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An evaluation of grid size uncertainty in empirical soil loss modeling with digital elevation models

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This paper presents a study on the effect of topographic variability on grid-based empirical estimation of soil erosion and sediment transport with raster geographic information systems (GIS). An original digital elevation model (DEM) of 10 m resolution for a case watershed is resampled to six realizations of greater grid sizes for a comparative examination. The Universal Soil Loss Equation (USLE) and a distance-based sediment delivery equation are applied to the watershed to calculate soil loss from each cell and total sediment transport to streams, respectively. The results suggest that the selection of the DEM gird size has considerable influence on the soil loss estimation with the empirical models. The estimate of total soil loss from the watershed decreases significantly with the increasing DEM cell size as the spatial variability is reduced by the cell aggregation. The empirical modeling approach is a useful tool for qualitative assessment of soil erosion, provided that spatial variability can be adequately represented by applied DEMs. However, discretion is suggested for its applications to quantitative estimation of soil loss concerning the sensitivity to the grid size selection.

Keywords: soil loss, empirical modeling, Universal Soil Loss Equation, GIS, digital elevation models, grid size, spatial variability

1. Introduction

Topography poses a critical factor in controlling water dispersion and soil movement in watershed landscape. Land surface characterization is required in spatially distributed modeling of many hydrologic processes including soil erosion and sediment transport. Raster-based digital elevation models (DEMs) are commonly used for representing elevation surface in soil erosion studies supported by geographic information systems (GIS). There are various resolutions of DEMs depending on data sources and areas of interest. For example, the United States Geological Survey (USGS) provides 30 m DEMs for all over the United States, and 10 m DEMs for part of the country. The United Kingdom's Ordnance Survey sells DEMs created from contour maps at multiple scales including 1 : 10,000 with 10 m spacing. The increasing availability and quality of digital elevation data have greatly enhanced GIS-supported watershed studies including soil erosion modeling.

Soil erosion models can basically be categorized as either theoretical or empirical models. Most theoretical models are simplified and combined with empirical components in practice, and thus considered as conceptual models. In terms of the treatment of spatial components of watershed hydrology, one further classification divides erosion models into two groups: lumped and distributed. The Universal Soil Loss Equation (USLE) and its revisions are most commonly used empirical models, and majority of their applications so far have been on the lumped basis to obtain global estimates of soil loss [1,2]. Lumped models utilize average values of the watershed characteristics affecting soil erosion process, likely leading to significant inaccuracies. Nevertheless, the USLE is considered a simple and practical tool for long-term soil loss assessment for a watershed.

A number of comprehensive models with the conceptual and distributed characteristics, such as ANSWERS [3] and AGNPS [4] have been developed and integrated with GIS for investigation of soil movement in watershed systems. Those models are intended to improve erosion modeling reliability with the use of theoretical elements and accounting for spatial variability in inputs and parameters. However, the applications of such models are cumbersome as a distributed framework requires substantial spatial-distributed data that are not readily available. This difficulty stemming from the model complexity presents a major disadvantage of the distributed simulation with comprehensive models.

There has been a tendency to utilize the USLE and its modifications in a distributed manner with the use of GIS in the past two decades. Many attempts were made to combine the empirical models with GIS to conduct soil loss assessments. In the USLE and its revised versions, effects of topography on soil loss are characterized by the topographic factor (*LS*) that can be obtained for each grid cell from a digital elevation model (DEM). Hession and Shanholtz [5] applied the USLE within a raster-based map analysis module, and the results were used to estimate sediment loadings to streams from an agricultural area with a sediment delivery ratio. Grid cells of 100 m $\times$ 100 m were used for most data except for the topographic factor which was calculated at 200 m resolution and then interpolated to 100 m grid size. James and Hewitt [6] incorporated a revised version of the USLE into an ARC/INFO-based river basin decision support system. The topographic factor values were estimated from 3 arc-second DEMs in the Grid module, but then resampled to a larger cell size, for conversion to vector format to ensure compatibility with other data layers. Olsen and Kristensen [7] developed a catchment-scale system to assess risks of nitrate leaching and erosion. The system combined digital information on soil types, climates, slopes and crops within a GIS. A slope map used for the USLE calculation was obtained from a DEM of 50 m × 50 m. A similar study conducted by Wijesekera and Samarakoon [8] addressed the extent of soil erosion in a watershed in a grid environment. The modeling with the USLE utilized square cells of 25 m spacing. A general approach to integrating GIS with the USLE for soil erosion assessment was presented in a work by Fistikoglu and Harmancioglu [9] with a case demonstration using a small river basin. The study employed a 30 m × 30 m raster DEM to calculate the topographic factor.

A common point stated in the above mentioned works was that the USLE applications in the grid environment with GIS would allow us to analyze soil erosion in much more detail since the process has a spatially distributed character. It is obviously more reasonable to use the USLE on a physical basis than to apply it to an entire watershed as a lump model. However, none of the literature gave justification regarding the use of a certain grid size of DEM although some of the researchers suggested that the DEM cell sizes should be properly selected to adequately reflect spatial variations. The applied DEM resolutions in these works were basically determined by availabilities of elevation data.

Representing no sediment deposition, the USLE does not account for interactions between neighboring cells. This leads to the concerns that the USLE applications in the grid environment may not be able to adequately reflect real situation of soil erosion. Thus, an issue exists in regards to how DEM grid size affects soil loss estimation with the USLE.

Effects of applied DEM grid sizes on terrain modeling and hydrologic simulations have been examined in a few studies using a distributed model called TOPMODEL, a model based on the contributing area concept. Quinn et al. [10,11] described the effect of grid resolution on calculations of the topographic index that is expressed as ln[secific catchment area/slope]. Zhang and Montgomery [12] documented the effect of grid cell resolution on topographic parameters and on hydrologic simulations of surface processes. Their results showed that increasing the grid size resulted in an increased mean topographic index because of increased contributing area and decreased slopes. Wolock and Price [13] found that increasing grid size resulted in higher minimum, mean, variance, and skewness of the topographic index distribution. They also found that the map scale used to produce the cartometric DEM has an observable but much smaller effect on the spatial distribution of topographic index than grid spacing. Bruneau et al. [14] conducted a sensitivity analysis on the space and time resolutions of the TOPMODEL. The analysis showed that the modeling efficiency is fairly high inside a relevant domain of space and time resolutions and that working outside this domain induces a strong decrease of modeling efficiency. In general, they found that finer grids gave more accurate results. The effect of DEM grid spacing on hydrologic simulation has also been examined using another model called the Basin Scale Hydrologic Model (BSHM) [15]. A series of DEMs (grid spacing from 37 m to 1097 m) were used on a basin of 1437 km^2. The study found that the frequency distributions of travel time and peak flows are almost identical for cell sizes smaller than 91 m. It suggested that 183 m spacing could be an appropriate selection in terms of the quality of hydrologic simulation and the amount of required computing time.

In this work we address the effect of DEM resolution on topography-based soil erosion modeling using the USLE with raster GIS. Elevation data for a case watershed at seven levels of the resolution are processed in ArcView GIS to delineate stream network and extract physiographic parameters. The GIS compiles data on a grid basis, and computes soil loss with the USLE for each cell. The total sediment transport to streams is then estimated using a selected empirical method from which a sediment delivery ratio (SDR) can be obtained. Furthermore, a dedicated analysis is conducted to measure the relative sensitivity of the estimation at each selected resolution level. The results with the topographic factor and soil loss estimation are comparatively analyzed and discussed in regards to the effect of DEM resolution.

2. The USLE and topographic factor

The Universal Soil Loss Equation (USLE) is a simple multiplicative model that was derived from over 10,000 plot years of data [1]. The values of its factors have been updated following the analysis of thousands of new measurements [2] and a revised version of the model has been substituted in place of the original one for farm conservation planning in the United States [16]. The USLE and Revised Universal Soil Loss Equation (RUSLE) can be written as:

$$A = RKLSCP \tag{1}$$

where,

A = soil loss in tonnes per acre;

R = the rainfall-erosivity factor;

K = soil erodibility factor;

L = slope length factor;

S = slope steepness factor;

C = cover-management factor;

P = supporting practices factor.

The slope length and steepness factors (L and S) are typically represented as a combined topographic factor, *LS*, that characterizes the effects of topography and hydrology on soil loss. Soil loss predictions are more sensitive to slope steepness than slope length. Moore and Burch [17] described a formulation of the *LS* factor based on unit stream power that can be calculated from a DEM:

$$LS = \left(\frac{g}{22.13}\right)^{0.4}\left(\frac{s}{0.0896}\right)^{1.3} \tag{2}$$

where,

g = upslope contributing area;

s = slope.

There have been a few modifications on the calculation of the *LS* factor. For example, the influence of profile convexity/concavity is considered using segmentation of irregular slopes [18–20] as a part of the RUSLE. To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area [17,19].

3. Sediment delivery

In erosion process, most sediment deposits within watershed and only a portion of soil eroded from hillslopes will reach streams or watershed outlet. This fraction of the delivered sediment expressed as a percentage is often referred to as the Sediment Delivery Ratio (SDR) in empirical modeling. In cell-based sediment transport analysis with GIS, the SDR may vary from cell to cell with changes in gradient, slope shape and length [21]. Other factors include land cover, surface roughness, soil texture, distance to drainage stream and water availability. Gross sediment eroded to streams or away from a watershed can be obtained by totaling the deliveries from all cells.

It is apparently difficult to obtain sediment delivery ratios accurately with a common procedure [22]. The U.S. Department of Agriculture, Soil Conservation Services (USDA-SCS), currently the Natural Resources Conservation Services (NRCS) has published a handbook in which the SDR is related to drainage area [23]. The relationship established for the sediment delivery ratio and drainage area is known as the SDR curve. An equation is given based on the relationship curve. However, it is not applicable to the grid-based soil loss estimation as a lump model for an entire watershed. Other empirical models for estimation of the SDR are also available. A distance- and relief-based method was proposed by Yagow et al. [24] in a water quality study for agriculture lands in Virginia. Another equation was established for North Carolina and Georgia forested landscape based on the regression with the application data of the WEPP model (Water Erosion Prediction Project). Its delivery ratio is also related to slope and distance to stream [25]. McNulty et al. [26] derived a simple distance-based equation specifically for forested landscapes from field measurements, which is expressed as:

$$M_d = A(l - 0.97D/L_d) \tag{3}$$

where,

M_d = the mass moved from each cell to the closest stream network (tonnes/acre/year);

D = the least-cost distance from a cell to the nearest stream network (meters);

L_d = $5.1 + 1.79A$, the maximum distance that sediment with mass A may travel (meters).

The combination of the USLE and an empirical SDR method renders a simple approach to the soil loss estimation under a spatially distributed domain. It is expected to obtain a better accuracy than applying the USLE to an entire watershed as a lumped model. However, this type of quasi-distributed application does not consider sediment deposition, channel erosion, and soil losses/gains between neighboring cells. It represents a major drawback of the estimation method since the USLE does not distinguish those parts of hillslope profiles experiencing net erosion and deposition. Another disadvantage with the USLE-SDR method is the lack of the capability of dealing with single storm events.

4. Data and study approach

The site for the case study is the Back Creek watershed, a sub-watershed in the Upper Roanoke River Basin in Southwest Virginia (figures 1 and 2). The Back Creek watershed encompasses a 152 km^2 drainage basin that originates in the Blue Ridge Mountains on Poor Mountain at an elevation of 1097 m above sea level. Back Creek flows in a northeasterly direction for about 40 km until it joins the Roanoke River near the borders of Roanoke, Bedford, and Franklin Counties. The watershed is currently dominated by forest and pasture with little residential or commercial development. However, urbanization with some extent of development is expected due to its proximity to Roanoke City.

The elevation data at 10 m resolution and 1 : 24,000 scale for the Back Creek watershed are obtained from the USGS data centre via the internet. The DEMs composed by the Back Creek watershed consist of those for four areas including Bent Mountain, Elliston, Garden City, and Hardy. The original DEMs in the USGS Spatial Data Transfer Standard (SDTS) format are converted to Grid DEMs for processing in GIS. ArcView GIS and its extensions are used for the analysis and display in this study. The watershed is delineated from its raw DEM using the Hydrologic Modeling extension (hydro11.avx). The 10 m resolution DEM of the delineated watershed is resampled to six DEMs of 30 m, 60 m, 100 m, 150 m, 200 m, and 250 m resolutions, respectively.

There are three commonly used DEM resampling methods, nearest neighbor, bilinear interpolation, and cubic convolution. The nearest neighbor assignment is the simplest method which assigns the value of the nearest cell in the input grid to the output cell. The bilinear interpolation identifies the four nearest input cell centers to the location of the center of an output cell on the input grid and assigns a new value for the output cell as a weighted average. The cubic convolution method calculates a distance weighted average of a block of 16 cells from the original DEM which surround the new output cell location. As an essential part of an extensive research on DEM grid size effect on environmental

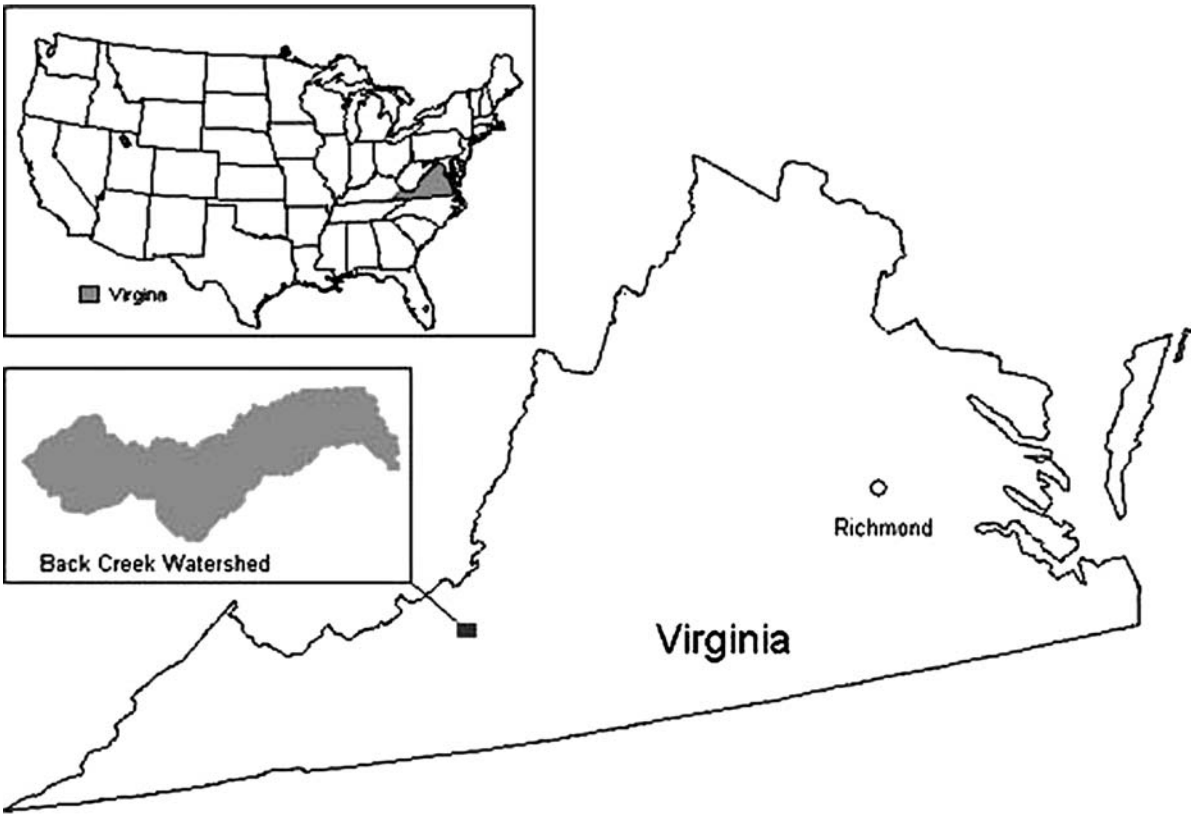

Figure 1. Location of Back Creek Watershed in the State of Virginia and the United States.

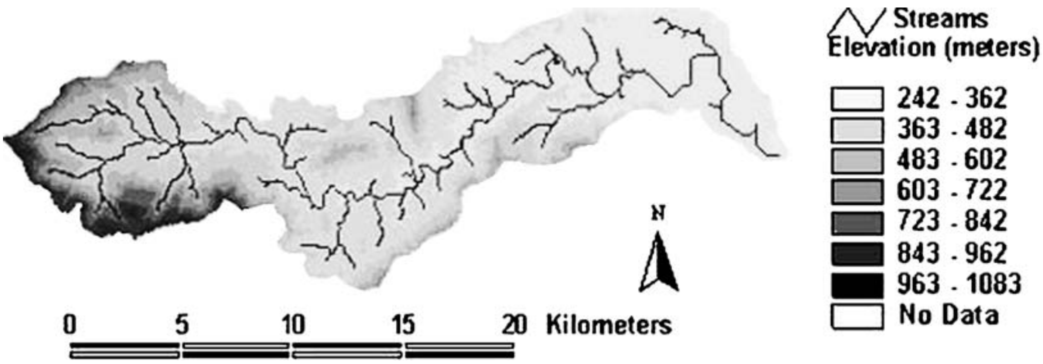

Figure 2. Elevation map of Back Creek Watershed (10 m resolution).

modeling, the 10 m DEM of the Back Creek watershed has been resampled with all the three methods to investigate the differences between them when resampling elevation data. Various topographical and hydrologic parameters including the *LS* factor and soil loss estimation by USLE were assessed with the original 10 m and the six resampled DEMs. The obtained distribution statistics have indicated no significant influence of resampling methods on the USLE application. The relatively large size of the study area is believed to be contributable to the outcome. Hence, results only with the nearest neighbor technique are presented in this paper as the selection of resampling method has no impact on overall conclusion of the comparative study.

The seven selected study resolutions fall primarily in the range of commonly used DEM grid spacing in recent watershed studies as previously reviewed. The use of low resolution DEMs in distributed watershed modeling is becoming fewer with the increasing availability of high resolution DEMs and subsequently elevated requirement for modeling accuracy. Many researches and applications applied 10 m DEM, especially for small-scale watersheds. As concluded by Zhang and Montgomery [12], grid sizes of 10 meters would suffice for many DEM-based applications of geomorphic and hydrologic modeling. Grid sizes of about 200 m are widely used for medium or large study areas. A study by Kienzle [27] on the effect of the grid size on spatial representation showed that fair results in terrain unit simulation were obtained from the grids of less than 250 m, and a larger spacing could fail to represent terrain units.

The aggregation process by the resampling apparently reduces the spatial viability of topographic surface and derived slope data. The reduction in spatial variability would definitely be captured by the *LS* factor in the USLE. It would then lead to changes in total soil delivery estimate in the study watershed which is obtained based on the calculated soil loss for each cell. A general profile about the DEM resolution effect can thus be obtained by comparatively analyzing the spatial characteristics of the *LS* factor and total soil delivery obtained with the seven DEM realizations. A further sensitivity analysis is performed on the estimates of total sediment transport to streams. Data regression is applied to the results to obtain dedicated quantitative information on the sensitivity of the soil loss estimation to the grid size at different levels.

The USLE presented by equation (1) is used to determine the gross soil loss in each grid cell of the DEMs. The *LS* factor value in each cell is calculated with equation (2). The upslope contributing area g_j for a given grid cell j is computed from the sum of the grid cells from which the water flows into the cell.

$$g_j = \frac{n\mu a}{b} \tag{4}$$

where,

n = number of cells draining into the cell;

μ = weight depending on the runoff generation mechanism and infiltration rates;

a = area of a grid cell;

b = DEM cell spacing.

For a regular grid-based DEM, $a = b \times b$, and we assume $\mu = 1$ [28]. Thus, the upslope contributing area for cell j can be simply calculated as:

$$g_j = nb. \tag{5}$$

A single rainfall runoff factor ($R = 60$ meter-tonnes/acre) is used to represent the annual average rainfall runoff condition for the whole watershed based on the rainfall data obtained from four rain gages in the proximity of Back Creek. The distribution of soil erodibility K factor for the watershed is taken from the STATSGO soil type database [29]. The values are contained in the "layer.dbf" table under the field named "kffact". The table is joined to the attribute table of the Back Creek watershed coverage using the MUID field. The cover-management factor C and the supporting practice factor P are combined as the land use factor CP. Due to the universal distribution of the vegetation across the watershed (pasture and forest), the factor does not have significant influence on the outcomes of the comparative study.

Equation (3) for sediment delivery estimation is employed in this study for its simplicity and practicability. The equation assumes that the soil moved to the nearest stream from a cell is basically proportional to the *LS* factor. The ultimate results of empirical soil loss modeling are expected to be dictated by the spatial variability in DEMs through the computation of the *LS* factor. The equation applies to an entire DEM cell by cell, and their results are totaled to be the estimated soil loss from the entire watershed. For the seven DEMs of different resolutions, the *LS* factor value of each cell and total soil delivery in the study watershed are estimated using the equations (1)–(5). Both visual examination and statistical analysis were undertaken to explore the effects of DEM resolution.

5. Results and discussion

Figure 3 shows the *LS* distributions of the seven DEMs of 10 m, 30 m, 60 m, 100 m, 150 m, 200 m and 250 m resolutions, respectively. The visual examination indicates that DEM resolution does have profound effect on the spatial pattern of the *LS* factor. It is obvious that the resampling from 10 m to a greater cell size results in a coarser *LS* distribution with a loss in data resolution in the DEM. The maximum and mean values of the *LS* factor were calculated, and their relations to the DEM grid size are plotted in figure 4. Apparently, both the mean and maximum values decrease as the grid size increases, but with varying patterns for different resampling extents. The maximum *LS* factor value declines dramatically with the grid size increasing from 10 m to 30 m, and then further to 60 m and 100 m. There is, however, little change with the maximum value when the grid size increases from 100 m to 150 m, 200 m and 250 m. This indicates that the cell size influence on the *LS* factor is much more pronounced at higher DEM resolutions in high-relief land areas. The 100 m resolution appears to be a threshold below that the "flattening effect" of grid cell aggregation on the maximum *LS* factor value is quite significant. The mean value of the *LS* factor over the entire watershed, which is more representative in terms of overall effect, has a different decreasing scenario. It keeps declining steadily throughout the resampling with increasing grid size from 10 m to 250 m. However, it can be observed that a turning point also exists at the 100 m grid size. The plot of the mean value can be divided into two parts, from 10 m to 100 m, and from 100 m to 250 m, respectively. While both present a near reverse-linear relationship between the *LS* mean value and grid size, the decrease of the *LS* value is apparently slower in the later part. This may indicate that the overall spatial variability in the watershed is a little more sensitive to the DEM aggregation at a smaller grid size than 100 m.

The cumulative frequency distributions of the *LS* factor against the fractions of the watershed area are depicted in figure 5 for the seven different DEM resolutions. It suggests that the resampling from 10 m to 30 m, and from 30 m to 60 m has a relative smaller effect on the *LS* factor distribution throughout the watershed, respectively. The values of the *LS* factor derived from the 30 m and 60 m DEMs remain well distributed although majority of top values were eliminated. However, the resampling further to 100 m and then to 250 m caused much more significant reductions in terms of the *LS* distribution. For the DEMs at 100 m and above, most of the watershed area has quite small calculated *LS* factor values.

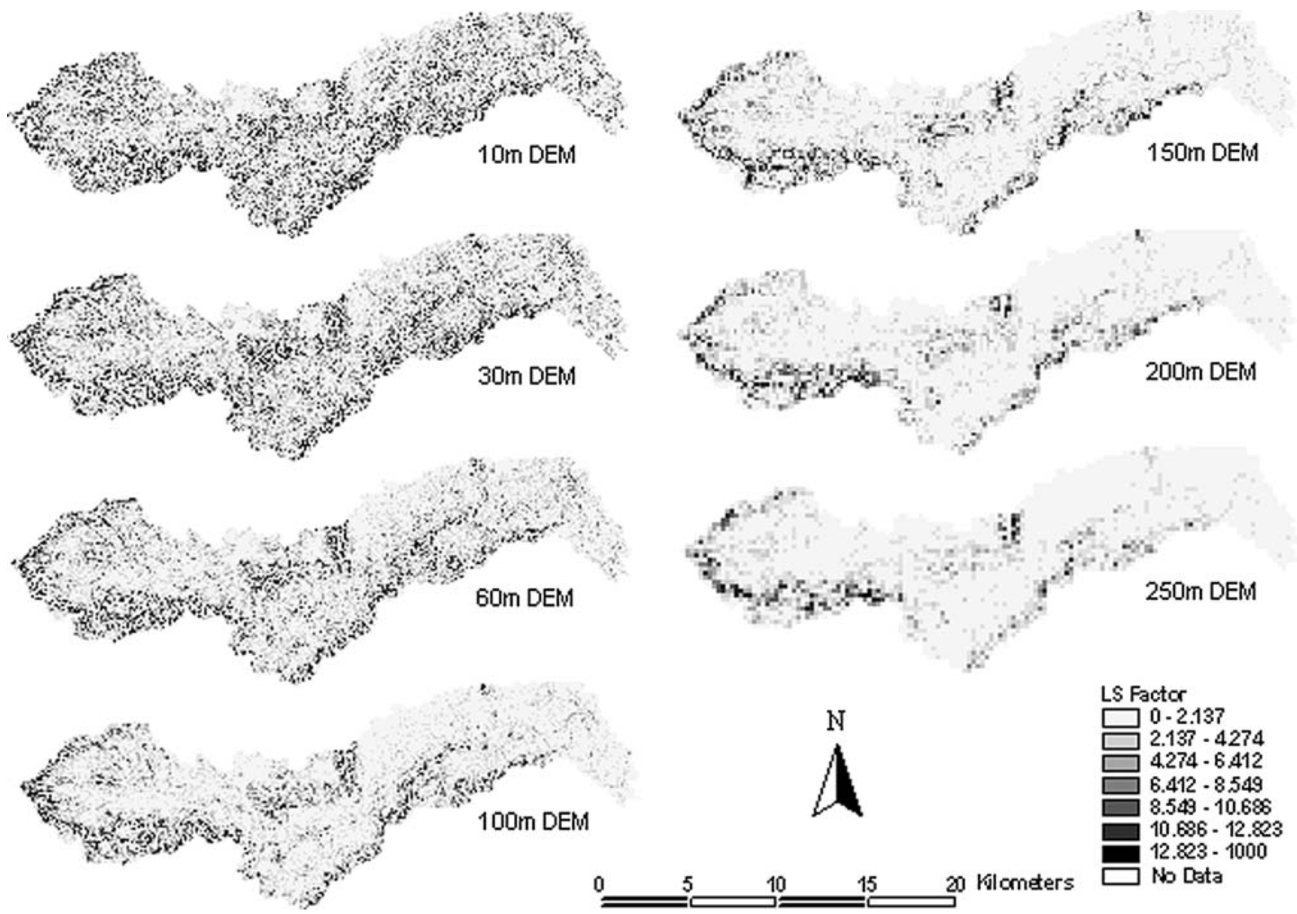

Figure 3. Distributions of the *LS* factor value for the DEMs of different resolutions.

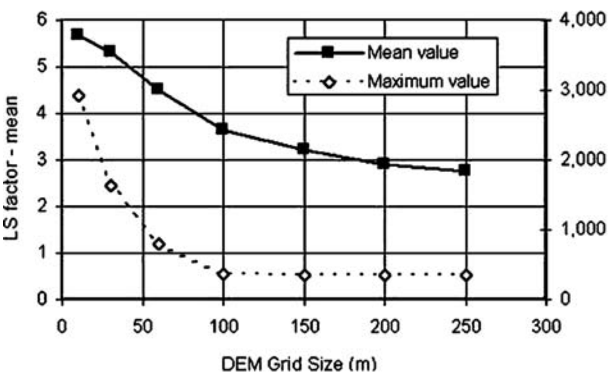

Figure 4. The *LS* factor versus DEM grid size.

The soil erosion from each cell estimated by the USLE equation was obtained from the GIS for all the seven DEMs. The mean values of the estimates are presented in figure 6. It suggests that the relationship profile of mean soil erosion estimates under different DEM resolutions is almost identical to that for the *LS* factor. This is reasonable because the soil types, land use and conservation are similar throughout the case watershed. Those conditions determine the other elements in the USLE than the *LS* factor. The soil loss from each cell to streams is calculated using equation (3). As shown by the routing function given in the equation, the contribution of a cell to the total soil loss to streams is dictated jointly by both the *LS* factor and the cell's distance to the nearest stream. Thus, there could be substantial difference in term of the contribution from cell to cell. This can be seen from the calculation results which indicate that only small portion of cells have significant amount of deposit transported to streams. Figure 7 illustrates comparative profiles of cell contributions of soil loss for the seven DEM realizations of different resolutions. The calculated total soil erosion certainly decreases with the increasing grid sizes as the spatial variability presented by the *LS* factor is essentially the determining factor. As depicted in figure 7, little soil from a cell could reach its nearest stream for the areas far away from stream networks, especially for the DEMs of lower resolutions. The preceding discussion has indicated that areas (cells) with steeper landscape get more reduction in terms of the *LS* factor in the DEM aggregation by resampling. However, those high-relief areas are relatively distant from streams in most cases. The capability of contributing eroded soil to streams is reversely proportional to the distance from a cell to its nearest stream.

The estimated sediment transports from cells to streams shown in figure 7 were totaled for each of the different DEM realizations, and plotted in figure 8. The estimate declines at a greater rate with the increasing grid size, as compared to the mean soil loss from cells (figure 6), and the mean *LS* factor value (figure 4). The estimated loss to streams

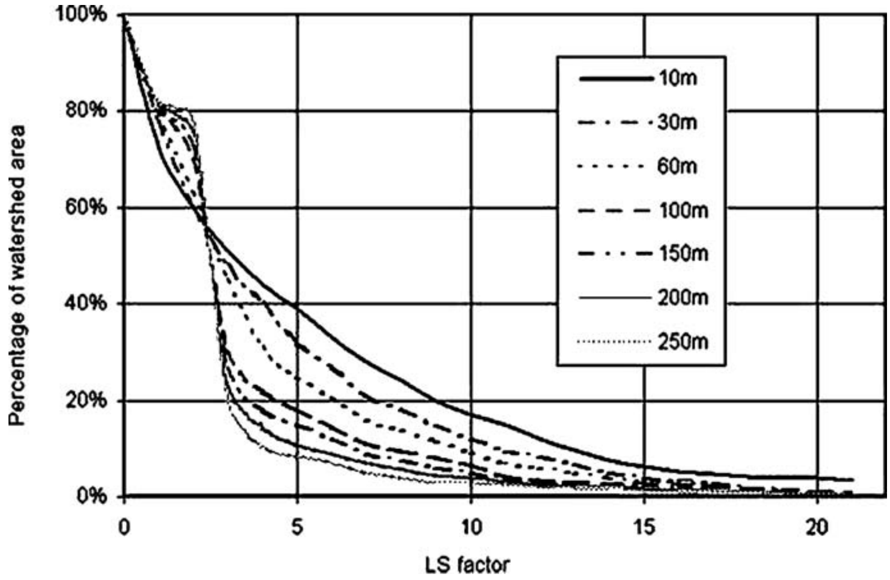

Figure 5. Cumulative frequency distribution of the *LS* factor at different DEM resolutions.

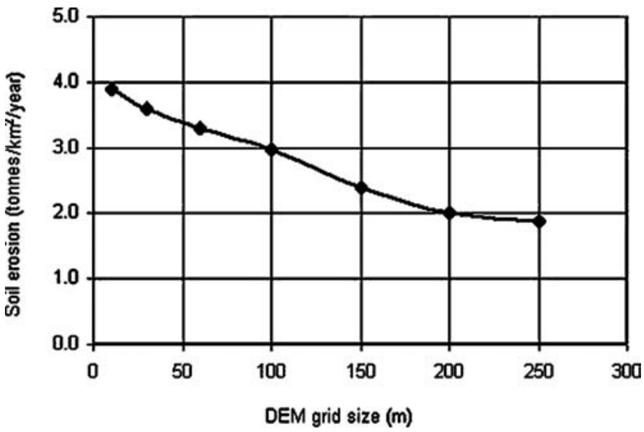

Figure 6. Soil erosion estimates at different DEM resolutions.

for the entire watershed drops from 2281 tonnes/year to 912 tonnes/year, when the DEM is resampled from 10 m to 250 m, suffering a 60% reduction. A linear regression on the data in figure 8 gives a slope of -5.6 tonnes/year/meter with an R-square value of 0.971. Acceptance of the linear relationship means that any 1 m increase in the applied DEM cell size would bring down the soil loss estimation for about 5.6 tonnes/year. The same data can be modeled more exactly by an exponential regression with the following relationship generated at an R-square value of 0.997.

$$y = 2301\mathrm{e}^{-0.0038x} \qquad (6)$$

where,

y = total soil transport to streams (tonnes/year),

x = DEM grid size (m).

Figure 9 presents the total soil loss sensitivity at each selected grid size level obtained based on equation (6). The figure shows that the sensitivity drops significantly with the resampling to lower DEM resolutions. A cell size increase by 1 m at the original 10 m level causes a decrease of 8.4 tonnes/year in the soil loss estimation, while the same change at the 250 m level leads to only 3.4 tonnes/year decrease. Hence, the total soil loss estimation is much more sensitive to the DEM grid size change at high resolution levels.

The results presented above indicate that the DEM resolution has profound effect on the distribution of topographic variability represented by the *LS* factor. This effect further exerts on the empirical soil loss and transport modeling for watersheds, leading to differences in the estimation using different resolutions of DEMs. The estimated total soil loss to streams is found to be in an exponential decreasing relationship with the DEM resolution. Zhang and Montgomery [12] have attempted to attain general conclusions on appropriate DEM grid sizes used for distributed hydrologic modeling by similar comparative approaches. They indicated that grid sizes of 10 m would be adequate for many hydrologic modeling. Garbrecht and Martz [30] argued that the selection of DEM resolution for simulation applications depends not only on the scale of the processes being modeled, but also on the numerical simulation approach and the specific landscape parameters that are extracted from the DEM. The argument, apparently reasonable, could shed some light on the grid size issue for the empirical modeling of soil loss with GIS. Different from common techniques for distributed simulation, the empirical modeling with GIS, as originally intended for lumped applications, does not account for sediment deposition. Thus, its use deserves more conservative consideration, concerning the fact that the selection of the grid size would dominate modeling results.

Among the studies using the USLE in the grid environment, some made efforts to identify high priority areas for soil conservation. Their successful applications have proved that the empirical modeling with raster GIS is an ideal tool for the purpose of qualitative assessment of soil erosion. As

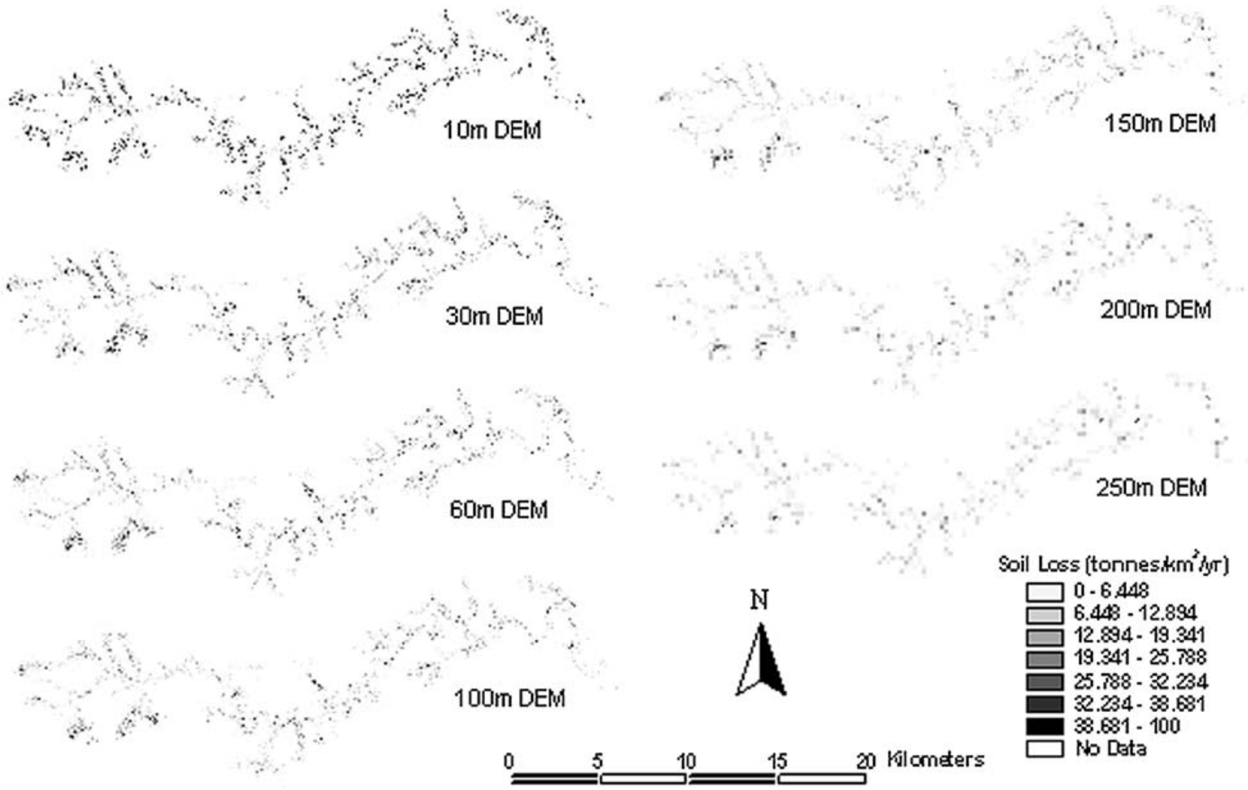

Figure 7. Distributions of cell contribution to total soil loss at different DEM resolutions.

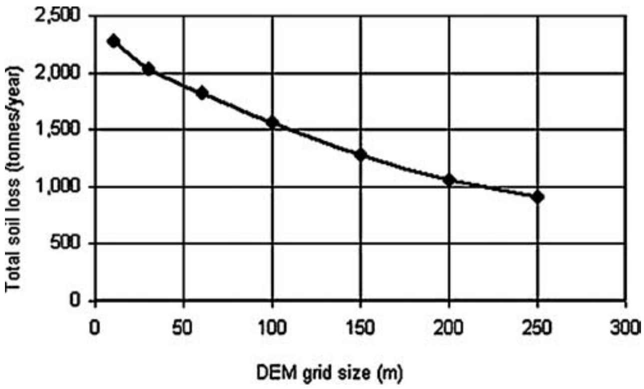

Figure 8. Estimates of total sediment transport to streams.

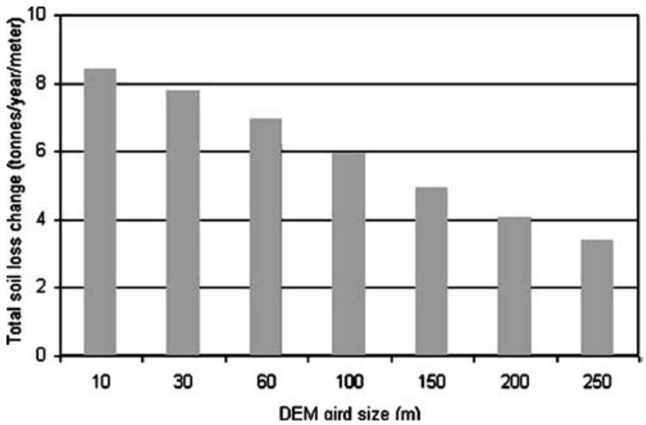

Figure 9. Sensitivity of total soil loss estimation to DEM grid size.

the basic requirement for grid size selection in this type of study, spatial variability should be well represented in the DEM to assure risky spots be located. Hence, the smallest available grid size can be recognized as the best DEM resolution. The results presented in this paper could imply that a DEM of 100 m or higher resolution would suffice for the applications. The regularly used 30 m USGS DEM is believed to be adequate for the assessment purpose. Discretion is needed when using a DEM of a lower resolution than 100 m. Erosion scenarios may not be adequately represented due to possible significant loss of spatial variability represented by the *LS* factor in the USLE.

Many other studies have attempted to use the DEM-based USLE approach as shown in this paper to acquire quantitative knowledge about the amount of soil loss from an area of interest. We would agree that a smaller cell size would more possibly render a higher accuracy in the estimation. However, considering the outcomes from this study on the cell size effect, we suggest that the grid-based method may not be able to obtain significantly improved results beyond the lumped USLE application to the entire study area as desired. In another word, the best grid size may not be necessarily the smallest available one. There is no doubt that the soil erosion and transport estimation using simple models like the USLE and the equation (3) for sediment delivery ratio in the grid environment are still hard to attain any adequate accuracy due to their intuitive empirical features and difficulties in parameterization.

6. Conclusions

The grid-based soil loss modeling using the USLE is widely used with the application of raster GIS in land management assessment and planning. However, uncertainty exists in the modeling with respect to the use of different grid sizes of digital elevation models. This study investigates the effects of DEM resolution on the empirical estimation of soil loss and sediment transport at the watershed level. An original 10 m DEM for a case study watershed was resampled to six lower resolutions of realizations that were then applied for a comparative study. It has been found that the modeling results are dominated by the spatial variability represented by the topographic factor (*LS*) in the USLE. The mean value of the *LS* factor in the entire watershed decreases notably with the increase of DEM gird size, especially at finer resolutions. A similar relationship is present for total estimated sediment transported to streams. The effect of the grid size change becomes weaker at lower resolution levels as shown by the sensitivity analysis on the total soil loss estimation. However, the spatial variability obtained from low resolutions of DEM may not be adequate for any modeling purpose.

The results have generally suggested that the selection of DEM resolution could have significant influence on the empirical estimation using the USLE. This study is an attempt to examine the effect of the empirical modeling to DEM resolution, but not to find an appropriate grid size for the modeling. It is difficult to determine the best grid size for a modeling study towards a quantitative understanding due to the empirical nature of the USLE model, while it is a common belief that the grid size should not be arbitrarily chosen. The bottom line is that spatial variability must be well represented by the *LS* factor under selected DEM cell size to assure effective application of the USLE. The integration of the USLE with raster GIS is of best use for land classification in terms of soil erosion potential. For qualitative assessment, the smallest available grid size should be selected with regards to DEM availability and consistency with the scales of other factors. This work justifies the necessity of assessing uncertainties created by the DEM horizontal accuracy, and offers an initiation for such kind of analyses on empirical watershed modeling with GIS.

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