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GIS and RS Based Soil Erosion Modelling in Sri Lanka: A Review

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ABSTRACT

Purpose : *Over the seventy years, various soil erosion modeling methods were developed in the world with different input requirements and complexity. Some of these soil erosion models have been applied in Sri Lanka covering several regions of the country at different scenarios over the past twenty years. Thus, the prime objective of this study is to compare commonly practiced GIS/ RS based soil erosion assessment models and derivation techniques of model parameters used in Sri Lanka.*

Research Method : *Scholarly research articles, conference proceeding papers, and previously published literature on GIS/ RS based soil erosion models over the past twenty years were critically reviewed, examined, and compared to find various methodologies in the derivation of soil erosion model parameters, analysis methods, and applications with special reference to Sri Lanka.*

Findings : *The results revealed that, in each case, the empirical soil erosion models have been applied to predict soil erosion rates in terms of rill and sheet erosion excluding gully erosion. Furthermore, soil loss at the catchment or entire country scale has been assessed in each case by using different derivation methods. The assessed soil erosion model parameters are R factor (rainfall erosivity), K factor (soil erodibility), LS factor (slope gradient), C factor (crop management factor), and P factor (support practice factor).*

Originality/ Value : *Different derivation methods of soil erosion model parameters (R, K, LS, C, and P) were critically evaluated in order to find the most appropriate methods that can be applied in Sri Lanka in future research studies.*

Keywords: *GIS, InVEST-SR/SDR, Remote sensing, RUSLE, Soil erosion models, USLE*

INTRODUCTION

Soil erosion can be simply defined as a naturally occurring process of the removal and transportation of topsoil due to erosive agents *viz*. water, wind, and gravity (Gunawan *et al.*, 2013) while the soil erosion has been accelerated by human-induced activities *viz*. intensive agricultural practices, urbanization, and improper land management practices (Hewawasam, 2010; Udayakumara *et al.*, 2010; Udayakuamara and Gunawardena, 2016). This soil erosion process consists of three steps as soil loosening, transport, and deposition (FAO, 2015) and in the phenomenon of soil erosion, individual soil particles are removed and transported from its original place to downstream by detaching from the topsoil layer. As the ultimate result of this process, the rich nutrient and carbon-containing topsoil are transported into drainage channels and eroded materials are accumulated in drainage channels (Shi *et al.*, 2012; Issaka and Ashraf, 2017). These undesirable consequences of soil erosion lead to degrading agricultural lands and natural environments rapidly (Shougang and Ruishe, 2014). Thus, soil erosion is listed and classified as a severe environmental issue that

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the world is facing (Panditharathne *et al*., 2019). As explained by Castro Filho *et al*. (2001), loss of soil due to erosion is found to be the main causative factor of land degradation in the world while 85% of land degradation is occurred due to the erosion process which reduced arable lands up to 17% (Singh and Panda, 2017; Wijesundara *et al*., 2018). This results in increasing the expenses for fertilizers and ultimately lands are abandoned (Singh and Panda, 2017) due to nutrient loss of arable lands, increasing the runoff by exposed impermeable soil and reducing the retained water availability (Ganasri and Ramesh, 2016). Moreover, Soil erosion paves the way to loss of esthetic values of the natural environment (Panditharathne *et al*., 2019) and habitat losses take place due to soil erosion while habitat loss is considered as one of the most prominent causes of biodiversity degradation (Dissanayake *et al*., 2019). Furthermore, as explained by Jayasekara and Kadupitiya (2018), due to the existence of long term soil erosion in drainage basins, the water storage capacity of reservoirs also gets reduced due to the delivery of sediments into reservoirs. Thus, it is clear that soil erosion has not only caused environmental and agricultural related problems but also negatively affected the global socio-economic and global sustainable development (Udayakumara *et al.,* 2012; Han *et al*., 2016).

According to the previous scientific findings, major regulatory factors of soil erosion have been experimentally identified as R factor, K factor, LS factor, C factor, and P factor (Smith, 1999). Out of these major driving factors of soil erosion, Phai *et al*. (2007) has scientifically proven that the most significant factor that contributes to soil erosion is the R factor. Nonetheless, soil erosion is a natural phenomenon, this process has been hastened by anthropogenic activities *viz.* intensive agriculture, using steep slopes for agricultural activities, improper land management practices, and deforestation (Wickramasinghe, 1988; Nayakekorala, 1998; Wijesekera and Chandrasena, 2001; Jayarathne *et al*., 2010). Furthermore, clearance of primary forest cover, mining, urbanization, and improper construction activities are major human-based causative practices that accelerate the natural soil erosion rates (Pimentel *et al*., 1987; Udayakumara *et al.,* 2012; Diyabalanage *et al*., 2017; Cheng *et al*., 2018). In Sri Lankan highlands, it has been quantified that the natural erosion rate has increased by a factor of up 100 due to these human-based activities (Hewawasam *et al.,* 2003; Hewawasam, 2010). Thus, before going to soil conservation strategies, accurate and timely evaluation and assessment of soil erosion rates should be carried out referring to the acceptable/permissible soil loss tolerance limits (T values). T value denotes the amount of soil loss that is less than or equal to the rate of formation of soil and it is a basis for judging whether the soil has a potential risk of erosion (Li *et al.,* 2009). Also, it is necessary to have knowledge of terrain, cropping system, and soil management practices (Jahun *et al*., 2015). Because of that, researchers from all around the world have been carrying out soil erosion related research studies to understand the mechanisms and rates of soil erosion (Onyando *et al*., 2005; Bhattarai and Dutta, 2007; Jaramillo, 2007; Anejionu *et al*., 2013; Gunawan *et al*., 2013; Balasubramani *et al*., 2015; Biswas and Pani, 2015; Devatha *et al*., 2015; Ganasri and Ramesh, 2016; Wijesundara *et al*., 2018; Dias *et al*., 2019; Fayas *et al*., 2019).

As explained by Zachar (2008), the soil erosion rates can be determined either by conventional field-based direct methods (using leveling, volumetric, pedological, morphometric, photogrammetric, and vegetation techniques) or indirectly by analyzing the constituents of removed soil *viz.* deluates, deflates, etc. When compared with conventional soil erosion assessing methods, soil erosion modeling is the most convenient and reliable tool for soil erosion assessments that permits the suitable selection of soil erosion control measures (Moehansyah *et al*., 2004). One of the main reasons for soil erosion modeling as so widely used throughout the world is certainly its high degree of flexibility and data accessibility, a parsimonious parameterization, extensive scientific literature, and comparability of results allowing to adapt the model to nearly every kind of conditions and regions (Allewel *et al.,* 2019). Concentrating on the most broadly applied soil erosion models, Universal Soil Loss Equation (USLE) and its derivative models are the most prominent soil erosion models that have been applied all over the world in different scenarios (Igwe *et al*., 2017). In Sri Lanka, several research studies have been carried out in order to predict the soil erosion rates based on GIS and RS modeling and shown that soil erosion has emerged as one of the most severe environmental issues in Sri Lankan highlands (Wickramasinghe 1988; Nayakekorala 1998; Wijesekera and Chandrasena 2001; Wijesekera and Samarakoon, 2001; Hewawasam *et al.,* 2003; Jayarathne *et al.,* 2010; Hewawasam, 2010).

Moreover, in Sri Lanka, the previous researchers have used various derivation techniques for model parameters of USLE (Universal Soil Loss Equation), RUSLE (Revised Universal Soil Loss Equation), and InVEST-SR/SDR (Integrated Valuation of Ecosystem Services and Tradeoffs – Sediment Retention/ Sediment Delivery Ratio) model. Thus, the prime objective of this study is to compare commonly practiced GIS/ RS based soil erosion assessment models and derivation techniques of model parameters used in Sri Lanka.

Introduction to Soil Erosion Models

The assessment and prediction of soil erosion have been a challenge for a long time (Udayakumara, 2010) due to the fact that field-based conventional soil erosion assessing methods are labour intensive and time-consuming (Devatha *et al.,* 2015). Thus, several soil erosion models have been developed since the 1930s (Lal, 2001; Laflen and Flanagan, 2013) that can be classified into empirical models, physically-based models, and conceptual models (Devatha *et al.,* 2015). Presently, the USLE by Wischmeier and Smith (1965), and the RUSLE by Renard *et al*. (1991) are the most widely used soil erosion models. Soil erosion modeling guides comprehensive control of the soil erosion process by estimating soil erosion rates and sediment yields quantitatively and consistently (Igwe *et al*., 2017). The application of such soil erosion models mainly relies on climate variability, soil variability, land-use type, topography, and land management (C and P factors) of the study area, and those wide ranges of soil erosion models vary in their data requirement, complexity, and validation methods (Merritt *et al*., 2003; Anejionu *et al*., 2013). Soil erosion modeling plays an important role in estimating potential soil loss, sediment export, and sediment retention and future scenario analysis of various types of land use classes in order to plan future land management strategies and to monitor government policies on land management practices (Smith, 1999). All the developed soil erosion modeling techniques have been categorized into three model classes as empirical models, conceptual models, and physically-based erosion models (Devatha *et al*., 2015). Out of those three model classes, Empirical models are mathematically and practically the simplest models that can be applied in conditions with limited data availability (Igwe *et al*., 2017). Empirical models have limitations of applicability to regions and ecological conditions other than from which data were used in their development (Merritt *et al.,* 2003). According to Smith (1999), the disadvantages of Empirical models are that they: (1) are based on a statistical analysis of important factors in the soil erosion process and yield only approximate and probable outcome; (2) are not practical for the prediction of soil loss on an event basis; (3) estimate soil erosion on a single slope, instead of within catchments; (4) do not represent the process of sedimentation; (5) are restricted to the sheet and/ or rill erosion; and (6) soil losses and gains over neighbouring areas are not considered (Igwe *et al*., 2017). In empirical models mostly field-based data is utilized and as explained by Parveen and Kumar (2012), USLE (Universal soil loss equation), RUSLE (Revised universal soil loss equation) and MUSLE (Modified universal soil loss equation) are some prominent examples for empirical soil erosion models. Physically-based models are responsible for modeling the sediment exports and sediment retention in the specific study area and it has the capability to recognize the temporal and spatial variabilities of sediment export and retention processes (Chandramohan *et al*., 2015). Physically-based models provide an understanding of fundamental sediment producing processes and have the capability to access the spatial and temporal variations of sediment entrainment, transport, and deposition processes (Chandramohan *et al.,* 2015). They described processes involved with the help of mathematical equations dealing with the laws of conservation of energy and mass

(Morgan, 2005). WEPP (Water erosion prediction project) is one of the most prominent example for physically-based models. In conceptual models, the soil erosion process is conceptualized using soil erosion parameter inputs *viz.* rainfall-runoff erosivity, soil erodibility, and sediment retention is considered as model output (Chandramohan *et al*., 2015). AGNPS (Agricultural non-point source pollution) is an important example of a conceptual soil erosion model that was developed to assess potential soil erosion in agricultural watersheds (Lee and Lee, 2006; Jaramillo, 2007). Furthermore, as explained by Anejionu *et al*. (2013), other numerous erosion models *viz.* CORINE (Coordination of information on the environment), KINEROS (Kinematic runoff and erosion model), EPM (Erosion potential model), PESERA (Pan-European soil erosion risk assessment), and SLEMSA (Soil Loss Estimation model of Southern Africa), have been developed under different methodologies (Smith, 1999). Moreover, as explained by Jaramillo, (2007) and Merritt *et al*. (2003), ANSWERS (Areal nonpoint source watershed environment response simulation), CREAMS (Chemicals runoff and erosion from agricultural management systems), and MMF (Morgan, Morgan and Finney model) are the other widely applied soil erosion models in the world.

Application of USLE, RUSLE and InVEST-SR/SDR Model in Sri Lanka

USLE, RUSLE, and RUSLE based InVEST-SR/SDR model are the most prominent soil erosion models that have been applied in Sri Lanka. Table 01 shows the details *viz.* scale of application, study area, and objectives of each study. According to the Sri Lankan context, ~50% of the studies have used RUSLE for the soil erosion modeling while ~29% and ~21% of the studies have used USLE and InVEST-SR/SDR models respectively. Furthermore, ~65% of the studies have been carried out in catchment or sub-catchment scale whereas ~35% of studies have been applied in Divisional Secretariat Division, Provincial, and entire country scale. Moreover, as shown in Table 01, the prime aim of each study is to predict soil erosion hazards of the area of interest while each study consists of secondary objectives.

Table 01: Soil erosion modelling studies applied in Sri Lanka with their model type, scale, geographical location and objectives.

S/N	Authors	Model Applied	Scale	Location	Objectives
01	(Wijesekara and Samarakoon, 2001)	USLE	Catchment	A catchment of Kegalle District	To extract soil erosion parameters and to model soil erosion using GIS in a grid environment
02	(Senanayake *et al.,* 2013)	USLE	Province	Uva Province	To prepare soil erosion hazard map for Uva province To prepare regional crop suitability map for Uva province
03	(Jayarathne *et al.,* 2010)	USLE	Divisional Secretariat	Kandeketiya Divisional Secretariat	To develop a model for predicting land degradation using USLE together with some socio-economic factors
04	(Senanayake *et al.,* 2020)	RUSLE	Province	Sabaragamuwa Province	To identify the vulnerable landscape areas using landslide frequency ratio and land-use change associated soil erosion hazard
05	(Dissanayake *et al.,* 2019)	RUSLE	Catchment	Kotmale Catchment	To assess the annual soil loss in Kotmale catchment To identify conservation priority areas by using hot and cold spot analysis

06	(Panditharathne *et al.,* 2019)	RUSLE	Catchment	Kalu Ganga River Basin	To estimate the mean annual soil loss in Kalu Ganga river basin
07	(Wijesundara et *al.,* 2018)	RUSLE	Catchment	Kirindi Oya River Basin	To prepare soil erosion hazard map to prioritize soil conservation areain Kirindi Oya river basin
08	(Lekamge *et al.,* 2018)	RUSLE	Sub-Catchment	Kalu Oya and Mudun Ela in Gampaha District	To assess the vulnerability to soil erosion in Kalu Oya and Mudun Ela.
09	(Fayas *et al.,* 2019)	RUSLE	Catchment	Kelani River Basin	To assess the annual soil loss in Kelani river basin To identify soil conservation prioritized areas in Kelani river basin
10	(Thuraisingham and Weerasinghe, 2009)	RUSLE	Catchment	Bibili Oya River Basin	To calculate average annual sediment yield using sediment delivery ratio and average annual soil loss To prepare soil erosion hazard map for Bibili Oya river basin
11	(Piyathilake *et al.,* 2020)	InVEST-SR/SDR with RUSLE	Province	Uva Province	To model predictive assessment of soil erosion related hazards at the Uva province in Sri Lanka
12	(Jayasekara and Kadupitiya, 2018)	InVEST-SR/SDR with RUSLE	Country	Sri Lanka	To construct the map of soil erosion hazard zones of Sri Lanka
13	(Dias *et al.,* 2019)	InVEST-SR/SDR with RUSLE	Sub-catchment	Uma Oya Sub-catchment	To assess average annual soil erosion rate in Uma Oya sub-catchment
14	(Udayakumara and Gunawardena, 2016)	InVEST-SR/SDR with RUSLE	Sub-catchment	Uma Oya Sub-catchment	To assess sediment retention in Uma oya sub-catchment

Derivation of Rainfall Runoff Erosivity Factor (R)

R factor (MJ mm (ha hr)$^{-1}$) directly quantifies the impact of rainfall intensity and the mean annual rainfall on soil erosion and it reflects the capability of rainfall to force the soil erosion process with the time (Renard *et al*., 1997). R factor is the most important parameter in erosion estimation as suggested by several researchers and its correlation with soil loss is high in many regions in the world (Breiby, 2006; Anejionu *et al*., 2013; Balasubramani *et al*., 2015; Devatha *et al*., 2015). In order to calculate R factor, different methods and equations have been used worldwide concerning the suitability of the methodologies to the area of interest (Igwe *et al*., 2017) and as explained in Table 02, three types of equations have been used in Sri Lanka to calculate R factor. In soil erosion modeling studies of Sri Lanka, ~76% of cases, R factor values have been calculated using the mean annual rainfall values with the correlation developed for Sri Lanka by Wickramasinghe and Premalal (1988) whereas ~15% and ~8% of the studies in Sri Lanka have used Roose equation (Roose, 1996) and K.E. > 25 Index method respectively. The soil erosion modeling study that has been conducted in the Uva province, Sri Lanka by Senanayake *et al*. (2013) is the only study that has used K.E. > 25 Index method to determine R factor, and this method was presented by Wischmeier and Smith, (1965). According to Wischmeier and Smith (1965), the best soil erosion estimation can be achieved by using K.E. > 25 method. The theory behind this method is when all other parameters are constant, the R factor is directly proportional to the product of the kinetic energy of the rainfall (E) and its maximum 30-minute rainfall intensity (I) which is obtained by converting the rainfall data (mm) into mm/hour. This product value is denoted as the IE_{30} index and this index is continuously utilized to compute monthly and annual rainfall erosivity values. K.E. > 25 method is more advantageous than the other two methods, since it derives considering many records less than 25 mm/hour, and uses a lesser amount of rainfall data (Hudson, 1971). But, the major limitation of the EI_{30} index method is that it has been introduced under USA conditions and is not found appropriate for the Asian regions to estimate the R factor (Hudson, 1971). The studies carried out by Dias *et al*. (2019) and Udayakumara and Gunawardena, (2016), have used the Roose equation to calculate the R factor and the remaining studies used the regression correlation developed for Sri Lanka. These two methods may be suitable for the Sri Lankan conditions since the constants used in these two equations have been developed under tropical, sub-tropical, and Sri Lankan conditions. Furthermore, studies carried out by Jayarathne *et al*. (2010); Wijesundara *et al*. (2018), and Panditharathne *et al*. (2019) show that one mapping tool of R factor is the Kriging tool in ArcGIS™ and QGIS™ and the other method is Inverse Distance Weighted (IDW) in ArcGIS™ and QGIS™ environment. However, with carrying out of cross-validation, it has been revealed that the IDW method has provided the least error for mapping rainfall variability and R factor over the Kriging method (Panditharathne *et al.,* 2019).

Table 02: Methods used to calculate R factor in GIS and RS based soil erosion modelling studies in Sri Lanka

S/N	Authors	Method Used to Calculate R Factor	Equation
	(Senanayake *et al.,* 2013)	K.E. > 25 Index method improved with available additional data points	Where, KE is rainfall kinetic energy and I_{30} is the maximum rainfall intensity for a 30-minute period (mm)
	(Piyathilake *et al.,* 2020) (Senanayake *et al.,* 2020) (Dissanayake *et al.,* 2019) (Panditharathne *et al.,* 2019) (Fayas *et al.,* 2019) (Wijesundara *et al.,* 2018) (Jayasekara and Kadupitiya, 2018) (Jayarathne *et al.,* 2010) (Thuraisingham and Weerasinghe, 2009) (Wijesekara and Samarakoon, 2001)	Correlation developed for Sri Lanka using annual rainfall values by Wickramasinghe and Premalal, (1988)	Where, AF is Annual rainfall (mm)
	(Dias *et al.,* 2019) (Udayakumara and Gunawardena, 2016)	Calculated using Roose equation as explained by Roose (1996)	Where, a is constant or 0.3 (standard in tropical mountain areas), AF is annual rainfall (mm)
	(Lekamge *et al.,* 2018)	Not mentioned	Not mentioned

Derivation of Soil Erodibility Factor (K)

K factor (t ha hr (MJ ha mm)$^{-1}$) represents the susceptibility of a given soil type to soil erosion process under the standard unit plot maintained in natural conditions (Sharma, 2010). According to Renard *et al*. (1991), K factor values vary between 0.05 to 0.45 and it directly depends on the existing soil type in the interested study area. Clay soils have the lowest K factor values ranges from 0.05 to 0.15 due to having high resistance to soil detachments while soil containing high fractions of sand and silt show relatively high K factor values that range from 0.25 to 0.45. In order to measure the erodibility factor, Wischmeier and Smith (1978) proposed a simple procedure measuring five soil properties *viz.* percentage of organic matter (OM), sand, silt, structure, and permeability. According to scientists, the best method in deriving these soil properties as input to soil erodibility include field-based soil sampling and testing of the area of interest as employed by Yitayew *et al*. (1999) and then nomography method can be used to derive K factors for each soil type from soil characteristics found by sampling. However, the shortcoming of this method is its time consumption and laborious nature. But, the general trend in the world for determining K factor is to use existing data from previous research studies.

As shown in Table 03, approximately ~85% of the soil erosion modeling studies in Sri Lanka has obtained K factor values for the area of interest from the available literature of previous studies whereas, only Dissanayake *et al*. (2019) and Wijesundara *et al*. (2018) have used nomography to calculate the K factor values based on properties of soil *viz.* percentage of organic matter (OM), sand, silt, structure, and permeability. However, using the field-based data and nomography for the derivation of K values can be more accurate compared to the K values obtained from previously published literature since K values can vary according to the climate conditions and the data from previous experiments show that K is not constant and its variations with seasons (Renard *et al*., 1991). Nevertheless, since Sri Lanka is a tropical country that does not experience seasonal changes, K values mostly remain constant for each soil type inside the country. Thus, K values of above ~85% of studies are more accurate while K values of Dissanayake *et al*. (2019) and Wijesundara *et al*. (2018) are the most accurate according to the explanation by Renard *et al*. (1991).

Table 03: Methods used to calculate K factor in GIS and RS based soil erosion modelling studies in Sri Lanka

S/N	Authors	Method Used to Derive K Factor	References
01	(Wijesekara and Samarakoon, 2001)	From available literature of previous studies	(Joshua, 1977)
02	(Senanayake *et al.,* 2013)	From available literature of previous studies	(Bandara and Somasiri, 1991) (Zijister, 1989)
03	(Jayarathne *et al.,* 2010)	From available literature of previous studies	(Wijesekera and Samarakoon, 2001)
04	(Senanayake *et al.,* 2020)	From available literature of previous studies	(Fayas *et al.,* 2019) (Senanayake *et al.,* 2013) (Wijesekara and Samarakoon, 2001)
05	(Dissanayake *et al.,* 2019)	Nomography is used to compute the values of K based on soil properties	(Wischmeier and Smith, 1978) (Ganasri and Ramesh, 2016) (Mapa *et al.,* 2010)
06	(Panditharathne *et al.,* 2019)	From available literature of previous studies	(Jayarathne *et al.,* 2010) (Wijesundara *et al.,* 2018) (Fayas *et al.,* 2019)

S/N	Authors	Method Used to Derive K Factor	References
07	(Wijesundara *et al.,* 2018)	From available literature and Nomography is used to compute the values of K based on soil properties	(Joshua, 1977) (Wijesekara and Samarakoon, 2002) (Mapa *et al.,* 2010)
08	(Lekamge *et al.,* 2018)	From available literature of previous studies	Not mentioned
09	(Fayas *et al.,* 2019)	From available literature of previous studies	(Joshua, 1977) (Wijesekera and Samarakoon, 2001)
10	(Thuraisingham and Weerasinghe, 2009)	From available literature of previous studies	(Joshua, 1977)
11	(Piyathilake *et al.,* 2020)	From available literature of previous studies	(Fayas *et al.,* 2019) (Hasselo and Sikurajapathy, 1985) (Jayarathne *et al.,* 2010) (Joshua, 1977) (Mapa *et al.*, 2010) (Wijesekara and Samarakoon, 2002) (Wijesundara *et al.*, 2018) (Zijister, 1989)
12	(Jayasekara and Kadupitiya, 2018)	From available literature of previous studies	(Joshua, 1977)
13	(Dias *et al.,* 2019)	From available literature of previous studies	(Weerasinghe *et al.,* 2016)
14	(Udayakumara and Gunawardena, 2016)	From available literature of previous studies	(Hasselo and Sikurajapathy, 1985)

Derivation of Slope Gradient Factor (LS)

The slope gradient factor (LS) represents the collective effect of the slope length (L) and slope steepness (S) on the soil erosion process (Wischmeier and Smith, 1978). Generally, the L and S factor considered together as the slope gradient factor, and both L and S factor values are equal to 1 for the standard unit plot conditions of 9% steepness and 72.6 ft. length (Renard *et al*., 1997). Haan *et al*. (1994), revealed that when the LS factor is increased, a corresponding increase in erosion owing to increased velocity of the water flow can be seen. Thus soil loss increase proportionately with the increase in length and incline of slope and the combined effects of slope length and slope incline gives a good estimate of soil erosion rate (McCool *et al*., 1987).

According to the previous studies of soil erosion modeling in Sri Lanka, in order to calculate the LS factor, manual methods that have been originally proposed by Wischmeier and Smith (1978) and GIS/RS-based calculation methods have been used. According to Table 04, different equations and methodologies have been used to calculate LS factors and in ~85% of the studies, LS factor has been calculated using GIS-based methods while only Jayarathne *et al*. (2010) and Wijesekara and Samarakoon, (2001) have calculated LS factors using manual methods. At the catchment or small scale, this manual derivation methods of LS factors are accurate and manageable whereas it is hardly possible at whole country or large scales in terms of its practicability. Also, another criticism of the manual methods of calculating LS factors is its narrow applicability to complex variable topography (Desmet and Govers, 1996). But, with the improvements in GIS/RS technology, the derivation methods of LS factor have become more significant and this method explicitly accounts for modeling soil erosion over a for more topographically complex landscapes over a large extent (Wilson and Gallant, 2000). Thus, ~85% of the cases in Sri Lankan studies have used GIS/RS based derivation methods of LS factor with the disadvantages *viz.* requirement of high-resolution DEMs for an accurate representation of the topography, cannot capture the convergence and divergence of flow network of a catchment that ultimately drives to accuracy issues as explained by Benavidez *et al*. (2018).

Table 04: Methods used to calculate LS factor in GIS and RS based soil erosion modelling studies in Sri Lanka

S/N	Authors	Method Used to Derive LS Factor
01	(Senanayake *et al.,* 2013)	The LS layer has derived directly from slope and flow accumulation layers, both of which can be computed using the digital elevation model (DEM). $LS = \left(\frac{Flow\ accumulation \times Cell\ size}{22.13}\right)^{0.4} \times Sin\left(\frac{Slope\ angle\ in\ degrees}{0.0896}\right)^{1.3}$
02	(Senanayake *et al.,* 2020)	
03	(Jayarathne *et al.,* 2010)	$L = (\mu/72.6)^m$ Where, μ is slope length and m is a slope dependent parameter. Value for m was taken as 0.3 for slopes less than 5%, 0.6 for slopes greater than 10% and 0.5 for slopes in between
04	(Wijesekara and Samarakoon, 2001)	$S = (0.43 + 0.3s + 0.043s^2)/6.613$ Where, S is the slope gradient in percentage (Wijesekera and Samarakoon, 2001)
05	(Panditharathne *et al.,* 2019)	$L = (\lambda/22.1)^m$ Where, λ is horizontal projected slope length (m) (λ = flow accumulation *cell size), and m is slope length exponent. (Renard *et al.,* 1997) $S = 10.8 sin\theta + 0.03$ for slope percent < 9% $S = 10.8 sin\theta - 0.50$ for slope percent ≥ 9% θ is slope angle in degrees (Wischmeier and Smith, 1978) LS factor has been calculated using flow accumulation and slope gradient. Ultimately, LS map has been prepared by the multiplication of both L and S factors in raster calculator in ArcGIS.
06	(Fayas *et al.,* 2019)	
07	(Wijesundara *et al.,* 2018)	
08	(Thuraisingham and Weerasinghe, 2009)	
09	(Dissanayake *et al.,* 2019)	$LS = \left(\frac{QaM}{22.13}\right)^{y} \times (0.65 + 0.045 \times S_g + 0.65 \times S_g^2)$ Where, Q is the flow accumulation grid, M is the grid size, y is the dimensional exponent and S_g is the angle of the slope. (Balasubramani *et al.*, 2015; Ganasri and Ramesh, 2016; Lu *et al.,* 2004) LS factor has been calculated using flow accumulation and slope gradient. Ultimately, LS map has been prepared by the multiplication of both L and S factors in raster calculator in ArcGIS.

S/N	Authors	Method Used to Derive LS Factor
10	(Piyathilake *et al.,* 2020)	$L = (\lambda/22.1)^m$ Where, λ is horizontal projected slope length (m) (λ = flow accumulation *cell size), and m is slope length exponent. (Renard *et al.,* 1997) $S = 10.8 sin\theta + 0.03$ for slope percent < 9% $S = 10.8 sin\theta - 0.50$ for slope percent ≥ 9% θ is slope angle in degrees (Wischmeier and Smith, 1978) The LS factor is derived from the InVEST-SR/SDR model, both of which can be computed using the digital elevation model (DEM) (Sharp *et al.,* 2018)
11	(Jayasekara and Kadupitiya, 2018)	
12	(Dias *et al.,* 2019)	
13	(Udayakumara and Gunawardena, 2016)	
14	(Lekamge *et al.,* 2018)	Not mentioned

Derivation of Cover Management Factor (C)

The C factor characterizes the effects of land use on soil erosion rates in a standard unit plot at a given time (Jayasekara and Kadupitiya, 2018). C factor values are possibly one of the most important factors since it indicates how soil conservation practices affect the mean annual soil loss rates and how soil erosion potential is distributed over the study area. C factor values generally vary from 0 to 1.5 whereas, 0 or nearly 0 values assigned for the finely protected lands with proper crop management systems and 0 < values assigned for considerably tilled lands that are highly vulnerable to soil erosion (Renard *et al*., 1997). According to the previous studies, two derivation methods of C factor have been presented as (1) Referencing from previously conducted studies for similar land use classes in similar countries or regions. (2) Novel derivation method of C factor using NDVI (Normalized difference vegetation index) with RS and satellite imagery techniques (Benavidez *et al*., 2018).

As shown in Table 05, out of the above mentioned two methodologies, ~93% of the Sri Lankan studies (Piyathilake *et al.,* 2020; Senanayake *et al.,* 2020; Dias *et al*., 2019; Fayas *et al*., 2019; Panditharathne *et al*., 2019; Jayasekara and Kadupitiya, 2018; Lekamge *et al.,* 2018; Jayarathne *et al*., 2010; Thuraisingham and Weerasinghe, 2009; Udayakumara and Gunawardena, 2016; Wijesundara *et al*., 2018; Wijesekara and Samarakoon, 2001) have used previous literature to determine C factor which is the simplest and time-saving method since the NDVI method requires advance RS applications *viz.* satellite imagery, aerial photography, and image processing. According to the Sri Lankan studies, Dissanayake *et al*. (2019) has found to be the only study that has used the NDVI method to determine the C factor by computing the vegetation cover in the area of interest. NDVI is an effective method of investigating surface land use practices and vegetation cover (Ranagalage *et al*., 2018). In Sri Lanka studies, Dissanayake *et al*. (2019) has used the following equation to derive the C factor where, α is equal to 1, β is equal to 2 (Alexakis *et al*., 2013).

$$C = \exp\left[-\alpha \frac{NDVI}{(\beta - NDVI)}\right]$$

Many scientists also have used the NDVI method for the derivation of C factor in the world *viz.* (Prasannakumar *et al*., 2012; Alexakis *et al.,* 2013; Adarsh *et al*., 2016 and Dutta, 2016) and found that this approach is effective and gives accurate C factor values in different scenarios. Although ~93% of studies have incorporate C factor values to model soil erosion using GIS/ RS technologies, Senanayake *et al*. (2013) explains that, since the C factors are highly localized and vary at individual farm level, its effects are scattered and it will not vital to apply C factor for regional-scale studies. Thus, the only land cover factor has been taken into consideration.

Derivation of Support Practice Factor (P)

The P factor reflects the support practices and soil conservation practices *viz.* terracing and contouring that affect the rate of soil erosion through conserving and transforming the flow patterns (Renard *et al*., 1997). According to Bagherzadeh (2014), the P factor ranges from 0 to 1 whereas 0 denotes well-conserved soil with good land management practices that mitigate soil erosion and 1 denotes poor soil conservation practices that allow the soil to lose and export easily. For instance, the P factor of 1 reflects conventional tillage practices in highlands which allow the soil to erode without obstructions while the P factor of 0.25 reflects the soil conservation practice which is capable of reducing the soil loss by 75%. Furthermore, P factors can also be utilized as a direct recognition of how soil conservation practices are effective in land management practices (Benavidez *et al*., 2018).

Table 05: References used for the determination of C factor in GIS and RS based soil erosion modelling studies in Sri Lanka

S/N	Authors	References Used to Determine C Factor
01	(Panditharathne *et al.,* 2019)	(Wijesundara *et al.,* 2018) (Fayas *et al.,* 2019) (Munasinghe *et al.,* 2001) (Biswas and Pani, 2015)
02	(Jayarathne *et al.,* 2010)	Not mentioned
03	(Wijesundara *et al.,* 2018)	(Munasinghe *et al.,* 2001) (Senanayake *et al.,* 2013)
04	(Fayas *et al.,* 2019)	(Munasinghe *et al.*, 2001) (Senanayake *et al.,* 2013) (Wijesundara *et al.,* 2018)
05	(Thuraisingham and Weerasinghe, 2009)	(Wijesekera and Samarakoon, 2001)
06	(Jayasekara and Kadupitiya, 2018)	(Kuok *et al.,* 2013)
07	(Dias *et al.,* 2019)	(Udayakumara and Gunawardena, 2016) (Weerasinghe *et al.,* 2016)
08	(Udayakumara and Gunawardena, 2016)	(Kuok *et al.,* 2013)
09	(Lekamge *et al.,* 2018)	Not mentioned
10	(Piyathilake *et al.,* 2020)	(Biswas and Pani, 2015) (Kuok *et al.,* 2013) (Munasinghe *et al.*, 2001) (Senanayake *et al.,* 2013) (Udayakumara and Gunawardena, 2016) (Weerasinghe *et al.,* 2016) (Wijesekera and Samarakoon, 2001) (Wijesundara *et al.,* 2018)
11	(Wijesekara and Samarakoon, 2001)	Not mentioned
12	(Senanayake *et al.,* 2020)	(Senanayake *et al.,* 2013) (Munasinghe *et al.*, 2001)

Similar to the C factor, P factors can also be obtained referring to previously published literature related to the interested area or region that the study about to be conducted. As explained by Adornado and Yoshida, (2010), some of the soil erosion modeling studies that have been carried out on a large scale omitted including the P factor for the model due to the complexity and diverse nature of soil conservation methods that scattered throughout the large study area. In such cases, scientists have replaced the P factor by the value of 1. This method has been used in the Sri Lankan context by Jayarathne *et al*. (2010) to determine P factors for the area of *Kandeketiya* Divisional Secretariat. Furthermore, one of the most possible reasons for omitting the P factor in some studies is due to some C factor values already describe support practices with their C factor values. For instance, Senanayake *et al*. (2013) has given C factor values concerning land management practices as well and in this case, the P factor is omitted. Moreover, ~86% of Sri Lanka soil erosion modeling studies have used previously published data for obtaining P factor values for each land use and land cover classes (Wijesekara and Samarakoon, 2001; Thuraisingham and Weerasinghe, 2009; Udayakumara and Gunawardena, 2016; Lekamge *et al.,* 2018; Jayasekara and Kadupitiya, 2018; Wijesundara *et al*., 2018; Dias *et al.,* 2019; Fayas *et al*., 2019; Panditharathne *et al*., 2019; Piyathilake *et al.,* 2020; Senanayake *et al.,* 2020).

CONCLUSIONS AND RECOMMENDATIONS

USLE, along with its family of soil erosion models *viz.* RUSLE and RUSLE based InVEST-SR/SDR models are the most extensively applied models in Sri Lanka. Although these models are recommended for small scale spatially distributed catchments, it has been established that these models estimate soil losses and sediment delivery ratios accurately in different geographical scales such as large catchment, divisional secretariat, province, and whole country scales. Previous literature on soil erosion models in Sri Lanka has shown that the different erosion modeling components (R factor, K factor, LS factor, C factor, and P factor) can be derived using many data sources and materials *viz.* DEM data, rainfall data, the spatial distribution of soil types data, and delineated river basin maps and some advance equations in soil erosion studies.

However, this review explains the methodologies that have been used for the derivation of soil erosion model parameters in Sri Lankan studies and it clearly shows the most appropriate derivation methods and equations of five soil erosion model parameters depending on the geographical scale of the study and availability of data adapting to the unique conditions of the study area. Furthermore, this review clarifies how future researchers will be able to select the best method of deriving R, K, LS, C, and P factor overcoming the challenges *viz.* limited data availability and complexity of applying soil erosion models that are associated with running soil erosion models.

The following recommendations are worth mentioning for future soil erosion studies with USLE, RUSLE, and RUSLE based InVEST-SR/SDR models in a GIS/ RS environment:

- Although K.E. > 25 method is a comparatively more advantageous method of deriving K factor compared with other methods, it has been introduced under USA conditions and is not found appropriate for the Asian regions to estimate the R factor. Thus, using the Roose equation and the regression correlation developed for Sri Lanka to calculate the R factor may be the most suitable methods for the Sri Lankan conditions since the constants used in these two equations have been developed under tropical, sub-tropical, and Sri Lankan conditions.
- The method of using Soil Erodibility Nomography based on soil properties (percentage of organic matter (OM), sand, silt, structure, and permeability) is the comparatively more accurate method of deriving K factor in soil erosion modeling.
- At the catchment or small scale, manual derivation methods of LS factors are more accurate and manageable whereas it is hardly possible at large scales or at complex

topographies where GIS-based methods can be recommended.

- Although many studies have used previously published literature to derive C factor, the comparatively more accurate method is to use the NDVI method, since it uses satellite imagery, aerial photography of the exact study area to derive C factor for each land use type.
- Further development of a method to effectively derive P factor is highly required since all the previous soil erosion studies have obtained P factor referring to the previously published literature.
- When we consider soil erosion assessments, R, C, and P factors are more decisive factors of soil erosion in any region as they change during a very short period. Even though, the C and P factors are considered decisive factors of soil loss, while applying proper soil and water conservation measures their impact can be minimized. However, the K and LS factors are not changed during a very short period and they can be considered as less important factors for short term soil erosion predictions.

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