Research article

Estimation of Soil Erosion Based on USLE and GIS in Gardez Basin of Paktya Province, Afghanistan

ABDUL MALIK DAWLATZAI
Graduate School of Agriculture, Tokyo University of Agriculture, Tokyo, Japan
Email: abduldawlatzai@gmail.com

MACHITO MIHARA*
Faculty of Regional Environmental Science, Tokyo University of Agriculture, Tokyo, Japan
Email: m-mihara@nodai.ac.jp

Received 13 December 2016 Accepted 26 June 2017 (*Corresponding Author)

Abstract Soil erosion is a serious problem in Afghanistan, which has been accelerated by improper land management day by day and a growing problem especially in agricultural land. The land in the country is facing continuous soil loss and sediment accumulation due to the irregular topography, deforestation and desertification. It does not only reduce agricultural and livestock production, but also decrease the water availability for irrigation purpose. This study focused on the estimation of the rate of soil loss and soil erosion risk using Universal Soil Loss Equation (USLE) and ArcGIS for the Gardez basin Paktya Province, Afghanistan. All factors used in USLE (R, K, L, S and C) were calculated for the study area using local data. The best equation for estimating the R value from the annual rainfall was discussed on the basis of the observed annual rainfall with the installed rain gauge. Also, all factors were presented by raster layers in ArcGIS platform then multiplied together to predict soil loss (A). The results indicated that the annual soil loss within Gardez Basin ranges from 0 to greater than 100 t ha^{-1} y^{-1}. The value was divided into five (5) risk classes. The result showed that slight class of soil loss having a range of soil loss between 0 to 5 t ha^{-1} y^{-1}, moderate class having rates between 5 to 10 t ha^{-1} y^{-1}, high class having rates between 10 to 50 t ha^{-1} y^{-1}, severe class rates between 50 to 100 t ha^{-1} y^{-1} and very severe class rates greater than 100 t ha^{-1} y^{-1}, covering 64.31%, 13.95%, 19.76%, 1.76% and 0.22% of the Gardez Basin area, respectively. Most of the agricultural lands are slight to high soil loss categories. However, high soil erosion is found in the barren land, rangeland and rainfed agricultural land. The soil erosion risk is extremely higher on steep slope and foothills. Based on the mean soil erosion value of different land use classes, target land use for conserving strategies was discussed for planning soil conservation practices.

Keywords USLE, ArcGIS, Gardez Basin, soil loss, Afghanistan

INTRODUCTION

Erosion is one of the major ecological problems which threaten our national reserves as well as the whole world. It also reduces soil fertility significantly and crop yields. Afghanistan is located in the south and central Asia which is under high soil erosion effect mostly due to deforestation, arid and semi-arid climates and irregular topography. Soil erosion has resulted in prolonged and great impact on social and economic development in the region, in fact, recent environmental assessments indicated that decades of war and continuous drought have caused widespread environmental degradation throughout the country.

The Universal Soil Loss Equation (USLE) was developed by Wischmeier and Smith in 1978. It has been the most commonly used model for predicting soil erosion loss. The USLE and its modified versions such as RUSLE (Renard et al., 1997) and MUSLE (Williams, 1975) have been widely used in various scales and regions.

Soil erosion has received scanty attention in Afghanistan. However, the study conducted by Sahaar, (2013) using combined Revised Universal Soil Loss Equation (RUSLE) model and Geographic Information System (GIS), the annual soil loss of Kabul Rivers was estimated 19 t acr^{-1} y^{-1}, (4748 t km^{-2} y^{-1}). The excessive sedimentation clogs stream channels and increase costs for maintaining water passage structures. Similarly, the annual soil loss of the Lower Harirud watershed in Heart province used RUSLE model and GIS ranges from 0.025 to 778 Mg ha^{-1} y^{-1}, which is 3.6 times greater than maximum tolerable soil erosion (Ehsan, 2015). Field study conducted by US Military Agricultural Development Team, (2011) in the Dawlatzai village of Paktya Province, soil erosion depended on area ranges between 500 t/ha to 1200 t/ha.

Estimation of soil erosion is economically and environmentally very important in Paktya province, Afghanistan. Soil erosion does not only reduced soil fertility and water quality but also severe interrupts irrigation network. Poor vegetation cover, steep slopes, deforestation and high intensity rainfall in short time are the main factors influencing soil erosion in Paktya province. Therefore, to evaluate the impact of these factors on sustainable agriculture and environment, to quantify the extent of soil erosion it needs for appropriate and applicable erosion model. For this reason, the USLE model has been widely used worldwide approximately more than four decades to predict soil erosion. Recently, there are many types of research conducted regarding the USLE model in conjunction with GIS technology which has been used to predict the annual soil loss. The objective of this study is to evaluate soil erosion risk using ArcGIS technique and empirical Universal Soil Loss Equation in Gardez basin of Paktya Province, Afghanistan.

MATERIALS AND METHODS

Study Area

The study was conducted in Gardez Basin located east part of the country and also it is the capital of Paktya Province, Afghanistan. The basin covers approximately 48,104 ha (481.04 km^2) as shown in Fig 1. It is geographically positioned between latitude N 33° 46′ 0″- N 33° 28′ 0″ and longitude E 69° 26′ 30″- E 69° 26′ 30″. It topographically ranges in slope between 0 to 65 degrees with an elevation of approximately 3663 m above sea level. The rainfall data was obtained from the daily automatic rain gauge installed in the study area for one-year duration (July 15, 2015 to July 14, 2016), the annual rainfall is 354.6 mm y^{-1} and exhibits a dry climatic condition with a minimum and maximum temperature of -11 °C and 41 °C, respectively.

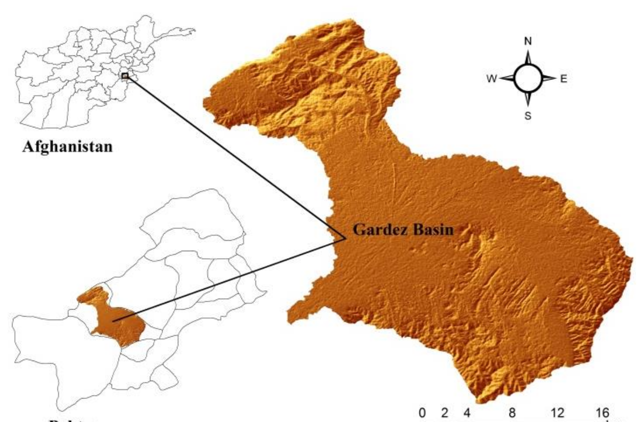

Fig. 1 Map of study area in Paktya Province, Afghanistan

Methods

The USLE model was developed by Wischmeier and Smith (1978), as an equation representing the main factors controlling soil erosion, namely climate, soil characteristics, topography and land cover management. The expression is shown in Eq. 1.

$$A= R\times K\times L\times S\times C\times P \quad (1)$$

Where A is computed annual soil loss per unit area (t ha^{-1} y^{-1}), R is runoff erosivity factor (MJ mm ha^{-1} y^{-1}), K is soil erodibility factor (t ha hr ha^{-1} MJ^{-1} mm^{-1}), L is slope length factor, S is slope steepness factor, C is cover management factor and P is supported practice factor.

In the present study, annual soil loss rates and scale were computed based on USLE in GIS platform and different data sources were referred to analyze the estimation of soil loss in the study area. A digital elevation model (DEM) with 30 m resolution was obtained from Aster Global Digital Elevation Model (Available online: https://asterweb.jpl.nasa.gov/gdem.asp), the elevation range is from 2205 m to 3663 m as shown in Fig. 2. The DEM was used to estimate slope gradient, flow direction, basin area, flow length and flow accumulation for the study area using ArcGIS 10.3.1. The slope length and slope steepness (LS) factor required by USLE was calculated. The land cover classification map developed by Food Agriculture Organization (FAO, 2016), was used for the analysis of crop management factor (C-value). Soil classification map developed by United States Department of Agriculture, Soil Conservation Services (USDA-SCS, 2001) was used for analyzing the soil erodibility factor (K-value). Analysis of rainfall erosivity factor (R-value) was derived from area automatic rain gauge data in Gardez city and mean annual rainfall data in surrounding areas.

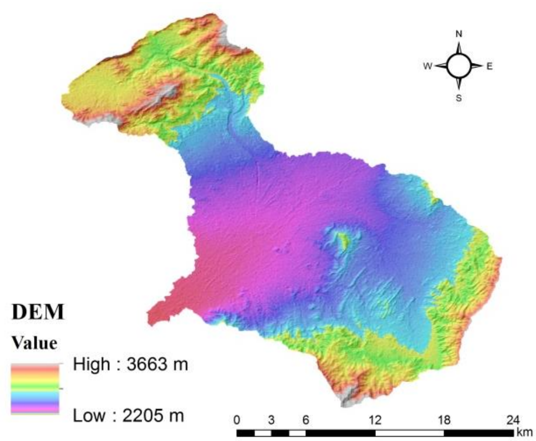

Fig. 2 DEM map of Gardez Basin

RESULTS AND DISCUSSION

Rainfall Erosivity Factor (R)

Rainfall erosivity is defined as the aggressiveness of the rain to cause erosion. Rain has a direct impact on the surface of the soil. The kinetic energy of the raindrops destroys the soil aggregates, making them susceptible to transfer by runoff water. The R factor was computed using the Eqs. 2 and 3 developed by Wischmeier and Smith (1978).

$$KE = 11.87 + 8.73 \log I \quad (2)$$

Where I is the rainfall intensity (mm h^{-1}) and KE is the kinetic energy (Jm^{-2} mm^{-1}).

$$R = \frac{\sum EI_{max}}{1000} \quad (3)$$

R is rainfall erosivity factor in MJ m km^{-2} h^{-1} y^{-1} and EI is the total storm energy in Jm^{-2} mm^{-1}. The R value was calculated from energy-intensity relationships. Daily rainfall data was recorded using automatic rain gauge located in the study area for the duration of one year, (July 15, 2015 to July 14, 2016). Using Eq. 2 and 3, the data in Table 1 was obtained.

Table 1 Calculation of the erosivity factor

Max. intensity ($mm\ hr^{-1}$)	Total energy ($J\ m^{-2}$)	Rainfall erosivity ($MJ\ m\ km^{-2}\ hr^{-1}\ y^{-1}$)	Rainfall erosivity ($MJ\ mm\ ha^{-1}\ hr^{-1}\ y^{-1}$)
3.95	402.06	1.59	15.9
3.72	343.16	1.28	12.8
3.57	272.62	0.97	9.7
3.98	270.63	1.08	10.8
21.27	292.55	6.22	62.2
8.20	294.06	2.41	24.1
11.11	341.36	3.79	37.9
15.88	277.45	4.41	44.1
Total		21.75	217.5

Using the data obtained from the automatic rain gauge installed in the study area for one-year duration, the R-factor value was calculated as 21.75 MJ m km^{-2} hr^{-1} y^{-1} (217.5 MJ mm ha^{-1} hr^{-1} y^{-1}). The original method for calculating the R value for a storm event requires rainfall amount in mm, intensity in mm h^{-1} and the maximum 30 minutes intensity in mm h^{-1}. Due to lack of adequate metrological data and long-term rainfall intensity data in some countries such as Afghanistan, it is hard to apply Eq. 2 and 3. It is therefore necessary to interpolate between available data hence, the attention should be paid to investigate new methods and equations to calculate the erosivity factor using annual rainfall. R factor based on annual precipitation were computed using various equations shown in Table 2.

Table 2 List of equations used to investigate correlation

No	Reference	Equation
1	Morgan, 1974	R = 2.28P - 8,838
2	Foster et al., 1981	R = (0.27P75)/100
3	Cooper, 2011	$R = 9.17P^{0.20}$
4	Eltaif et al., 2010	$R = 23.61e^{(0.0048P)}$
5	Deumlich et al., 2006	R = 12.98 + 0.0783P
6	Renard and Fremund, 1994	$R = 0.04830P^{1.510}$
7	Yu and Roswell, 1996	$R = 0.0438P^{1.61}$
8	Parveen and Kumar, 2012	R = 29 + 0.363P
9	Singh et al., 1981	R = 79 + 0.363P
10	Arnoldus, 1980	$R = 0.03P^{1.9}$
11	Renard and Freimund, 1993	$R= 0.07397F^{1.847}/17.02$
12	Roose, 1975	R = 0.5P

However, the erosivity index calculated using Eq. 4 by Singh et al., 1981 showed the best fit was achieved between R value calculated with USLE and the mean annual rainfall for the Gardez Basin. The results based on Eq. 4 was summarized in Table 3.

$$R = 79 + 0.363P \quad (4)$$

Where P is the mean annual precipitation (mm) and R is the erosivity factor (MJ mm ha^{-1} hr^{-1} y^{-1}). In terms of ArcGIS layers, each weather station was represented by a point. The Inverse Distance Weighted (IWD) interpolation method in ArcGIS was used to create a raster map for R factor. However, rainfall erosivity (R) was calculated using rainfall data from six rainfall stations across the Gardez Basin. The high erosivity was found in the northeast and low erosivity was found in the southwest part of Basin. The R-factor varied from 157.58 to 199.72 MJ mm ha^{-1} hr^{-1} y^{-1} as shown in Fig. 3.

Table 3 Rainfall erosivity, (R value)

No	Station	Rainfall (mm y^{-1})	R value (MJ mm ha^{-1} hr^{-1} y^{-1})
1	Tera Garden (Gardez city)	333	199.88
2	Rhoni Baba farm (Zarmat District)	216	157.41
3	Khost (Province)	330	198.79
4	Sharana (Paktika Province)	219	158.50
5	Urgoon (Paktika Province)	252	170.48
6	Logar (Province)	294	185.72

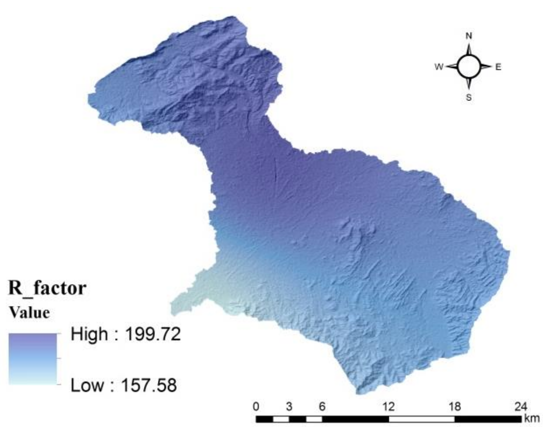

Fig. 3 Rainfall erosivity map of Gardez Basin

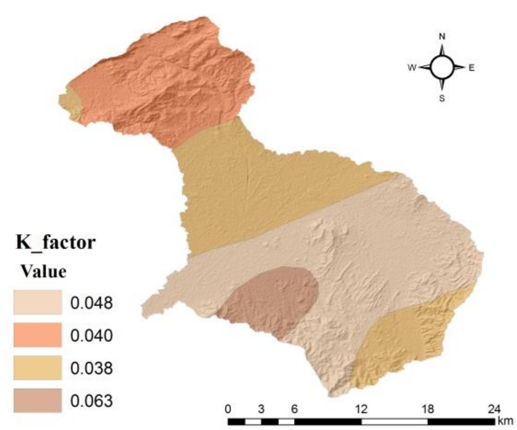

Fig. 4 Soil erodibility map of Gardez Basin

Soil Erodibility Factor (K)

The soil erodibility factor indicates susceptibility of soil particles or surface materials to be detached and transported by rainfall and runoff (Renard et al, 1997). Soil erodibility factor was obtained from soil classification map of the country which is presented by USDA-SCS, 2001 as shown in Fig. 4. Based on the classification of soil and soil texture classes, the K factors (t ha hr ha^{-1} MJ^{-1} mm^{-1}) are shown in Table 4.

Table 4 Soil classification and erodibility values

No	Soil classification	Soil texture	Order	K value
1	Xerochrepts with Xerorthents	Silt loam	Xeric	0.048
2	Haplocambids with Torriorthents	Silt loam	Aridic	0.040
3	Torriorthents with Torrifluvents	Silt clay loam with cobbly loam	Aridic	0.038
4	Haplocambids with Torriorthents	Silt loam with fine sand	Aridic	0.063

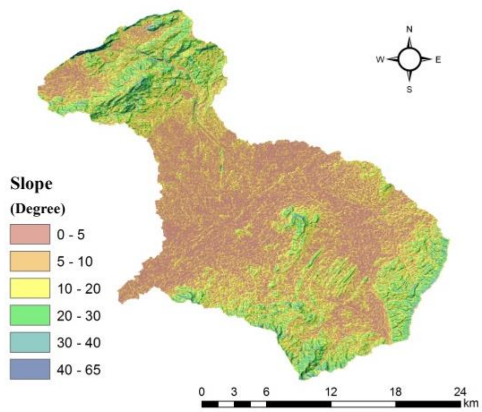

Fig. 5 Slope map of the Gardez Basin

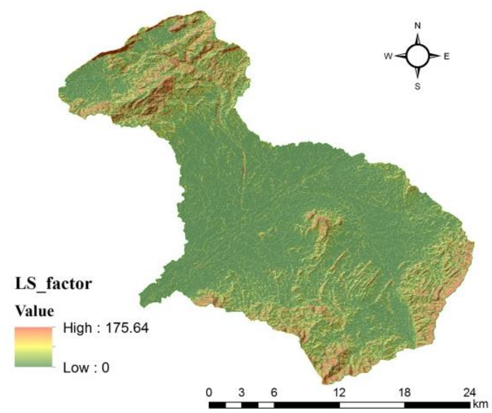

Fig. 6 LS-factor map of Gardez Basin

Slope Length and Slope Steepness Factor (LS)

The LS factor has been used in a single index, which expresses the ratio of soil loss as defined by Wischmeier and Smith, 1978.

$$LS = (X/22.1)^m (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.065) \quad (5)$$

Where, X is slope length (m); θ is the angle of slope in degrees; and m is a constant dependent on the value of the slope gradient: 0.5 if the slope angle is greater than 2.86 degree, 0.4 on slope of 1.72 to 2.85 degrees, 0.3 on slope of 0.57 to 1.72 degrees, and 0.2 on slopes less than 0.57 degrees. Erosion increases as slope length and slope steepness increases. The slope length (L) and slope steepness (S) are combined in a single topographic index termed LS-factor was computed for the Gardez Basin by using spatial analyst extension in ArcGIS software has used to generate raster layers of the slope. The slope of Gardez Basin range values between 0 to 65 degree and was derived from the DEM as shown in Fig. 5.

First step, the elevation value was modified by filling the sinks in the grid. Second step Flow direction was generated from the fill grid. Third step the flow accumulation was calculated and generated from the flow direction. Flow accumulation tool identifies how much surface flow accumulates in each cell; cells with high accumulation values are usually stream or river channels and also recognizes local topographic feature such as mountain peaks and ridgelines. Finally, raster calculator function under Spatial Analyst tool was used to input the modified Eq. 5. To compute LS factor. The values between 0 to 175.64 as shown in Fig. 6.

Crop Management Factor (C)

The crop management factor (C factor) is the ratio of soil loss of a specific crop to the soil loss under the condition of continuous fallow (Renard et al., 1997). It measures the effect of canopy and ground cover on the hydraulics of raindrop impact and runoff.

C factor is a relation between erosion on bare soil and erosion observed under a cropping system. It varies from 1 on bare soil to 1/1000 under dense forest, 1/100 under grasslands and plants and 1 to 4/10 under root and tuber crops (Morgan, 2005). Based on the national land cover map published by FAO-UN, 2016, the land cover classification of the Gardez basin has 11 classes. Therefore a crop management factor (C factor) was assigned for each land use type from the literature reviewed as shown in Fig. 7.

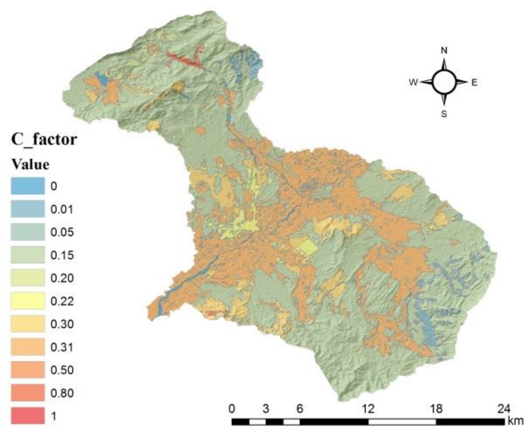

Fig. 7 C factor map of Gardez Basin

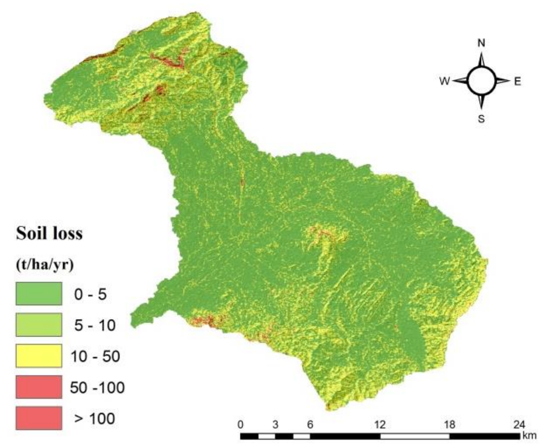

Fig. 8 Soil loss map of Gardez Basin

Conservation Practice Factor (P)

Factor P in USLE model expresses the effect of conservation practices that reduce the amount and rate of water runoff, which decrease erosion. It is the ratio of soil loss with specific support practice to corresponding soil loss with upslope and downslope parallel tillage (Renard et al, 1997 and Wischmeier and Smith, 1978). Currently, there are no support practices in the study area, hence P is assigned value of 1 in the calculation.

Estimated Soil Loss

The data layers (maps) extracted for R, K, LS and C factors of the USLE model were multiplied within the raster calculator of ArcGIS spatial analyst in order to generate the map of soil loss for Gardez Basin. The final map presents the annual soil loss t ha^{-1} y^{-1} a pixel level. The soil loss values estimated for Gardez basin ranges from 0 to > 100 t ha^{-1} y^{-1} which is shown in Fig. 8.

The annual soil loss map obtained was classified into 5 classes. The results presented in Table 5 shows that about 64.31% of the study area is classified as slight erosion risk (0 - 5 t ha^{-1} y^{-1}), 13.95% of the area is classified as moderate soil erosion risk (5 - 10 t ha^{-1} y^{-1}), 19.76% of the area is classified as high soil erosion risk (10 - 50 t ha^{-1} y^{-1}), 1.76% of the area is classified as severe soil erosion risk (50 - 100 t ha^{-1} y^{-1}) and 0.22% of the area is classified as very severe soil erosion risk (greater than 100 t ha^{-1} y^{-1}). The higher soil loss is due to high slope steepness, very poor vegetation and no conservation practices which are the most prominent causes of soil erosion, severe and very severe soil erosion risk classes mainly located in mountains/foothills.

Table 5 Annual soil loss rate and risk categories

Soil loss (t ha^{-1} y^{-1})	Risk categories	Area (ha)	Area (%)
0 - 5	Slight	30,934	64.31
5 - 10	Moderate	6,713	13.95
10 - 50	High	9,503	19.76
50 - 100	Severe	847	1.76
> 100	Very severe	107	0.22
Total		48,104	100.00

(Morgan et al., 2004)

The land use map of country was developed by FAO-UN 1993 and subsequently updated in 2016 (FAO-UN). Land use classification map of Gardez basin consists of 11 classes as shown in Fig. 9, that are explained as follows; irrigated agricultural land, rainfed agricultural land, rangeland, rangeland/barren land, barren land, barren land/rangeland, forest and shrubs, fruit trees, vineyards, built up and water bodies and marshland. Rangeland is the most scattered land covering over 59% of the total area, irrigated agricultural land covers 24.5%, forest and shrubs covers 2.1% and built up areas covers 3.2% of the Gardez basin as shown in Table 6.

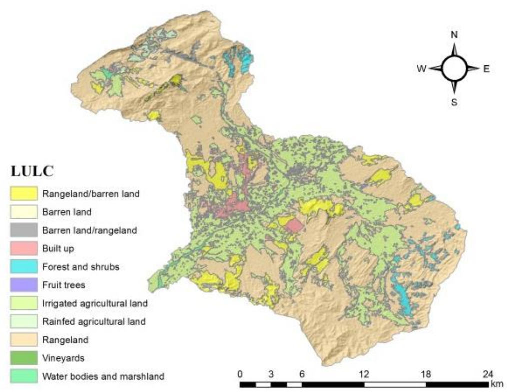

Fig. 9 land use map of Gardez Basin (FAO, 2016)

Table 6 Dominate land use/land cover in different mean annual soil loss rate

No	LULC	Area (ha)	Area (%)	Mean soil erosion (t ha^{-1} y^{-1})
1	Rangeland	28529	59.31	7.18
2	Rangeland/barren land	3731	7.76	11.26
3	Forest and shrubs	1045	2.17	2.21
4	Built-up	1687	3.51	2.67
5	Irrigated agriculture land	11806	24.54	3.48
6	Water bodies and marshland	427	0.89	2.77
7	Fruit trees	273	0.57	2.28
8	Vineyards	4	0.01	2.86
9	Rainfed agriculture land	409	0.85	6.39
10	Barren land	2	0.00	11.54
11	Barren land/rangeland	191	0.40	74.81

In order to identify average soil erosion rates for different land use classes of Gardez Basin, land use/land cover map of the study area was intersected with classified soil erosion map. From Table 6, it is clear that high levels of soil erosion classes are found on the fallow land, barren land/rangeland, barren land, rangeland/barren land, rangeland and rainfed agricultural land. The annual average soil erosion is lower in the forest/shrubs and fruit trees. Moreover, slight, moderate, high, severe and very severe soil loss area which was obtained based on land use map approximately, 30,933.96, 6,713.24, 9,503.04, 846.89 and 106.87 ha shown at Table 7, respectively. In addition, irrigated and rainfed agricultural lands area is about 12,215 ha of the total area and also most parts soil losses occur in slight to high soil loss categories. Since most of the agricultural lands are slight to high soil loss classes, immediate attention of soil conservation practices is required. To suggest site specific sustainable land use practices for controlling slight to high soil erosion risks, this result allows assessment of soil loss quantitatively, identify the risk zones and draw appropriate planning measure for implementing optimal land use management practices.

Table 7 Risk categories of Gardez Basin area (ha) based on land use/land cover

No	Risk categories	Slight	Moderate	High	Severe	Very severe	Total
	LULC	0 – 5 t ha^{-1} y^{-1}	5 – 10 t ha^{-1} y^{-1}	10 – 50 t ha^{-1} y^{-1}	50 – 100 t ha^{-1} y^{-1}	> 100 t ha^{-1} y^{-1}	
1	Rangeland	16804.82	3920.66	7215.25	570.58	17.73	28529.04
2	Rangeland/barren land	2089.36	511.15	893.20	210.80	26.49	3731.00
3	Forest and shrubs	909.15	46.29	89.35	0.16	0.00	1044.95
4	Built-up	1365.96	215.94	102.06	2.36	0.67	1687.00
5	Irrigated agriculture land	8813.18	1888.96	1074.35	27.15	2.36	11806.00
6	Water bodies and marshland	384.00	35.48	7.00	0.30	0.21	427.00
7	Fruit trees	259.00	12.99	0.79	0.22	0.00	273.00
8	Vineyards	3.80	0.20	0.00	0.00	0.00	4.00
9	Rainfed agriculture land	252.60	74.07	77.10	5.24	0.00	409.00
10	Barren land	0.00	0.00	2.00	0.00	0.00	2.00
11	Barren land/rangeland	52.09	7.49	41.94	30.08	59.40	191.00
	Total	30933.96	6713.24	9503.04	846.89	106.87	48103.99

CONCLUSION

The present study indicates that using GIS technologies for soil loss mapping, based on the USLE model provided satisfactory results. Different components of USLE model were used with mathematical equations; the rainfall erosivity R-factor calculated, using USLE method (rainfall in mm, intensity in mm hr^{-1}, maximum 30 minutes intensity in mm hr^{-1}) from daily automatic rain gauge is 217.5 MJ mm ha^{-1} hr^{-1} y^{-1} and the R-factor calculated based on annual rainfall amount using various equations, range between 157.58 to 199.72 MJ mm ha^{-1} hr^{-1} y^{-1}. However, the best fit was achieved between the R value from USLE method and annual rainfall for Gardez Basin. Soil erodibility factor (K) which was obtained from soil classification map range between 0.038 to 0.063 t ha hr ha^{-1} MJ^{-1} mm^{-1}. Slope length and slope steepness factor (LS) values obtained from DEM between 0 to 175.64. Crop management factor (C) values were obtained from land cover classification map range between 0 to 1.

The final map presents the annual soil loss, the values range from 0 to greater than 100 t ha^{-1} y^{-1}, and classified into five (5) classes; includes that about 64.31% of the study area is slight erosion risk (0 - 5 t ha^{-1} y^{-1}), 13.95% of the area is moderate soil erosion risk (5 - 10 t ha^{-1} y^{-1}), 19.76% of the area is high soil erosion risk (10 – 50 t ha^{-1} y^{-1}), 1.76% of the area is classified as severe soil erosion risk (50 – 100 t ha^{-1} y^{-1}) and 0.22% of the area is classified as very severe soil erosion risk (greater than 100 t ha^{-1} y^{-1}).

Most of the agricultural lands are classified slight to high soil loss. However, high soil erosion is found in the barren land, rangeland and rainfed agricultural land. The soil erosion risk is extremely higher on the steep slope and mountains/foothills. The land use map of the study area was prepared and the average annual soil loss for different land use will be highly useful in recognizing the priority areas for application of land use practices and soil conservation measures in Gardez Basin. The rainfed and irrigated agricultural lands require immediate attention for soil conservation practices. Based on the result of this study, the estimated soil loss and proposed land use map could be an effective input for the future planning and implementing soil conservation strategy in the eastern part of Afghanistan.

ACKNOWLEDGEMENTS

The authors are profoundly grateful to Department of Agriculture Engineering, Tokyo University of Agriculture and Japan International Cooperation Agency (JICA).

REFERENCES

Arnoldus, H.M.J. 1980. An approximation of the rainfall factor in the universal soil loss equation. In De Boodt M, Gabriels D (eds) Assessment of Erosion. Wiley, Chichester, 127-132.

Cooper, K. 2011. Evaluation of the relationship between the RSULE R-factor and mean annual precipitation. http://www.engr.colostate.edu/~pierre/ce_old/Projects/linkfiles.

Deumlich, D., Funk, R., Frielinghaus, M.O., Schmidt, W.A. and Nitzsche, O. 2006. Basics of effective erosion control in German agriculture. Journal of Plant Nutrition and Soil Science, 169, 370-381.

Ehsan, M. 2015. Estimation of soil erosion potential in Herat Province, Afghanistan. Graduate School of Life and Environmental science, Shimane University, Japan.

Eltaif, N.I., Gharaibeh, M.A., Al-Zaitawi, F. and Alhamad, M.N. 2010. Approximation of rainfall erosivity factors in north Jordan. Pedosphere, 20 (6), 711-717.

FAO. 1993. Land cover database of Afghanistan. www.fao.or/publications.

FAO. 2016. Land cover database of Afghanistan. www.fao.or/publications.

Foster, G.R., Lane, L.J., Nowlin, J.D., Laflen, J.M. and Young, R.A. 1981. Estimating erosion and sediment yield on field sized areas. Transactions of the American Society of Agricultural Engineers, 24, 1253-1263.

Morgan, R.P.C. 1974. Estimating regional variations in soil erosion hazard in Peninsular Malaysia, Malayan Nature Journal, 28, 94-106.

Morgan, R.P.C. 2005. Soil erosion and conservation, (3rd edition). National Soil Resource Institute Cranfield University.

Morgan, R.P.C., Hann, M.J., Shilston, D., Lee, E.M., Mirt Skhoulava, Ts.E., Nadirashvili, V., Topuria, L., Clarke, J. and Sweeney, M. 2004. Use of terrain analysis as basis for erosion risk assessment, A case study from pipeline rights of way in Georgia.

Parveen, R. and Kumar, U. 2012. Integrated approach of universal soil loss equation (USLE) and geographical information system (GIS) for soil loss risk assessment in Upper South Koel basin, Jharkhand. Journal of Geographic Information, 4 (6), 588-596.

Renard, K., Foster, G., Weesies, G., McDool, D. and Yoder, D. 1997. Predicting soil erosion by water, A guide to conservation planning with the revised universal soil loss equation (RUSLE). Agriculture Handbook, 703, USDA-ARS, USA.

Renard, K.G. and Freimund, J.R. 1993. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology, 157, 287-306.

Roose, E.J. 1975. Erosion et ruisellement en Afrique de l'ouest: vingt annies de measures enpetites parcelles experimentales. Cyclo. ORSTOM, Adiopodoume, Ivory Coast.

Sahaar, A.S. 2013. Erosion mapping and sediment yield of Kabul River Basin, Afghanistan. M.Sc. thesis presented at the Department of Civil and Environmental Engineering. Colorado State University, USA.

Singh, G., Babu, R., Narain, P., Bhushan, L.S. and Abrol, I.P. 1981. Soil loss and prediction research in India. Bulletin, No. T, 12/D9. Central Soil and Water Conservation Research Training Institute, Dehra Dun, India.

US. Agriculture Development Team (US-ADT). 2011. Dawlatzai watershed report and project proposal.
USDA-SCS. 2001. Soil map and soil climate map. Soil Science Division, World soil resources. Washington D.C. USA. http://soils.usda.gov/use/worldsoils/mapindex/afghanistan-soil.html.
Williams, J.R. 1975. Sediment yield prediction with universal equation using runoff energy factor. In Present and Prospective Technology for Predicting Sediment Yield and Sources ARS, s-40, USDA, WA, USA.
Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses, A guide to conservation planning. U.S. Department of Agriculture, Agriculture Handbook No. 537, USA.
Yu, B. and Rosewell, C.J. 1996. Technical notes, A robust estimator of the R-factor for the universal soil loss equation. Transactions of American Society of Agricultural Engineers, 39 (2), 559-561.