE5 to HE9 and HE11 have been identified as the high priority category, and the other 7 as medium category micro-watersheds for soil erosion susceptibility. Only HE2, near the outlet of the sub-watershed, has been identified as a low priority category. Thus, the paddy farming activities in 13 micro-watersheds have already impacted badly on the soil and water resources of this sub-watershed. Therefore, 6 highly sensitive and 7 moderately sensitive micro-watersheds need immediate attention on implementing proper soil and water conservation measures to reduce the susceptibility for potential soil erosion from frequent land preparation activities of paddy cultivation.

Further, soil erosion in these 13 sensitive micro-watersheds would be enhanced due to increasing rainfall intensities that can be resulted from inevitable predicted climate change. As reported by Mamuye and Kebebewu (2018) and Marshall and Randhir (2008), climate change is now universally accepted to be occurring, and more change is unavoidable and it will further affect the timing and magnitude of runoff and sediment yield towards more soil erosion

Therefore, the findings of this study, though they are only model outputs, would elucidate the need of sustainable management plans and policies for soil and water conservation in all the studied 14 micro-watersheds of Hungamala Ela sub-watershed at different priority levels.

5 Conclusion

The study depicts the utility of Remote Sensing and GIS techniques in prioritizing micro-watersheds based on morphometric and land use analysis which could be valuable for planning sustainable development and management practices in Hungamala Ela sub-watershed.

The results of morphometric analysis revealed that, Hungamala Ela stream network extends up to the 7th order according to the Strahler's (1957) classification, showing a dendritic drainage pattern. Drainage density varies from 2.43 km/km^2 – 6.44 km/km^2, resulting in coarse to very fine drainage texture. Mean bifurcation ratio varies from 1.75 to 4.65 and the higher values clearly represent the structural control on the drainage pattern. Form factor values are between 0.23 (HE6) and 0.72 (HE10), indicating that HE10 is more circular in shape and it would generate a flatter peak flow. Circulatory ratio varies from 0 for HE14 to 0.52 for HE8, with higher values clearly representing the late maturity stage of topography.

The results of watershed prioritization displayed that micro-watersheds HE5, HE6, HE7, HE8, HE9 and HE11 can be identified as high priority, and hence, they are in the severe soil erosion susceptibility area of the studied sub-watershed. HE1, HE3, HE4, HE10, HE12, HE13 and HE14 can be identified as medium priority micro-watersheds with moderate soil erosion susceptibility. Therefore, it can be proposed that these 13 micro-watersheds require immediate attention to proceed with mechanical soil conservation measures to avoid further loss of topsoil and soil erosion that can inevitably occurr with frequent land preparation activities of paddy farming in the Hungamala Ela sub watershed.

Land use analysis results emphasized the urgent need of sustainable management plans and policies for soil and water conservation in the studied 14 micro-watersheds of Hungamala Ela sub-watershed at different priority levels as paddy land uses have already increased from 2003 to 2020 drastically even in the identified very sensitive micro-watersheds.

Finally, it can be concluded that this study provides vital information on watershed management which may be useful for planners and policy makers for planning micro-watershed level soil and water conservation measures in paddy growing Hungamala Ela sub-watershed which nourishes a main branch, Hungamala Ela, of Mahaweli river basin of Sri Lanka. Field verification, planned as the next step of this modeling study, would further strengthen these findings.

Acknowledgement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author Contributions

Conceptualization, methodology, analysis, writing - original draft preparation, N.S.W., and writing - review and editing, G.D.J.M.A. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The authors declare no conflict of interest.

References

Biswas, S., Sudhakar, S., Desai, V., 1999. Prioritisation of subwatersheds based on morphometric analysis of drainage basin: A remote sensing and GIS approach. Journal of the Indian Society of Remote Sensing, 27: 155-166. DOI:https://doi.org/10.1007/BF02991569

Chorley, R. J., Malm, D. E., Pogorzelski, H. A., 1957. A new standard for estimating drainage basin shape. American Journal of Science, 255(2): 138-141.

Clarke, J. I., 1966. Morphometry from maps. Essays in Geomorphology, 252: 235-274.

Faniran, A., 1968. The index of drainage intensity: a provisional new drainage factor. Aust J Sci, 31(9): 326-330.

Farhan, Y., Anaba, O., 2016. A remote sensing and GIS approach for prioritization of Wadi Shueib Mini-Watersheds (Central Jordan) based on morphometric and Soil erosion susceptibility analysis. Journal of Geographic Information System, 8(1): 1-19. DOI:10.4236/jgis.2016.81001

Garde, R. J., 2006. Fluvial Morphology. River Morphology. New Age International (P) Limited, New Delhi, pp. 71-109.

Gov-SL, 2011. Report of the commission of inquiry on Lessons Learnt and Reconciliation. Colombo.

Gregory, K. J., Walling, D. E., 1973. Drainage Basin Form and Process: A Geomorphological Approach. Halsted Press, USA

Horton, R. E., 1932. Drainage-basin Characteristics. Transactions, American Geophysical Union, 13(1): 350-361. DOI:https://doi.org/10.1029/TR013i001p00350

Horton, R. E., 1945. Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. Geological Society of America Bulletin, 56(3): 275-370. DOI:https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2

Javed, A., Khanday, M. Y., Rais, S., 2011. Watershed prioritization using morphometric and land use/land cover parameters: a remote sensing and GIS based approach. Journal of the Geological Society of India, 78: 63-75. DOI:https://doi.org/10.1007/s12594-011-0068-6

Kale, V. S., Gupta, A., 2001. Introduction to Geomorphology. The Orient Blackswan, New Delhi.

Mamuye, M., Kebebewu, Z., 2018. Review on Impacts of Climate Change on Watershed Hydrology. Journal of Environment and Earth Science, 8(1).

mapcarta, 2022. https://mapcarta.com/. [Accessed on: 12 May 2022].

Marshall, E., Randhir, T., 2008. Effect of climate change on watershed system: a regional analysis. Climatic Change, 89: 263-280. DOI:https://doi.org/10.1007/s10584-007-9389-2

Miller, V. C., 1953. A Quantitative Geomorphic Study of Drainage Basin Characteristics in the Clinch Mountain Area, Virginia and Tennessee. Technical Report 3. Columbia University New York.

Montgomery, D. R., Dietrich, W. E., 1989. Geographic Information System – Based Morphometric Analysis of Bharathapuzha River Basin, Kerala, India. Applied Water Science, 25(3): 1907 – 1918.

Nag, S. K., 1998. Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Purulia district, West Bengal. Journal of the Indian Society of Remote Sensing, 26: 69-76. DOI:https://doi.org/10.1007/BF03007341

Nag, S. K., Chakraborty, S., 2003. Influence of rock types and structures in the development of drainage network in hard rock area. Journal of the Indian Society of Remote Sensing, 31: 25-35. DOI:https://doi.org/10.1007/BF03030749

Nissanka, S. P., Punyawardena, B. V. R., Premalal, K. H. M. S., Thattil, R. O., 2011. Recent trends in annual and growing seasons' rainfall of Sri Lanka. Proceedings of the International Conference on the Impact of Climate Change in Agriculture, Faculty of Agriculture, University of Ruhuna, Mapalana, Sri Lanka, pp. 249-263.

Nooka Ratnam, K., Srivastava, Y. K., Venkateswara Rao, V., Amminedu, E., Murthy, K. S. R., 2005. Check dam positioning by prioritization of micro-watersheds using SYI model and morphometric analysis—remote sensing and GIS perspective. Journal of the Indian Society of Remote Sensing, 33: 25-38. DOI:https://doi.org/10.1007/BF02989988

Schumm, S. A., 1956. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jersey. Geological Society of America Bulletin, 67(5): 597-646. DOI:https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2

SD-SL, 2007. National Atlas of Sri Lanka. Survey Department of Sri Lanka, Sri Lanka.

Smith, K. G., 1950. Standards for grading texture of erosional topography. American Journal of Science, 248(9): 655-668.

Strahler, A. N., 1957. Quantitative analysis of watershed geomorphology. Eos, Transactions American Geophysical Union, 38(6): 913-920. DOI:https://doi.org/10.1029/TR038i006p00913

Uniyal, S., Gupta, P., 2013. Prioritization based on morphometric analysis of Bhilangana watershed using spatial technology. International Journal of Remote Sensing and Geoscience, 2(1): 49-52.

Withanage, N. S., Dayawansa, N. D. K., De Silva, R. P., 2015. Morphometric analysis of the Gal Oya River Basin using spatial data derived from GIS. Tropical Agricultural Research, 26(1): 175-188.