Earth Sci Inform (2013) 6:87–98
DOI 10.1007/s12145-013-0113-7

RESEARCH ARTICLE

Regional rating curve models of suspended sediment transport for Turkey

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Received: 7 December 2012 / Accepted: 24 March 2013 / Published online: 13 April 2013

Abstract Estimations of annual suspended sediment loads are required for various types of water resources studies. Often estimation of the sediment load is needed for ungauged watersheds. Regionalization methods provide a practical solution to solve such problems. The purpose of this study is to classify suspended sediment yields in watersheds into homogeneous regions in order to identify their regional sediment rating curves. This study has been carried out for suspended sediment stations on 26 main basins of Turkey. Long term-scale suspended sediment rating curves of 115 gauging stations in Turkey were classified using cluster analysis on the basis of hydrological homogeneity. An agglomerative hierarchical clustering algorithm is used so that stations from different geographical locations are considered in the same cluster independently of their geographical location. 115 gauging stations were clustered into 4 different homogenous regions and the regional suspended sediment rating curve was developed for each region. The performance efficiencies of the developed regional rating curves were evaluated for 8 test stations and compared to the performances of rating curves in test sites. A regionalization model is developed for estimating suspended sediment rating curves for ungauged sites in Turkey. The developed regional rating curve models result in very close performances to those of their corresponding site rating curves.

Keywords Suspended sediment yield · Rating curve · Regionalization · Cluster analysis · Turkey basins

Communicated by: Hassan Babaie

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Introduction

Estimation of suspended sediment (SS) load in rivers is very important for issues of soil erosion, soil loss, malfunctioning of hydropower plants, interactions between sediment and water quality, river restoration, reservoir sedimentation, water pollution, channel navigability, in-stream mining, fish and invertebrate habitat, and other ecological impacts (Walling 1977; Williams 1989; Horowitz 1995; Horowitz et al. 2001). Sediment loads, especially in alluvial rivers, often depend on the suspended load which is the major transporting mechanism in streams worldwide (Wood 1977; Francke et al. 2008).

Accurate estimation of sediment concentration and total volume of sediment is critical in rivers carrying excess amount of suspended sediment (Francke et al. 2008). Compared to streamflow monitoring stations, there is limited number of suspended sediment concentration monitoring stations in the world. As a matter of fact, Tramblay et al. (2010) report that in North America due to budgetary reasons the number of suspended sediment monitoring stations has been decreasing over the past 3 decades. Hence, reliable estimation techniques have been developed to compensate for the lack of sediment concentration and load measurements (e.g. Walling 1977; Bray and Xie 1993; Asselman 2000; Horowitz 2003). For instance, Walling (1977) investigated and assessed accuracy of many of the previously developed suspended sediment rating curves over a small basin of the river Creedy in England. Bray and Xie (1993) developed a regression based method for estimating suspended sediment yields for ungauged watersheds in Atlantic Canada. Using different fitting procedures, Asselman (2000) explored the spatial differences in the relations between discharge and suspended sediment transport for different locations in the Rhine drainage basin and related these differences to variations in the sediment transport regimes. Asselman (2000) also analyzed inaccuracies in estimated sediment loads and investigated the physical meaning of the regression coefficients. Like Walling (1977), Horowitz (2003) also assessed various sediment rating curves and evaluated their skills in estimating suspended sediment concentrations for subsequent flux calculations of 11 sites in USA.

Sampling frequencies has significant impacts on the accuracy of sediment rating curves; the accurate estimation of sediment rating curves depends on the number of data available at a site (Walling and Webb 1981; Horowitz 2003). Sediment rating curves are often used to estimate suspended sediment loads where the sampling program is insufficient to define the continuous record of sediment concentration (Walling 1977). The relationship between suspended sediment concentration or load and water discharge generally shows considerable scatter (Walling 1977).

Since it is extremely rare to monitor daily suspended sediment transport and scant to monitor instantaneous suspended sediment transport in rivers, estimation techniques and models have been developed to predict future or deficient suspended sediment transport in rivers. Among the many methods developed for SS concentration/load (Horowitz 2003), the rating curve technique remains to be the simplest and most popular for describing the relationship between water discharge and suspended sediment concentration (Fenn et al. 1985; Horowitz 2003).

Although watershed land use, soil types, precipitation, other parameters may affect suspended sediment transport rate in rivers, it is usually difficult to collect proper and accurate data for all watersheds. Human activities in the basin have a significant impact on suspended sediment load (Wang et al. 2008; Hu et al. 2011). Furthermore, the impacts of the human activities on suspended sediment loads in rivers have been assessed in many parts of the world but it is hard to measure its quantity (Milliman et al. 1987; Sutherland and Bryan 1991; Tiffen et al. 1994; Peart 1997; Chen et al. 2001; Jiongxin 2004; Walling 1990; Poulos et al. 1996; Kuhnle et al. 1996; De Boer 1997; Isik et al. 2008).

Frequently, it is required to estimate the suspended sediment transport from a basin that does not have a gauging station with a record of suspended sediment data (Bray and Xie 1993). When the estimation of the sediment yield is needed at a point or a basin that does not have a suspended sediment monitoring station, regionalization analyses can be a powerful method to estimate the suspended sediment yields in ungauged basins (Bray and Xie 1993; Tramblay et al. 2010). Numerous methods have been developed to forecast suspended sediment transport at gauged sites but only few studies are available for ungauged basins or sites (Bray and Xie 1993; Tramblay et al. 2010; Morehead et al. 2003). Regionalization methods are common tools to estimate hydrologic parameters of ungauged basins. For instance, Tramblay et al. (2010) estimated extreme values of suspended sediment concentrations for ungauged basins in North America. They tested regionalization techniques using the climatic, topographic, land cover, and soils attributes of the watersheds. Raux et al. (2011) determined the factors controlling the hydrosedimentary response of some of the largest drainage basins in the world and to classify them according to their hydrogeomorphological parameters using cluster analysis.

A number of large hydropower projects have been implemented in Turkey for last 4 decades. In recent years emphasis has shifted toward the development of small hydropower or run-of-river plant projects (Balat 2007; Isik and Singh 2008). However, there are not enough gauging stations at desired sites where small hydropower plants are to be constructed. Since suspended sediment loads have posed great challenges in the operation of small hydropower plants (Bishwakarma and Stole 2008), estimation of suspended sediment loads at desired sites is very important to assess their effects (Walling 1977; Horowitz et al. 2001).

The vast majority of river gauging stations in Turkey have either no or very sparse suspended sediment data. Further, most watershed scale parameters (e.g. soil parameters) are usually not available for many watersheds in Turkey. Hence, the regionalization method remains an effective technique in order to estimate suspended sediment loads in ungauged sites.

The main objectives of this study are (i) to cluster suspended sediment monitoring stations in 26 watersheds in Turkey to obtain homogenous regions, (ii) to develop regional rating curves for each homogenous region, and (iii) to test 8 randomly selected stations from those homogenous regions (none were used in development of the regional raring curves) to assess the predictive power of the regional rating curves.

Methodology

Study area and data

Turkey lies from 26 to 45° of longitude east between Asia and Europe and 36–42° of latitude north between Black Sea and Mediterranean Sea (Fig. 1). This study has been carried out at stations where suspended sediment and streamflow data has been collected on either the main stem or the tributaries of 26 main watersheds in Turkey. A total of 123 suspended sediment monitoring stations have been selected. All of these stations had at least 10 years of data. There are actually many more stations, but for consistency stations with less than 10 years of measurements and inconsistent data were excluded. Out of 123 gauged stations, 115 and 8 were used for regionalization and cross-validation purposes, respectively. Electrical Power Resources Survey and

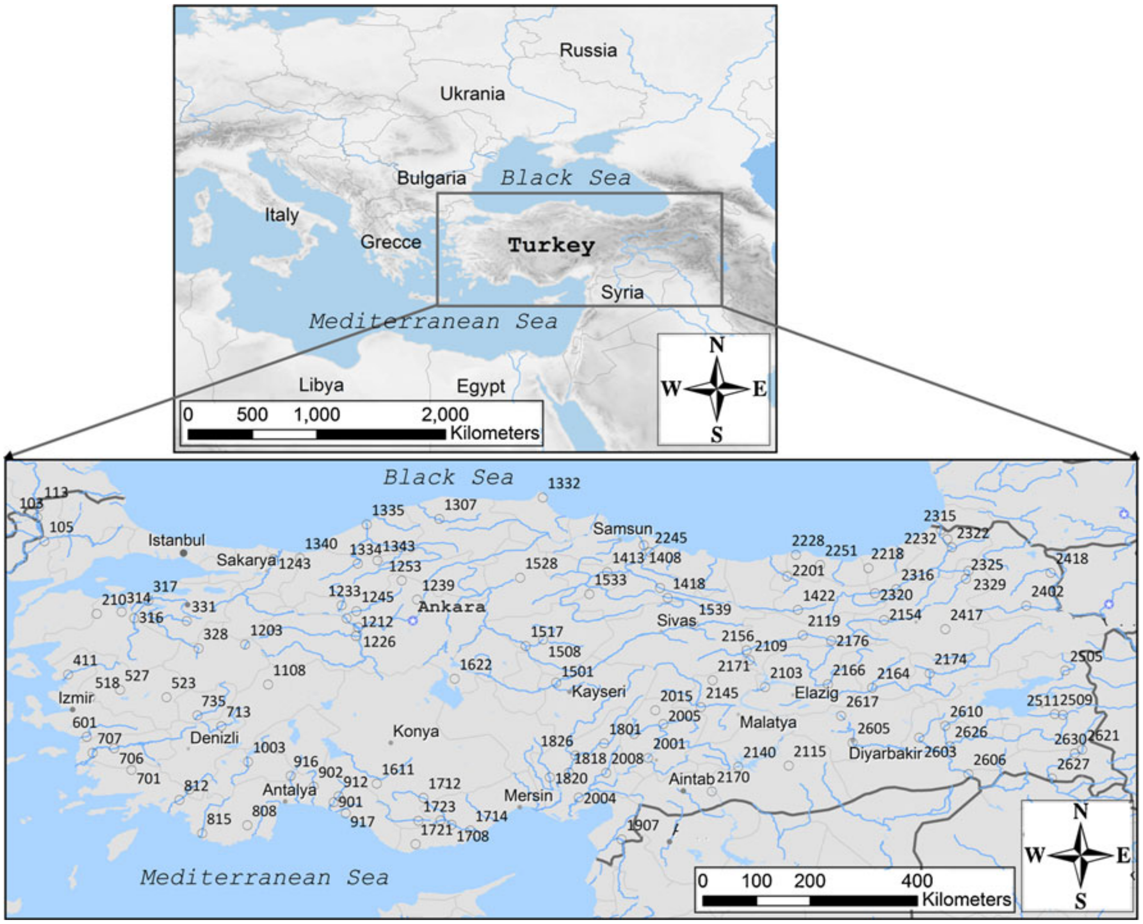

Fig. 1 Map of study area shows suspended sediment monitoring stations with their numbers

Development Administrations (EIE) and State Hydraulic Works (DSI) operate river gauging stations in Turkey (EIE 2003; DSI 2000). The sites, generally located on main tributaries, operated by EIE were selected in this study. The frequency of data collection varies from time to time and from site to site. Map of study area shows suspended sediment monitoring stations with their number in Fig. 1. Table 1 summarizes selected site and data properties. Drainage areas of the selected sites vary from 94.4 to 63873.6 km^2 and the suspended sediment monitoring record length varies from 10 to 44 years with an average of 24 years. While water yields of selected sites range from 0.01 to 974,683 m^3/s/km^2 with a standard deviation of 16,255 m^3/s/km^2, sediment yields vary between 0.003 and 87,407 kg/d/km^2 with a standard deviation of 3,487 kg/d/km^2. Although sediment transport is affected by regulations in rivers, in practice sediment rating curves or sediment load estimates are needed for those sites as well. Hence, those sites were not ignored in this study. Data at stations on basins with major dams or reservoir were corrected by subtracting drainage areas upstream of the dams. Most or all of monitoring data in those sites were collected after the construction of dams, thus data used in analyses are consistent.

Table 1 Summary of selected site properties and associated data

	Area (km^2)	q (m^3.s^{-1}/km^2)	q_s (kg.d^{-1}/km^2)	a* (×10−3)	b	Monitoring durations (years)
Ave.	7 279	2992	692	3.895	1.798	24
Min.	94	0.01	0.003	0.003	1.192	10
Max.	63 874	974683	87407	65.646	2.832	44
St. Dev.	10 856	16255	3487	7.550	0.321	10

*a,b: site specific constants

Sediment rating curves

The rating curve method relates suspended sediment concentration or load to flow rate through a power function (Walling 1974):

$$C = \alpha Q^{\beta} \text{ or } Q_s = \alpha Q^{\beta} \tag{1}$$

where C is the suspended sediment concentration (M/L^3); Q is streamflow rate (L^3/T); Q_s is suspended sediment load (M/T); and α and β are site specific constants or rating coefficients. The specific streamflow or specific water yield (q) of a watershed is defined as discharge rate divided by basin area (A) (Isik and Singh 2008).

$$q = \frac{Q}{A}[L/T] \tag{2}$$

Similarly, suspended sediment yield (q_s) from a watershed can be defined as

$$q_s = \frac{Q_s}{A}\left[M/T/L^2\right] \tag{3}$$

Since catchment areas of available and desired locations vary from one to another, it is essential to work with an independent and unit sediment parameter in analyses in order to develop a regional rating curve for use in ungauged sites. Suspended sediment load (Q_s) at a desired location can easily be computed by multiplying suspended sediment yield (q_s) and catchment area of the location.

Equation (1) can be rewritten as:

$$(q_s A) = \alpha (qA)^{\beta} \text{ or } q_s = aq^b \tag{4}$$

Taking the logarithm of both sides transforms of Eq. (4) into, the following general regression equation:

$$\log(q_s) = \log(a) + b\log(q) \tag{5}$$

where a and b are site specific constants for the regression equations at a given site on a river system. Estimates of sediment yield based on rating-curve calculations will in most cases involve errors which can be ascribed primarily to the scatter associated with the rating relationship (Walling 1977), and the suspended sediment load is likely to be underestimated using the regression equation (Ferguson 1986, 1987; Jansson 1985; Singh and Durgunoglu 1989; Cohn et al. 1992; Asselman 2000). Hence the estimates should be corrected with a log-normally distributed error term ε (bias correction factors) (Ferguson 1986, 1987; Jansson 1985; Koch and Smillie 1986). Equation (5) can be written as:

$$\log(q_s) = \log(a) + b\log(q) + \varepsilon \tag{6}$$

In Eq. (6) ε is an additive log-normally distributed error term ($\varepsilon \sim \log N(0, \sigma^2)$) with mean zero and variance σ^2. If ε is transformed to an multiplicative error, $\eta_{i,}$, it can be written as:

$$\varepsilon_i = \log(\eta_i) \tag{7}$$

Then the expectation of η_i is given by Ferguson (1986) as:

$$E(\eta_i) = \exp\left\{\sigma^2(\ln 10)^2/2\right\} \tag{8}$$

Although a sediment rating curve may be considered as a 'black box' type of model, in which the rating coefficient "a" and exponent "b" have no physical meanings and are inversely correlated (Asselman 2000), there are many studies that attribute physical meanings to them. For instance, according to (Syvitski et al. 2000) the rating exponent "*b*" and coefficient "*a*" depend on meteorological factors and hydrological parameters of a basin. They are believed to represent the erosion characteristics of the catchment (Asselman 2000; Rodgers et al. 2011). The "*a*" coefficient represents an index of erosion severity (soil erodibility) of the river (Morgan 1995; Asselman 2000) and the "*b*" exponent represents the erosive power (soil erosivity) of the river, with large values being indicative of rivers (Asselman 2000). High "*a*" values denote intensively weathered materials, which can easily be transported. A small increase in discharge (Q) yields a strong increase in erosive power "*b*" (Asselman 2000). In other words, steep rating curves with low "*a*" and high "*b*" values indicate little sediment transport at low discharge values while a small at large Q values increase in discharge yields a large increment of suspended sediment transport (Asselman 2000).

The site specific constants, a and b, in Eq. (4), which represents the relationship between q_s and q, were used to cluster sediment rating curves for homogenous regions in Turkey rivers in this study.

For each site, specific streamflow (q) and suspended sediment yield (q_s) were computed from observed streamflow and sediment concentrations. The relationship was constructed between q and q_s for each station in the form of Eq. (6). The site specific constants, "a" and "b" were estimated through linear regression for regional analysis. Data were standardized using the following equation before clustering, so that they receive equal attention during the clustering process.

$$y_{ij} = \frac{(x_{ij} - \bar{x})}{\sigma} \tag{9}$$

Where y_{ij} is the standardized data of j^{th} data at the site i; x_{ij} is data of j^{th} data at the site i; $\bar{x}$ is the mean value of all data; and σ is the standard deviation of all data.

Cluster analysis

Hydrological regionalization is often employed in order to enable the estimation of homogenous regions in unmonitored areas. Hierarchical cluster analysis techniques are commonly used for hydrological regionalization (e.g. Mosley 1981; Yu et al. 2002; Burn et al. 1997; Stahl and Demuth 1999; Lecce 2000; Isik and Singh 2008; Kahya et al. 2008). A brief discussion about hierarchical cluster analysis approach used in this study is provided below. A more detailed description of hierarchical cluster analysis methodology is can be found in Isik and Singh (2008). The objective of the hierarchical cluster is to identify clusters of stations based on a measure of similarity or dissimilarity of data such that the stations within a cluster are similar while there is dissimilarity between the stations in different clusters (Burn et al. 1997). Many clustering algorithms are available and the choice depends on the type and structure of the data to be classified. In this study the Ward-Method was employed, which minimizes the distance within a cluster and is commonly used for hierarchical clustering. The Euclidean distance (the square root of the sum of the squared distances over all variables) was employed as a similarity measure, and can be defined as:

$$d_{1,2} = \sqrt{\sum (x_1 - x_2)^2} \tag{10}$$

where $d_{1,2}$ is the Euclidean distance between x_1 and x_2 over the available data points.

Hierarchical classification can be depicted by a two-dimensional diagram known as a dendrogram (Everitt et al. 2001). Cluster analysis methods do not automatically determine the number of clusters in a data set, so deciding where to cut the stems of a dendrogram is a subjective evaluation (Isik and Singh 2008). The dendrogram should be cut in order to determine the number of clusters. In addition to the visual assessment of a dendrogram, Isik and Singh (2008) proposed a technique called distance test that can be applied to transfer the information from the dendrogram of clustered data to a graphical test. In this method, the distances are plotted against the number of clusters, which eventually provides an idea for deciding the number of clusters. Some graphical statistical tests are also available, such as root-mean-square standard deviation (*RMSSTD*), and R-squared (*RSQ*), that can be performed to determine the optimum number of clusters. The hierarchical analyses in this study were performed using MATLAB version 7.10.0 (2010).

Once the number of clusters is determined, data from stations within each homogenous region were conglomerated in order to construct the regression models in form of Eq. (6).

Model assessment

The performances of the regression models were measured with the coefficient of determination (R^2) and Nash–Sutcliffe efficiency (E_N) for selected test sites (Kalin and Hantush 2006). Mass balance error (*MBE*) root mean square error (*RMSE*), and index of agreement (*d*) were also used to show the predictive power of developed models. The coefficient of determination is a measure of linear correlation between two values and is given by

$$R^2 = \left[\frac{n\sum x_i y_i - (\sum x_i)(\sum y_i)}{\sqrt{n(\sum x_i^2) - (\sum x_i)^2}\sqrt{n(\sum y_i^2) - (\sum y_i)^2}} \right]^2 \tag{11}$$

where x and y represent observed data and model outputs and n is the number of data points. The Nash–Sutcliffe efficiency statistic (E_N) is commonly used to assess the predictive power of hydrological models (Nash and Sutcliffe 1970). It is defined as:

$$E_N = 1 - \frac{\sum (x_i - y_i)^2}{\sum (x_i - \bar{x})^2} \tag{12}$$

where $\bar{x}$ is the mean of the observed data. E_N theoretically varies from $-\infty$ to 1 with 1 corresponding to a perfect model. It is a measure of how the plot of observed versus simulated data deviates from a 1:1 line.

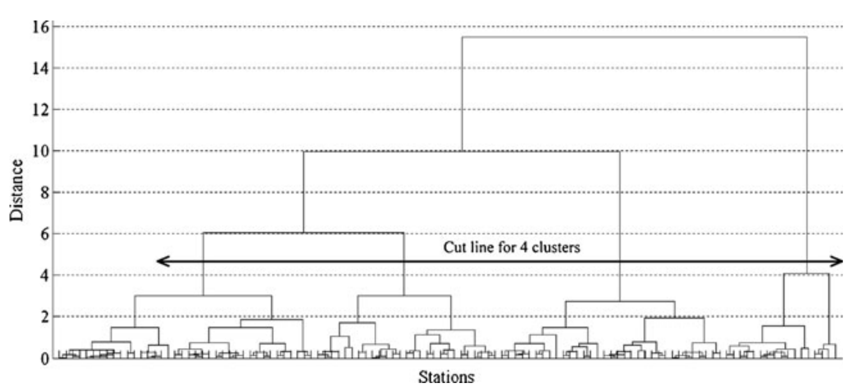

Fig. 2 Dendrogram representing suspended sediment classification

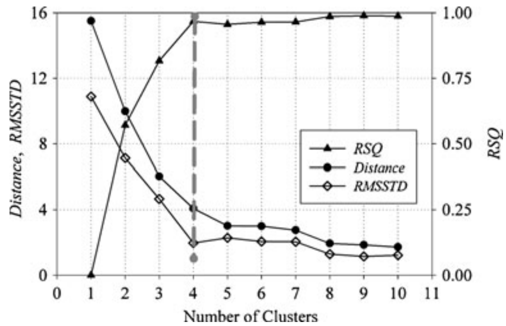

Fig. 3 Distance, *RMSSTD*, and *RSQ* tests

The mass balance error (*MBE*) is defined as:

$$MBE = \frac{\overline{y} - \overline{x}}{\overline{x}} \tag{13}$$

where $\overline{y}$ is the mean of the model outputs.

The root mean square error (*RMSE*) measures the differences between the observed and predicted values. It is defined as:

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(x_i - y_i)^2}{n}} \tag{14}$$

Index of agreement (*d*) proposed by Willmot (1981) to overcome the insensitivity of E_N and R^2 to differences in the observed and predicted means and variances. It represents the ratio of the mean square error and is defined as:

$$d = 1 - \frac{\sum_{i=1}^{n} (x_i - y_i)^2}{\sum_{i=1}^{n} (|y_i - \overline{x}| + |x_i - \overline{x}|)^2} \tag{15}$$

The range of *d* lies between 0 with no correlation and 1 with perfect fit.

Results and discussions

One hundred fifteen sites were clustered based on their site specific constants ("a" and "b") using an agglomerative hierarchical clustering technique to obtain a regional

Table 2 Statistical parameters of data in each cluster

		Area (km^2)	q (m^3.s^{-1}/km^2)	q_s (kg.d^{-1}/km^2)
Cluster 1	Ave.	6896	1039	638
	Min.	100	0.52	0.03
	Max.	50039	105885	217354
	Median	4444	352	36
	97.5 %	33504	5972	6852
	St. Dev.	10215	2646	4176
Cluster 2	Ave.	6851	1331	998
	Min.	94	14.71	0.11
	Max.	53043	50864	199851
	Median	3539	592	50
	97.5 %	53043	6779	8884
	St. Dev.	11256	2144	5066
Cluster 3	Ave.	7520	861	496
	Min.	134	0.74	0.01
	Max.	63874	38799	220021
	Median	2549	285	26
	97.5 %	30589	5580	3407
	St. Dev.	13118	1822	3967
Cluster 4	Ave.	7750	1419	1266
	Min.	915	43	0.22
	Max.	36642	35299	193401
	Median	3711	736	70
	97.5 %	36642	6069	10617
	St. Dev.	9219	1856	5944

regression model for each homogenous region. Figure 2 shows the dendrogram of clustered data. Since it is hard to decide the number of cluster from the dendrogram, a number of graphical tests such as distance test, *RSQ*, and *RMSSTD* were performed to determine the number of homogenous regions. From graphical tests as shown in Fig. 3., it can be seen that the optimal number of homogenous regions is 4 since each graph reaches a plateau after cluster #4. By cutting the dendrogram at 4 clusters, the specific stations in each cluster were determined. There are 38, 27, 33 and 17 stations in clusters 1, 2, 3, and 4, respectively.

Table 2 shows some statistical parameters of data in each cluster. While water yields range from 0.52 to 105,885 m^3/s/km^2, sediment yields vary from 0.03 to 217,354 kg/d/km^2 in Cluster#1. Average of sediment yields in this cluster is 638 kg/d/km^2 with a standard deviation of 4,176 kg/d/km^2 and a 97.5 percentile of 6,852. In Cluster#2, sediment yields vary between 0.11 and 199,851 kg/d/km^2 with a standard deviation of 5,066 kg/d/km^2 and a 97.5 percentile of 8,884. These numbers are not average values of sites in each cluster; instead they are instantaneous values in all sites. In Cluster#3, average values of water yield and sediment yield are 861 m^3/s/km^2 and 496 kg/d/km^2, respectively. Sediment yield in this cluster vary from 0.01 to 220,021 kg/d/km^2 with a standard deviation of 3,967 kg/d/km^2. In Cluster#4, sediment yield range from 0.22 to 193,401 kg/d/km^2 with a standard deviation of 5,944 kg/d/km^2. Averages of watershed areas in 4 clusters did not show large variations with a range of 6,851 and 7,750 km^2 (Table 2). The suspended sediment transport in an ungauged watershed can be estimated using the developed regional rating curves.

Median sediment yields, which are proportional to their average values, are 36, 50, 26, and 70 kg/d/km^2 in 4 clusters, respectively. Hence, Cluster#3 has lowest sediment yield values while Cluster#4 has the highest sediment yield values. This can be validated through online maps in Turkey State agencies.

Erosion risk (qualitative) and land cover maps of Turkey are on the website of Ministry of Forestry and Waterworks (ARIS 2013a, b). Cluster 2 and 4, which have higher sediment yields, were located on high erosion risk areas of the erosion map while Cluster 1 and 3, which have lower sediment yields, were located on low erosion risk area. Dominant land covers are generally cultivable areas, forest and areas with no or little vegetation in Cluster#1 sites in the western Turkey while areas with little vegetation and scrublands are dominant land covers in the eastern part. Scrublands, areas with no or little vegetation, and cultivable areas are dominant land covers in Cluster# 2. Forest is dominant land cover in Cluster# 3 while scrublands are dominant land cover in Cluster #4.

The spatial precipitation distribution map of Turkey is also available on Meteorological Service website of Turkish State (MGM 2013). Average and median sediment yields are proportional to the magnitudes of precipitation in 4 clusters. Sites in Cluster#1 fit on spatial precipitation map of 351–775 mm while sites in Cluster#2 are located on

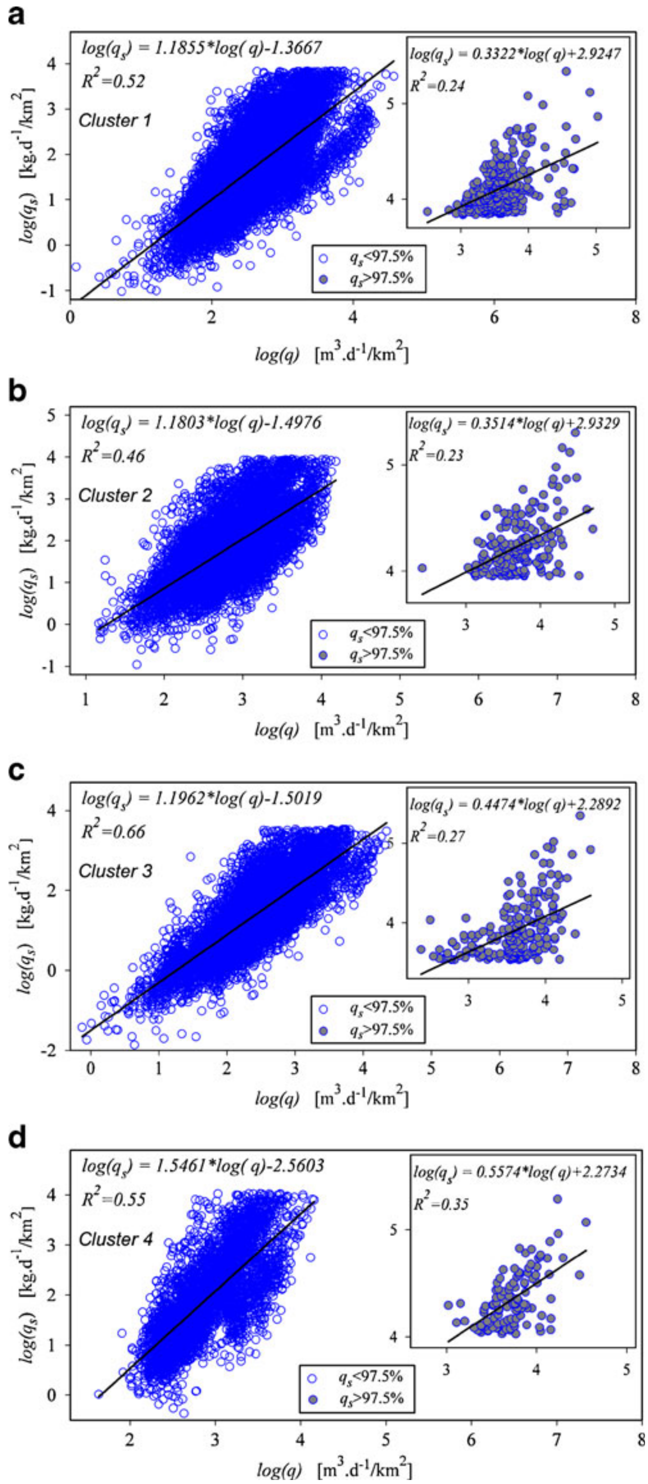

Fig. 4 Regional suspended sediment rating curves for ungauged sites in Turkey (q: specific water yield; q_s: suspended sediment yield; q_{sc}: corrected suspended sediment regression line)

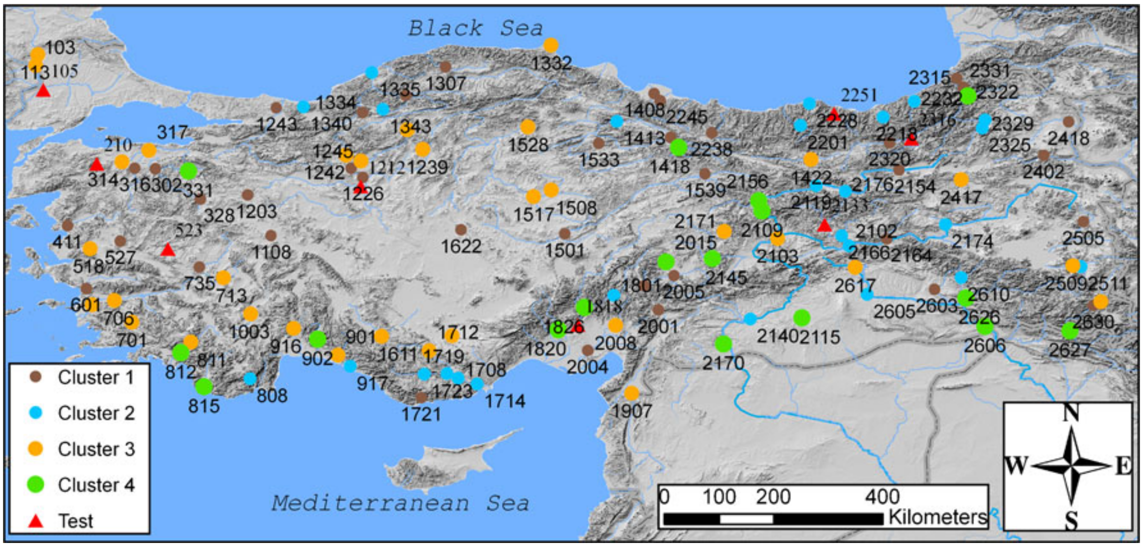

Fig. 5 Suspended sediment yield distribution map of Turkey

spatial precipitations between 691 and 2,203 mm. Sites in Cluster#3 and #4 were generally located on spatial precipitation map between 501–915 and 601–775 mm, respectively.

The suspended sediment loads and corresponding discharges of all stations were assembled for each homogenous group to construct regional regression models. The developed regional regression models were corrected using error term in Eq. (8) for all clusters. Figure 4 depicts the relationships between suspended sediment yields and water yields from all sites in each cluster. Since there are a large number of data in each cluster region, scatter plots shows high variation. Hence, data in each cluster region were split into 2 strata at 97.5 percentile because few data exceed the sum of mean and standard deviation (Table 2). Rating curves for both <97.5 % and >97.5 % of the data were plotted in the same figure for each cluster (Fig. 4.).

Figure 5 shows the suspended sediment yield distribution map of Turkey. In Cluster#1, there are 38 stations mostly located north-west and north-east of Turkey. The coefficients of determination (R^2) are 0.52 and 0.24 for <97.5 % and >97.5 %, respectively. The stations in the second cluster appear to be in southern and eastern part of Turkey having 27 sites. The stations of the third cluster are distributed all over Turkey with 33 sites. R^2 values are 0.66 and 0.23 in both strata, respectively. There are 17 stations in the fourth cluster. They are mostly located in southeastern Turkey with low "*a*" and high "*b*" values indicating high sediment transports at high discharge rates or vice versa.

Eight test stations were selected before starting the cluster analysis to measure the performances of the developed regional rating curves. These stations were not used at all during the development of clusters or regional rating curves. The cluster region of test sites can be decided by using cluster regions surrounding sites of a test site. The cluster region of most of surrounding sites around a test sites can be taken as the cluster region of the test site. For instance, there is no problem in case of test site #523 because 3 closest sites around site #523 lie on Cluster#1. In the case of test site # 1818, there 4 closest stations around site #1818, but 3 of

Table 3 Performances of regional regression models for 8 test sites

Station	Cluster	Regional rating curve model (Q_{sc})					Site rating curve (Qsr)				
		R^2	E_N	*MBE*	*RMSE*	*d*	R^2	E_N	*MBE*	*RMSE*	*d*
105	3	0.68	0.58	−18 %	4103	0.80	0.71	0.68	21 %	3597	0.92
210	3	0.76	0.48	−24 %	249	0.71	0.77	0.14	−80 %	320	0.29
523	1	0.69	0.10	−81 %	2508	0.26	0.71	0.20	−78 %	2374	0.39
1212	1	0.39	0.26	−7 %	137	0.47	0.47	0.42	−11 %	121	0.69
1818	4	0.54	0.17	−53 %	4010	0.33	0.74	0.62	−6 %	2705	0.83
2133	2	0.48	0.37	−1 %	2908	0.61	0.55	0.55	−1 %	2462	0.83
2251	2	0.63	0.52	45 %	1895	0.76	0.76	0.33	−60 %	2245	0.54
2316	1	0.65	0.50	−21 %	883	0.74	0.65	0.59	10 %	801	0.89

them are in Cluster#4 and one of them is in Cluster #1. Since most of the surrounding sites which are also closer than the other are in Cluster#4, It can be concluded that the test site #1818 is in Cluster#4.

The coefficient of determination (R^2), Nash-Sutcliffe efficiency (E_N), mass balance error (*MBE*), root mean square error (*RMSE*), and index of agreement (*d*) values were computed for the regional rating curve and the site rating curves in each test station. The R^2, E_N, *MBE*, *RMSE*, and *d* values are based on measured suspended sediment load for each model, but their values of the regional rating curve were compared with those of the site rating curves. Under

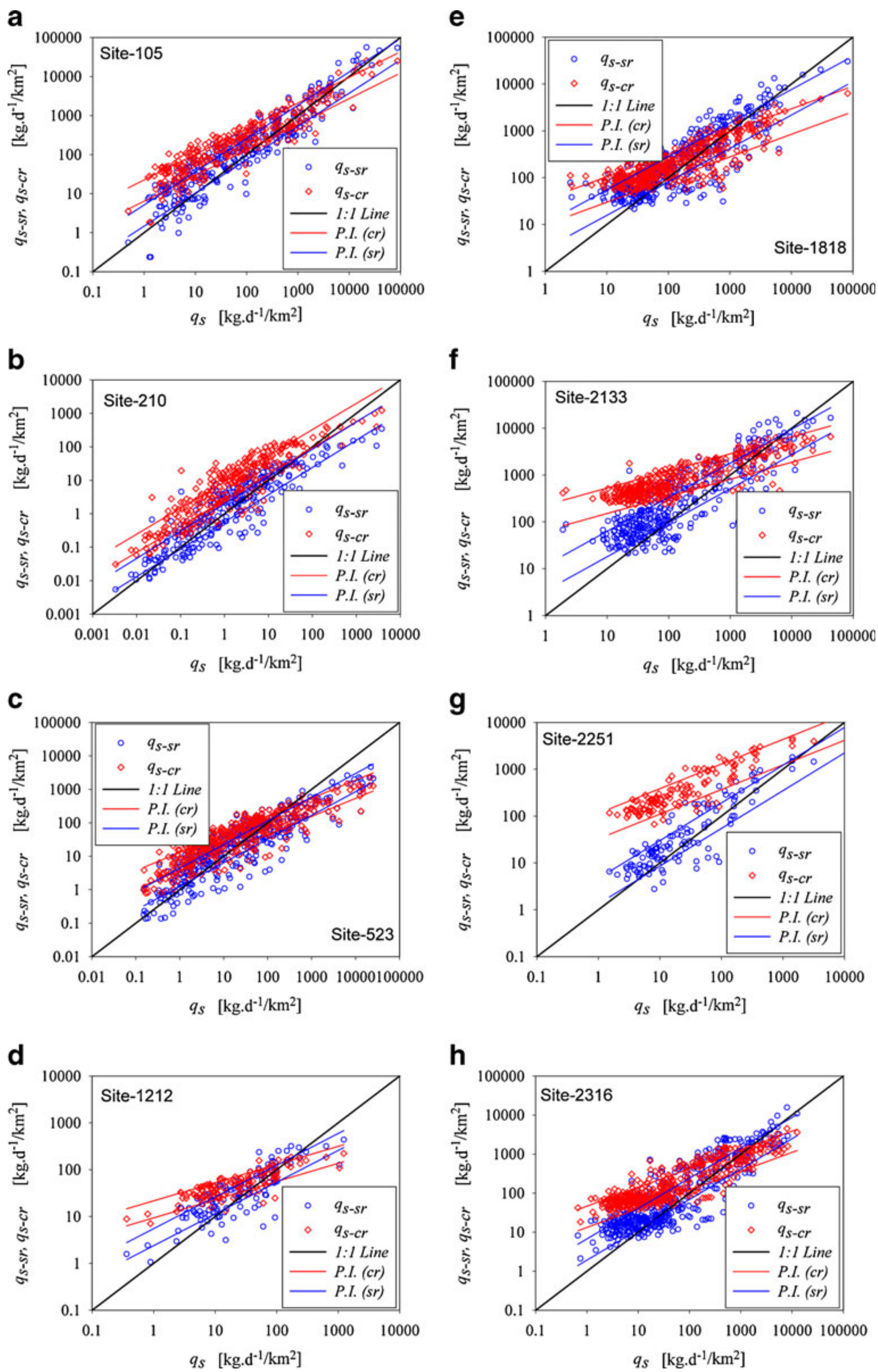

Fig. 6 Scatter plots for measured suspended sediment (SS) load (*Qs*) versus SS load of site rating curve (Q_{sr}) and SS load of regional model (Q_{sc}). ($q_{s\text{-}cr}$ is the developed rating curve model; $q_{s\text{-}sr}$ is the site rating curve model; 1:1 Line is the perfect fit. P.I. is 75 % prediction interval).

ungauged conditions, if the model prediction is close to the site prediction, it indicates that it is a reasonable result. The performances of the regional models and the site rating curves are shown in Table 3. While the values of R^2 are very similar for each model in each station with a range from 0.39 to 76, E_N values show variation in each site. While E_N values are 0.68 and 0.58 for site rating curve and cluster model in station 105, respectively, their d values are 0.92 and 0.80, respectively. Stations, 523, 1212, and 2316, have E_N values of 0.10, 0.26, and 0.50, respectively, for cluster models, whereas their values for site rating curves are 0.20, 42, and 0.59, respectively. E_N values for site rating curves are 0.55 and 0.33 for stations, 2133 and 2251, respectively, but their values for cluster models are 0.37 and 0.52, respectively. d values vary between 0.26–0.80 and 0.29–0.92 for regional rating curves and site rating curves, respectively. *RMSE* values for both rating curves at all sites are very close each other. While *MBE* values for regional rating curves at all sites range from −81 % to 45 %, their values for site rating curves vary between −80 % and 21 %.

Comparisons of the developed regional rating curve models ($q_{s\text{-}cr}$) and the site rating curve models ($q_{s\text{-}sr}$) are depicted in Fig. 6. for 8 stations. The scatter plots of $q_{s\text{-}cr}$ vs. q_s and $q_{s\text{-}sr}$ vs. q_s were constructed to compare the models and to visualize the performances of their estimations with 1:1 line. Their prediction intervals (*P.I.*) with 75 % confidence level are also shown in the figure. Rating curve prediction intervals, *P.I.*(*cr*), are very close to site rating curve prediction intervals, *P.I.*(*sr*). The results in Fig. 6. are also consistent with those in Table 3. Prediction intervals show parallel results with R^2 values. Although the developed regional rating curve models cannot result in high performances as much as those of their corresponding site rating curves, their performances are very close each other. The developed models yield satisfactory results at desired unmonitoring sites. The regional rating curve models can be employed for suspended sediment transport estimation in unmonitored sites in Turkey.

Since most watershed scale parameters (e.g. soil parameters, land use and land cover) are usually not available for many watersheds in Turkey, regionalization on lithology and land use are beyond this study. Unal et al. (2003) performed hydrometeorology regionalization of Turkey and proposed 7 climatic regions. Isik and Singh (2008) and Kahya et al. (2008) found 6 homogenous hydrological regions in Turkey by using 80 and 1,410 sites, respectively. The results in both studies are very similar in terms of hydrologic regionalization. It is difficult to compare 6 hydrologic homogenous regions with 4 regions defined in this study. However, they can be generally compared. If 6 hydrologic homogenous regions were redefined according to the magnitude of their water yields, 71 % of the sites in this study match with the sites in Isik and Singh (2008) study. This can be considered as quite reasonable, because the natures of problems are different in both cases. Furthermore, depended parameters of water yield and sediment yield in a watershed are different. Since sediment yield is the output of complex interactions of climate, topography, soil, land use, and diversion structures in the watershed of a site, characteristics of sites can be explored and justified with their watershed properties in a small scale study.

Conclusion

A regionalization model is developed for estimating suspended sediment rating curves for ungauged sites in Turkey. An agglomerative hierarchical clustering technique, based on Euclidean distance and Ward's algorithm, was employed to gauged sites with similar hydrologic characteristics. Statistical tests were applied to select the optimum number of clusters. The efficiency of rating curve models in estimating suspended sediment loads was evaluated using the Nash-Sutcliffe model efficiency criteria (E_N), the coefficient of determinations (R^2), mass balance error (MBE), root mean square error (RMSE), and index of agreement (d). The regional rating curve models were developed for four homogenous regions. Their performances for 8 independent test stations varied from 0.10 to 0.58 of E_N and from 0.39 to 0.76 of R^2. The performances were also compared to those of the original rating curves in test sites. A number of general conclusions emerge from these analyses: (i) the model enables to identify homogeneous regions; (ii) the developed model yields satisfactory results at desired unmonitoring sites; (iii) suspended sediment yield distribution map of Turkey was obtained and can be successfully employed at unmonitoring sites; (iv) although in most sites the developed regional rating curve models do not perform as well as site curve rating models, they remain potential for sediment yield estimation for ungauged sites. The future work will focus on the further development of regional rating curve models with the consideration of more controlling factors.

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