How important is sediment graph development in Iran?

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Abstract A careful measurement and analysis of sediment data is a basic pre-requisite for the successful planning and design of any soil and water conservation programme. However, the proper evaluation on the aptness of available measurement and estimation techniques is rarely made worldwide. The problem is much more complicated and neglected in developing countries like Iran. The present paper aims to review the soundness and applicability of available procedures of infrequent and irregular suspended sediment sampling and estimation of total sediment yield by using sediment rating curves. The results of the existing and oft-applied method were then compared with those obtained through developing the sediment graphs on the storm basis. The study was formulated based on data intensively collected for some study watersheds in Iran. The results of the study verified the inapplicability of sediment rating curves for giving accurate estimation of suspended sediment yield in the study areas. The results of sediment graph analysis not only proved its aptness to estimate sediment yield in the study areas, but it could also mirror all changes made in the watershed which had been masked at the time of applying sediment rating curves. These findings clearly verified the necessity of sediment graph development in a country like Iran governed by very natural and changing anthropogenic conditions.

Key words changing ecosystems; Iran; sediment graph; sediment rating curve; sediment yield

INTRODUCTION

The rate of sediment yield from the watershed can reflect the balance or imbalance level in a system. Studying suspended sediment yield processes as one of the most important exports of the watershed is proposed as a principle tool in soil and water resources management. Adverse effects resulting from sediment problems are increasing in less-developed countries, where high levels of demand obviously contradict limited resources. The existing imbalanced conditions affect live and inactive organisms, which consequently lead to further instability in the ecosystems. Nevertheless, no practical and country-wide solution and strategy has been adopted to manage the sediment-related problems, since no accurate understanding of the watershed system has yet been made. Nonetheless, the sound management of watersheds cannot be achieved until proper magnitude of soil erosion and sediment yield can be assessed (Sadeghi *et al.*, 2008).

Fluvial behaviour depends on numerous circumstances, varying with respect to climate, vegetation cover, and soil type (Lai & Detphachanh, 2006) and need to be continuously monitored in such a way as to present and understand the governing situation in a watershed within an appropriate time and space scale in order to protect the safety of the people and arrive at economically productive, socially equitable, and environmentally sustainable watersheds (Ghazanfari *et al.*, 2003; Singh, 2003; Sadeghi *et al.*, 2009). A variety of newly introduced approaches, along with improvements in instrumentation and data collection, enable monitoring of land systems at increased temporal and spatial resolutions. Numerous studies (e.g. Walling, 1977, Chen & Kuo, 1986; Banasik & Walling, 1996; Lana-Renault *et al.*, 2007; Sadeghi *et al.*, 2008) have highlighted the pattern of sediment concentration during single hydrological events which have shown that the bulk of sediment in most streams is transported during single floods and that the relation between suspended sediment concentration (SSC) and water discharge during floods is highly variable.

The development of a storm-wise sediment graph is a reasonable solution to understanding the complexities and to reducing the uncertainties. The sediment graph (SG), which is the temporal distribution of sediment load during flood incidents (Sadeghi & Singh, 2005), has many merits and basically produces realistic estimates of total sediment yield (Kothyari *et al.*, 1997). Sediment availability, location, rainfall specification, effective precipitation, and transmission losses, flow hydrograph components and characteristic and antecedent soil moisture conditions are important parameters controlling sediment transport and the consequent shape of SGs and their importance varies as the watershed changes (e.g. Walling & Webb, 1982; Klein, 1984; Sharma & Murthy, 1996; Sayer *et al.*, 2006; Lana-Renault *et al.*, 2007; Sadeghi *et al.*, 2008).

Iran, comprising 1 645 000 km^2, currently faces many sediment-related problems. Since the 1960s many attempts were made to obtain a proper view of sediment yield rates in the country and led to many, and mainly very unreliable, estimates of from 0.8 to even 8 billion tonnes per annum, i.e. some 7–70 t ha^{-1} year^{-1}, based on which many short-term infrastructure designs and mid- and long-term plans were made. Thus, an accurate methodology is badly needed to draw a reliable conclusion on sediment yield in the country. Towards this attempt, the present study has therefore tried to criticize the accuracy of the oft-used technique of sediment rating curve (SRC) development for estimation of suspended sediment concentration (SSC). The appropriate solution of SG development for critical periods was then introduced as a reliable alternative.

MATERIALS AND METHODS

In order to assess the necessity of development of SGs in Iran, a comprehensive study was conducted through analysing water discharge and SSC data sets collected on a storm basis during the last few years. The entire data had been manually and precisely collected during short periods allocated to each study. The data analyses were made for three watersheds, viz. Amameh, Khanmirza and Tarbiat Modares Educational Forest (TMU or Kojour) watersheds located under different agroclimatic conditions (Fig. 1).

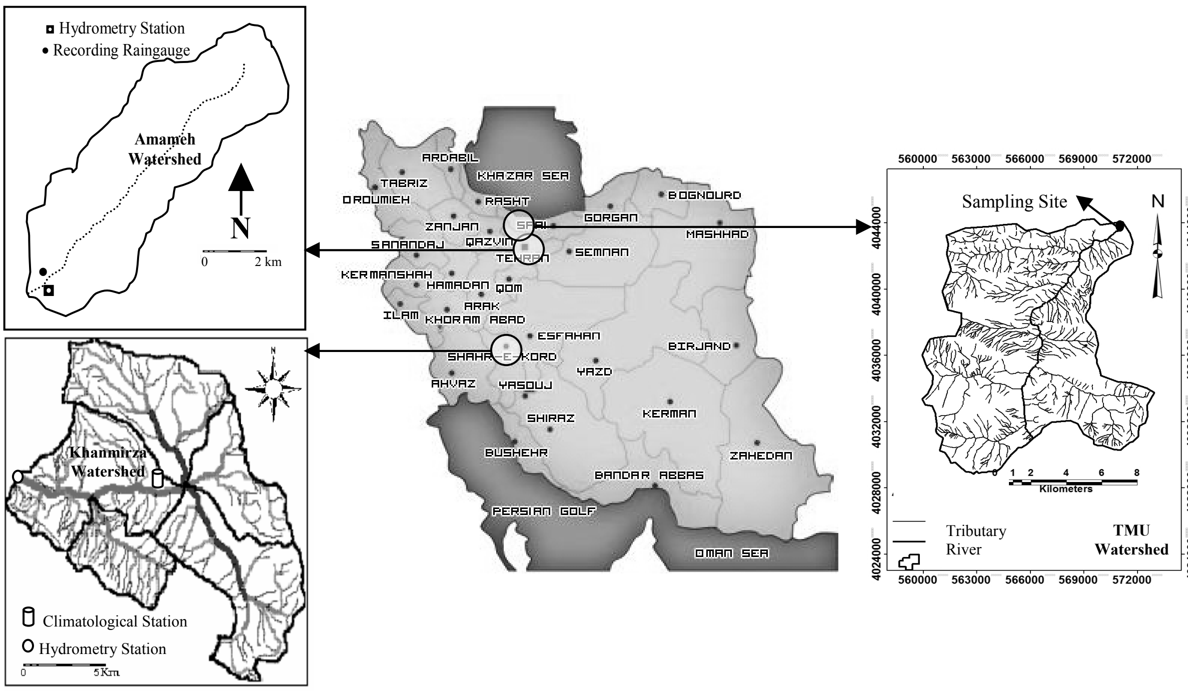

Fig. 1 General feature and location of study watersheds.

The Amameh experimental watershed is located on the outskirts of the Alborz mountain range, 40 km from the capital of Iran, Tehran. It extends between 35°51′00″ to 35°75′00″N latitudes and 51°32′30″ to 51°38′30″ E longitudes and covers an area of 3712 ha. The area is mostly covered by mountainous rangelands with an average precipitation of 848.4 mm, of which almost 73% falls during winter and spring (Sadeghi & Singh, 2005).

The Khanmirza watershed is a part of North Karoon and lies between 31°22′04″ to 31°37′30″N latitude and 50°55′00″ to 51°18′30″E longitude. The main watershed covers about 395 km^2 and is located in Chaharmahal and Bakhtiari Province, western Iran. It drains into the Karoon River and finally leads to the Persian Gulf. The mean annual precipitation of the watershed based on available data is 625 mm, of which 97% falls during late October–early April, and is characterized by a dry and warm Mediterranean climate (Sadeghi *et al.*, 2009).

The Tarbiat Modares watershed (36°32′33"N latitude, 50°49′40"E longitude), encompasses 13 263 ha and is located in Mazandaran Province, north of Iran, and drains to the Caspian Sea. Around 75% of the lower part of the watershed area is native deciduous forest, with the reminder developed mainly for livestock grazing in uplands. Elevation ranges from 150 to 2650 m a.m.s.l. The mean annual precipitation of the study watershed is 1308.8 mm at Nowshahr Plain meteorological station, and just 30 km away it decreases as elevation increases, so that the mean annual precipitation at Kojour station located at the highest point of the study watershed is 250 mm (Sadeghi *et al.*, 2009).

As already mentioned, the essential prerequisite data sets of SSC were provided through field sampling, mainly during the wet season and on a storm basis. Calculation of suspended sediment load at the study sites has been based on the analysis of depth integrated water and suspended sediment samples (Edwards & Glysson, 1999) collected during the study period through applying 1- or 2-L capacity polyethylene containers. Some samples were analysed by applying filtration techniques. The other suspended sediment samples by 1-L volume were allowed to stand undisturbed in containers for 48 hours until complete settlement of the sediment was assumed to be attained. The upper layer of water was then discharged cautiously, without disturbing the settled materials, and saved for analysis. The disposed sediments obtained through both methods were then washed by distilled water into the preweighted aluminum foil dishes and oven dried for 24 h at 105°C. The dried sediment was then weighed by high precision scale (0.0001 g) and the SSCs were ultimately determined (Tennessee Valley Authority, 1941; Putjaroon & Pongboon, 1987). The SRCs were developed accordingly for the entire collected data and the concept of regression model was also implemented to find out two separate equations defining SRCs in two important segments of the hydrograph, i.e. rising and falling limbs. The importance of SG development was then evaluated by comparing the inter-variability of sediment rating curves (SRC) derived for two important phases of rising and falling limbs. The total amount of sediment yield obtained through applying SRCs, as well as SGs, was used as the comparison criterion.

RESULTS AND DISCUSSION

In order to assess the necessity of SG development in study watersheds in comparison with SRC, the entire data were collectively and separately analysed for each watershed. The results of analyses of SSC samples and corresponding oft-suggested power type SRCs are summarized in Table 1.

The results of analyses in all data sets indicated rather high variations in SSC and discharge values. Data available at present for these watersheds also showed that the pattern of the relation between SSC and water discharge is highly variable, and is related mainly to the complex interplay of many determinant factors. It clearly verified high variation in both the study variables with the

Table 1 SRCs developed for different datasets and three study watersheds in Iran.

Watershed	No. of Data	Data subsets Total		Falling limb		Rising limb	
Amameh	291	$Q_S=7.19Q_w^{1.878}$	$R^2=0.85$	$Q_S=2.84Q_w^{2.052}$	$R^2=0.88$	$Q_S=16.41Q_w^{1.842}$	$R^2=0.88$
Khanmirza	80	$Q_S=2.57Q_w^{0.481}$	$R^2=0.74$	$Q_S=1.45Q_w^{0.500}$	$R^2=0.86$	$Q_S=4.96Q_w^{0.471}$	$R^2=0.61$
TMU	511	$Q_S=12.18Q_w^{1.085}$	$R^2=0.39$	$Q_S=0.94Q_w^{0.651}$	$R^2=0.531$	$Q_S=37.75Q_w^{0.971}$	$R^2=0.25$

Q_S and Q_w represent SSC in g L^{-1} and water discharge in m^3 s^{-1}, respectively.

higher rate for the SSCs, which agrees with Sadeghi *et al.* (2008). It can be inferred from the results that the high relative variance of suspended sediment data in comparison with discharge, demonstrates the significant and complex effects of changeful factors such as discharge on SSC, as reported by Gomi *et al.* (2005). Different governing conditions on each watershed also had a significant effect on performance of SRCs so that the smaller and less complicated the circumstances the more accurate SRC.

It is also revealed from Table 1 that the SSC for a similar discharge value in rising limb generates almost 8, 4 and 37 times more than those obtained for the falling limb in Amameh, Khanmirza and TMU watersheds, although the power values in corresponding equations are not exactly alike. The models developed based on the entire data almost represent average conditions. This led to greatly different SRCs for each study watershed and data subsets so that no one can be substituted by another, even in a particular watershed. It could be just related to inter- and intra-variability of affecting factors during categorized data sets as reported by Walling & Webb (1982), Gomi *et al.* (2005) and Sadeghi *et al.* (2008).

Contrary to the general application of common SRC models, drastic differences could be obtained in applying the developed models in the estimation of total suspended sediment yield. It is clearly understood from the results that the SRC models are just able to simulate governing conditions partially, and thus application of SGs is a must for proper prediction of suspended sediment yield in watersheds, especially where the output sediment is controlled by a set of affecting factors. These SGs therefore have to be either developed through continuous SSC sampling at any control point, or synthetically derived, for which further understanding of the watershed systems are required.

The results of the study further show that fragmentation of the data sets into small time scales on an individual storm basis, scrutinizing the governing processes, and then generalizing, may be a reasonable approach that can be used to distinguish fluvial responses at the watershed scale. Similar emphases have been made by Sadeghi *et al.* (2008) in studying determinant factors on suspended sediment yield in a reforested watershed in Japan. The location of the main sediment sources, the change in the relative contribution of runoff processes during a storm response, type, location and level of human interferences, influence of temporal characteristics of storm water and recognition of other affecting factors, can only be interpreted through developing and scrutinizing SGs. This approach is more important in large and diversified natural and anthropogenic countries like Iran, where more complicated conditions control watershed behaviours.

CONCLUSION

The present study was conducted to realize the importance of SG development in three study watersheds located in different parts of Iran. From the results of the present study it can be concluded that the proper assessment of sediment yield and better understanding of the factors governing changing watershed systems, despite the common application of sediment rating curves, needs intensive data collection and analysis, which can be practically achieved. Further comparative wide-ranging studies on sediment graph development and sediment rating curves involving a great deal of data collection to further understanding of the sediment yield processes is therefore advised. By extending such studies to longer periods and to various watersheds throughout the country, it is logically possible to increase the generality of findings of the present study.

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