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Quantifying Erosion Risk for Little Washita River Watershed Using GIS Technique Integrated with USLE Model

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Abstract

Universal Soil Loss Equation (USLE) erosion model has been utilized in order to quantify soil erosion risk in Little Washita River Watershed, Oklahoma. The objectives of this study were to 1) quantify the average annual soil loss in Little Washita River Watershed using Geographic Information System (GIS) technique integrated with USLE model, and 2) compare the erosion risk in 2006 with those in 1992 for Little Washita River Watershed. Huge amount of information and data, usually pending from different sources and available in different formats and scales were utilized to determine erosion risk. Topography, vegetation type, soil properties and land use/cover influenced the soil erosion in this watershed. Average annual soil losses were performed by multiplying six factors of USLE model: slope steepness factor, slope length factor, rainfall runoff erosive factor, the soil erosive factor, cover management factor, and support practice factor. The highest soil erosion risk values were 35.4 and 17.7 tons/ha/yr with mean value equal to 0.03 and 0.017 tons/ha/yr for 2006 and 1992, respectively. The percentage change between soil erosion risk in 2006 and 1992 give us the idea about the variation in the soil loss during this duration.

Keywords: USLE Model, GIS, Little Washita River Watershed, Soil Erosion Risk.

Introduction

Watershed degradation is a global problem in the world. Soil erosion by water one of significant problems to cause the degradation. Most of soil erosion in watershed area can be found in rivers. Oklahoma State is one of the states in the United State that suffering from soil erosion in many major rivers such as Arkansas River, Canadian River, Washita River, and Red River. A geographic Information System (GIS) have been used to estimate the soil erosion in different areas in the world. GIS has been integrated with many techniques to determine erosion risk such as the Universal Soil Loss Equation (USLE).

Numerous Studies have been conducted to study and determine soil erosion using USLE model. The first study to estimate soil erosion using USLE model was in 1978 by Wischeimer and Smith. They used this model to predict the average rate of soil erosion for each feasible alternative combination of topography, rainfall pattern, soil type, crop system, and management practices. Many studies are integrated GIS technique with USLE model to estimate predict soil erosion to river watersheds (Singh et al., 1981; Romken, 1983; Reusing et al., 2000; MA et al., 2003; Khosrowpanah et al, 2007; Sheikh et al., 2011; Saygin et al., 2014). Other studies were integrated GIS, Remote Sensing, and USLE model to determine erosion risk in many Watershed Rivers (Jain et al., 2001; Dabral et al., 2008; Sheikh et al., 2011; Saygin et al., 2014). Therefore, GIS technique is very helpful to calculate soil erosion in river watershed.

In this study, GIS and USLE model are combined to determine the soil erosion in Little Washita River Watershed, Oklahoma. Many researchers have been studied several issues on Little Washita River such as rainfall, runoff, hydrology, soil moisture, soil type, degradation,……., etc (Ryzhkov et al., 2000; Xue et al., 2003; Van Liew and Garbrecht, 2003; Van Liew et al., 2003; Van Liew et al., 2007; Tyagi et al., 2010; Rosero et al., 2011; Moriasi et al., 2014), but no one has been studied the soil erosion in this watershed area using USLE model. Quantifying the soil erosion using GIS integrated with USLE model was performed in Little Washita River Watershed.

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The objectives of this study are to 1) quantify the average annual soil loss in Little Washita River Watershed using GIS technique integrated with USLE model, and 2) compare the erosion risk in 2006 with those in 1992 for Little Washita River Watershed.

Materials and methods

Study Area and Database

The Little Washita River located about 80 km southwest Oklahoma City, Oklahoma. It is located between (34° 46' 15" - 35° 0' 9") N and (97° 51' 33" - 98° 17' 22") W. It has a drainage area of 626 km^2 and crosses three counties in Oklahoma State which are Coal County, Caddo County, and Comanche County (Figure 1). The length of river is 60 km and it has about 11 creeks such as Bills Creek, Charlie Creek, Little Rush Creek and others. The average annual rainfall for this watershed around 795 mm. Topography of Little Washita Watershed is propertied by gentle to moderately rolling hills with an average elevation 400 m as maximum and 183 m as minimum. Soil types are primarily consisted of silt loams, loams, clay loam, fine sandy loams, and sandy loams (Van Liew and Garbrecht, 2003; Van Liew et al., 2003). Land use land cover types included grassland (58%), cropland (22%), forest (11%), and (9%) miscellaneous, this was for 2006. For 1992, the land use land cover was (48%) grassland, (22%) grains, (10%) cropland, (10%) forest and (10%) miscellaneous.

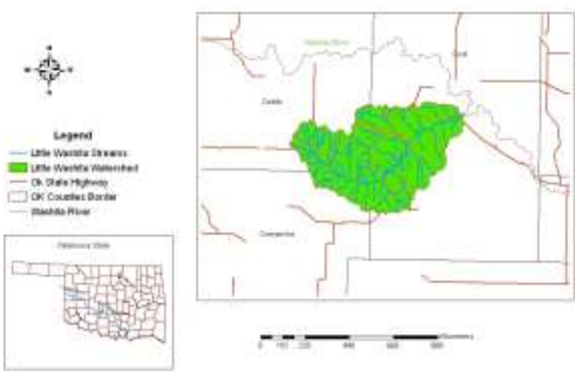

Figure 1. Located of Little Washita River Watershed in Oklahoma State.

Several types of database have been collected from different sources for Little Washita River Watershed. The digital Elevation Model (DEM) was downloaded from USGS website with grid size (30 * 30) m for Little Washita Watershed. The shape files for Oklahoma boundaries, Counties Boundary, Oklahoma Major Rivers, and Oklahoma Highways were downloaded from National Agriculture Imagery Program data (NAIP) for Oklahoma State (OCGI website). Land use land cover, Soil types map, and participation map can be downloaded from DATA GATEWAY website with (30*30) m grid size for raster data. The rainfall data were collected from 1971 to 2000. The soil type map was up dated until July, 2006. Land use land cover in 1992 was downloaded from USGS website for Little Washita River. In this study, all Raster data and Vector features files are projected to "USA Contiguous Albers Equal Area Conc. USGS" Coordinate System with 30 m grid size for Raster layers.

Methodology

Several methods were used to estimate the soil erosion for watershed using GIS technique. In this study, USLE model was utilized to predict the soil erosion for Little Washita River Watershed. The USLE model has been widely performed for several parts in the world. It could be predicted the average annual soil loss and its spatial distribution on watershed. It can predict the soil risk erosion for a given site as a product of six major erosion factors. The USLE formula is expressed as (Wischeimer and Smith, 1978; Ma et al., 2003):

$$E_r = S * L * R * K * C * P \qquad (1)$$

where E_r is the spatial average annual soil loss, tons/ha/year, S is the slope steepness factor, L is slope length factor, R is rainfall runoff erosive factor, K is the soil erosive factor, C is cover management factor, and P is support practice factor.

The watershed area should be delineated for Little Washita River using Hydrology tool in Arc Toolbox in GIS. Then, the whole work has to set the environment analysis to Little Washita River Watershed. The procedure to determine USLE model factors using GIS technique followed the following description. The slope steepness factor, S, represents one of the terrain factors and it is expressed as (Wischeimer and Smith, 1978):

$$S = \frac{(0.43+0.3s+0.043s^2)}{6.613} \qquad (2)$$

where s is terrain slope in percentage. It could be computed from surface analysis in Spatial Analyst. The slope length factor, L, represents the other terrain factors. It is expressed as (Wischeimer and Smith, 1978; McCool et al., 1987):

$$L = \left(\frac{\mu}{22.13}\right)^m \qquad (3)$$

where μ is field slope length, m, and it is equal to grid size (30 m) in this study, and m is exponent varied from 0.2 to 0.5. The exponent m can be varied based on different percentage slope. Equation (3) could be accomplished using Raster Calculator tool in Spatial Analyst of GIS technique.

Rainfall data for Little Washita River Watershed were recorded for 30 years from 1971 to 2000. The rainfall runoff erosive factor, *R*, could be calculated from the following relationship (Singh et al., 1981):

$$R = 79 + 0.363p \qquad (4)$$

where p is the average annual rainfall, mm. The p values can be created from rainfall map. The soil erosive factor, *K*, represents the soil's resisting to erosion force depends on soil types and it is expressed (Romken, 1983; Ma et al., 2003):

$$K = 0.0034 + 0.0387e^{\left[-0.5\left(\frac{logD_g+1.5333}{0.7671}\right)^2\right]} \qquad (5)$$

where D_g is size of soil particles, mm. The (D_g) ranges from 0.001 mm for clay to 0.048 mm for sandy clay loam and these data can be obtained from Soil Map. Equation (5) can be determined using Raster Calculator tool in ArcGIS.

The land cover factor, *C*, is used within the USLE model to reflect the effects that vegetation cover, cropping, and management practices have on the erosion rate (Khosrowpanah et. al., 2007). The values of *C* factor depended on canopy cover (percentage of vegetation area to the total area) and percentage of ground cover. These data were originally developed in Ohio, USA in 1979 and can be determined from land use land cover maps (Khosrowpanah et. al., 2007). The support practice factor, *P*, represents the calculation of soil rates with a value of 1 (Khosrowpanah et. al., 2007; Reusing, 2000). The *P* factor layer can be created by reclassifying the DEM layer for Little Washita River Watershed. The soil erosion risk was determined using USLE Model in 1992 and 2006 according to available data.

Results and discussion

Multi maps were created in this study which represented the factors of USLE Model for both 2006 and 1992. The layer for slope steepnes factor (*S*) was created by applying equation (2) as shown in Figure (2). The value of *S* factor depended on percentage slope layer (% *s*) which is created from DEM map for Little Washita Watershed. The values of *s* layer ranged between 0 and 63.07. Accordingly, the watershed was classified to eight classes for *S* factor. It is clear form Figure (2) that the values of *S* range from 28.8 to 0.065. The histogram shows that about 38% from the watershed area has *S* factor less than 0.3, 36% has *S* factor between 0.3 to 0.6, 23% has *S* factor between 1.3 to 2, and the remained data have *S* factor more than 2.

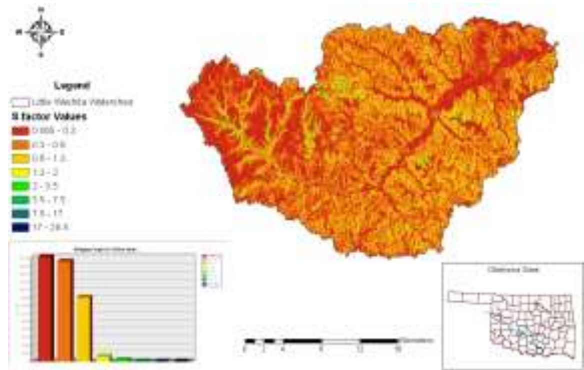

Figure 2. Slope steepness factor (S) for Little Washita Watershed.

According to equation (3), the slope length factor (*L*) layer depends on μ and m values. The value μ was fixed and equal to grid size (30 m), while the values of m value are varied depend on (% *s*) value layer. Figure (3) shows four classes of the *L* factor values for Little Washita River Watershed varied between 1.06 and 1.17. It can be observed that the variation of *L* factor values were very small because *L* factor was depend on m values only and it's varied from 0.2 to 0.5. The *L* factor layer was created from power function in Raster Calculator tool in ArcGIS.

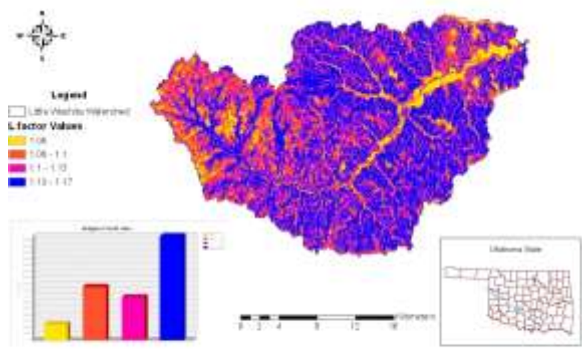

Figure 3. Slope length factor (L) for Little Washita Watershed.

The rainfall runoff erosive factor rainfall runoff erosive factor (*R*) map was derived depend on rainfall recorded from 1974 to 2000. The *R* factor according to equation (4) depends on average annual rainfall (p) which was ranged between 780 mm to 795 mm according to precipitation map. Two classes have been created for the *R* factor layer which is ranged between 362.14 and 367.6. According to histogram graph, less than 23% from the watershed area has *R* factor equal to 362.14 and more than 75% has *R* factor between 362.14 to 367.6.

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The soil erosive factor (K) values assigned to each soil type which was referenced directly to soil map for Little Washita Watershed. They can be determined from equation (5) using Raster Calculator tool in ArcGIS software as shown in Figure (4). This map shows four classes for K factor with highest value of 0.012 and lowest value of 0.0048. The majority values were between 0.0048 to 0.01 for K factor.

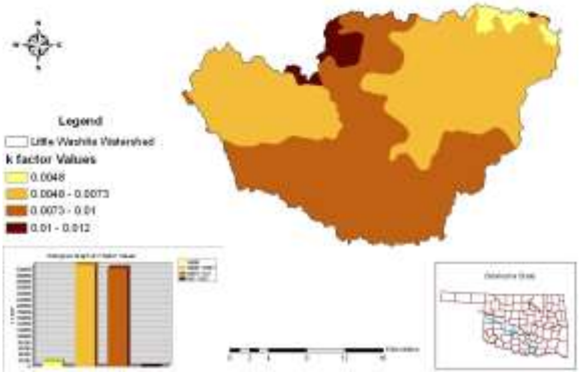
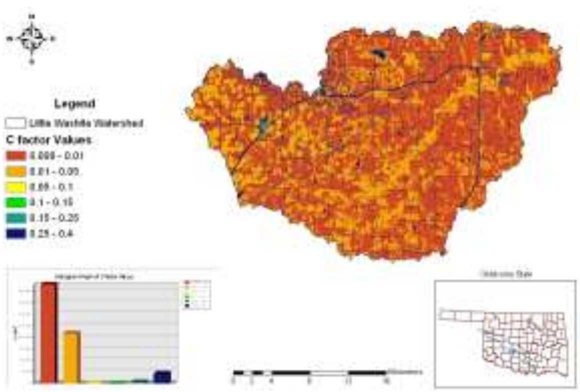


Figure 4. Soil erosive factor (K) for Little Washita Watershed.

a)For 2006



b)For 1992

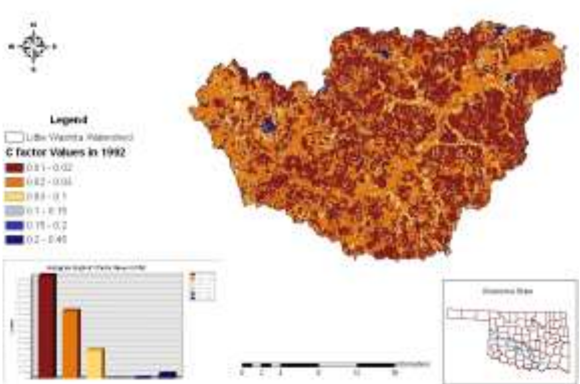


Figure 5. C factor values for Little Washita Watershed in (a) 2006 and (b) 1992.

Figures (5a, b) show the C factor values for Little Washita River Watershed in 2006 and 1992. The C factor values were obtained from table which was suitable for a wide land type within United State (Khosrowpanah et. al., 2007). For 2006, Figure (5a) shows six classes of C factors. The highest cover management factors are 0.4 which were assigned for Barren Land (Rock/Sand/Clay) and the lowest cover management factors are (0.008) which were assigned for High intensity developed and Emergent Herbaceous Wetlands areas. The majority of C factors were between 0.008 to 0.05. About (6 %) from whole data have C factor between (0.25-0.4) and the other data had C factor between (0.05-0.25). Accordingly, the C factor values for 1992 are shown in Figure (5b) with six classes of C factors. The highest C factor is 0.45 which was assigned for Barren Land and the lowest C factor is 0.01 which is assigned for grassland area. The majority of C factors range from 0.01 to 0.1 and others between (0.1-0.45).

The average annual soil loss, E_r, was calculated by multiplying the developed raster layers from each USLE analysis (see equation 1). The output maps for USLE Model in 2006 and 1992 are shown in Figures (6a, b). For 2006, the map shows five classes of soil loss starting from very slightly erosion risk to very high erosion risk. The highest computed of soil erosion is 35.4 tons/ha/year and the lowest value is 0.001 tons/ha/year. The mean annual soil loss for the whole watershed area was 0.03 tons/ha/year. It can be observed from Figure (6a) that more than 91% from the area has very slightly erosion risk (0.001-0.1) tons/ha/yr, about 6.6 % from the watershed area have slightly erosion risk (0.1-1) tons/ha /yr, and less than 3% have moderate to very high erosion risk (5-35.4) tons/ha/yr. This is mean that Little Washita River Watershed is far away from erosion risk for majority of its area except for few regions that located under high risk.

The output map for USLE Model in 1992 is shown in Figure (6b). This map shows four classes of soil loss begin from very slightly erosion risk to high erosion risk. The highest computed of soil erosion is 17.7 tons/ha/year and the lowest value is 0.001 tons/ha/year. The mean annual soil loss for the whole watershed area was 0.017 tons/ha /year. It can be observed from Figure (6b) that about 93.7% from the area has very slightly erosion risk (0.001–0.1) tons/ha/yr, 5.8 % from the watershed area has slightly

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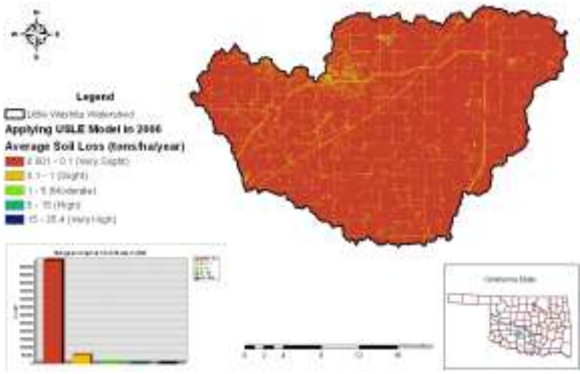
erosion risk (0.1-1) tons/ha /yr, others have moderate to high erosion risk (1-17.7) tons/ha/yr.

a)For 2006



b)For 1992

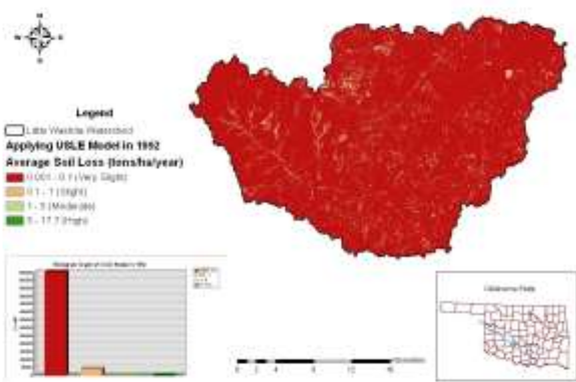


Figure 6. Average soil loss using USLE Model for Little Washita Watershed in (a) 2006 and (b) 1992.

The average annual soil loss, E_r, was calculated by multiplying the developed raster layers from each USLE analysis (see equation 1). The output maps for USLE Model in 2006 and 1992 are shown in Figures (6a, b). For 2006, the map shows five classes of soil loss starting from very slightly erosion risk to very high erosion risk. The highest computed of soil erosion is 35.4 tons/ha/year and the lowest value is 0.001 tons/ha/year. The mean annual soil loss for the whole watershed area was 0.03 tons/ha/year. It can be observed from Figure (6a) that more than 91% from the area has very slightly erosion risk (0.001-0.1) tons/ha/yr, about 6.6 % from the watershed area have slightly erosion risk (0.1-1) tons/ha /yr, and less than 3% have moderate to very high erosion risk (5-35.4) tons/ha/yr. This is mean that Little Washita River Watershed is far away from erosion risk for majority of its area except for few regions that located under high risk.

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Figure (7) shows the percentage change in annual soil loss between 2006 and 1992. The percentage change ranges between -0.98% to 39%. The value -0.98 means that the annual soil loss in 1992 was more than in 2006 about 0.98% and the value 39% means that the annual soil loss in 2006 is more than those in 1992 about 39%. The *C* factor values play a significant factor to cause these changes. The Tabulate Area Tool in Spatial Analyst was very helpful to figure out the type of land use that changes from 1992 to 2006. For instant, the percentage change between (-0.98% - 0) means that most of open water, developed, and shrub land areas in 1992 were changed to Grassland areas for 2006. The percentage change between (0-1%) means that most of small grains areas in 1992 were varied to Hay and cultivated crops areas in 2006. Finally, the percentage change between (5%-39%) means that most of Grassland areas in 1992 were changed to barren land areas in 2006.

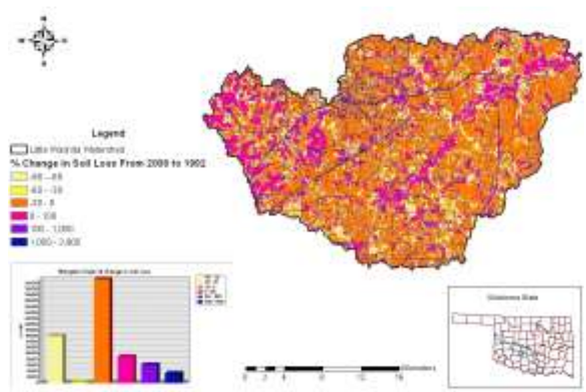

Figure 7. Percentage changing in soil loss for Little Washita Watershed between 1992 and 2006.

Conclusion

In this Study, the developed method was created to combine the USLE Model with ArcGIS technique to compute the annual soil loss for Little Washita River Watershed. Digital maps of elevation, land use, soil

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types, precipitation were processed according to USLE Model and the average annual soil erosion for each grid cell was calculated. Multi maps were created and represented the six factors in USLE Model. These factors are slope factor (*S*), length slope factor (*L*), rainfall erosive factor (*R*), soil erosive factor (*K*), cover management factor (*C*), and support practice factor (*P*). Raster Calculator, Join Tables, Field Calculation, Select by Attribute, Conversion Tools were utilized to create these layers. Two layers were created for factor (*C*) in 2006 and 1992.

The highest soil risk for USLE Model was 35.4 tons/ha/yr for 2006 and 17.7 tons/ha/yr for 1992 with mean value equal to 0.03 tons/ha/yr for 2006 and 0.017 tons/ha/yr for 1992 and the lowest value was 0.001 tons/ha/yr for both years. The majority of watershed area had very slightly to slightly erosion risk (0.001 – 1) tons/ha/yr. This is mean that Little Washita River Watershed is far away from erosion risk for majority of its area except few regions are located under high risk. The percentage change between USLE Model in 2006 and 1992 give us the idea about the varaition in soil loss between these years. For instant, the percentage change between (5%-39%) means that most of Grassland areas in 1992 were varied to barren land areas in 2006.

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