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# GIS-Based Estimation of Soil Loss from Hilly Urban Area Incorporating Hill Cut Factor into RUSLE

**Sagarika Patowary[1] · Arup Kumar Sarma[1]**

**Abstract** Unplanned residential development in hilly areas leads to steep cuts in natural hillslopes, which in turn, results in excessive soil loss. GIS-based Revised Universal Soil Loss Equation (RUSLE), applied in such a case, underestimates soil loss since such near vertical surfaces are not completely projected in orthorectified satellite images. This paper introduces a "hill cut factor $(H_f)$", which is input into the cover management factor of RUSLE model. Model is validated with observed soil loss data of a mini hilly urban watershed located in Japorigog hill of Guwahati city. GIS-based soil loss estimation has been carried out for two scenarios: with and without consideration of $H_f$. Results reveal that consideration of $H_f$ in GIS-based RUSLE replicates the picture of erosion more accurately and gives a similar result with observed soil loss data. Without consideration of $H_f$, RUSLE underestimates annual soil loss from the studied watershed by almost 28% than the observed value. Adequate design of drainage system by using more accurate soil loss information, derived in this way, can lower the urban flood problem caused due to blockage of drains and culverts with sediments brought down from the inhabited hills in a city.

**Keywords** Soil loss · Urban settlement in hill · Hill cut factor · GIS-based RUSLE

## 1 Introduction

Soil erosion is a major global environmental hazard. Surface erosion by water is being exacerbated due to the removal of natural vegetative covers resulted from urban settlements. Consequently, the frequency of urban flash flood hazard increases caused by lowering of

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drainage capacity of flow channels as a result of sedimentation. At the same time, it also increases the maintenance cost of the drainage system (Fernandez et al. 2003). In addition to the deposition of sediment on river banks or into the reservoirs, some percent of sediments carried by rivers are transported to the ocean. Fine sediments are more dangerous for water quality and also to the balance of aquatic ecosystem (Nelson and Booth 2002). In India, 130 million hectares of land i.e. 45% of the total geographical area is having serious soil erosion (Kothyari 1996; Ganasri and Ramesh 2016). Approximately 5334 million tons of soil is detached yearly; of which 29% is transported by rivers into the sea and 10% is settled down in reservoirs reducing the storage capacity (Narayana and Babu 1983). On the other hand, nature requires a period of 200–400 years to form a top-soil layer of 1 cm depth (Singh and Phadke 2006). In case of hills, where steep slopes are naturally more vulnerable to soil erosion, the removal of the natural land surface is adding fuel to the flame. Soil particles from a bare land surface easily get detached when they are stricken by raindrops (Singh and Phadke 2006). Steep slopes provide more speed to runoff which in turn increases the energy of water to detach more soil particles and to carry the sediments with it. All these points exclusively indicate the urgent need for soil loss information such that management plans can be implemented to tackle the constantly increasing soil erosion hazard with the increase of land degradation process in today's world.

Numerous models are available for estimation of soil surface erosion. These models are mainly of two types: physical models and empirical models (Bhattarai and Dutta 2007). WEPP (Nearing et al. 1989), LISEM (De Roo et al. 1996), EUROSEM (Morgan et al. 1998) etc. are some widely used physical models in this case. Though these models are based on real processes, they contain large numbers of input parameters with extensive computation. Also, simulation of these for a specific area requires observed sediment loss data which are not available for ungauged watersheds (Beven 1996; Bhattarai and Dutta 2007). Empirical models are simple to apply and contain fewer numbers of input parameters. Universal Soil Loss Equation (USLE) developed by (Wischmeier and Smith 1961) is one of the most extensively used empirical soil loss estimation models. This is a plot-scale model which considers numbers of factors like topographical condition and soil characteristics of watersheds, local rainfall pattern, land use land cover type or land management practices to calculate long-term average annual rill and inter-rill soil erosion (Smith 1999). Many watershed models like EPIC (Williams et al. 1984), GWLF (Haith and Shoemaker 1987), SWAT (Arnold and Allen 1992), SEDD (Ferro and Porto 2000) estimates soil loss based on USLE. One limitation of USLE is that it is basically applicable to small sized watershed having negligible gully and channel erosion (Simanton et al. 1980). MUSLE (Modified Universal Soil Loss Equation; Williams 1975) and RUSLE (Revised Universal Soil Loss Equation; Renard et al. 1991) are the upgraded version of USLE. Initially USLE model was valid only for cropland having a mild slope. RUSLE resulted from the revised estimation of different input parameters has expanded the area of applicability of USLE to different land use types with a variable range of slopes (Gelagay and Minale 2016). Similarly, MUSLE was improved by substituting the rainfall erosivity factor with runoff factor which makes the soil loss estimation better as runoff depends on both the antecedent moisture content and the rainfall intensity (Zhang et al. 2009). MUSLE can estimate the soil loss resulted from a single event where both RUSLE and USLE estimate the long-term average annual soil loss (Lim et al. 2005).

Use of remote sensing and GIS techniques in USLE/RUSLE model is another milestone in the history of soil loss estimation. Soil loss map derived from GIS-based RUSLE helps in identifying the erosion-prone areas. Researchers from different parts of the world have

extensively used GIS techniques to measure the amount of soil loss from watersheds with the help of USLE/RUSLE (Fistikoglu and Harmancioglu 2002; Pandey et al. 2007; Biswas and Pani 2015; Gelagay and Minale 2016). By using the same techniques, substantial efforts have also been made by researchers on assessment of soil erosion from hilly watershed (Dabral et al. 2008; Chen et al. 2011). Residential development in hills is generally associated with hill cutting by the dwellers, which convert a forested stable slope into a steep unstable bare slope. This is very common in hills located near the plain urban areas since inhabitants of such hilly area are generally not indigenous hill tribes. As these dwellers are habituated with the living in plain areas, they often cut the hill slope steeply to have a more plain area for residential purpose. In orthorectified satellite image or in a topographical map, while plain urban settlements are visible as it is, only the projections (horizontal) of the bare steep hill cuts are visible as bare areas within the urban settlement. As a result, this may lead to an underestimation of total soil loss from urban hilly watersheds when urban landuse data in hills are derived from satellite images or maps. This may also cause misinterpretation of sediment delivery ratio defined as the ratio of sediment yield observed at the watershed outlet to total soil loss from the watershed. Hence, in order to take account of the soil loss occurred from the actual steep hill cut area (instead of only the projected area of steep hill cut), this study introduces a new dimensionless factor called "hill cut factor ($H_f$)", which is incorporated into RUSLE model. The model has been validated with the observed data of soil loss from a mini hilly watershed of Guwahati city, India.

## 2 Methodology

### 2.1 RUSLE

RUSLE uses the same basic equation of USLE consisting of six factors. This is given by,

$$A = R \times K \times LS \times C \times P \tag{1}$$

where, A is the average annual soil loss per unit area (t ha$^{-1}$ year$^{-1}$). R is the rainfall-runoff erosivity factor (MJ mm ha$^{-1}$ h$^{-1}$ year$^{-1}$) representing the eroding capability of rainfall (Renard et al. 1997); K is the soil erodibility factor (ton h MJ$^{-1}$ mm$^{-1}$), defined as the amount of soil loss per unit rainfall eosivity factor from a plot of clean fallow land with a uniform slope of 9% and slope length of 22.1 m (Renard et al. 1997; Brady and Weil 2008); LS is the slope length and slope steepness factor accounting the effect of topography on soil loss (Renard et al. 1997); C is the cover management factor defined as the ratio of soil loss from a plot of land having a particular land cover condition (natural or artificial) to that in continuous tilled fallow condition on the same soil (Renard et al. 1997) and P is the support or conservation practices factor being the ratio of soil loss from a plot of land having a specific soil conservation practice to that from straight row cultivation with up and down slope (Pandey et al. 2007).

### 2.2 Derivation of Hill Cut Factor $H_f$

To derive the mathematical expression of "hill cut factor ($H_f$)", let us consider a rectangular plot of land (it can also be referred as inhabited urban settlement area) of width 'W' and length 'B' in a hilly watershed. Figure 1a shows the schematic diagram of the steep hill cut caused by

urban settlement in a hill. Let 'L' is the height (inclined) of the steep hill cut produced due to the considered plot of land, and 'h' and 'm' be the vertical and horizontal projections of 'L' (Fig. 1b). The average slope (natural) and average hill cut angle of the hilly portion of the watershed are θ and β, respectively. Here, $(W + L) \times B$ is the actual soil loss risk area (caused by the urban settlement area) comprising plot area $(= W \times B)$ and steep hill cut area $(= L \times B)$ (Fig. 1a). In orthorectified satellite images or maps, only the projection of this total urban settlement area (actual soil loss risk area) becomes visible and this projected area is equal to $(W + m) \times B$ (Fig. 1c).
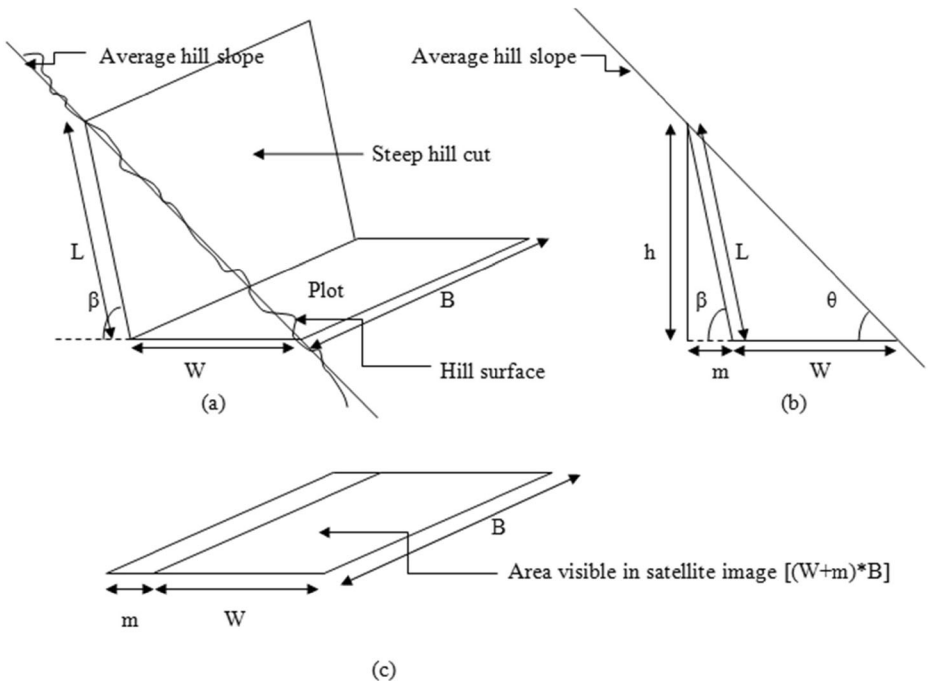
From Fig. 1b,

$$\frac{h}{m} = \tan\beta \Rightarrow m = h \cot \beta \tag{2}$$

Again,

$$\frac{h}{m + W} = \tan\theta \tag{3}$$

Substituting Eq. (2) in Eq. (3),

$$\begin{aligned}
\text{Eq.}(3) &\Rightarrow \frac{h}{h \cot\beta + W} = \tan\theta \\
&\Rightarrow h = h\cot\beta \tan\theta + W \tan\theta \\
&\Rightarrow h (1 - \cot\beta \tan\theta) = W\tan\theta \\
&\Rightarrow h = \frac{W \tan\theta}{1 - \cot\beta \tan\theta}
\end{aligned} \tag{4}$$



Fig. 1 **a** Schematic diagram of steep hill cut caused by urban settlement in hill **b** vertical and horizontal projection of the steep hill cut **c** projected urban settlement area in satellite image

Similarly, $\frac{h}{L} = \sin\beta$

$$\Rightarrow L = h\, \text{cosec}\beta \tag{5}$$

Substituting Eq. (4) in Eq. (5),

$$\text{Eq.}(5) \Rightarrow L = \frac{W\, \tan\theta\, \text{cosec}\beta}{1 - \cot\beta\, \tan\theta} \tag{6}$$

Therefore, steep hill cut area, which is not visible in the satellite image,

$$A_{hc} = B \times L - B \times m$$

Here, $(B \times m)$ is the projected area of the steep hill cut area $(= L \times B)$.

Hence, the hill cut factor $H_f$, which is defined as the ratio of the steep hill cut area, not visible in satellite image to the projected settlement area in satellite image or map, can be expressed as,

$$H_f = \frac{B \times L - B \times m}{(W + m) \times B} = \frac{L - m}{W + m} \tag{7}$$

Substituting Eq. (6) in Eq. (7),

$$
\begin{aligned}
H_f &= \frac{W\, \tan\theta\, \text{cosec}\beta}{1 - \cot\beta\, \tan\theta} \times \frac{1}{m + W} - \frac{m}{m + W} \\
\Rightarrow H_f &= \frac{\sin\theta}{\sin\beta\cos\theta - \cos\beta\sin\theta} \times \frac{W}{m + W} - \frac{m}{m + W}
\end{aligned}
\tag{8}
$$

This $H_f$ is input into the cover management factor of urban settlement and a new cover management factor is obtained, applicable to the urban settlement located in hills only. Due to the inclusion of $H_f$ factor, cover management factor for the urban settlement lying in the hilly portion of the watershed will have a higher value than that for urban settlement, in general, lying in a plain area. Cover management factor for urban settlement in a hill can be expressed as,

$$C_{hu} = C_{add} + C_u$$

where, $C_{add}$ is the cover management factor for hill cut area not visible in satellite image or map, and $C_u$ is the cover management factor for visible urban settlement area of hills in the satellite image. That means the expression of RUSLE for urban settlements located in hills will be,

$$A = R \times K \times LS \times C_{hu} \times P = R \times K \times LS \times (C_{add} + C_u) \times P$$

Additionally, $C_{add}$ depends on the surface condition of the steep hill cuts i.e. whether they are well protected by retaining wall or covered by grass; creeper etc. or they are in bare condition. Hence, $C_{add}$ is given as,

$C_{add} = f$ ($H_f$, Condition of steep hill cuts associated with urban settlements in hills).

The composite value of $C_{add}$ can be written as,

$$C_{add} = \left( \sum_{i=1}^{n} a_i C_i \right) \times H_f \tag{9}$$

where, $i = 1, 2, 3, \ldots\ldots, n$ be types of surface covers.

$a_i$ = Fraction of the total steep hill cut area covered by the $i^{th}$ type of surface cover.

$$\sum_{i=1}^{n} a_i = 1$$

$C_i$ = Cover management factor of the $i^{th}$ type of surface cover.

Substituting the expression of $H_f$ of Eq. (8) in Eq. (9),

$$\text{Eq.}(9) \Rightarrow C_{add} = \left( \sum_{i=1}^{n} a_i C_i \right) \times \left[ \frac{\sin\theta}{\sin\beta\cos\theta - \cos\beta\sin\theta} \times \frac{W}{m+W} - \frac{m}{m+W} \right] \quad (10)$$

Similarly, a composite value is also calculated for the cover management factor ($C_u$) of the urban settlement area visible in the satellite image. Because the projection of the actual soil loss risk area [=(W + m) × B] caused by the urban settlement in hill consists of two types of area:

(1)  Projection of the steep hill cut area = m × B.
(2)  Projection of the inhabited urban settlement area (or, plot area) =W × B.

Now,

$$\frac{\text{Projection of steep hill cut area}}{\text{Visible urban settlement area in image}} = \frac{m \times B}{(W+m) \times B} = \frac{m}{W+m} = \frac{h\cot\beta}{h\cot\theta}$$

$$= \frac{\sin\theta\cos\beta}{\sin\beta\cos\theta} \quad (11)$$

$$\frac{\text{Projection of plot area}}{\text{Visible urban settlement area in image}} = \frac{W \times B}{(W+m) \times B} = \frac{W}{W+m} = \frac{h\cot\theta - h\cot\beta}{h\cot\theta}$$

$$= 1 - \frac{\sin\theta\cos\beta}{\sin\beta\cos\theta} \quad (12)$$

Therefore,

$$C_u = \underbrace{\frac{m}{W+m} \times \left( \sum_{i=1}^{n} a_i C_i \right)}_{\text{For projection of steep hill cut area}} + \underbrace{\frac{W}{W+m} \times C_g}_{\text{For projection of plot area}} \quad (13)$$

where, $C_g$ is the cover management factor for urban settlement located in plain areas. This is also applicable to the inhabited settlement area (or, plot area = W × B) in a hill since before settling in a plot of land, people usually make it plain.

Finally, by adding Eq. (10) and Eq. (13), the cover management factor for urban settlement located in a hill can be expressed as,

$$C_{hu} = \left( \sum_{i=1}^{n} a_i C_i \right) \times \left[ \frac{\sin\theta}{\sin\beta\cos\theta - \cos\beta\sin\theta} \times \frac{W}{m+W} - \frac{m}{m+W} \right] + \frac{m}{W+m}$$

$$\times \left( \sum_{i=1}^{n} a_i C_i \right) + \frac{W}{W+m} \times C_g \quad (14)$$

Substituting the expressions of $\frac{m}{W+m}$ and $\frac{W}{W+m}$, respectively from Eq. (11) and Eq. (12) in Eq. (14),

$$\text{Eq.}(14) \Rightarrow C_{hu} = \left(\sum_{i=1}^{n} a_i C_i\right) \times \left[\frac{\sin\theta}{\sin\beta\cos\theta}\right] + \left(1 - \frac{\sin\theta\cos\beta}{\sin\beta\cos\theta}\right) \times C_g \qquad (15)$$

If the projected area of steep hill cuts is very less in comparison to the visible urban settlement area in satellite image [i.e., if $m \times B \ll (m + W) \times B = > m \ll (m + W)$], the following two simplifications can be made in Eq. (8) and Eq. (13),

(i)　$\frac{m}{m+W} \ll 1$. Hence, $\frac{m}{m+W}$ term can be considered as negligible [=0].
(ii)　$m + W \approx W$ and hence, $\frac{W}{m+W}$ can be taken as 1.

In such a case,

$$\text{Eq.}(8) \Rightarrow H_f = \frac{\sin\theta}{\sin\beta\cos\theta - \cos\beta\sin\theta} \qquad (16)$$

$$\text{Eq.}(13) \Rightarrow C_u = C_g \qquad (17)$$

Hence, for projected area of steep hill cuts being very less in comparison to the visible urban settlement area in the satellite image, the cover management factor for urban settlement in a hill can be expressed in the following simplified form.

$$C_{hu} = C_{add} + C_u = \left(\sum_{i=1}^{n} a_i C_i\right) \times H_f + C_g \qquad (19)$$
$$= \left(\sum_{i=1}^{n} a_i C_i\right) \times \frac{\sin\theta}{\sin\beta\cos\theta - \cos\beta\sin\theta} + C_g$$

## 3 Model Validation

Guwahati is the fastest developing urban centre in Northeast India. It is experiencing high sediment loss, beyond its estimated value, because of unplanned residential development in its hilly terrain (Sarma et al. 2013; Sarma et al. 2015). Blockage of drains and culverts due to sediment, brought down from the inhabited hills are exacerbating the urban flash flood problem of Guwahati city (Desai et al. 2014). Hence, hilly watersheds of Guwahati city can be considered as an ideal case-study area in this context. However, observed soil loss data from hilly watersheds of Guwahati city is very scarce. Sarma et al. (2005) observed soil loss at the outlet of a mini-watershed, located in Japorigog hill of Guwahati city for the period from June 2003 to May 2004. In this study, this observed data has been used for validation of the proposed "hill cut factor" incorporated in RUSLE model. Figure 2 shows the location of the study watershed.

Watershed delineation has been carried out in ArcSWAT interface of the SWAT model using an SRTM (Shuttle Radar Topography Mission) DEM (Digital Elevation Model) of 1 arc-second resolution. Both Slope map and DEM are shown in Fig. 2. Elevation of the watershed changes from 59 m to 177 m and slope ranges from $0^\circ$ to $32.9^\circ$. The R-factor value has been
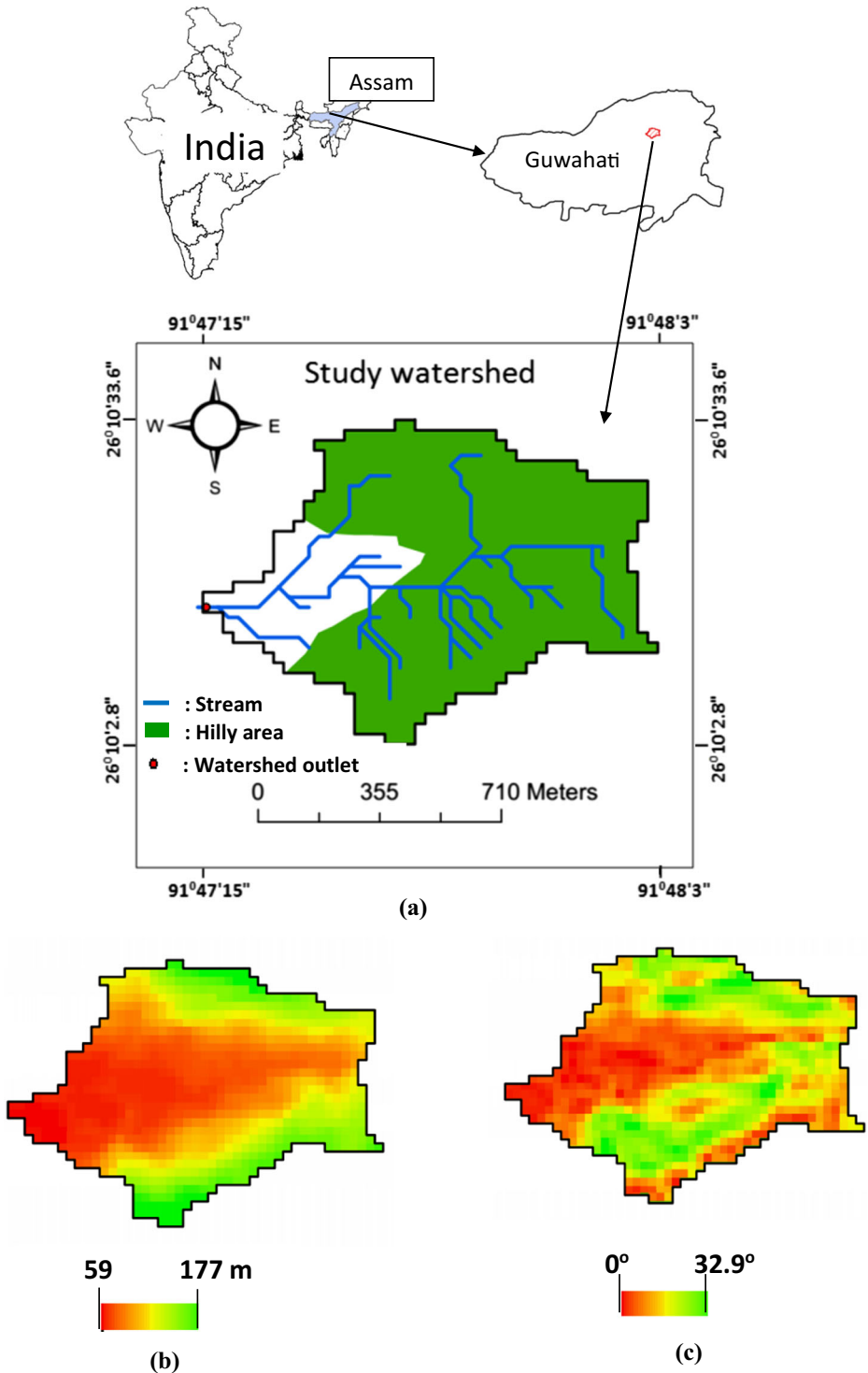
Fig. 2 a Location b elevation map c slope map of the study area

**Table 1** C factor values for LULC of the study watershed

| LULC type | C factor |
|---|---|
| Bare soil | 1 (Sarma et al. 2005; Sarma 2011) |
| Forest | 0.01 (Sarma et al. 2005; Gelagay and Minale 2016) |
| Scrubland | 0.014 (Wischmeier and Smith 1961; Gelagay and Minale 2016) |
| Urban settlement in plain area, $C_g$ (60% impervious, 40% bare) | 0.4 ($=0 \times 0.60 + 1 \times 0.4$) |

taken as 9259 MJ.mm ha$^{-1}$ h$^{-1}$ year$^{-1}$ as calculated by Sarma et al. (2005). Sarma et al. (2015) also used this R-factor value. According to Das (1992), soil type of study area is clay loam. As given in Stewart et al. (1976), depending on soil texture class and organic content (2%) K-factor value is taken as 0.032925 t h MJ$^{-1}$ mm$^{-1}$. Necessary unit conversion of K factor has been done as per Foster et al. (1981). Again, Eq. (20) (Moore and Burch 1986; Desmet and Govers 1996a) has been applied to prepare the raster map of LS factor in ArcGIS platform. This raster map gives the pixel-level values of LS factor for the watershed. In many studies, this equation has been applied (Moore and Wilson 1992; Gelagay and Minale 2016).

$$LS = \left(\frac{A_c}{22.13}\right)^{0.6} \times \left(\frac{\sin\theta}{0.0896}\right)^{1.3} \tag{20}$$

where, $A_c$ and $\theta$ are the specific catchment area (m$^2$) and natural slope angle (degree), respectively. There have not found any support practices in the study watershed. Hence, P-factor has been taken as 1. Values of C factor are assigned based on the LULC map of the watershed prepared by using IKONOS (panchromatic) and LISS III (multispectral) image of capture dates 28th January and 11th December of 2003, respectively. Areas covered by forest, bare land, scrubland and urban settlement in the study watershed are found as 21.5%, 1.8%, 62.35 and 14.35%, respectively. C factor values assigned to these four types of LULC found in the hilly watersheds are given in Table 1. For general urban settlement located in plain area, C-factor value ($C_g$) has been assigned by considering 60% of the settlement area being impervious and the remaining 40% being in bare condition [According to Guwahati Metropolitan Development Authority [GMDA] (2006), maximum coverage area of building in a plot of land can be 60% of plot area]. C-factor value for the impervious area is taken as '0' (Sarma 2011).

In order to have an idea about the condition of hill cuts in Guwahati city, 100 numbers of steep hill cuts were randomly selected. A sample field survey was performed in those hill cuts to measure the area and angle of hill cuts, and also the type and approximate quantity of the surface covers of hill cuts. It was found that at an average, only 1% of the total area of hill cuts is protected by retaining wall, 39% area is having grass or creepers and the remaining 60% area is

**Table 2** Data used for calculation of $H_f$ and $C_{hu}$ for the study watershed

| Types of surface covers in hill cuts ($i$) | $a_i$ (%) | C factor ($C_i$) | $\beta^0$ | $\theta^0$ | $H_f$ | $C_{hu}$ |
|---|---|---|---|---|---|---|
| Vegetation (grass, creepers) | 39 | 0.01 (Sarma 2011) | 70 | 14.1725 | 0.2959 | 0.5787 |
| Bare (uncovered) | 60 | 1 (Sarma 2011) | | | | |
| Retaining wall | 1 | 0 (impervious, Sarma 2011) | | | | |

**Table 3** Calculated and observed values of soil loss from the study watershed

| Calculated rate of soil loss (t ha$^{-1}$ year$^{-1}$) | | Watershed Area (ha) | Calculated total soil loss (t year$^{-1}$) | | Observed suspended load (t year$^{-1}$) (Sarma et al. 2005) | Observed total soil loss (t year$^{-1}$) (Sarma et al. 2005) |
|---|---|---|---|---|---|---|
| With H$_f$ | Without H$_f$ | | With H$_f$ | Without H$_f$ | | |
| 239 | 182 | 74.47 | 17,798.33 | 13,553.54 | 15,854.81 | 17,440.29 |

uncovered or in bare condition. Again, the average gradient of the hill cuts is obtained as 70$^0$ (= β). These field survey data have been used for calculation of H$_f$ of the study watershed (Table 2). The average slope angle of the hilly portion of the watershed is taken from the slope map of the hilly area prepared from the DEM in ArcGIS. By putting the values of angle β and angle θ in Eq. (11), it is found that average projected area of steep hill cut is only 0.08 times the urban settlement area visible in the satellite image. That means the projected area of steep hill cut is very less in comparison to the visible urban settlement area in the satellite image and hence, the simplified expression of C$_{hu}$ (Eq. (19)) is used for urban settlement in hills of Guwahati city.

# 4 Results and Discussions

For the study watershed, soil loss (t ha$^{-1}$ year$^{-1}$) maps are generated by multiplying pixel-based values of all the factors of RUSLE in "Map Algebra" tool of ArcGIS software. Two types of raster maps of soil loss rate have been produced- (i) considering H$_f$ (ii) without considering H$_f$. All the factors of RUSLE other than the C-factor are same for these two scenarios. By taking the arithmetic mean of pixel values of every type of the soil loss raster maps, an average soil loss rate has been calculated. Sarma et al. (2005) measured suspended sediment yield at the outlet of the study watershed and considered an additional 10% of this suspended load as bed load. By comparing the calculated and observed values (Sarma et al. 2005) of total soil loss from the study watershed in Table 3, it is clear that without considering H$_f$, RUSLE underestimates the
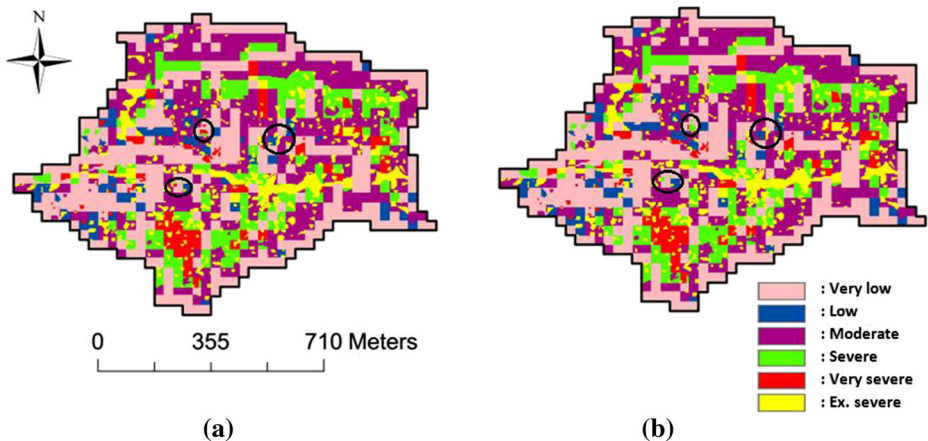


**Fig. 3** Soil loss (t ha$^{-1}$ year$^{-1}$) map of the study watershed (**a**) with consideration of H$_f$ (**b**) without consideration of H$_f$ (Round marks include areas having change in soil loss class)

**Table 4** Area (%) of the study watershed lying in different classes of soil loss rates

| Soil loss rate (t ha$^{-1}$ yr.$^{-1}$) | Class | Area (%) | |
|---|---|---|---|
| | | With H$_f$ | Without H$_f$ |
| 5 | Very low | 36.44 | 36.44 |
| 5–12 | Low | 5.37 | 5.37 |
| 12–50 | Moderate | 29.72 | 29.72 |
| 50–100 | Severe | 12.86 | 12.92 |
| 100–200 | Very severe | 4.74 | 4.71 |
| >200 | Extremely severe | 10.86 | 10.83 |

total soil loss by almost 28% than the observed one. The mini watershed considered in this study is not having any landslide or gully erosion. Hence, it is clear that this difference of soil loss between the observed and estimated values (without consideration H$_f$) is not due to some other sources of soil loss like landslides or gully erosion in the watershed. On the other hand, considering H$_f$, RUSLE has estimated the total soil loss from the watershed with a sediment delivery ratio equal to 0.98. For small hilly watershed located in Guwahati city, Sarma (2011) and Sarma et al. (2013) considered sediment delivery ratio equal to 1. Hence, soil loss estimation from the study watershed by incorporating H$_f$ into RUSLE, which gives a sediment delivery ratio equal to 0.98, is acceptable. However, the hill cut angle β used in the derivation of the hill cut factor of the study area have been calculated as an average of the hill cut angles obtained from a sample field survey. Due to this, at 95% of confidence level, an error margin of (±) $3.02^0$ is found for the sample mean of the angle. Due to this margin of error, the computed value of the total annual soil loss from the study-watershed may vary by (−0.43%) to (+1.2%).

Every pixel of the maps of soil loss rate of the study watershed has been classified as per the soil loss classes, given by Irvem et al. (2007) (Fig. 3). Accordingly, the amount of watershed area lying under every soil loss class has been estimated (Table 4). It is worth mentioning that although there is a 31.3% difference in total soil loss between the two scenarios: with and without consideration of H$_f$, the two classified soil loss maps of the study watersheds are found almost same. Again, almost 28% of the watershed area has been identified as having soil loss rate greater than 50 t ha$^{-1}$ yr.$^{-1}$ (severe class), which indicates a widespread vulnerability of soil loss from the watershed.

## 5 Conclusion

Blockage of storm drains due to sediments coming from hills is a serious problem in many cities like Guwahati where urban settlements in hilly areas are occurring in a much-unplanned way. Underestimation of soil loss from hills is one of the prime reasons of inadequate design of drains, culverts and silt traps. Settlement in hilly areas causes unscientific steep cuts in hills. Since only the horizontally projected area is visible in the orthorectified satellite image, the amount of steep hill cut area visible in satellite image is less than the actual area of steep hill cuts caused due to the urban settlement in hills. This basically leads to underestimation of soil loss from urban hilly watersheds. In this study, an effort is made to determine the amount of soil loss from urban hilly areas in a more accurate way by using RUSLE model in GIS platform. A new factor called "hill cut factor (H$_f$)" has been introduced here to take account of the soil loss occurring from steep hill cuts. This "hill cut factor H$_f$" is defined as the ratio of the steep hill cut area, not visible in satellite

image to the area of urban settlement visible in satellite image or map. This factor is incorporated into the cover management factor of the RUSLE model. The general expression of "hill cut factor, $H_f$" developed here is applicable to any hilly watershed experiencing urban settlement. However, the applicability of the proposed factor has been tested against a mini hilly watershed, located in Guwahati city. Model validation proves that in GIS platform, incorporation of $H_f$ into RUSLE can give the more accurate estimation of total annual soil loss from urban hilly watersheds. Even though, two similar soil loss class maps of the study-watershed were obtained for the scenarios both "with" and "without" consideration of $H_f$, the "without consideration of $H_f$" scenario underestimated the annual soil loss by almost 28%. Due to the scarcity of observed soil loss data from hilly watersheds of Guwahati city, the applicability of the "hill cut factor" has been evaluated only with respect to the observed soil loss data of a single watershed. Validation of the factor with more numbers of observed soil loss data will help to get insight into the factor more deeply. In that case, for hills of Guwahati city, the efficiency of the $H_f$-incorporated RUSLE model could have been possible to express in a more detail way. Again, for the validation of the model, an SRTM DEM of 1 arc-second resolution has been used. Therefore, the testing of the model with finer-resolution-elevation data against observed soil loss data of a number of urban hilly watersheds is an important future scope of this study.

It is noteworthy that this study does not consider the massive amount of sediment loss resulted from the potential landslide or channel/gully erosion. It only considers the soil loss due to rill and inter-rill erosion from the steep hill cuts. Traditional methods of soil loss assessment are very time-consuming, pricey and labour intensive (Dabral et al. 2008; Ganasri and Ramesh 2016). In such a case, GIS-based estimation of soil loss from urban hilly watersheds with the incorporation of $H_f$ into RUSLE can be very useful from the viewpoint of cost-effectiveness, swiftness and, accuracy for the adequate design and management of urban drainage system.

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