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Prediction of storm-related sediment-associated contaminant loads in a watershed scale

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Abstract

Suspended sediment moving in watersheds provides a pathway for the transport of sediment-associated contaminants. Information about sediment and nutrients exported from catchments as well as related erosive processes are required by catchment managers and decision-makers. Due to lack of adequate data in this respect, the Modified Universal Soil Loss Equation (MUSLE) model has been applied in storm-related sediment yield predictions in the Kojour watershed, Iran, to estimate the phosphorus (P) and organic matter (OM) loads associated with storm-related sediments The results of this study showed that a calibrated MUSLE model could estimate storm-related OM and P losses in the study area within an acceptable estimation error (RE) of 33% and 23%, respectively.

Key words: sediment-associated contaminant, organic matter, phosphorus loss, MUSLE, sediment graph, chemographs.

1. Introduction

Soil erosion affects downstream water bodies. Eutrophication, low oxygen levels and high nutrient (nitrogen and phosphorus) concentrations in reservoirs, canals and other water bodies are common water pollution indicators. Some contaminants are associated with sediment and, thus, their transport and fate in the environment is determined by the fate of the sediment. Accordingly, suspended sediment moving in a watershed provides a pathway for the transport of sediment-associated contaminants (Schoellhamer *et al.* 2007; Fazli, Noor 2013).

Phosphorus (P) is one of the major nutrients controlling eutrophication in surface waters (Yanai 1992; Ide *et al.* 2008). Irregular P load pulses caused by heavy rainfall may damage the ecological quality of downstream waters (Meyer, Likens 1979; Ide *et al.* 2008).

Many soil scientists advocate the conservation of soil organic matter (SOM) because of the modifying effects organic matter has on soil properties. This includes greater water retention and availability, the ability to retain nutrients within the root zone, and a greater buffering capacity against pH change which contribute to soil structure and form stable aggregates. SOM also influences environmental processes at a global scale. Topsoil is 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 including nutrients, pesticides and heavy metals adsorb on SOM, and therefore, if erosion process dramatically increases their loss to freshwaters will also increase along with organic matter content (OM) loss in soil.

To develop effective watershed management strategies, it is important to quantify the sediment and sediment-associated nutrient and OM loads in watersheds. The greatest OM and P losses from watersheds are exported in the particulate form during rainfall events that result in rapid temporal variations in their loads (Hatch *et al.* 1999; Ide *et al.* 2008). This makes it difficult to accurately estimate the OM and P loads because of the need for intensive water sampling during periods of highly fluctuating discharge. In the absence of actual measurement data, hydrologists have used models to predict sediment and sediment-associated contaminant loads at the watershed scale. Nutrient and other chemical losses are predicted using simulation models. The Agricultural Non-Point Source (AGNPS) model is a non-point source pollution model developed by the US Department of Agriculture, Agricultural Research Service (USDA-ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service (SCS) in the USA (Young *et al.* 1987). Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) was developed by Beasley *et al.* (1980). The Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS) model was developed by Knisel (1980) as a tool to evaluate the relative effects of agricultural practices on pollutants in surface runoff and in soil water below the root zone. The Environmental Management Support System (EMSS) is a software tool developed to aid water quality management in catchments and waterways in the South-East Queensland region of Australia (Vertessey *et al.* 2001). The Hydrologic Simulation Program, Fortran (HSPF) was developed based on the 1960s Stanford Watershed Model, for the simulation of watershed hydrology and water quality (Walton, Hunter 1996). It should be noted that all the input data for these models are not available in Iran.

Many researchers indicated that the losses of particulate P and OM components in surface runoff from upland fields are higher than dissolved ones transported by suspended sediment (Mihara *et al.* 2005; Zhang *et al.* 2005; Ide *et al.* 2008). Therefore, appropriate erosion and sediment models can potentially be applied to predict OM and P losses.

Among available soil erosion and sediment yield models, the Universal Soil Loss Equation (USLE) and its revised version (RUSLE) and modified version (MUSLE) are used in hydrology and environmental engineering (Williams 1975b; Madeyski, Banasik 1993; Mishra *et al.* 2006; Pandey *et al.* 2009). A large number of the existing erosion and sediment transport models are based on the USLE (Banasik *et al.* 2005). The USLE was basically developed for estimating the annual soil loss from small plots of an average length of 22 m in gently sloping agricultural areas (Wischmeier, Smith 1978). Therefore, its application to individual storm events and large areas can be associated with errors (Finney *et al.* 1993; Kinnell 2005; Sadeghi, Mizuyama 2007; Pandey *et al.* 2009). However, there is no direct consideration of runoff in the USLE so this permits better assessment of storm-related sediment yields at the watershed outlets (Williams 1975a; Hrissanthou 2005; Sadeghi, Mizuyama 2007). This model is also not considered appropriate for water quality modeling as it requires shorter time increments than one year.

An improved erosivity factor was introduced by Williams (1975a) to take into account the runoff shear stress effect in order to modify the effects of runoff volume and peak discharge on soil detachment for single storms. Williams (1975a) showed that the estimate of stream sediment yields 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-related 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. By using the runoff index sediment yield prediction has been improved because runoff is a function of antecedent moisture condition as well as rainfall energy (Williams 1975a; Williams, Berndt 1977; Kinnell 2005; Zhang *et al.* 2009).

The MUSLE model predicts sediment yield for a given watershed as a product of six major erosion factors, whose values at a particular location can be expressed numerically in the following form:

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

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, soil erodibility ($t\ h\ t^{-1}\ m^{-1}\ cm^{-1}$), slope length (dimensionless), slope steepness (dimensionless), crop management (dimensionless) , soil erosion control practice (dimensionless) coefficients, respectively, and a and b are location coefficients (Williams, Berndt 1977; Madeyski, Banasik 1993; Sadeghi, Mizuyama 2007; Pandey *et al.* 2009). Presently, the MUSLE model is preferably applied in storm-related sediment yield prediction in developing countries, such as Iran.

Mihara *et al.* (2005) developed equations for predicting nitrogen and phosphorus losses during soil erosion processes on the basis of the USLE model. However, the application of the MUSLE model has not been reported in the prediction of nutrient and OM losses.

On the basis of available statistics (Raiesi *et al.* 2010), 300 m^2 area of forest is being continuously depleted per second in Iran. Forest degradation is therefore a major issue in Iran, as well as in many other developing countries (Sadeghi *et al.* 2009), owing to complicated natural and anthropological drivers.

The Hyrcanian area extends along the northern face of the Alborz Mountain range (northern Iran) and therefore receives considerable annual precipitation, ranging from 600 to 2000 mm. A considerable number of rivers flow in this part of the country because of humid climate. Many wetlands, dams and other water bodies vital for economic uses and ecological life are endangered by the transport and deposition of suspended sediment and associated nutrients in this region. This justifies the necessity for sediment and nutrient studies in this area. The present study was therefore formulated to assess the applicability of the MUSLE for the prediction of P and OM losses in the Kojour watershed as a representative watershed in northern Iran. This watershed originates from the Alborz Mountain range and drains to the Caspian Sea.

2. Materials and methods

The Kojour watershed is located south east of the Nowshahr town in the Mazandaran Province, northern Iran. The general features of the study area are shown in Fig. 1. The basin area is about 500 km^2 and mainly consists of forest lands in the middle and downstream of the basin and rangeland in the upstream area. The highest and lowest altitudes of the watershed are 2650 m and 150 m above mean sea level, respectively. The watershed is deeply incised, with a gradient of between 25% and 60% (Raiesi *et al.* 2010). Soil in the watershed is brown forest soil, which is classified as Pesdogelly having a loamy sand texture.

The mean annual precipitation is 1309 mm based on at the data obtained from the meteorological station, located at the downstream of the study area. The mean annual precipitation inversely decreases as elevation increases so that it declines to about 250 mm at the upland meteorological station (Raiesi *et al.* 2010). The region including the study site has a humid subtropical climate with a distinct dry season in winter in its lower part and a semi-arid and cold climate in the upper areas of the watershed, based on the Köppen climate classification.

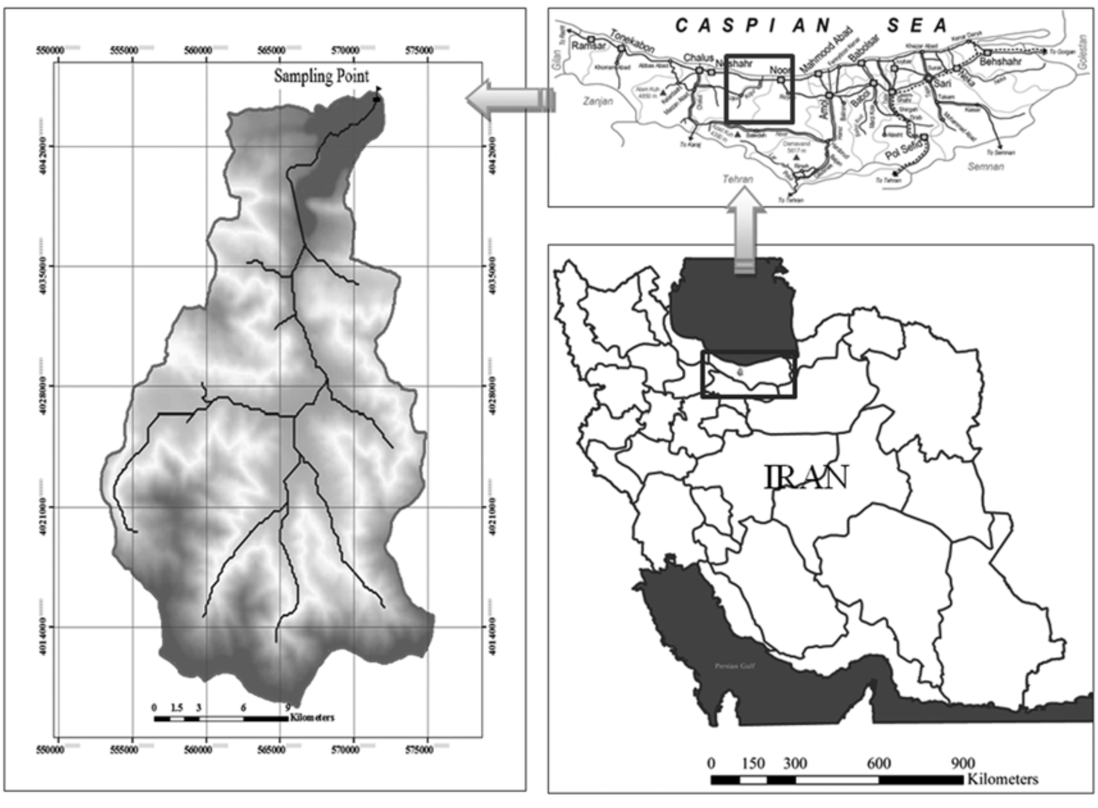

Fig. 1. Location and general view of the study watershed, northern Iran.

In order to evaluate the MUSLE model in the study watershed under this study, ten storm events were selected. Water flow and suspended sediment concentration (SSC) were monitored at the downstream outlet, with the emphasis on sampling major runoff events. The runoff discharge was estimated using wet cross-section and flow velocity data. The SSC data were also manually obtained using the depth integration method during storm events with water samples collected in 2 liter polyethylene containers (Edwards, Glysson 1999). Samples were regularly obtained during the flood event at 1 hour intervals. The SSC values were then determined through settling, decantation and drying by oven and air. The air dried samples were transported to the laboratory and available P and OM were analyzed using the Olsen and LOI (Loss On Ignition) methods (Parker 1983), respectively. On October 10, 2008, the occurrence of mass movement of sediment in the river caused increasing sediment concentrations during a period when flow was decreasing; therefore, this storm was omitted from the evaluation.

The corresponding hydrographs and measured sediment concentration graphs and chemographs (P and OM) were then obtained and analyzed. The amounts of total storm-related P and OM adsorbed to sediments were then calculated based on their concentrations in conjunction with the hydrographs.

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

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

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

Where λ is the projected horizontal distance (m) 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 the horizontal axis. The vegetation cover management factor (C) was estimated using a vegetation cover map of the study area (Raiesi *et al.* 2010). The average density was estimated to be about 75%. The conservation practice factor (P) was also supposed to be considered as a unit, but, since no conservation measures were applied in the study watershed, this factor was not considered (Ozhan *et al.* 2005; Sadeghi, Mizuyama 2007).

The MUSLE model was then run on the storm-event basis using the data set collected for the ten individual storm events that occurred during the rainy season; i.e. from late 2008 to early 2009. The P and OM losses were estimated using the MUSLE model for each individual storm, and the results along with the coefficient of determination (R^2) and relative estimation error (RE) (Green, Stephenson 1986) were ultimately compared with the observed data. A calibrated version of this model was then developed for the study area and its corresponding performance was reevaluated using the same statistical criteria. At the end, conclusions were accordingly made for the better application of the MUSLE model in the study area.

3. Results and discussion

The average weighted values of 0.031, 90, 0.11 and 1 were allotted to the watershed factors of soil erodibility (K), topography (LS), crop management (C) and conservation practice (P), respectively. The erosivity factors were also calculated using the measured hydrographs (Table I).

The MUSLE model was then applied for the selected storm events. The P and OM losses were estimated for each individual storm, and were compared with the observed values.

The comparison between the estimated and observed sediment yields showed that the MUSLE model greatly overestimated the suspended sediment yield in the study watershed. The results obtained in this study are consistent agree with those presented by Asokan (1981) and Sadeghi and Mizuyama (2007). The MUSLE model deterministically estimates the sediment yield with no regard to the processes governing or controlling runoff generation (Sadeghi, Mizuyama 2007). The considerable contribution of other flow components (i.e. interflow) in the generation of total runoff in the lower part of the study watershed and the uneven distribution of rainfall, can be a controlling factor in the weak performance of the unmodified MUSLE model.

3.1. OM loss estimation

The result of the comparison made between measured and estimated OM losses is shown in Table II. According to these results, the MUSLE model has considerably under-estimated the OM losses in the study watershed. The mean of predicted and observed values of OM losses were found to be 709 and 1683 kg, respectively. Along with the estimation error of greater than 57%, the differences between data sets indicate the incompatibility of the MUSLE model for the study's purpose. However, the high level of correlation between the observed and estimated values, suggests the potential calibration of the model in the following form:

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

Where OM is the OM loss (kg), Ln is the natural logarithm and the other variables are as defined in Eq.1. The mean values of the predicted and observed OM loads were 1739 and 1683 kg, respectively. A graphical comparison between the estimated OM losses obtained using the calibrated MUSLE (C-MUSLE) model and the observed data is shown in Fig. 2.

Because the average of estimation error was 33%, the predicted and observed OM losses show no difference. As seen from Table II, the estimation error values for a single storm are high (Ev. 1 i.e. 1164 %), indicating the unsuitability of the MUSLE model for predicting sediment yields from small storms, as noted by Sadeghi and Mizuyama (2007).

3.2. P loss estimation

The results of the statistical analysis (Table II) show that the un-calibrated MUSLE model does not produce acceptable estimates of P losses in the Kojour watershed. However, the good correlation, a coefficient greater than 97%, suggests that a reasonable relationship between the estimated and observed P losses can be used for calibration of the MUSLE model for the Kojour watershed.

The MUSLE model has not performed well in the case of P loss estimation in the study watershed. However, the high correlation coefficient between the observed and estimated values indicates high potential for calibration of the model. The result has been simplified into the following equation:

$$P\ loss = 0.037\ (Q.\ q_p)^{0.42}\ K.\ L.\ S.\ C.\ P \qquad (5)$$

Where the P loss is in kg and other variables are as defined in Eq.1. The absolute estimation error for the calibrated C-MUSLE model was calculated as 23%. Fig. 3 shows the relationship between estimated and observed P losses using the C-MUSLE model in the Kojour watershed.

The comparison of predicted and observed OM and P losses indicates that the data points were found to be very close the optimum line. Scrutinizing the results shown in Figs. 2 and 3 suggests that the C-MUSLE has performed well in the prediction of storm-related sediment-associated OM and P losses in the Kojour watershed.

The results of this study show that an erosion and sediment model can predict nutrient associated sediment loads and provide a useful tool for soil and water conservation planning. The acceptable performance of the C-MUSLE model suggests its

Table I. Observed runoff, sediment yield, and P and OM losses for the study storms in the Kojour watershed.

No	Events	Volume (m^3)	Peak runoff (m^3/s)	Sediment yield (ton)	Phosphorus losses (g)	Organic matter losses (kg)
1	2008/10/02	2210	0.14	0.81	*	**40.5**
2	2008/10/10	3680	0.52	258	2950	**12580**
3	2008/10/28	3830	0.22	24.3	378	**1030**
4	2008/10/30	1700	0.08	0.5	*	**27.9**
5	2008/11/01	2160	0.19	16.2	200	**890**
6	2008/11/08	44570	1.8	146	1680	**4490**
7	2008/12/01	4940	0.5	6.1	540	**
8	2008/12/02	40820	2.2	163.9	1480	**3620**
9	2008/12/03	4400	0.3	2.85	90	**
10	2008/12/16	4397	0.3	2.85	*	**10.5**

* Data for P not available, ** Data for OM not available

Table II. Results of application the MUSLE model for prediction of storm-related OM and P losses.

Estimation errors (%)	OM estimation (kg)	Estimation errors (%)	P estimation (kg)	Events
1164	513	-	-	2008/10/02
37	1408	673	188	2008/10/28
100	0	-	-	2008/10/30
4	856	669	125	2008/11/01
21	3352	1540	2394	2008/11/08
-	-	5486	341	2008/12/01
13	4316	1456	2550	2008/12/02
-	-	8318	240	2008/12/03
100	0	-	-	2008/12/16

potential application for the study area and probably for other areas with similar agro-climatological conditions, especially owing to its simplicity and the accessibility of the required inputs. The capability of the revised C-MUSLE model in the above evaluation, without direct involvement of rainfall characteristics, agrees with the findings of Williams and Berndt (1977), Mishra *et al.* (2006) and Sadeghi and Mizuyama (2007). They all emphasize the fact that sediment yield from upland areas is generally better correlated with observed runoff than rainfall, although a longer and more widespread record of sediment loading is needed to better define the natural conditions and the response of sediment yield to a specific event.

Conclusion

The MUSLE model is often used as the first alternative for estimating sediment yield at different scales. However, its application in the prediction of nutrients associated with sediment has not been reported. The present study was conducted in the Kojour watershed, Iran, to test the applicability of the MUSLE model for estimating storm-related OM and P losses. The results of this study showed that, despite the limited number of storms considered here, the performance of the model was satisfactory for planning purposes. The consideration of this simple model, with its reasonably accurate estimation of the system response at the watershed scale, especially in situations where limited information exists, is strongly advised.

References

Asokan, K. 1981. Runoff and sediment yield from Bino subwatershed of Ramganga catchment. M-Tech Thesis. Govind Ballabh Pant University of Agriculture and Technology. Pantnagar, India.

Banasik, K., Barszcz, M., Branski, J. 2005. Major components of a sediment budget for four river catchments in Poland. *Int. Sym. on Sediment Budgets held at the 7th Scientific Assembly of the International-Association-of-Hydrological-Sciences*. Foz do Iguaco, Brazil. April 3-9, 2005. IAHS Publ. **292**, 32-36.

Beasley, D.B., Huggins, L.F., Monke, E.J. 1980. ANSWERS – a model for watershed planning. *Trans-*

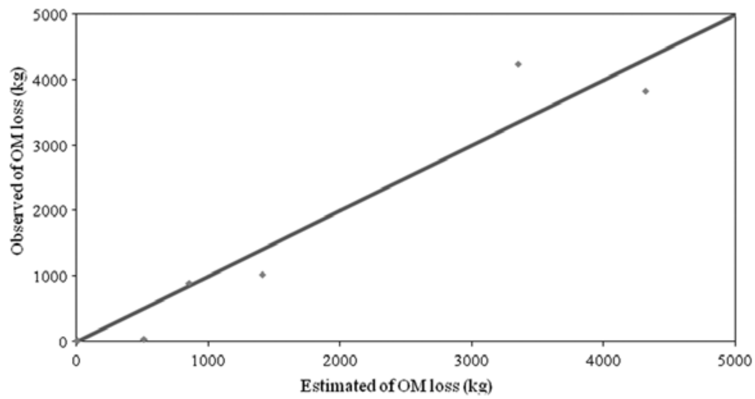

Fig. 2. Relationship between OM losses estimated with the C-MUSLE and observed data in the study watershed.

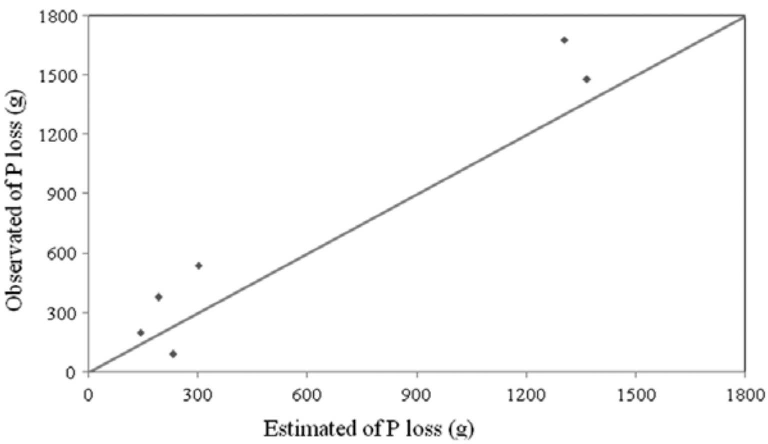

Fig. 3. Relationship between estimated and observed P losses using the C-MUSLE model.

action of American Society Agriculture Engineering **23**, 938-944.
Edwards, T.K., Glysson, G.D. 1999. Field methods for measurement of fluvial sediment. USGS Open-file Report, 1-97 p. Available from: http://water.usgs.gov/osw/techniques/Edwards-TWRI.pdf1999.
Fazli, S., Noor, H. 2013. Storm-wise sediment yield prediction using hillslope erosion model in semi-arid abundant lands. *Soil and Water Research* **8**, 42-48.
Finney, V.L., Banasik, K., Needham, S., Young, A. 1993. Comparision of DR-USLE, SEGMO and AGNPS with two rainfall events. *Proc. Int. Symposium "Runoff and Sediment Yield Modelling"*. Warsaw Agricultural University Press, Sept.14-16, Warsaw, Poland, pp. 195-200.
Green, I.R.A., Stephenson, D. 1986. Criteria for comparison of single event models. *Hydrology Science Journal* **31**, 395-411.
Hatch, L.K., Reuter, J.E., Goldman, C.R. 1999. Daily phosphorus variation in a mountain stream. *Water Resource Research* **35**, 3783-3791.
Hrissanthou, V. 2005. Estimate of sediment yields in a basin without sediment data. *Catena.* **64**, 333-347.
Ide, J.I., Haga, H., Chiwa, M., Otsuki, K. 2008. Effects of antecedent rain history on particulate phosphorus loss from a small forested watershed of Japanese cypress (Chamaecyparis obtusa). *Journal of Hydrology* **352**, 322-335.
Kinnell, P.I.A. 2005. Why the universal soil loss equation and the revised version of it do not predict event erosion well. *Hydrological Processes* **19**, 851-854.
Knisel, W.G. 1980. CREAMS: A field scale model for chemicals, runoff and erosion from agricultural management systems. USDA.
Lal, R. 2005. Influence of soil erosion on carbon dynamics in the world, In: Roose, E.R., Lal, R., Feller, C., Barthes, B., Stewart, B.A. [Eds.], *Soil erosion and carbon dynamic.* CRC, Boca Raton.
Madeyski, M., Banasik, K. 1993. Applicability of modified universal soil loss equation in small Carpathian watersheds. *Catana Supplement* **14**, 75-80.
Meyer, J.L., Likens, G.E. 1979. Transport and transformation of phosphorus in a forest stream ecosystem. *Ecology* **60**, 1255-1269.
Mihara, M., Yamamoto, N., Ueno, T. 2005. Application of USLE for the prediction of nutrient losses in soil erosion processes. *Paddy Water Environment* **3**, 111-119.
Mishra, S.K., Tyagi, J.V., Singh, V.P., Singh, R. 2006. SCS-CN-based modeling of sediment yield. *Journal of Hydrology* **324**, 301-322.
Ozhan, S., Balc, A.N., Ozyuvaci, N., Hızal, A., Gokbulak, F., Serengil, Y. 2005. Cover and management factors for the universal soil-loss equation for forest ecosystems in the Marmara region, Turkey. *Forest Ecology and Management* **214**, 118-123.
Pandey, A., Chowdary, V.M., Mal, B.C. 2009. Sediment yield modeling of an agricultural watershed using MUSLE, remote sensing and GIS. *Paddy Water Environment* **7**, 105-113.
Parker, J.G. 1983. A comparison of methods used for the measurement of organic matter in marine sediment. *Chemistry and Ecology* **1**(3), 201-209.
Raiesi, M.B., Sadeghi, S.H.R., Noor, H. 2010. Accuracy of time-area method in sediment graph development in Kojour watershed. *Rangeland* **4**(2), 320-333 [in Persian].
Rodrıguez Rodrıguez, A., Guerra, A., Arbelo, C., Mora, J.L., Gorrın, S.P., Armas, C. 2004. Forms of eroded soil organic carbon in andosols of the Canary Islands (Spain). *Geoderma* **121**, 205-219.
Sadeghi, S.H.R., Mizuyama, T. 2007. Applicability of the Modified Universal Soil Loss Equation for prediction of sediment yield in Khanmirza watershed, Iran. *Hydrology Science Journal* **53**, 1253-1269.
Sadeghi, S.H.R., Saeidi, P., Noor, H., Raeisi, M.B. 2009. Understanding sediment yield process in a Hyrcanian forest watershed. In: *International Conference Land Conservation LANDCON 0905*.
Schoellhamer, D., Mumley, T.E., Leatherbarrow, J.E. 2007. Suspended sediment and sediment-associated contaminants in San Francisco Bay. *Enviromental research* **105**, 119-131.
Sparling, G.P., Wheeler, D., Vesely, E.T, Schipper, L.A. 2006. What is soil organic matter worth? *Journal Environmental Quality* **35**, 548-557.
Vertessey, R.A., Watson, F.G.R., Rahman, J.M., Cuddy, S.D., Seaton, S.P., Chiew, F.H., Scanlon, P.J., Marston, F.M., Lymbuner, L., Jeanelle, S., Verbunt, M. 2001. New software to aid water quality management in the catchments and waterways of the south-east Queensland region. In: *Proceedings of the Third Australian Stream Management Conference*, August 27-29, 611-616.
Walton, R., Hunter, H. 1996. Modeling water quality and nutrient fluxes in the Johnstone River catchment, North Queensland. In: *23rd Hydrology and Resources Symposium*, Sydney.
Williams, J.R. 1975a. Sediment routing for agricultural watersheds. *Water Resources Bulletin* **11**, 965-974.
Williams, J.R. 1975b. Sediment yield prediction with universal equation using energy factor. In: *Present and Prospective Technology for Predicting Sediment Yield and Sources: Proc. Sediment-Yield Workshop*. ARS-40, USDA – Sedimentation Laboratory, Oxford, MS, 224-252.
Williams, J.R., Berndt, H.D. 1977. Sediment yield prediction based on watershed hydrology. *Transactions of ASAE* **20**, 1100-1104.
Wischmeier, W.H., Smith, D.D. 1978. *Predicting soil erosion losses: a guide to conservation planning.* USDA Agricultural Handbook No. 537, 58 pp.
Yanai, R.D. 1992. Phosphorus budget of a 70-year-old northern hardwood forest. *Biogeochemistry* **17**, 1-22.
Young, R.A., Onstad, C.A., Bosch, D.D., Anderson, W.P. 1987. AGNPS, agricultural nonpoint source pollution. A watershed analysis tool. In: *Conservation Research Report* **35**. US Department of Agriculture, Washington, D.C.
Zhang, F., He, X., Gao, X., Zhang C., Keli, T. 2005. Effects of erosion patterns on nutrient loss following deforestation on the Loess Plateau of China. *Agriculture, Ecosystems and Environment* **108**, 85-97.
Zhang, Y., Degroote, J., Wolter, C., Sugumaran, R. 2009. Integration of Modified Universal Soil Loss Equation (MUSLE) into a GIS framework to assess soil erosion risk. *Land Degradation and Development* **20**, 84-91.