Int. J. Forest, Soil and Erosion, 2011 2 (2):101-104
ISSN 2251-6387

Research Paper

Prediction of sediment associated Organic mater loss in a Hyrcanian watershed, Iran

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Received: September 6, 2011 **Accepted:** March 2, 2012

Abstract: Suspended sediment moving in watershed provides a path way for the transport of sediment associated contaminant. Information on sediment and nutrient export from catchments and about related erosive processes is required by catchment managers and decision-makers. Presently, only the MUSLE model is preferably applied in storm-wise sediment yield prediction in developing country such as Iran, due to a lack of adequate data in one side and necessity of getting access to accurate sediment yield estimates for running developmental projects in other side. The present study aims to estimate the Organic matter (OM) associate sediment due to storm rainfall and runoff in the Kojour forest watershed, Iran. The prediction was made using the MUSLE. The results of the study approved the efficient application of the Calibrated MUSLE in estimating storm-wise OM losses in the study area with an acceptable estimation error of some 33%. The results could facilitate the application of given methods obtained in the present study to other ungauged watershed with similar conditions and leading to the suitable soil and water management.

Keywords: sediment associated contaminant, OM loss, MUSLE, Kojour forest watershed

This article should be referenced as follows:
Noor H, Mirnia S K and Raiesi M B (2012**)**. Prediction of sediment associated Organic mater loss in a Hyrcanian watershed, Iran, **International Journal of Forest, Soil and Erosion**, 2 (2): 101-104.

Introduction

Some contaminant associate with sediment and, thus, their transport and fate in environment is determined by the fate of sediment. Accordingly, suspended sediment moving in watershed provides a path way for the transport of sediment- associated contaminant (Schoellhamer et al. 2007).

Many soil scientists advocate the conservation of soil organic matter (SOM) because of the modifying effects organic matter has on soil properties. Effects include greater water retention and availability, the ability to retain nutrients within the root zone, greater buffering capacity against pH change, contribute to soil structure and form stable aggregates. SOM also influences
environmental processes at a global scale. Topsoils are a huge terrestrial reservoir of carbon (C), which has a modifying effect on carbon dioxide concentrations in the atmosphere and can thus influence climate warming (Rodrıguez Rodrıguez et al., 2004; Lal, 2005; Sparling et al., 2006). Several pollutants such as nutrient, pesticide and heavy metals adsorb on SOM, therefore, in erosion process dramatically eroded along organic matte (OM).

To develop effective watershed management strategies, it is important to quantify the sediment and sediment-associated Nutrient and OM load from watersheds. The most OM Loss from watersheds is exported in particulate form during rainfall events resulting in rapid temporal variations in their load (Hatch et al., 1999; Ide et al., 2008). This makes it difficult to accurately estimate the OM load because of the need for intensive water sampling during periods of highly fluctuating discharge. In the absence of actual measurement data, hydrologists have used model to predict Sediment and sediment associated contaminant in watershed scale. Nutrient and the chemical losses are predicted using simulation models such as ANSWERS, CREAMS, SPNM, EPIC, SWRRB, HSPF and AGNPS (Yoon et al. 1992; Chung et al. 2002). But the input data of these models are not available in Iranian watersheds.

Many researches indicated that the losses of particulate OM components in surface runoff from upland fields were much higher than dissolved ones, and sediment and suspended solids transported these components (Mihara et al., 2005; Zhang et al., 2005; Ide et al., 2008). Therefore, convenient erosion and sediment models can apply to predict OM losses.

Among available soil erosion and sediment yield models, The Universal Soil Loss Equation (USLE) and its revised versions (RUSLE) and its modified version (MUSLE) are used in hydrology and environment engineering (Mishra et al., 2006; Pandey et al., 2009). A large number of the existing erosion and sediment transport models are based on the USLE (Das, 2000). The USLE was basically developed for estimation of the annual soil loss from small plots of an average length of 22 m located in agricultural gentle slope area. Therefore, its application to individual storm events and large areas expects leading to large errors (Kinnell, 2005, Change, 2006; Sadeghi et al, 2007; Pandey et al, 2009). There is no direct consideration of runoff in the USLE for better assessment of storm wise sediment yield at the watershed out let (ASCE, 1970; Williams, 1975; Hrissanthou, 2005; Sadeghi et al, 2007). This model is also not considered an appropriate model for water quality modeling such modeling requires shorter time increments than one year, as well as consideration of both runoff and sediment parameter as transports of pollutants.

An improved erosivity factor was introduced by Williams (1975) to take into account the runoff shear stress effect in terms of product of runoff volume and peak discharge on soil detachment for single storms. Williams (1975) showed that the estimate of stream sediment yield for individual storms could be simplified by using the USLE with its rainfall factor (R) replaced by a runoff index, as the best single indicator for storm-wise sediment yield prediction at the outlet of the watershed. This improves the sediment yield prediction, eliminates the need for delivery ratios, and allows the equation to be applied to individual storm events. Sediment yield prediction is improved because runoff is a function of antecedent moisture condition as well as rainfall energy (Williams, 1975; Williams and Berndt, 1977; Kinnell, 2005; Zhang et al., 2009; Noor et al., 2010).

The MUSLE predict sediment yield for a given watershed as a product of 6 major erosion factors, whose values at a particular location can be expressed numerically and general following form:

$$S = a\,(Q.\,qp)^{\,b}.\,K.\,L.\,S.\,C.\,P \qquad (1)$$

Where S is sediment yield in tons, Q is volume of runoff in m^3, q_p is peak flow rate in $m^3\ s^{-1}$ and K, L, S, C and P are, respectively, the soil erodibility ($t\ h\ t^{-1}\ m^{-1}\ cm^{-1}$), slope length (dimensionless), slope steepness (dimensionless), crop management and soil erosion control practice (dimensionless) (Williams and Berndt, 1977; Das, 2000; Change, 2006; Sadeghi et al, 2007; Pandey et al, 2009; Noor et al., 2010). Presently, only the MUSLE is preferably applied in storm-wise sediment yield prediction in developing country such as Iran, this is due to a lack of adequate data which would otherwise be required.

Mihara et al. (2005) predicted equations of nitrogen and phosphorus losses during soil erosion processes on the basis of the USLE. But, the application of MUSLE has not been reported to predict of nutrient and OM losses yet.

On the basis of available statistics, $300 m^2$ of forests is being continuously depleted per each second in Iran. Forest degradation has therefore become as a major issue in Iran as same as many other progressing countries (Sadeghi et al, 2009) owing to complicated natural and anthropologic driving force. The Hyrcanian area is mainly extended in northern faced aspect of Alborz Mountain range (northern Iran) and therefore receive considerable annual precipitation ranges from 600 to 2000 mm. So, many Iranian rivers flow in this part of the country because of humid climate. Many wet lands, dams and water bodies that economical use and ecological life of which are endangered by the suspended sediment and associated nutrients, located in this region, which logically justify the necessity of sediment and nutrient studies. The present study was therefore formulated to assess the applicability of the MUSLE and to develop and evaluate a calibrated MUSLE for prediction of OM loss in Kojour watershed as a representative watershed parallely located in north of Iran. These watersheds originate from Alborz Mountain range and drain to Caspian Sea.

Materials and methods

The Kojour watershed is located at south east of Nowshahr Township in Mazandaran Province, northern Iran. The general features of the study area is shown in Fig. 1. The basin area is about $500 km^2$ and mainly consisting of forest lands in mid and downstream and rangelands in upstream areas. The highest and the lowest altitude of the watershed are 2650 and 150 m above mean sea level, respectively. The watershed is deeply incised with a dominant hillslope gradient of 25–60% (Sadeghi et al, 2009; Raiesi et al. 2010). Soil in The watershed is brown forest soil, which is classified as Pesdogelly with loamy sand texture.

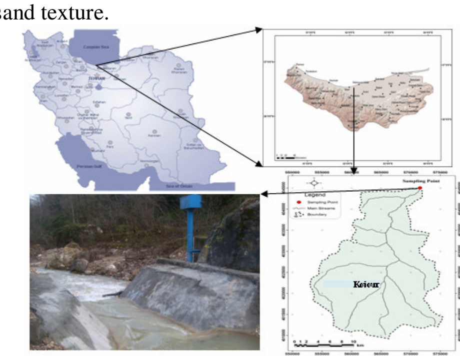

Fig. 1 Location and general view of study forest watershed, northern Iran.

Mean annual precipitation is 1308.8 mm at a plain meteorological station, which reversibly decrease as elevation increases so that the mean annual precipitation at upland station declines to some 250 mm (Raiesi et al. 2010; Noor et al., 2010).

The region including the study site has a humid subtropical climate with a distinct dry season in winter at the lower part and semi-arid and cold at the upper areas of the watershed based on Köppen climate classification.

In order to apply the MUSLE model to the study watershed, 9 storm events were minutely selected. Water flow and suspended sediment concentration (SSC) were monitored at main outlet, with the emphasis on sampling major runoff events. Discharge was calculated by incorporating cross-section and flow velocity data. SSC data were also manually obtained through depth integration method during storm events with the help of 2 lit capacity polyethylene containers (Edwards and Glysson, 1999). Samples were regularly obtained during the flood at 1 hour interval. The SSC values were then determined through settling, decantation and drying by oven and air. Then, the air dried samples were transported to laboratory OM were analyzed with LOI (loss on ignition) method. In 10/10/2008, occurrence of mass movement in river caused increasing sediment concentration when flow was decreasing, therefore, this storm is outed of evaluation.

The corresponding recorded hydrographs and measured sediment graphs and chemographs of OM were then developed and analyzed. The amounts of total storm wise OM adsorbing sediment were then calculated based on their concentration and in conjunction with hydrographs.

The erosivity factor was computed for all the individual rainfall events as a reduced form of the volume and peak rates of runoff were monitored at the mean outlet of the watershed. The soil erodibility factor (K) was determined with the help of soil characteristics for the study watershed (Raiesi et al., 2010). The topographic factor of slope length (L) and steepness (S) were also calculated using following formulae (Sadeghi et al, 2007):

$$L = (\lambda / 22.13)^{\,m} \qquad (2)$$

$$S = 65.4 \sin^2\theta + 4.56 \sin\theta + 0.0654 \qquad (3)$$

Where λ is the projected horizontal distance in meters between the onset of runoff and the point where runoff enters a channel larger than a rill or deposition occurs, m varies from 0.2 for slopes <1% to 0.6 for slopes >10% and θ is the angle to horizontal. The cover management factor (C), was estimated using vegetation cover map of the study area (Raiesi et al., 2010). The average density cover was estimated some 75% (Sadeghi et al, 2009). The conservation practice factor (P) was also supposed as unit, since no conservation measures were applied in the study watershed (Ozhan et al, 2005; Sadeghi et al, 2007).

The MUSLE was then run on a storm basis using the data set collected for 9 individual storm events occurred during an annual rain season, i.e. late 2008 to early 2009. The P and OM loss per each individual storm were ultimately compared with those obtained through observed data with the criteria of the coefficient of determination (R^2), relative estimation error (RE) and efficiency coefficient (CE) (Green and Stephenson, 1986). A calibrated version of the model was then developed for the study area and its corresponding performance was reevaluated using some statistical criteria. The appropriate conclusions were accordingly made for the better application of the MUSLE in the study area.

Results and discussion

The average weighted values of 0.031, 90.3, 0.1 and 1 were thus allotted to the watershed factors of soil erodibility (K), topography (LS), crop management (C) and conservation practice, respectively. The erosivity factors were also calculated using the measured hydrographs (Table 1).

Table 1. Runoff, sediment yield, OM loss for the study storms in Kojour watershed, Iran

No	Events	Volume (m^3)	Peak runoff (m^3/s)	Sediment yield (ton)	Organic matter losses (kg)
1	2008/10/2	2205	0.14	0.81	12557.5
2	2008/10/10	3677	0.52	258.00	12577.5
3	2008/10/28	3827	0.22	24.33	1027.5
4	2008/10/30	1697	0.08	0.50	100
5	2008/11/1	2161	0.19	16.23	889.3
6	2008/11/8	44569	1.8	145.99	4489.6
7	2008/12/2	40815	2.2	163.9	3623.8
8	2008/12/16	4397	0.3	2.85	10.5

The MUSLE was then applied for the selected storm events. The sediment yield and OM losses were estimated per each individual storm and were compared with those obtained through observed value.

Table 2 Results of application the MUSLE for prediction storm-wise OM loss

Events	OM Estimation (kg)	Estimation errors(%)
2008/10/2	512.13	1164.53
2008/10/28	1407.95	37.03
2008/10/30	0	100
2008/11/1	856.01	3.74
2008/11/8	3351.17	21.09
2008/12/2	4315.30	12.81
2008/12/16	0	100

Comparison between the estimated and observed sediment yield whit estimation error showed that the MUSLE has highly overestimated the suspended sediment yield in the study watershed. The results obtained during the present study agree with Asokan (1981) and Sadeghi et al (2007) who reported the over-estimation of the MUSLE in watershed scale. The MUSLE deterministically estimates the sediment yield disregarding to the processes governing or controlling the runoff generation (sadeghi et al, 2007). The considerable contribution of other flow components viz. interflow in the generation of total runoff in the lower forest part of the study watershed and uneven cover distribution of rainfall, can be supposed to be controlling factor for weak performance of the original MUSLE in the study.

OM loss estimation

The result of the comparative evaluation between measured and estimated OM loss has been showed in Table 2. According to the results shown in table 2, it is simply understood that the MUSLE has considerably under-estimated the OM loss in the study watershed. The mean of predicted and observed OM were found 709 and 1683 respectively. It along with the estimation error of average beyond 57% showed a difference between data set indicating the incompatibility of the MUSLE for the study's purpose. The high correlation between two observed and estimated values verifies the potential calibration of the model in following form:

$$OM = \text{Ln}\,(11.8\,(Q.\,qp)^{0.56}\,K.\,L.\,S.\,C.\,P) \qquad (4)$$

Where OM is OM loss (kg), Ln is neprien logarithmic and other variable similar to Eq.1. The mean of predicted and observed OM were also found 1739 and 1683 respectively. Graphical comparison between C-MUSLE predicted OM loss and observed data in study watershed was showed in Fig 2.

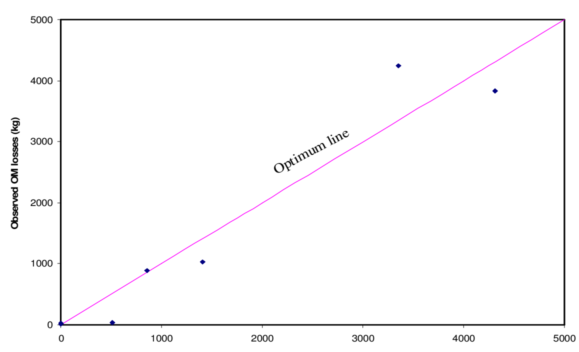

Fig. 2 Relationship between C-MUSLE predicted OM loss and observed data in study watershed.

It along with the estimation error of average some 33%, that showed no significant difference. As seen from Table 2, the estimation error values of 1 storm is high (Ev. 1), this might be just because of the smallness of the event in view of flood discharge and unsuitability of the MUSLE for prediction Sediment yield for small storms, as noted by Sadeghi and Mizuyama (2007).

The result of this study show that erosion and sediment model could predict nutrient associate sediment load and useful to soil and water conservation planning. The acceptable performance of the C-MUSLE suggested its application for the study area and probably for other areas with similar agroclimatological conditions owing to its simplicity and accessibility of required inputs. The capability of the revised MUSLE in the above evaluation without direct involvement of rainfall characteristics agreed with, Williams and Berndt (1977), Mishra et al. (2006), Sadeghi and Mizuyama (2007) and Noor et al (2010) who stated sediment yield from upland areas is generally better correlated with observed runoff than rainfall, although a longer and widespread record of sediment loading is needed to better definition the natural condition and the response of sediment yield.

Conclusion

Some contaminant associate with sediment and, thus, their transport and fate in environment is determined by the fate of sediment. The MUSLE is often used as the first alternative for estimation of sediment yield in different scales. However, its application in prediction of nutrient associate sediment has not been reported yet. The present study was conducted in the Kojour watershed, Iran, to test the applicability of the MUSLE for estimation of storm wise OM loss. The results of this study clearly showed that despite the limited number of storms studied, the performance of the model was found to be satisfactory to study purpose. The consideration of this simple model with reasonable accurate estimation of system response at watershed scales where limited information exists is strongly advised.

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