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An Assessment of Specific Sediment Yield of Geological Formations Using Investigated Sedimentary Deposits in Reservoirs and Fingerprinting

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ABSTRACT

Sediment yield data, collected for most regions in Iran has been insufficient and not so reliable and there is still not any sufficiently reliable methodology available for sediment yield assessment in the country as a whole. On the other hand, an attainment of reliable sediment yield data is a must and key requirement for the design of effective sediment management as well as control strategies. Sediment deposition in reservoirs is assumed as a very useful tool in providing such data. The main objective of the present research was to discuss a combination of both source fingerprinting technique and reservoir sediment survey to provide reliable data on sediment yield of geological formations for three small catchments in Semnan Province, Iran. Throughout the study, the volume and mass of deposited sediments in reservoirs were initially assessed. Fingerprinting technique was employed to identify the contribution to, as well as the specific sediment deposition yield of each geological formation into reservoir sediments. Results indicate that there is a high spatial variation in Specific Sediment Yield (SSY) among the geological formations in all the three catchments varying from 2.98 t ha^{-1} year^{-1} to 0.16 t ha^{-1} year^{-1}. The results also emphasize the importance of Quaternary Units and Upper Red Formation as the dominant surface sources within some vast areas of the catchments.

Keywords: Fingerprinting, Geological formation, Iran, Reservoir, Specific Sediment Yield.

INTRODUCTION

Throughout the world, several million reservoirs have been constructed for irrigation purposes, water supply and/or flood control (Verstraeten and Poesen, 2002). Sediment yield can be monitored through an assessment of sediment deposition rates in lakes, reservoirs or small ponds (McManus and Duck, 1985; Neil and Mazari, 1993; Foster, 1995; Verstraeten and Poesen, 1999; 2001c). since in many of these reservoirs, sediment deposition can be monitored, this large number of potentially available sediment yield data makes the use of reservoir sediments very attractive for regional-scale studies of sediment delivery. From a management perspective, the understanding of nature and relative importance of the principle sediment sources within a catchment is needed to support the design and implementation of sediment control strategies in catchments (Collins *et al.,* 2001). Any attempt to identify the primary sediment sources within a catchment and to assess their relative contributions to the sediment load at the catchment outlet will face a number of important problems (Peart and Walling, 1988; Collins and Walling, 2004). In response to these problems, the fingerprinting approach has been increasingly adopted as an alternative

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and a more direct and reliable means of assembling such information. In particular, source fingerprinting techniques provide a relatively simple and cost-effective basis for assembling spatially as well as temporally integrated data for catchments of different scales (Collins and Walling, 2004; Walling, 2005; Walling *et al.,* 2008). The application of this approach comprises two basic steps, namely: the selection of diagnostic properties which distinguish potential sediment sources, and a comparison of sediments and catchment source samples using these properties to establish sediment provenance (Walling *et al.,* 2008). Existing research has provided valuable information on the range of properties that can be successfully employed to discriminate potential sediment sources in drainage basins. These have included mineralogy, and colour (Grimshaw and Lewin, 1980), particle size (Stone and Saunderson, 1992), mineral magnetism (Caitcheon, 1993; Kouhpeima *et al.,* 2011), geochemical composition (Foster and Walling, 1994), environmental radionuclides (Wallbrink and Murray, 1996), organic constituents (Collins and Walling, 2002), acid extractable metals (Collins and Walling, 2002) and clay minerals (Kouhpeima *et al.,* 2010). So far, there has been no study carried out in sediment yield assessment in the country as based on this methodology. Therefore, the objectives of this study were: (1) to assess the sediment deposition in reservoirs using a survey of sediment deposition, (2) to identify the contribution of each geological formation to sediment yield using Fingerprinting technique and (3) to assess the Specific Sediment Yield (SSY) as based on both source fingerprinting technique and reservoir sediment survey to provide reliable data on Specific Sediment Yield of geological formations for a number of three small catchments in Semnan Province, Iran.

The Study Catchments

Three catchments along with their reservoirs, constructed at the outlet of each catchment, have been selected for the study. The selected reservoirs are earth embankments constructed to harvest seasonal runoff. Some more details of the catchments are presented in Table 1. A location map of the catchmentsis also presented in Figure 1.

MATERIALS AND METHODS

Survey of Sediment Deposition

Sediment deposits in reservoirs were used to assess the total sediment yield from the corresponding catchment areas using Equation (1), as proposed by Verstraten and Poesen (2002). Here, the term Total Sediment Yield (TSY) refers to the mass of sediment that annually enters the reservoir.

$$TSY= 100\times M/(STE\times Y) \quad (1)$$

Where, *TSY* is total sediment yield (t year^{-1}), *M* is sediment mass (t), *STE* is Sediment Trap Efficiency (%), *Y* represents the age of the reservoir (years), and

$$M = Sv\times dBD \quad (2)$$

Where, *Sv* is the assessed sediment volume in the reservoir (m^3), dBD is area-weighed average dry bulk density of the sediment (g cm^{-3}).

Sediment thickness was evaluated through an observation of sediment profiles (between 0.7 and 2.8 m of depth) in pits along transects, with 40 to 100 pits per reservoir depending on the size and nature of the bedrock of the reservoir (see examples in Figure 2). Sediment volume was computed by constructing a Digital Elevation Model

Table 1. Some characteristics of study catchments (Kouhpeima, 2009).

Catchment	Area (ha)	Mean annual rainfall (mm)	Mean slope (%)	Low elevation (m)	High elevation (m)
Attary	628.48	180.4	15.95	1750	2220
Ali Abad	121.96	176.9	16.20	1775	2093
Ebrahim Abad	505.64	182.9	29.31	1825	2070

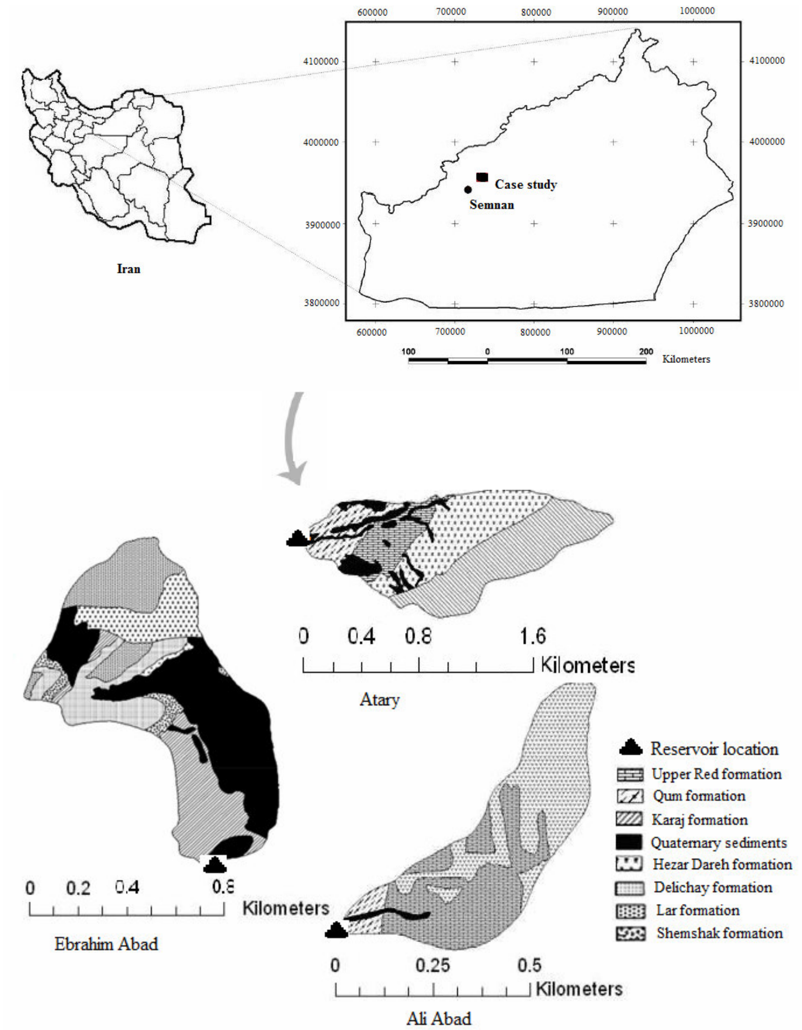

Figure 1. Location map of the study area and the geological formations of each study catchment basin.

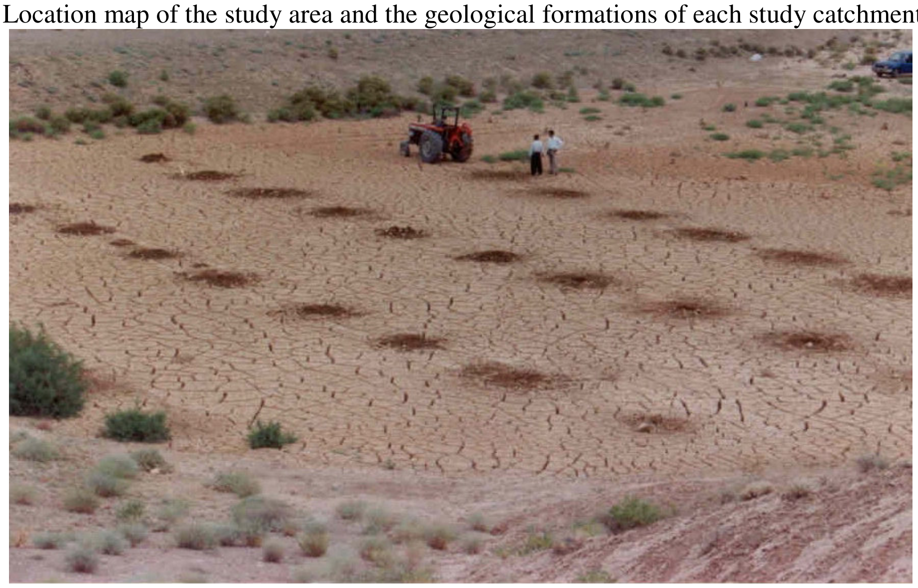

Figure 2. Some examples of the profile pits.

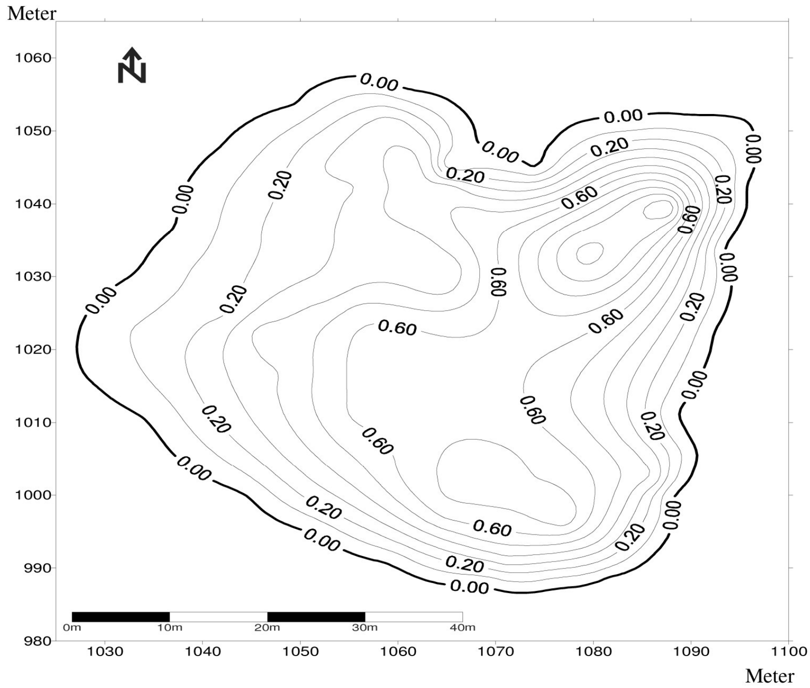

Figure 3. Topographic mapping related to Attary Reservoir.

(DEM) with a resolution of 1 m using Triangular Irregular Network (TIN) interpolation in IDRISI software and taking sediment thickness as the *z* value (Haregeweyn *et al.,* 2005). (see the Figure3)

The trap efficiency of the reservoirs was assessed based on one year field monitoring (2008) and interviewing the local farmers regarding the history of the reservoir. All reservoirs are less than 10 years old and spillage has never occurred for any of the reservoirs since their construction. Dry Bulk Density (dBD) was determined through gravimetric method. In each reservoir 8 to 10 undisturbed representative sediment samples were taken at a minimum of two different depths in the profile pit using core rings (volume 1×10^{-4} m^3). samples were collected from such parts as near the dam axis, in the middle, at the boundaries as well as at the inlet to the reservoir.

The variability in dBD was determined as based on the method of Haregeweyn *et al.* (2005). In this method the vertical variability of dBD was considered by taking the average dBD values obtained from different depths in a profile, while the horizontal variation was accounted for by producing a dBD map, using Thiessen Polygons in IDRISI software with point dBD values obtained from all pits in the reservoirs. The map drawn through Thiessen Interpolation produced the expected distribution of dBD both along and across the reservoir. A map of the mass of accumulated sediment per unit area was then produced by multiplying the sediment DEM and dBD map layers. Then the total mass of the sediment accumulated over the years was determined by using the "EXTRACT" module in IDRSI software.

Fingerprinting Procedure

Source and Sediment Sampling

Potential sediment sources were categorized through a study of surface soils coming from different geological formations. For the case of Attary Catchment, there are five sediment sources distinguished as: Quaternary, Karaj, Qum, Upper Red and Hezar Darreh formations. As for the Ali Abad catchment, three sediment sources were determined, namely: Quaternary, Upper Red and Qum formation and finally for the case of Ebrahim Abad catchment, Quaternary, Hezar Darreh, Karaj, Lar, Delichay and Shemshak formations were realized as the pertinent sediment sources (See Figure 1). Field sampling involved the collection of representative samples from both main geological formations within each study catchment and as well from the sediments deposited in reservoirs. Ten representative samples were collected from each geological formation per catchment. The samples were collected using a stainless steel spade while care being taken to ensure that only material susceptible to erosion (the surface 0–2 cm) was collected (Walling *et al.,* 2008). The source material samples were air-dried and subsequently dry-sieved to < 63 µm to facilitate the direct comparison with sediment samples, collected from reservoirs (Walling *et al.,* 2008). Ten undisturbed representative sediment samples were taken (using a stainless steel spade) per reservoir and from all sediment parts. The samples were subsequently air-dried prior to laboratory analysis. Oven-drying was avoided, in order to prevent any potential geochemical digenesis that might have occurred under high temperatures (Carter *et al.,* 2003).

Selecting Fingerprint Properties and Laboratory Analyses

Selection of fingerprinting properties for use in the investigation was based on previous experience of source discrimination, as well as on the constraints of available analytical facilities and the time available for analytical work. Because there is a potential problem that some tracer properties may be discharged from point sources to rivers in solution and be subsequently absorbed onto the existing suspended sediments in the river (Owens and Walling, 2002), thereby elevating the property concentration of the sediment, it is necessary to exclude properties that show an elevated concentration in sediment before the fingerprinting exercise is carried out. The 15 properties finally selected (Table 2) were comprised of five groups of fingerprinting properties, including organic constituents (C, N and P), base cations (Na, K, Ca and Mg), acid extractable metals (Cr and Co), clay minerals (Smectite, Chlorite, Illite and

Table 2. Results of applying Kruskal–Wallis test to assess the capability of each tracer property to discriminate among surface materials from different sediment sources collected.

Tracer property	*p*-value		
	Ebrahim Abad	Ali Abad	Attary
N	0.01*	0.03*	0.26
P	0.00*	0.00*	0.00*
C	0.00*	0.00*	0.00*
Ca	0.00*	0.03*	0.00*
Cr	0.08	0.32	0.04*
Co	0.02*	0.06	0.01*
Mg	0.00*	0.00*	0.00*
K	0.01*	0.23	0.00*
Na	0.00*	0.01*	0.00*
Smectite	0.00*	0.00*	0.00*
Chlorite	0.00*	0.00*	0.00*
Ilite	0.00*	0.00*	0.00*
Kaolinite	0.01*	0.01*	0.01*
Xlf	0.00*	0.00*	0.00*
Xfd	0.00*	0.00*	0.00*

*Significant at P= 0.05.

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Kaolinite) as well as mineral magnetism (X_{lf} and X_{fd}). C and N were determined directly using a Carlo Erba Elemental Analyzer, while P was determined calorimetrically using UV Visible Spectrophotometry, following extraction with perchloric acid (Olsen and Dean, 1965). Ammonium acetate was used to extract Na, Mg, Ca and K (Qui and Zhu, 1993). Acid extractable metals were extracted using direct acid digestion (Allen, 1989). Clay minerals were determined using X-ray diffraction (Garrad and Hey, 1989) and mineral magnetisms determined, employing a Bartington meter and MS2B dual frequency sensor (Caitcheon, 1998).

Sediment Source Discrimination

The capability of the range of fingerprinting properties employed in the study to discriminate between the potential sediment sources was tested statistically using the two-stage procedure proposed by Collins *et al.* (1997). In stage one; the Kruskal–Wallis *H*-test was used as a basis for eliminating the redundant fingerprint properties, by testing the potential capaability of individual constituents to distinguish the potential sediment sources in an unequivocal manner. In stage two, multivariate stepwise Discriminate Function Analysis (DFA) was employed to test the ability of the properties passing the Kruskal–Wallis test to classify all the source material samples from a given catchment into the correct categories and to identify the optimum (i.e. smallest) combination of properties, or composite fingerprint, for discriminating the source material samples from that catchment.

Quantitative Ascription of Geological Formation Using a Multivariate Mixing Model

A multivariate mixing model based on that employed by Collins *et al.* (1997) was used to estimate the relative contribution of the potential sediment sources to the individual sediment samples collected from each designated catchment (See Equation (3)). In this method, the proportions P contributed by the *m* individual sources *s* are established by minimising the sum of the squares of the residuals (Res) for the n tracer properties involved. *Cssi* is the concentration of the tracer property *i* in the sediment sample, *Csi* represents the mean concentration of tracer property i in source group *s* while *Ps* is the relative proportion from source groups.

$$R_{es} = \sum_{i=1}^{n} \left(\frac{C_{ssi} - \left(\sum_{s=1}^{m} c_{si} \cdot p_{s} \right)}{C_{ssi}} \right)^2 \quad (3)$$

To ensure that equal weight is given to the individual fingerprint properties, included in the linear equations within the mixing model, and thus contributing to the overall sum of squares of the residuals, all property concentrations were scaled while the range 0–1. The goodness of fit provided by the optimized mixing model was assessed through a comparison of the actual fingerprint property concentrations for the sediment samples with the corresponding values predicted by the mixing model, based on the estimates of the magnitude of the contributions from each of the sources. Walling and Collins (2000) suggest that relative errors < 15% indicate that the mixing model provides an acceptable prediction of the fingerprint property concentrations associated with a sediment sample and that consequently the relative contribution of the potential sources estimated by the mixing model are likely to be reliable. The mean relative errors (average for all properties within each composite fingerprint) for the mixing model calculations were typically around 11%, confirming that the relative contributions from the individual source types generated by the mixing model were meaningful.

RESULTS AND DISCUSSION

Survey of Sediment Deposition

The results of Total Sediment Volume (TSV), Total Sediment Mass (TSM) and Total Sediment Yield (TSY) assessment are presented in Table 3 There are some

Table 3. Assessment of sediment volume, sediment mass, as well as sediment yield.

Reservoirs	TSV[a] (m^3)	dBD[b] (g cm^{-3})	TSM[c] (t)	Age (year)	TE[d] (%)	TSY[e] (m^3 $year^{-1}$)	TSY (t $year^{-1}$)
Attary	2676.1	1.41	3778.65	10	100	267.61	377.865
Ali Abad	1035.89	1.35	1395.34	10	100	103.589	139.534
Ebrahim Abad	1244.4	1.43	1786.95	10	100	124.44	178.695

[a] Total Sediment Volume; [b] dry bulk density; [c] Total Sediment Mass; [d] Trap Efficiency; [e] Total Sediment Yield.

variations observed in TSY among catchments e.g. from 377.865 t $year^{-1}$ to 139.534 t $year^{-1}$ for Attary and Ali Abad Catchments, respectively. These values are low when compared with the values reported in most semi arid regions of Iran. Several factors as follows may explain the difference: most values reported had been obtained through river sediment statistics, especially in periods of high sediment load (winter and sprig), and use had not been made of the reservoir sediments. Furthermore, sediment load may increase with catchment size, as channel erosion becomes dominant (e.g. Church *et al.,* 1999).

The profile dBD analysis resulting from pits indicates that dBD varies both spatially within the reservoir and vertically in the profile. For instance, in the case of Attary, 10 pits were sampled and it was found that dBD varies between 1.22 gr cm^{-3} at the inlet and 1.42 gr cm^{-3} near the dam. The results seem to be reasonable because of the deeper and more compressed nature of sediments nearer to the dam. For the same number of pits (n= 10), analysis of vertical variation of dBD was made through an analysis of dBD values from cores taken in two regions at two depths (upper and lower) in a profile pit. There exist some variations of dBD between the upper and lower zones, i.e. 1.12 gr cm^{-3} and 1.25 gr cm^{-3}, respectively. A similar trend exists in other reservoirs. In general, associated errors during sediment volume and sediment yield determination are low for two reasons: Firstly, sufficient precision was obtained both during sediment surface mapping, sediment thickness measurement (with precision of 1 cm) and during sampling for dBD analysis and during DEM generation (1 m by 1 m), and secondly, the effect of STE determination in the overall error is very low as none of the reservoirs have ever spilled since the time of their construction.

Sediment Source Discrimination

Kruskal–Wallis test was employed to assess the possibility of the tracer properties be used in discriminating between the source types occuring in the catchments (results presented in Table 2. In the case of Attary catchment, the majority of tracer parameters exhibit *p*-values well below the significance value of 0.05 indicating that they can be used to strongly discriminate between the four source types. Only one parameter (N) was found to be of no significance in making the discrimination, and it was, therefore, removed at this stage. The optimum multicomponent fingerprint, comprised of: Na, C, X_{lf}, and Kaolinite was potentially able to correctly distinguish 91.7% of the source material samples and therefore provided a powerful means of discrimination between the potential sources. The results of Kruskal–Wallis test for Ali Abad Catchment indicate that 12 properties were shown to be helpful in discriminate between the geological formations. However, multivariate stepwise discriminant function analysis showed that 100% of the samples could be correctly classified using the optimum multicomponent fingerprinting, comprised of: Na, X_{lf}, Ca, C as well as Smectite, and therefore, provided a powerful means of discrimination between the potential sources (Table 4).

The results of the Kruskal–Wallis test, shown in Table 2 indicate that, with the exception of Cr, the entire fingerprint properties initially selected evidenced statistically significant differences between the source types in the Ebrahim Abad Catchment. Table 4 indicates that the final composite fingerprint comprised of three properties (Illite, Mg and C) was capable of allocating 95.8% of the source samples to the correct source type and therefore, provided a powerful means of discriminating between the potential sources. Looking into the results of the Multivariate Stepwise Discriminant Function Analysis, the results presented emphasize that the optimum multicomponent fingerprints are from several different property groups for all the catchments (Table 4) and confirm the need to use properties with different environmental controls to obtain a composite fingerprint that affords a high degree of discrimination (Collins and Walling, 2002). One of the problems attributed to fingerprinting technique is that sediment samples are generally enriched in fines as compared to source materials (Walling *et al.,* 2000), resulting in sediment samples exhibiting higher concentrations of many constituents than the source material. Peart and Walling (1986) noted that sediment is likely to be enriched in organic matter, which may then act as a scavenger for many elements (Carter *et al.,* 2003). However this subject is complex and difficult to generalize (Walling *et al.,* 1999) and therefore such correction was not taken into account in this study.

Quantitative Ascription of Geological Formations

Table 5 examines the results of relative contribution, sediment yield as well as specific sediment yield from each sediment source to the reservoir sediment, sampled at the three catchments. The extent of Sediment Yield (SY) for each sediment source was obtained by multiplying each sediment source contribution (column 3) by Total Sediment Yield (TSY) obtained from total catchment area (Table 3). *SY* was divided by the area covering each sediment source to compute the specific sediment yield from each sediment source. For the case of Attary, the sediment yield from Upper Red Formation (90.68 t $year^{-1}$) is the first relative contribution, followed in descending order by the Hezar-Darreh Formation (79.35 t $year^{-1}$), both Quaternary Units and Qum Formations (75.57 t $year^{-1}$)

Table 4. Results of using Stepwise Discriminant Function Analysis to identify which combination of tracer properties provides the best composite fingerprint for discriminating source materials.

Catchment	Step	Tracer property	Wilks' Lambda	Cumulative geology samples classified correctly (%)
Attary	1	Na	0.412	48.90
	2	C	0.062	77.80
	3	Xlf	0.030	88.90
	4	Kaolinite	0.009	91.70
Ali Abad	1	Na	0.502	47.20
	2	Xlf	0.127	61.60
	3	Ca	0.036	61.10
	4	C	0.004	81.10
	5	Smectite	0.00	100
Ebrahim Abad	1	Ilite	0.104	59.30
	2	Mg	0.021	88.50
	3	C	0.001	95.80

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as well as Karaj Formation (56.67 t $year^{-1}$). These results demonstrate that all parts of the catchment basin provide significant contributions to the sediment formationat the reservoir in Attary Catchment. By using these estimates and the proportions of the catchment area, supplying these contributions (Table 5) the specific sediment yield from these geological formations are estimated to be Ca in 1.22 t ha^{-1} $year^{-1}$ from the Upper Red Formation, 1.19 t ha^{-1} $year^{-1}$ from Quaternary Units, 1.18 t ha^{-1} $year^{-1}$ from Qum Formation, 0.42 t ha^{-1} $year^{-1}$ from Hezar Darreh Formation and 0.23 t ha^{-1} $year^{-1}$ from Karaj Formation. In these catchments, Upper Red Formation reflects the first specific sediment yield while Quaternary Units the second. The results of mean contributions of each sediment source to the sediment samples collected from Ali Abad Catchment (presented in Table 5) indicate that the sediment yield from the Upper Red Formation (128.37 t $year^{-1}$) is dominant, reflecting the dominance of this particular geological formation in the catchment (higher than 90% of the catchment area), followed in descending order, by the Qum and Quaternary Formations (5.58 t $year^{-1}$). It is also important to take into account the proportions of the catchment areas making these contributions, and thus the equivalent specific sediment yields. Based on the proportions of the catchment areas occupied by Quaternary Units and Upper Red as well as Qum Formations (1.87, 114 and 6.09 ha, respectively), the specific sediment yield from these three source types may be estimated for Ca at 2.98 t ha^{-1} $year^{-1}$ from Quaternary Units, as 1.12 t ha^{-1} $year^{-1}$ from Upper Red Formation and 0.91 t ha^{-1} $year^{-1}$ from Qum Formation. Here, Quaternary Units and Upper Red Formation reflect the dominant specific sediment yields too. The results of sediment yield and specific sediment yield from each geological formation and in Ebrahim Abad Catchment are further elaborated in table 5. Sediment yield from the Quaternary Units is most significant (125.08 t $year^{-1}$), followed in descending order by Karaj Formation (17.86 t $year^{-1}$), Hezar Darreh Formation (16.08 t $year^{-1}$), Delichay Formation (10.72 t $year^{-1}$) and Shemshak Formation (8.93 t $year^{-1}$). The sediment yield of Lar Formation is rated as zero, because the contribution from Lar Formation is negligible (or so low that it is not recognized by the mixing model). Based on the proportions of the catchment occupied by Quaternary Units, Hezar Darreh, Karaj, Delichay and Shemshak Formations (i.e., 192.76, 55.66, 88.27, 66.08 and 20.40 ha, respectively), the specific sediment yields from these geological formations may be estimated to be Ca in

Table 5. Mean contributions of each sediment source to the sediment samples.

Catchment	Sediment sources	Contribution (%)	SY (t $year^{-1}$)	Area (ha)	SSY (t ha^{-1} $year^{-1}$)
AtTary	Quaternary Units	20.00	75.57	63.11	1.19
	Hezar-Dareh Formation	21.00	79.35	186.33	0.42
	Upper Red Formation	24.00	90.68	73.81	1.22
	Qum Formation	20.00	75.57	63.97	1.18
	Karaj Formation	15.00	56.67	241.26	0.23
Ali Abad	Quaternary Units	4.00	5.58	1.87	2.98
	Upper-Red Formation	92.00	128.37	114	1.12
	Qum Formation	4.00	5.58	6.09	0.91
Ebrahim Abad	Quaternary Units	70.00	125.08	192.76	0.64
	Hezar-Dareh Formation	9.00	16.08	55.66	0.28
	Karaj Formation	10.00	17.86	88.27	0.20
	Lar Formation	0.00	0.00	82.47	.000
	Delichay Formation	6.00	10.72	66.08	0.16
	Shemshak Formation	5.00	8.93	20.40	0.43

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0.64 t ha^{-1} $year^{-1}$ from Quaternary Units, 0.43 t ha^{-1} $year^{-1}$ from Shemshak Formation, 0.28 t ha^{-1} $year^{-1}$ from Hezar Darreh Formation and 0.16 t ha^{-1} $year^{-1}$ from Delichay Formation. For the case of Ebrahim Abad, Quaternary Units reflect the most important specific sediment yield (in this catchment, Upper Red Formation is not present). Looking into the results presented in Table 5, there is a high spatial variation observed in *SSY* between geological formations in all the catchments: i.e. from 2.98 t ha^{-1} $year^{-1}$ to 0 t ha^{-1} $year^{-1}$. The high spatial variation in *SSY* is mainly attributed to differences in lithology, ground cover, extent of bank gullies as well as human activities. This approach leads to risky or uneconomical design of reservoirs. Hence, it is recommended that the local conditions controlling sediment yield should be considered during the planning phases of the reservoirs.

Looking into the specific sediment yield of the geological formations, the results presented emphasize the importance of Quaternary Units and Upper Red Formation as the dominant surface sources within most of the catchments. Quaternary Units are located downstream and along the main drainage path, with its sediments entering the drainage path directly and not being trapped along the way, therefore, this sediment source bears the high specific sediment yield. Upper Red Formation also consists of evaporitic (haliferous and gypsiferous) marls and is hilly and deprived of vegetation in these areas. Most of the fingerprinting studies have used suspended sediment samples that are affected by variation in flow of the river during the study period, and by the timing of the collection of suspended sediment samples. Due to the wide range of discharges and suspended sediment concentrations when samples were collected, the relative contributions from each source for the individual sediment samples were weighted according to the values of discharge and suspended sediment concentration at the time of sampling (cf. Walling *et al.,* 1999; Owens *et al.,* 2002). This sediment load-weighting approach ensures that the importance of source contributions associated with periods of high sediment load is emphasized, and therefore provides a more realistic estimate of the proportion of the total suspended sediment load at a sampling site, contributed by individual sources, than a simple average of the percentage contribution values associated with individual suspended sediment samples. However, for the purposes of this study, there are no problems arising since the sediment samples had been collected from reservoir sediments.

CONCLUSIONS

A methodology, based on a combination of source fingerprinting technique plus reservoir sediment survey was investigated to provide reliable data on sediment yields in geological formations for three small size catchments in Iran. The volume and mass of the deposited sediments in reservoirs were initially assessed. The methodology involved several operations, namely: accurate topographical surveying, measuring the dry sediment bulk density to convert sediment volumes to sediment masses, as well as an assessment of the sediment trap efficiency of the reservoir. The sources of possible errors (ebulk density, trap efficiency) were fully considered throughout the investigation.

Fifteen property items, comprised of five groups of fingerprinting properties, namely: organic constituents (C, N, P), base cations (Na, K, Ca, Mg), acid extractable metals (Cr, Co), clay minerals (Smectite, Chlorite, Illite, Kaolinite) and mineral magnetism (X_{lf}, X_{fd}) were selected to be applied in the fingerprinting procedure. The capability of the range of fingerprint properties employed in the study, to discriminate between the potential sediment sources, was statistically tested using Kruskal–Wallis test and multivariate stepwise Discriminate Function Analysis (DFA). Finally a multivariate mixing model was employed to estimate the relative contribution of the potential sediment sources as well as the specific sediment contribution of each geological formation to reservoir sediment. The results presented emphasis on the importance of Quaternary Units and Upper Red Formation as the dominant surface sources within most of the catchment areas (Table 5). This is an important finding in the support of the design and implementation of sediment control strategies in these catchments. The findings are in consistence with those obtained for the catchment basin of another Iranian river (Hakim Khani *et al.,* 2007). These areas should be treated as erosion prone hazard zones where catchment management practices should be adopted to reduce the risk and rate of erosion.

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ارزیابی رسوبدهی ویژه سازندهای زمین شناسی با استفاده از بررسی رسوبات مخازن و منشایابی

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چکیده

داده های رسوبی بدست آمده از بیشتر نواحی ایران ناکافی و غیر قابل اعتماد بوده و هنوز روش نوینی برای ارزیابی رسوبدهی در کشور وجود ندارد. به هر حال به منظور طراحی استراتژی های مدیریتی و کنترل رسوب، تهیه داده های واقعی رسوب کاملا ضروری است. رسوبات نهشته شده در مخازن سدها به منظور دستیابی به این اهداف بسیار مناسب می باشند. هدف اصلی این تحقیق بررسی ترکیبی از دو روش منشایابی و ارزیابی رسوبات مخازن به منظور تهیه داده های واقعی رسوبدهی از سازنده ای زمین شناسی در سه حوزه کوچک واقع در استان سمنان ایران بود. بررسی ها ابتدا بر روی اندازه گیری رسوبات مخازن متمرکز گردید و سپس از تکنیک های منشایابی به منظور تعیین سهم هر سازند و رسوبدهی ویژه آنها استفاده گردید. نتایج نشان دهنده تغییرات زیادی رسوبدهی ویژه سازندها ی زمین شناسی در تمام حوزه ها از ۲/۹۸ تن در هکتار در سال تا ۰/۱۶ تن در هکتار در سال بوده است و نشان دهنده اهمیت واحدهای کواترنری و سازند قرمز بالایی به عنوان منابع اصلی تولید رسوب در بیشتر حوزه هاست.

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