Evaluation of the Relationships between Runoff-Rainfall-Sediment Related Nutrient Loss (A Case Study: Kojour Watershed, Iran)

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Abstract

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Suspended sediment (SS) resulted from distributed soil erosions facilitates soil organic matter and phosphorus (P) transportation and influences soil depletion and water quality. Organic matter (OM) in soil is the most important indicator of soil quality and productivity. P is one of the major nutrients controlling eutrophication of surface water. Irregular contaminant load pulsed by heavy rainfall may damage the ecological quality of downstream waters. Evaluation of OM and P, depleted by erosion processes in watershed scale, is necessary for better understanding the watershed system and should lead to appropriate management approaches. On the other hand, different behaviours of soil erosion as well as the necessity of regional studies have been proved. The present study was conducted in the Kojour watershed, Iran in order to (1) get some ideas about the storm-wise OM and P load in river, (2) evaluate the relationship between the peak of OM and P concentration and discharge during individual rainfall events, and (3) assess the applicability of rainfall and runoff variables of ten storm events in the prediction of storm-wise OM and P loss. The results showed that most of the OM and P peaks preceded the peak discharge, following a clockwise hysteretic loop that exhibited hysteresis with a greater OM and P concentration for a given discharge occurring on the rising limb rather than on the falling limb. The results also showed that regression models had good efficiency in estimation of storm-wise OM and P loss with coefficient of determination of 0.96 and 0.93, respectively.

Keywords: clockwise hysteretic loop; organic matter phosphorus loss; regression models; suspended sediment

The selective removal of plant nutrients with runoff sediment is important from both aspects of water quality and soil fertility (Sharply 1985). Soil erosion causes adverse agronomic, ecologic, environmental, and economic effects, both on-site and off-site. The on-site consequences involve primarily the reduction in soil productivity, while the off-site consequences are mostly due to the sediment and chemicals transported by streams away from the source into natural waters (Blanco & Lal 2008). Therefore, sediment yield provides a significant index of land degradation, severity, and trends. Some contaminants are associated with sediment, and thus their transport and fate in the environment is determined by the fate of sediment. Accordingly, suspended sediment moving in watershed provides a pathway for the transport of the sediment- associated contaminants (Schoellhamer *et al.* 2007; Raeisi *et al.* 2010; Fazli & Noor 2013). Eutrophication, low oxygen levels, and high nutrient and organic matter (OM) concentrations in reservoirs, canals, and other water bodies are common water pollution features (Ide *et al.* 2008).

Phosphorus (P) is one of the major plant nutrients and also one of the major nutrients controlling eutrophication of surface waters (McDowell *et al.* 2001; Blanco & Lal 2008; Noor *et al.* 2010). Many soil scientists advocate the conservation of

OM because of the modifying effects it has on soil properties. The effects include greater water retention and availability, the ability to retain nutrients within the root zone, greater buffering capacity against pH change, which contribute to soil structure and form stable aggregates (Sparling *et al.* 2006; Blanco & Lal 2008). OM also influences environmental processes at a global scale. Topsoil is a huge terrestrial reservoir of C, which has a modifying effect on carbon dioxide concentrations in the atmosphere and can thus influence climate warming (Lal 2005; Rodriguez *et al.* 2004; Sparling *et al.* 2006). Several pollutants such as nutrients, pesticides, and heavy metals adsorb on OM, therefore, in erosion process they dramatically transport with OM (Sparling *et al.* 2006; Noor *et al.* 2011).

In the developing countries where soil erosion is a serious problem, many reports have been produced on the effectiveness of soil conservation measures, and prediction of soil losses. However, only a few attempts have so far been made at investigating the associated movement of nutrients in soil erosion processes (Noor *et al.* 2010).

Also, to develop effective watershed management and water resources strategies, it is important to quantify the sediment and sediment-associated pollutant loads in watersheds. The most P and OM losses from watersheds are exported during rainfall events resulting in rapid temporal variations in their loads. This makes it difficult to accurately estimate the P and OM loads because of the need for intensive water sampling during periods of highly fluctuating discharge (Hatch *et al.* 1999; Ide *et al.* 2008; Noor *et al.* 2010).

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. It is generally due to the lack of accurate input data and even nonexistence of measured data for proper evaluation of the models.

Since P and OM loads depend on controlled variables in soil erosion and sediment transport, thus runoff and rainfall are two factors characterizing P and OM loads in a river. Therefore, with sufficient observed data from one watershed, a regression model can be developed relating the dependent variable and the independent one, such as rainfall and runoff characteristics (Chang 2006).

On the basis of available statistics, 300 m^2 of forests is being continuously depleted per second in Iran. Forest degradation has therefore become a major issue in Iran, as well as in many other developing countries, owing to complicated natural and anthropological driving forces. The Hyrcanian area mainly extends in the northern face of the Alborz Mountain range (northern Iran) and therefore receives considerable annual precipitation, ranging 600–2000 mm. So, a lot of rivers flow in this part of the country because of humid climate (Raeisi *et al.* 2010). 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 logically justifies the necessity of P erosion-associated studies. The present study was therefore formulated in order to (1) get some ideas about the storm-wise P and OM loss, (2) evaluate the relationship between the peak of nutrient and discharge in rainfall event, and (3) develop accessible regression model based on rainfall and runoff characteristics to predict P and OM loss in the Kojour watershed as a representative watershed located in the north of Iran. This watershed originates from the Alborz Mountain range and drains to the Caspian Sea.

MATERIAL AND METHODS

The Kojour watershed is located south east of Nowshahr Town in Mazandaran Province, northern Iran. The general features of the study area are shown in Figure 1.

The basin area is about 500 km^2 and consists mainly of forest lands in downstream and rangelands in upstream areas (Noor *et al.* 2011). The highest and the lowest altitudes of the watershed are 2650 m and 150 m a.s.l., respectively. The watershed is deeply incised, with a dominant hillslope gradient of 25–60% (Raeisi *et al.* 2010; Noor *et al.* 2011). Soil in the watershed is brown forest soil, which is classified as Pesdogelly with a loamy sand texture. The mean annual precipitation is 1308.8 mm at a plain meteorological station, which reversibly decrease as the elevation increases so that the mean annual precipitation at upland station declines to some 250 mm. The region including the study site has a humid subtropical climate with a distinct dry season in winter in the lower part and semi-arid and cold in the upper areas of the watershed based on the Köppen climate classification (Noor *et al.* 2010; Raeisi *et al.* 2010). In order to conduct the study, 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 l 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 (Noor *et al.* 2010) 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.

RESULTS AND DISCUSSION

Out of the many small as well as large storm events that occurred during the collection period from September 2008 to March 2009, only ten storm events with persistent and analyzable data could be selected due to the lack of synchronized data (Figure 2).

The descriptive statistics on OM and P for the study watershed have also been summarized (Table 1).

The results shown in Table 1 indicated rather high variations in OM, P, and discharge. The value of OM in the entire period ranged 0.04–5.30 g/l with coefficient of variation (CV) of 251.18%, whereas discharge variability ranged 0.01–2.20 m^3/s with CV of 79.86%. It can be inferred from Table 1 that the high relative variance of OM and P data in comparison with discharge demonstrates the significant and complex effects of changeful factors such as discharge on OM and P load in the river.

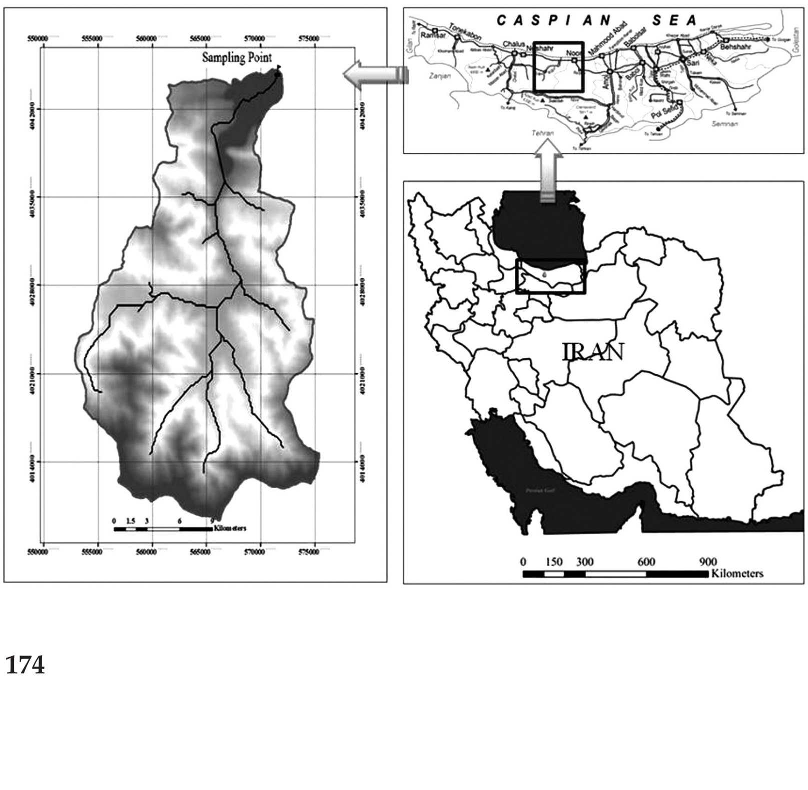

Figure 1. Location and general view of the study forest watershed, northern Iran

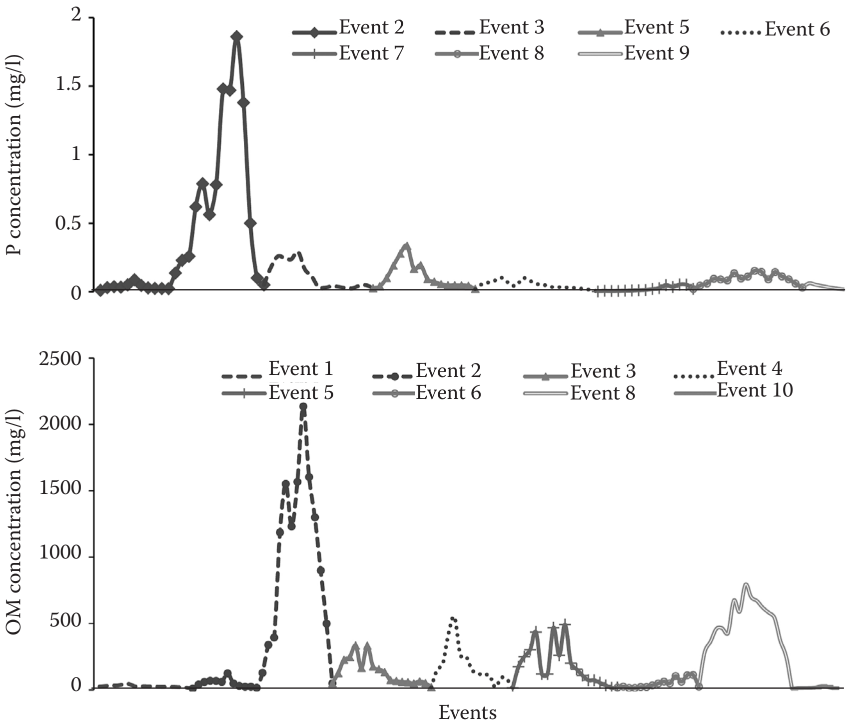

Figure 2. Phosphorus (P) (above) and organic matter (OM) (below) concentration in the Kojour River during selected rainfall events

Temporal variation of OM, P, and discharge

The suspended sediment concentration (SSC) and, therefore, associated compounds chemical versus stream discharge relationship during rain events usually exhibits differences between the rising and falling limbs of a hydrograph, i.e. a hysteresis loop (Williams 1975; Ide *et al*. 2008). In a majority of runoff events, their peak sediment concentration generally preceded or occurred simultaneously with their peak runoff rates. For most of events, the maximum peaks of OM and P loads, generally preceded or occurred simultaneously with the maximum peak discharge, which strongly suggests that the progressive decline mechanism is dominant in sediment supply in the study area. A postulated cause of positive hysteresis in the study area is a depletion of available P and OM before the

Table 1. Characteristics of runoff, rainfall, organic matter (OM) and phosphorus (P) loss during selected rainfall events in the Kojour watershed

No.	P loss (g)	OM loss (kg)	Type of hysteretic loop*	Runoff			Rainfall		
				volume (m^3)	peak	average	total (cm)	max	average
					(m^3/s)			(cm/h)	
1	no data	40.5	clockwise	2 205	0.14	0.06	1.58	0.48	0.26
2	2 950	12 577.5	anticlockwise	3 677	0.52	0.19	44.87	12.33	2.99
3	378	1 027.5	clockwise	3 827	0.22	0.13	10.10	1.17	0.37
4	no data	100	clockwise	1 697	0.08	0.04	15.67	3.20	0.74
5	200	889.3	clockwise	2 161	0.19	0.08	16.49	3.20	0.78
6	1 680	4 489.6	clockwise	44 569	1.80	0.22	39.73	4.68	2.20
7	540	no data	clockwise	4 937	0.50	0.17	11.30	1.60	0.94
8	1 480	3 623.8	clockwise	40 815	2.20	1.55	53.32	3.56	1.11
9	90	no data	clockwise	4 397	0.30	0.10	1.60	1.03	0.48
10	no data	10.5	clockwise	1 240	0.10	0.05	1.12	0.41	0.22

*hysteretic loop indicates the relationship between hydrograph and nutrients load water discharge has peaked and the concentrations rapidly decreased after the maximum peaks. These trends are indicative of the flushing effect.

The dominance of clockwise hysteresis loops in previous studies has been interpreted as suggesting that a rainfall produced a sufficient discharge to mobilize nearby sources of material along the channel and on nearby fields (Ide *et al.* 2008). These sources were postulated as being exhausted on the rising limb, resulting in lower concentrations of OM and P on the falling one.

Rainfall-runoff-P loss relationships

Analysis of the conditions such as rainfall-runoff relationships and recognition of their effects on nutrient erosion process is necessary. However, precise studies on the relationships between the aforesaid variables have been rarely taken into account in Iranian watersheds. In order to estimate OM and P loss in the Kojour watershed, the following rainfall and runoff variables were used. Independent variables in the predictions include total, average, maximum intensity rainfall and volume, peak, and average discharge of hydrograph. In this case, correlation analysis is used to relate the total OM and P to the main rainfall and runoff characteristics.

Different regression models were then established between OM and P loss observed and rainfall-runoff characteristics. The best-fit models between those variables were selected based on maximum determination coefficient (R^2) and minimum median of relative prediction error (RE). It is obvious from Table 2 that the models have the high R^2 from 0.648 to 0.949 for prediction of P loss. The exact study of Table 2 shows that multiple-variables and nonlinear models are more accurate than other models. Finally, equation 1 was selected for P load prediction in flood events at the Kojour watershed.

Table 2. Selected relationships between runoff-rainfall and P-OM loss in the Kojour watershed

No.	Equation	R^2
1	$P = 450.291NIp_{Max} - 865.938Q_p - 674.070$	0.931
2	$P = 1332.917NIp_{av} - 622.534Q_{av} + 847.133$	0.807
3	$P = 481.51NIp_{Max} - 101.395$	0.837
4	$P = 298.802(NIp_{Max} \times Q_p) + 736.935$	0.663
5	$P = 1574.16\ln(NIp_{Max} \times Q_p) + 733.868$	0.738
6	$P = -3581/(NIp_{Max} \times Q_p) + 4601.91$	0.648
7	$P = 658.458 \times 1.1545^{(NIp_{Max} \times Q_p)}$	0.660
8	$P = 616.846\ (NIp_{Max} \times Q_p)^{0.8097}$	0.840
9	$P = Exp(-2.0406(NIp_{Max} \times Q_p) + 8.5228)$	0.906
10	$P = Exp(0.1437\ (NIp_{Max} \times Q_p) + 6.4899)$	0.660
11	$P = Exp(0.1437\ (NIp_{Max} \times Q_p)) + 658.65$	0.660
12	$P = -29325/(NIp_{Max} \times Rv) + 8.2175$	0.649
13	$P = 0.3166 \times 0.771^{(NIp_{Max} \times Q_p)}$	0.688
14	$OM = 4.181\ln(Q_p) + 10.64$	0.920
15	$OM = 0.235(NIp_{av}) + 0.158$	0.781
16	$OM = 3.839\ln(Q_{av}) + 13.12$	0.965
17	$OM = 3.279\ln(Rv) - 23.22$	0.764

P – total phosphorus loss; OM – organic matter loss; NIp_{Max} – max of rainfall intensity; NIp_{av} – average of rainfall intensity; Q_p – peak of hydrograph; Q_{av} – average of runoff hydrograph; Rv – runoff volume

Rainfall-runoff-OM loss relationships

The initial results of the development of different types of rain and runoff-OM loss relationships in the study watershed showed that almost all different types of models do not establish good relationships in terms of correlation coefficient criterion. Although the models based on rainfall have not performed well in the case of OM estimation for the Kojour watershed, runoff characteristics can be used as a good predictor of OM loss.

Although runoff model developed has its own merits, equation 1 that is nonlinear and logarithmic is the only one which comprehensively meets acceptable statistic criteria. The RE calculated as 45% falls within the acceptable range of soil erosion and sediment yield modelling. Finally, equation 16 was selected for OM load in flood events at the Kojour watershed.

CONCLUSION

From the results of the study it can be concluded that the rainfall models did not perform well in the prediction of OM from the study watershed, but the acceptable performance of the runoff models suggested their applicability for the study area and probably for other areas with similar agroclimatological conditions, owing to their simplicity and accessibility of required inputs. The capability of the runoff models in the above evaluation without direct involvement of rainfall characteristics in estimation of sediment associated OM and P agreed with the findings of Williams and Berndt (1977), Hrissanthou (2005), and Noor *et al.* (2010),

2011) who stated that sediment and nutrient yield from upland areas is generally better correlated with observed runoff than with rainfall, although a longer and more widespread record of data is needed to better define the natural condition. The results of the present study can facilitate better understanding of the conditions in the Hyrcanian area, northern Iran, though more elaborated and comprehensive studies are essential for obtaining reliable conclusion in the future.

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