JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 3 No 1 2019

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

Spatial Targeting of Soil Loss Using RUSLE in GIS: the case of Asokore Mampong Municipality, Ghana

Gift Dumedah[1,*], Evans Kyeremanteng[1], Dari Ema[1]
Department of Geography and Rural Development, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana.
*Corresponding author e-mail: dgiftman@hotmail.com

Received: November 27, 2018
Accepted: January 20, 2019
Published: January 23, 2019

Abstract

Soil erosion is a serious environmental problem that is associated with societal impacts including flooding, poor water quality, and loss of plant nutrient leading to low agricultural productivity. Soil erosion wears away the top soil and is controlled by the interaction between several factors including rainfall, steepness of slope, length of slope, vegetation cover, and land management practices. This study developed Geographic Information System (GIS) graphical model based on the Revised Universal Soil Loss Equation (RUSLE), to calculate soil loss in the Asokore Mampong Municipality of the Ashanti region, Ghana. The estimated soil loss was examined the spatial patterns of soil loss and intensity per areas, as an important method for proper planning of management measures. The graphical model was developed using the popular open source GIS software, QGIS, ensuring the availability of the model, automation for any specific area, and its execution to the general public. Data sources used include Digital Elevation Model (DEM) derived from ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer), soil properties data obtained from the Global Soil Grids, land cover data from the Global Land Cover by National Mapping Organization (GLCNMO), NDVI (normalized difference vegetation index) data from MODIS (MOD13Q1, 16 Day), and rainfall data from GPCC version 7 (Global Precipitation Climatology Centre). Our results show high levels of soil loss (in tons per hectare per year) in the Municipality, with the capability to spatially target mitigation measures leading to cost effective environmental management.

Keywords: Soil erosion, Revised Universal Soil Loss Equation (RUSLE), GIS, QGIS, Graphical Modeler, Spatial targeting

1. Introduction

Soil erosion refers to the destruction, separation, removal and sedimentation of the earth's surface, soil and its parent material caused by water, wind, icying and defrosting, gravity and other external forces (Meyer, 1984). Soil erosion is a naturally occurring process that causes detachment and transport of soil materials by the erosive and transport agents: wind and water Foster et al. (2002). Soil erosion to water is triggered by a complex interaction process of many factors such as natural (climate, topography, soil, vegetation) and anthropogenic (tillage systems, soil conservation measures, overgrazing and deforestation Raissouni et al. (2012); Anurogo and Lubis (2018). A diversity of events dislocates the land surface of the earth, and thereby alter natural erosion rates. Estimation of potential soil loss is a critical step to realize soil management measures and attainment of reliable predictions of their efficiency in an area. Soil loss has been a threat to most nations worldwide. An intense soil loss can result in flooding, affect water quality, lead to loss of plant nutrient and hence low agricultural productivity. It consequently, dislocates people off their lands for settlement, agriculture, and industries. This infers that, there is a necessity to have specific evidence on soil erosion to support timely information for decision makers and land managers to select the right soil conservation methods. As diverse portions of the landscape vary in sensitivity to erosion through variances in their slope, soil and land use and cover characteristics, it is essential to spatially estimate rates of soil loss and develop a potential soil loss map of the study area using RUSLE within a GIS environment, which is needed to identify vulnerable areas and prioritize locations for specific soil conservation plans.

1.1 Problem description

Soil erosion has caused a lot of environmental and ecological problems such as land degradation, soil fertility loss, river siltation, making it a global investigation attention. Since the 1950s, to measure soil loss and determine its menace, several soil

JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 3 No 1 2019

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

erosion models were established based on measured information or the outcomes of earlier studies, and several study results were attained using Geographical Information Systems (GIS) Fujaco et al. (2016), (Joshi, 2018), Le Van Bien et al. (2014). One of the most applied models to estimate soil erosion is the Universal Soil Loss Equation (USLE) and its modified version the Revised Universal Soil Loss Equation (RUSLE) (Roose, 1975), (Wischmeier, 1978). Soil erosion is a catalyst to several environmental problems: decreased land productivity, challenges to agricultural sustainability, degradation of soil and water quality, and indirect pollution of the environment through the transport of contaminants such as agricultural and industrial waste attached to sediments to other parts of the environment and the water network [8]. Some of these problems are presently witnessed in the Asokore Mampong Municipality, the area of investigation for this study. A recent report shows that about 45% of the Municipality is affected by considerable sheet erosion and about 20% of the land area suffers severe sheet erosion (Amma, 2017).

Accordingly, this study provides the potential risks posed by erosion to both the environment and the populace by spatially identifying the areas that are likely to be affected by erosion and the extent to which they are affected. This is done by using various factors that determine the rate and intensity of erosion in the Municipality. These factors based on RULSE include: soil erodibility defined using soil properties such as soil texture, structure and organic matter content, rainfall erosivity based on rainfall amount, frequency and intensity, terrain based on slope length and steepness, and land cover use and practice. These factors were then integrated using the RULSE framework to model soil erosion and its mapping of high erosion risks. The resulting soil loss was analyzed in relation to the land use pattern, topography of the terrain, soil and rainfall distribution. The GIS capability allows the evaluation of spatial relationships between these factors and the spatial targeting of soil loss to identify critical locations. This provides the pattern of soil erosion in a methodical way and provide a reference basis for soil loss prevention in Asokore Mampong Municipality.

2. Materials and Methods

2.1. Study Area and data sets

The study area covers the Asokore Mampong Municipality in the Ashanti Region of Ghana, shown in Figure 1. Asokore Mampong Municipality covers a total land area of 24 km2 and it is located in the North-Eastern part of Kumasi Metropolis (GSS, 2018). It shares boundaries with Kumasi Metropolitan Assembly (KMA) to the East, South and West, Kwabre East District to the North-West and Ejisu Juabeng Municipal Assembly to the North-East. The general topography of Asokore Mampong Municipality is undulating, characterized by lowlands and highlands. The Aboabo River, Parko and Wewe streams are the main water bodies weaving through the municipality (GSS, 2014). The average minimum temperature is about 21.5 degrees Celsius and the maximum average temperature is 35.7 degrees Celsius. In general, the total annual rainfall is about 214.3mm in June and 165.2mm in September, which have a direct effect on soil loss (Ghana, 2012), (Ghana, 2014).

This study integrates measurable variables to estimate soil loss in a GIS environment. These variables were derived from several data sets including Digital Terrain Model (DEM) from Advanced Spaceborne Thermal Emission and Refection Radiometer (ASTER), and rainfall data from Global Precipitation Climatology Center (GPCC version 7). The soil properties data were obtained from the Global Soil Grid, land cover data from the Global Land cover by national mapping organization (GLCNMO), and the Normalized Difference Vegetation Index (NDVI) data from MODIS (MOD13Q1,16 Day).

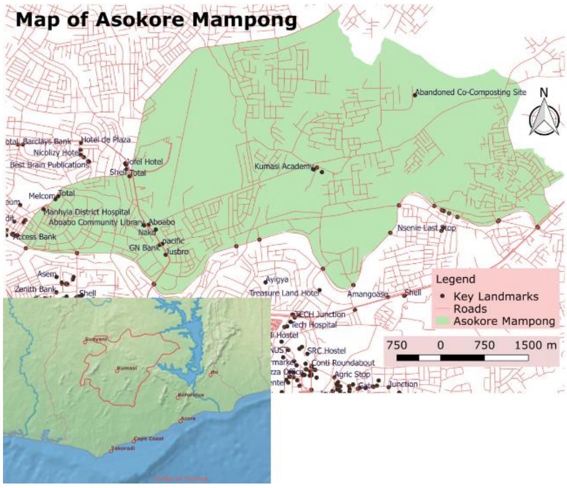

Figure 1. Map of Asokore Mampong municipality showing road networks and key landmarks

2.2. The Revised Universal Soil Loss Equation (RUSLE)

The factors in the RUSLE model include rainfall erosivity, soil erodibility, slope length and steepness, vegetation cover and management, and supporting practices (Roose, 1975), Wischmeier and Smith (1965). The revised universal soil loss equation (RUSLE) employed for this investigation Renard et al. (1997), Wischmeier and Smith (1978). In the RUSLE model, the average annual rate of soil loss can be estimated, and the spatial distribution of the soil erosion risk map can be established in a GIS environment. The study considered RUSLE model the most appropriate tool that can be used to predict soil erosion loss based on the available data in Asokore Mampong Municipality. The RUSLE model represents how rainfall, topography, soil and land use affect rill and sheet soil erosion caused by raindrop impact and surface runoff Renard et al. (1997), Sinha and Regulwar (2015). That is, RUSLE is limited to rill and sheet type of erosion, where the rate of surface runoff is excessive enough to displace soil particles in addition to those removed by rainfall. RULSE has been extensively used empirical model to assess soil erosion loss, to estimate soil erosion risk and to guide soil conservation plans to control soil erosion Millward and Mersey (1999), Prasannakumar et al. (2012). The RULSE framework is defined by the expression in Equation 1. The constituent variables are described in detail in the sections below.

Equation 1: $E = R * K * L*S * C* P$

E is average annual soil loss (tones/year)
R is the rainfall erosivity factor
K is the soil erodibility factor
L is the slope length factor
S is the slope steepness factor
C is the cover management factor
P is support practice factor.

2.2.1. Rainfall Erosivity

The rainfall erosivity factor (R-factor) is used to measure the ability of rainfall to cause soil loss under different conditions. It represents the soil erosion potential that is caused by rainfall. The rainfall data which was obtained from the Global Precipitation Climatology Center (GPCC version 7) was used to compute the R-factor using an equation: $R = 0.5*P$ (Roose, 1975), where P is the average annual rainfall (mm/year). The average annual rainfall was estimated from a 30-year period of yearly mean precipitation datasets from 1987 to 2016, compiled from precipitation records covering the Municipality.

2.2.2. Soil Erodibility

The soil erodibility factor (K-factor) is an empirical index that indicates the vulnerability of soil to rainfall and runoff detachment and transport based on soil texture, permeability and organic matter content. It thus reflects the ease with which the soil is removed by surface runoff during rainfall and/or by surface flow. It denotes the average soil loss per ton per acre per unit area for a particular type of soil. The K-factor was computed using the soil-erodibility equation; $K= 2.173\ [(2.1 *10^{-4}* M^{1.14} *(12-a)) + (3.25*(b-2)) + (2.5*(c-3))]\ /100$ developed in Wischmeier and Smith (1978), Wischmeier and Smith (1962), (Wischmeier, 1959), Belasri et al. (2017). The soil erodibility factor comprises four soil profile parameters which include; M = (% silt + very fine sand) *(100 – % clay), a = % organic matter, b = soil structure code and c = permeability class number. The above parameters were used to obtain the K-factor for the soil in the study area Belasri et al. (2017).

2.2.3. Slope Length and Steepness

LS-Factor in the RUSLE model, is the effect of topography on erosion which is accounted for by the slope length (L) and the slope steepness (S). The L factor is defined as the distance from the source of runoff to the point where either deposition begins, or runoff enters a well-defined channel that may be part of a drainage network. The S factor indicates the impact of slope steepness on erosion (Wischmeier, 1959), Wischmeier and Smith (1962), Wischmeier and Smith (1978). To compute the LS factor, Digital Elevation Model (DEM) obtained from (ASTER – Advanced Spaceborne Thermal Emission & Reflection Radiometer), was directly used in the graphical modeler in QGIS.

2.2.4. Cover Management

The cover and management factor (C-factor) is an index that shows how crop management and land cover affect soil erodibility. It accounts for all interconnected land cover and management practices Reenard et al. (1997). It is used to indicate the collective effects of reduction of runoff rate and protection of surface pores, of plants and soil cover as well as those of all other interconnected cover and management practices (Karaburun, 2010). The C-Factor was derived using the Normalize Difference Vegetation index (NDVI) data from (MODIS (MODIS 13Q1, 16 Day)). An average for the NDVI data was computed using the formula; C-factor = 0.431 – 0.805*NDVI, developed by (De Jong, 1994).

2.2.5. P-Factor

The factor P in the RUSLE is the fraction of soil loss per a precise support practice to the equivalent loss by up and down slope tillage Renard et al. (1997). The P values are between 0 and 1, where a value of 1 is when the land is tilled on the slope directly, and a value less than 1 is when the adopted conservation practice reduces soil erosion. Due to lack of data on conservation practices in the area under consideration, this study applies a P-factor of 1 over the entire study area.

2.3. The RUSLE workflow in QGIS

The methodology used in the study integrates the RUSLE into a GIS environment, specifically using QGIS. The QGIS is an open source GIS software fully featured with geospatial algorithms, integrated with established geocomputation platforms such as GRASS (Geographic Resource Analysis Support System), SAGA (System for Automated Geoscientific Analyses). QGIS was used to generate and process raster data sets for the individual input variables for RUSLE. A key facility of QGIS is the graphical modeler, a workflow development environment which allows access to data and geoprocessing functions and algorithms simultaneously. The graphical modeler facilitates complex geoprocessing workflows without resorting to programming, visualization of the workflows, and the execution of a sequence of multiple geoprocessing tasks to obtain a final output.

The graphical modeler for RUSLE workflow which is developed in QGIS by study is presented in Figure 2. The purple-colored boxes represent input data sets, the clear-colored or transparent boxes indicate geoprocessing algorithms/functions, and the blue-colored boxes represent geoprocessing outputs that are saved to file. Accordingly, the RUSLE workflow

JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 3 No 1 2019

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

takes data inputs including the DEM, proportions of sand, silt, clay and organic matter, soil structure code, permeability number, land cover management, NDVI, and rainfall. The resulting outputs include M-factor (for soil), K-factor, P-factor, C-factor, R-factor, and the final soil loss (erosion). The RUSLE workflow was implemented in this study to estimate the average annual soil loss from the area, thus automating the RUSLE procedure.

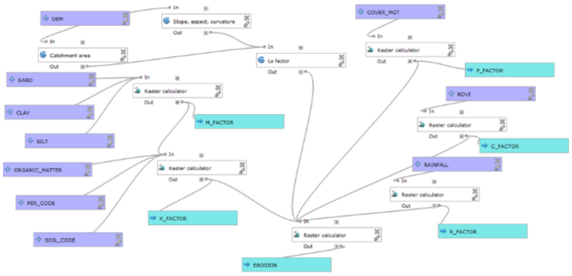

Figure 2. The graphical modeler in QGIS, showing the RUSLE workflow to estimate soil erosion

The resulting user interface generated from the graphical modeler in QGIS is presented in Figure 3. The user interface allows the user to specify the above data inputs and file paths for the RUSLE outputs, after which the program is executed to populate the outputs. This automation allows the input of various data sets for the calculation of the individual factors and provides the output for the individual features when executed.

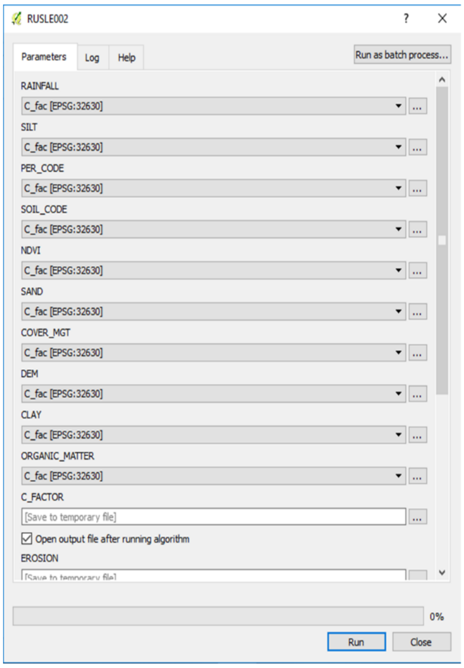

Figure 3. The user interface for the RUSLE workflow generated from the graphical modeler in QGIS

3. Results and Discussion

3.1. Estimation of soil erosion

The annual amount of soil loss to erosion in the Asokore Mampong Municipality was computed using RUSLE. The RUSLE layers derived for R, K, LS, C and P factors were integrated within the raster calculator option of the QGIS in order to calculate the soil erosion risk and severity map for the Asokore Mampong Municipality. The impact of environmental factors on spatial distribution of soil erosion loss including landscape units, elevation, gradient, and land use/cover were examined and evaluated. The results of the individual factors R, K, LS, C, P that are used to estimate the soil loss are presented in the following sections.

3.1.1. R_factor

The average annual rainfall erosivity factor (R) for the Asokore Mampong Municipality was found to be 1484mm. There is only one rainfall station covering the entire study area, thus there is no spatial distribution for the resulting R-factor. Using the formula from (Roose, 1975), the R-factor is computed as 1484 * 0.5 = 742. The high amount of rainfall experienced across the Municipality indicates the ease with which soil particles can be detached, which is indicative of potentially high soil erosion.

3.1.2. K_factor

The data inputs used to compute the K-factor are presented in Figure 4, showing the proportions for sand, clay, silt, and organic matter. These soil proportions were used to determine the soil texture by using SAGA (System for Automated Geoscientific Analyses) formulation, available in QGIS. The resulting soil texture has two texture groups which are loamy sand, and sandy clay. These soil texture groups were then used to derive the soil structure code number (denoted b) and the permeability class number (denoted c) Belasri et al. (2017).

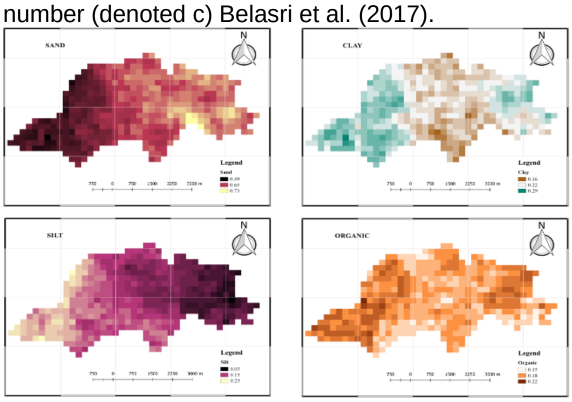

Figure 4. Soil data showing the proportions of sand – top left, clay – top right, silt – bottom left, and organic matter – bottom right

These variables were used to compute the K-factor which is presented in Figure 5. The soil erodibility factor, K-factor was found to have average values ranging from 0.01 to 0.24 t/ha/yr. Based on the soil properties alone, the K-factor output shows the extent to which the soil is likely to be eroded in Asokore Mampong Municipality. In general, locations of high erodibility are spatially associated with locations having high amounts of silt and sand content. Despite, the high and dominant occurrence of erodible soil across the entire Municipality, there are areas of soil which are resistant to erosion. These areas of soil are the dark-colored areas with minimum values of 0.01 in the Municipality indicating soil resistant to erosion in such areas.

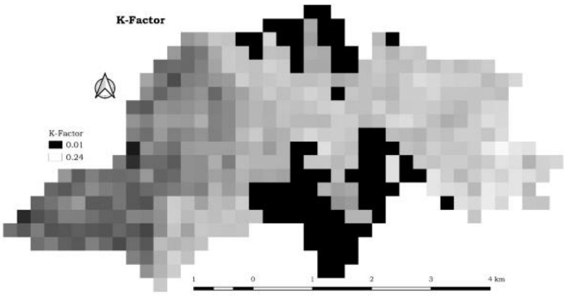

Figure 5. Map of K-factor derived from soil properties data

3.1.3. LS_factor

Mostly, as the slope length (L) and slope steepness (S) increase, total soil erosion per unit area also increases due to the acceleration of overland flow rate and erosivity of runoff in the downslope direction Ozsoy et al. (2012). The elevation data based on DEM which is used to derive the LS-factor are presented in Figure 6. The resulting LS factor varies from 0.065 to 10. The lowest values of the LS factor were spread throughout the study area, but of minimal impact to soil erosion. A greater portion of the study area is characterized by high LS values, an indication of high steep and slope length which influence high flow direction of the surface runoff resulting in high soil erosion

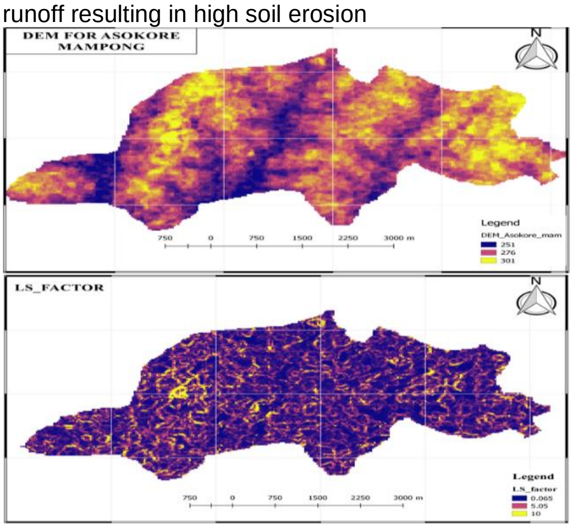

Figure 6. Map of digital elevation data – top image, and the derived LS-factor – bottom image.

3.1.4. C-factor

The cover management factor (C-factor) for the Asokore Mampong Municipality is presented in Figure 7, with values ranging from 0.01 to 0.44. The C-factor is computed from the average Normalize Difference Vegetation index (NDVI) data with the formula; C-factor = 0.431 – 0.805*NDVI (De Jong, 1994), to generate the C-factor output. The results indicate greater portion of the study area is residential areas with few scattered forest areas. The high C-factor values for settlement area indicate high vulnerability to soil erosion, as soil surfaces are unprotected, with only the few scattered forest areas protecting the land from soil erosion.

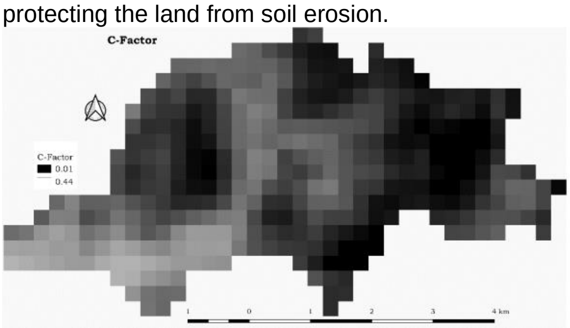

Figure 7. Map of C-factor derived using on NDVI data

3.1.5. P-factor

The Municipality lack support documents of land management practices, that is, there is no known management practice in this area. But the main known land use activities in the Municipality include urban areas, scattered crop farming, and construction. These human activities have impact on the landscape, such as increase the rate of soil loss in the Asokore Mampong Municipality. The P-factor of 1.0 was used, indicating that no management practice is under consideration.

3.2. The annual soil loss in Asokore Mampong municipality

The spatial distribution of soil loss in the Asokore Mampong municipality was obtained from multiplication of the five RUSLE factors (R, K, LS, C and P) using the raster calculator in QGIS software as shown in the graphical modeler. The resulting spatial distribution of the soil loss is presented in Figure 8, showing the rate of soil loss across the whole study area. The soil loss varies from a low value of 30tons/ha/yr to a high value of 440tons/ ha/yr. The result shows that a large portion of the soils in the Municipality have an annual soil erosion of about 30tons/ ha/yr. As observed, erosion is not intensely spread across the entire municipality, but concentrated at the south western part of the municipality. Areas characterized by the high soil loss should be spatially targeted for conservation measures to reduce or control the rate of soil erosion by means of conservation planning. Moreover, the management of moderate soil erosion hazard should be in place to protect areas of less erosion from further erosion, vegetation degradation and removal and maintenance through plantations.

JOURNAL OF APPLIED GEOSPATIAL INFORMATION

Vol 3 No 1 2019

http://jurnal.polibatam.ac.id/index.php/JAGI
ISSN Online: 2579-3608

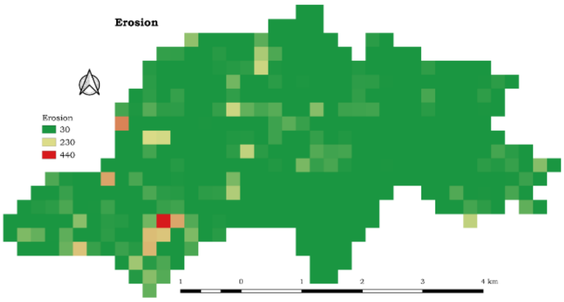

Figure 8. Map of spatial distribution of annual soil loss (in tons/ha/yr) in Asokore Mampong

4. Conclusion

This study has developed an automated workflow for the RUSLE model in QGIS to determine the average annual soil loss in Asokore Mampong municipality in Ghana. The automated workflow was developed using graphical modeler facility in QGIS, by simultaneously allowing access to data and geoprocessing functionalities to execute multiple tasks to obtain the final output. The automation procedure allows visualization of workflows, quick execution of several tasks, and is free of human error. The developed RUSLE workflow in QGIS ensure the availability of the model, automation for any specific area, and its execution to the general public.

The study found that soil erosion can be spatially targeted in a way that vulnerable areas are uniquely identified for remediation efforts. The spatial targeting of soil loss is crucial for cost-effective mitigation plans, in order to implement conservation practices that will result in optimal reduction in soil loss. The spatial nature of data inputs and the RUSLE output facilitates the examination of the impact of each factor on the resulting soil loss. The spatial distribution of the average annual soil loss in the study area was found to be largely controlled by topography, land cover/use and silt content. Areas dominated with vegetation and relatively flat terrain are mostly associated with low levels of soil erosion.

References

AMMA (2017). Asokore Mampong Municipal Assembly Medium Term Development Plan (2014-2017). Annual Report.

Anurogo, W., & Lubis, M. Z. (2018). Modified Soil-Adjusted Vegetation Index In Multispectral Remote Sensing Data for Estimating Tree Canopy Cover Density at Rubber Plantation. Journal of Geoscience, Engineering, Environment, and Technology, 3(1), 15-24.

Belasri A., Lakhouili A., and Halima Iben O. 2017. Soil erodibility mapping and its correlation with soil properties of Oued El Makhazine watershed, Morocco. Journal of Materials and Environmental Sciences. ISSN : 2028-2508. 8(9): 3208-3215.

De Jong, S. M. (1994) Application of Reflective Remote Sensing for Land Degradation Studies in a Mediterranean Environment (Utrecht: Netherlands Geographical Studies, University of Utrecht).

Foster GR, Yoder DC, Weesies GA, McCool DK, McGregor KC, Bringer RL (2002). User's Guide—revised universal soil loss equation version 2 (RUSLE 2). USDA-Agricultural Research Services, Washington, DC.

Fujaco Maria Augusta Gonçalves, Leite Mariangela Garcia Praça, and Neves, Antônio Henrique Caldeira Jorge. 2016. A gis-based tool for estimating soil loss in agricultural river basins. REM: Int. Eng. J., Ouro Preto, 69(4), 417-424, http://dx.doi.org/10.1590/0370-44672015690197.

Ghana Statistical Service (2014). Population and Housing Census, Ashanti Regional Analytical Report.

Ghana Statistical Service. (2012). Asante Akim North District; Ghana Statistical Service.

Joshi Veena U. 2018. Soil Loss Estimation based on RUSLE along the Central Hunter Valley Region, NSW, Australia. Journal Geological Society of India, Vol.91, May 2018, pp.554-562, doi: 10.1007/s12594-018-0904-z.

Karaburun Ahmet. 2010. Estimation of C factor for soil erosion modeling using NDVI in Buyukcekmece watershed. Ozean Journal of Applied Sciences 3(1): 77-85.

Kostadinov, S., (2002). Erosion and Torrent Control in Mountainous Regions of Serbia. Preceeding Keynote Paper, International Year of Mountainous Conference. Natural and Socio-economic Effects of Erosion Control in Mountainous Regions.

Le Van Bien, Phuoc Minh Truong, Thi An Tran, and Raghavan Venkatesh. 2014. An Open Source GIS Approach for Soil Erosion Modeling in Danang City, Vietnam. International Symposium on Geoinformatics for Spatial Infrastructure Development in Earth and Allied Sciences 2014.

Meyer, L. D (1984). Evaluation of the universal soil loss equation, J. Soil Water Conserv., 39, 99–104.

Millward A, Mersey JE (1999). Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena 38:109–129.

Ozsoy G, Aksoy E, Dirim M,Tumsavas Z (2012). Determination of Soil erosion risk in the Mustafa kemalpasa River Basin, Turkey using the revised universal soil loss equation, geographic information system, and remote sensing. Environ Manag 50:679–694.

Prasannakumar V, Vijith H, Abinod S, Geetha N (2012). Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using revised universal soil loss equation (RUSLE) and geo-information technology. Geosci Front 3:209–215.

Raissouni, A., L.K. Issa, A. El. Arrim, M. Maatouk and R Passalacqua (2012). GIS Based Model to Assess Erosion Sensitivity in Northern Morocco, Laou Watershed Case Study. International Journal of Geosciences, 2012, 3, 610-626.

Renard, K. G., Foster, G. R., Weesies, G. A., McCool, D. K., and Yoder, D. C (1997). A guide to conservation planning with the revised universal soil loss equation (RUSLE), S.US Department of Agriculture, Agricultural Handbook, No. 703.

Roose, E. J. (1975) Erosion et ruisellement en Afrique de l'ouest: vingt annees de mesures en petites parcelles experimentales Cyclo. ORSTOM, Adiopodoume, Ivory Coast.

Sinha, Abhishek P. and Regulwar D.G. 2015. Soil Erosion Estimation of Watershed Using Quantum Geographic Information System (QGIS) and Universal Soil Loss Equation (USLE). International Journal of Science and Research (IJSR). ISSN (Online): 2319-7064, pp: 173-176.

Wischmeier WH, Smith DD (1978). Predicting rainfall erosion losses: a guide to conservation planning. USDA Handbook 537, Washington DC.

Wischmeier, W. H. and Smith, D. D (1965). Predicting rainfall erosion losses from cropland east of the Rocky Mountains: guide for selection for practices for soil and water conservation, in: Agriculture handbook. Department of Agriculture, Science and Education Administration, Washington.

Wischmeier, W.H. (1959) A rainfall erosion index for a universal soil loss equation. Soil Sci. Sec. Amer., Proc., v.23, pp.246-249.

Wischmeier, W.H. And Smith, D.D. (1962) Soil loss estimation as a tool in soil and water management planning, Int. Assoc. Scient. Hydrol. Pub. 59, pp.148-159.