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Estimation of sediment sources using a fingerprinting procedure

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ABSTRACT

Sediment management strategies are a key requirement in developing countries including Iran because of the limited resources available. These targeting however hampered by the lack of reliable information on catchment sediment sources. This paper reports the results of using a quantitative composite fingerprinting technique to estimate the relative importance of the primary potential sources within the Amrovan and Royan catchments in Semnan Province, Iran. Fifteen tracers were first selected for tracing and samples were analyzed in the laboratory for these parameters. Statistical methods were applied to the data including Nonparametric Kruskal-Wallis test and Discriminant Function Analysis (DFA). For the Amrovan catchment three parameters (N, Cr and Co) were found to be not significant in making the discrimination. The optimum fingerprint, comprising C, P, Kaolinite and K was able to distinguish correctly 100% of the source material samples. For the Royan catchment, all of the 15 properties were able to distinguish between the six source types and the optimum fingerprint provided by stepwise DFA (Chlorite, X_{FD}, N and C) correctly classifies 92.9% of the source material samples. The mean contributions from each sediment source obtained by multivariate mixing model varied at two catchments. For the Amrovan catchment Upper Red Formation was the main sediment sources as this sediment source approximately supplied 36% of the reservoir sediment whereas the dominant sediment source For the Royan catchment was from Karaj formation that supplied 33% of the reservoir sediments. Results indicated that the source fingerprinting approach appears to work well in the study catchments and to generate reliable results.

Introduction

Decision-making for sediment management at the catchment scale represents a challenging task and is reliant upon the identification of those key sources requiring remediation (Collins et al., 2010). Because of the problems associated with traditional soil erosion estimation techniques, the fingerprinting approach has been increasingly adopted as a more direct and reliable means of assembling sediment source information. In particular, source fingerprinting techniques provide a relatively simple and cost-effective basis for assembling spatially and temporally integrated data for catchments of different scales (Collins and Walling, 2004; Walling, 2005). Fingerprinting technique is founded upon the link between the physical and geochemical properties of the sediment and those of its sources. If potential source materials can be distinguished on the basis of their fingerprints, the likely provenance of the sediment can be established using a comparison of the properties of the sediment with those of the individual potential sources (Walling et al., 2008). The application of this approach comprises two basic steps. These involve, first, the selection of diagnostic properties, which distinguish potential sediment sources, and secondly, a comparison of sediments and catchment source samples using these properties, in order 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 basin. These have included Infrared spectroscopy (Poulenard et al, 2009), color (Núria Martínez-Carreras et al, 2010), mineral magnetism (Caitcheon, 1998), environmental radionuclides (Smith and Dragovich, 2008), chemical tracers (Juracek and Ziegler, 2009), organic constituents (Collins and Walling, 2002) and particle size (Stone and Saunderson, 1992). Such procedures have proved successful in distinguishing individual source types, such as surface soils beneath different land uses and subsoil/channel banks (Collins et al, 2010); the spatial location of sediment provenance, such as discrete geologies or sub-catchments (Collins et al., 1996, 1998); a combination of both (Collins et al., 1997a; Walling and Woodward, 1995); and in reconstructing recent changes in sediment provenance using sediment cores (Collins et al., 1997b; Owens et al., 2000). In this paper a quantitative composite fingerprinting technique was investigated to establish the contribution of sediment sources to the reservoir sediment.

Study Area

This paper was carried out in two adjacent small catchments in the Semnan Province of Iran, (Fig. 1). The area is homogenous in different aspects such as land use, climate and hydrological condition but differs in its geological formation. However these properties make suitable condition for investigation of erosion and sediment of geological formations. All of the area is covered by shrubs. While no detailed soil mapping has been undertaken in the region, the geology map indicates that the soil in some parts of catchment includes evaporated marl, making it susceptible to erosion. The most important erosion features of the catchments are gully erosion, surface erosion, till erosion and river bed erosion. In order to display more details of the two catchments, the geology, erosion features and slop gradients are shown in Figure 1. The reservoirs

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in the two catchments, contained within earth embankments, were created by the Iranian government in 1993 to harvest seasonal runoff and spillage has never occurred since their construction. The mean sediment depth was measured by observing sediment profiles in pits along transects. It is surprising to observe such high sedimentation rates associated with low rainfall from a fluvial system, but rainfalls are generally severe and limit and the presence of sensitive geological formations makes the soils particularly vulnerable to water erosion. The role of Aeolian processes is discounted meaningless. Furthermore sediments mostly enter the reservoir via the river system during rainfall periods and they dry up in summer and autumn. Total area of the Amrovan catchment is 102.35 ha. The Altitudes range from 1795 meter at the catchment outlet to 1925 m in the upstream areas and the catchment slope average is commonly 11.4%. The mean annual precipitation is 174 mm. The geology is dominated by Quaternary, Hezar-Dareh and Upper Red Formations. The reservoir of Amrovan catchment has 6511 m^2 area and the mean sediment depth is 60 cm. The Royan catchment has a total area of 538.83 ha. The climate annual rainfall is 184 mm. Most of the rainfall occurs in winter and spring. The topography of the region mainly consists of highland parts up to 2000 meter and the catchment slope average is commonly 23.95%. The geology is dominated by Quaternary, Hezar-Dareh, Shemshak, Lar and Upper Red Formations. The reservoir of Royan catchment has 6682 m^2 area and the mean sediment depth is approximately 100 cm. (Kouhpeima, 2009).

Materials and Methods

Sampling

The sampling program started in Jun 2008 when reservoir sediments became relatively dry. Field sampling involved the collection of representative samples of both main potential sediment sources identified within each study catchment and the sediments deposited in reservoirs constructed in the outlet of catchments. Potential sediment sources were categorized surface soils from different geological formations and eroding gullies. It is important to know that gullies are not a separate spatial source of their own. They are in fact subsoil material from specific areas of the catchment. They may have different properties to the topsoil which makes them distinguishable from the topsoil material, but geologically they are not a spatial or areal source like, the Upper Red, Quaternary and Hezar Dareh formations are in the Amrovan catchment for example. They occupy the same spatial area as these samples they are just subsoil material. 10 representative samples were collected from different parts of each primary sediment sources using a stainless steel spade. Care was taken to ensure that only material susceptible to erosion (the surface 0–2 cm) was collected for surface materials. Subsurface source sampling included gully walls and collected material from the full vertical extent of the exposed profile. Each cut extended from the soil surface down to the top of the colluvial material which had collected at the base of the wall (Krause et al, 2003). Care was taken to ensure that a consistent amount of material was removed from the entire length of the profile. Sediment samples were collected from reservoir constructed in outlet of each catchment. 10 representative sediment samples were taken from different parts of each reservoir (near the dam axis, in the middle, side and at the inlet of the reservoir) in order to increase the representativeness of the individual samples and of the overall sampling strategy. To gain the sample of recently transported sediment, the samples were collected from surface 0-2 cm also. All source material and sediment samples were air-dried and subsequently dry-sieved to <63 µm to facilitate direct comparison together (Walling et al., 2008). Oven-drying was avoided in order to prevent potential geochemical digenesis under higher temperatures (Carter et al., 2003).

Selecting fingerprint properties and laboratory analyses

Selection of fingerprint properties for use in the investigation was based on previous experience of source discrimination in different parts of world, as well as being constrained by available analytical facilities and the time available for analytical work. Because there is the potential problem that some tracer properties may be discharged from point sources to rivers in solution and subsequently absorb onto existing suspended sediment 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 relative to those for the various potential sources before the fingerprinting exercise is carried out. The 15 properties finally selected comprised 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 Kaolinite) and mineral magnetism (X_{LF} and X_{FD}). Both C and N were determined directly using a Carlo Erba Elemental Analyzer, and P was determined calorimetrically using UV Visible Spectrophotometer, (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 were determined using a Bartington meter and MS2B dual frequency sensor (Caitcheon, 1998).

Sediment Source Discrimination

The discrimination of potential sediment sources afforded by the range of individual fingerprint properties and the groups of properties was tested statistically. First the Kruskal-Wallis test has been used for eliminating redundant fingerprint properties as a whole, then discrimination function analysis (DFA) was used to test the ability of the parameters passing the Kruskal-Wallis test to classify all the source samples from a given catchment into the correct categories. DFA calculates discriminant functions coefficients reflecting the explanatory power of the included variables and this procedure were employed in a number of ways. Firstly, it was used to assess the discriminatory power of individual fingerprint properties. Secondly, DFA was employed to assess the discrimination of potential catchment sediment sources afforded by composite fingerprints comprising constituents passing the Kruskal-Wallis test drawn from the individual groups of fingerprint properties. Finally, a multivariate stepwise selection algorithm, based on the minimization wilks'lambda, was used to identify the smallest combination of properties (the optimum composite fingerprint), drawn from any group that provided the maximum discrimination of the source categories within each study catchment. The minimization of wilks'lambda represents one of the five stepwise selection algorithms available within SPSS under the METHOD sub command (Nie et al., 1975). A lambda of one occurs when all source category means are equal, whilst values close to zero occur when inter-category variability exceeds within-category variability.

Table 1. Mean and standard deviation of sediment sources samples and reservoir sediment samples

Fingerprinting properties	Source samples		Reservoir sediment samples	
	Mean	Std. Deviation	Mean	Std. Deviation
N (%)	0.078652	0.044944	0.078652	0.033708
P (ppm)	11.23596	6.089888	8.078652	5.089888
C (%)	1.224719	1.089888	0.303371	0.05618
Cr (ppm)	147.7528	3.2809	118.7303	0.651685
Co (ppm)	13.8764	2.921348	15.35955	0.730337
Ca (%)	19.50562	4.067416	18.76404	1.269663
Mg (%)	3.707872	0.898876	3.224719	0.078652
K (%)	1.101124	0.292135	1.359551	0.101124
Na (%)	0.438202	0.146067	0.561798	0.139775
Smectite (%)	54.32584	2.07865	53.41573	1.213483
Chlorite (%)	29.46067	7.359551	34.24719	1.123596
Illite (%)	21.58427	7.168539	19.31461	2.325843
Kaolinite (%)	7.269663	4.820225	4.988764	1.089888
X_{LF} (10^{-6} m^3 kg^{-1})	17.83146	1.74157	8.651685	0.033708
X_{FD} (10^{-6} m^3 kg^{-1})	3.224719	1.404494	2.325843	0.988764

Table 2. Results of applying the Kruskal–Wallis test to assess the ability of each tracer property to discriminate between surface materials from different sediment sources collected from the Amrovan and Royan catchments

Fingerprinting property	Amrovan catchment			Royan catchment		
	p-value	H-value	%source type samples classified correctly	p-value	H-value	%source type samples classified correctly
N (%)	0.35	3.30	-	0.00*	20.18*	64
P (ppm)	0.00*	25.15*	65	0.00*	35.10*	80
C (%)	0.00*	26.67*	70	0.00*	34.50*	78
Cr (ppm)	0.19	4.80	-	0.03*	12.24*	40
Co (ppm)	0.06	7.41	-	0.00*	16.77*	53
Ca (%)	0.00*	14.99*	45	0.00*	17.10*	56
Mg (%)	0.00*	23.40*	55	0.00*	36.86*	83
K (%)	0.00*	24.77*	65	0.01*	15.80*	56
Na (%)	0.00*	18.65*	60	0.00*	19.19*	63
Smectite (%)	0.00*	16.20*	57.5	0.00*	22.77*	65
Chlorite (%)	0.00*	16.09*	52.5	0.00*	23.81*	68
Illite (%)	0.00*	16.35*	45	0.00*	22.24*	61
Kaolinite (%)	0.01*	11.21*	55	0.01*	15.00*	53
X_{LF} (%)	0.03*	9.28*	45	0.00*	16.77*	53
X_{FD} (%)	0.00*	16.67*	52.5	0.00*	33.05*	75

* Significant at $p<0.05$

Table 3. Results of using stepwise discriminate function analysis to identify which combination of tracer properties provides the best composite fingerprint for discriminating source materials from the Amrovan and Royan Catchments

Catchment	step	Tracer property	Wilks' Lambda	Cumulative geology samples Classified correctly (%)
Amrovan	1	C	0.162	66.70
	2	P	0.063	91.70
	3	Kaolinite	0.025	90.50
	4	K	0.002	100
Royan	1	Chlorite	0.097	57.10
	2	X_{FD}	0.049	75
	3	N	0.024	82.10
	4	C	0.004	92.90

Table 4. Mean contributions of each sediment sources to the sediment Samples collected from the Amrovan and Royan Catchments

Catchment	Sediment sources	Area (ha)	Contribution (%)	Specific sediment yield (t ha^{-1} $year^{-1}$)
Amrovan	Quaternary units	7.79	15	7.03
	Hezar-Dareh Formation	65.23	28	1.56
	Upper-Red Formation	31.33	36	4.19
	Gully erosion	31.71	21	2.41
Royan	Quaternary units	154.58	32	0.67
	Upper-Red Formation	47.02	2	0.14
	Karaj Formation	233.65	33	0.46
	Lar Formation	47.72	1	0.07
	Shemshak Formation	59.48	5	0.28
	Gully erosion	148.72	27	0.59

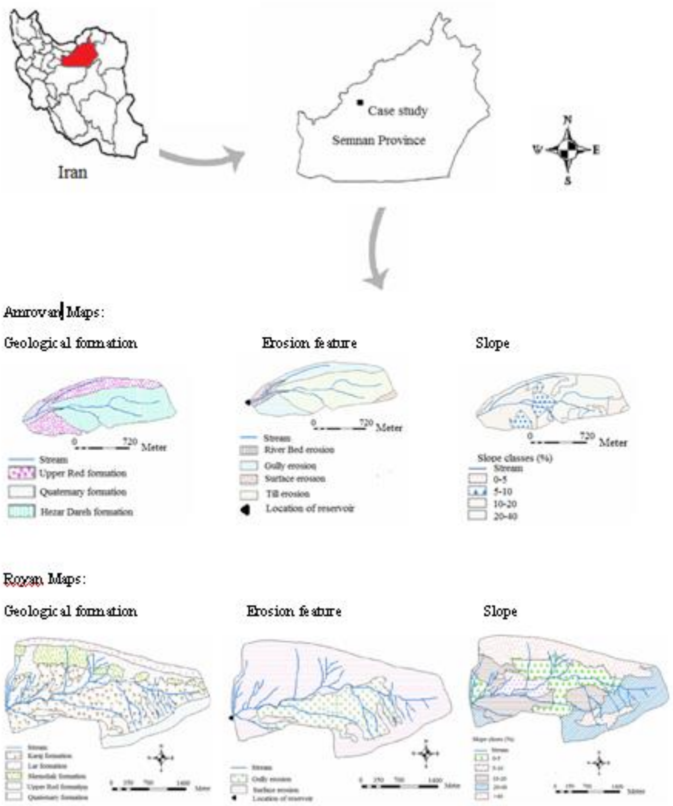

Fig 1. Map showing the location of the study catchments and Geological formation, feature erosion and slope maps in both Amrovan and Royan catchments

This approach afforded a rigorous basis for testing the assumption that composite fingerprinting comprising constituents drawn from different groups of fingerprint properties offer greater discriminatory power than those based on single group of properties. In recent years a number of sediment source tracing studies have used this statistical verification procedure (e.g. Bottrill et al., 2000; Carter et al., 2003; 2008; Collins et al 2010).

Sediment source contribution

A multivariate mixing model, as described by Collins et al. ((1997a) Eq. 1), was used to estimate the relative contribution of the potential sediment sources to the individual sediment samples collected from each designated catchment. Optimised estimates of the relative contributions of the each source types to each reservoir sample were provided by minimizing the sum of squares of the weighted relative errors, viz.:

$$\sum_{i=1}^{n}\left\{\left(C_i-\left(\sum_{s=1}^{m}P_sS_{si}Z_sO_s\right)\right)/C_i\right\}^2 W_i \quad (1)$$

where: C_i=concentration of fingerprint property (i) in sediment sample; Ps=the optimised percentage contribution from source category (s); Ssi=concentration of fingerprint property in source category (s); Z=particle size correction factor for source category (s); O=organic matter content correction factor for source category (s); Wi=tracer specific weighting; n=number of fingerprint properties comprising the optimum composite fingerprint; m=number of bed sediment source type categories. As a means of imposing physical reality, two linear boundary constraints were established for the sediment mixing model, in order to ensure that the relative contribution from each potential sediment source type was non-negative (Eq. 2) and that the contributions from the individual source types summed to unity (Eq. 3).

$$0 \leq P_s \leq 1 \quad (2)$$

$$\sum_{s=1}^{n} P_s = 1 \quad (3)$$

The particle size and organic matter content correction factors are included in the model to take account of the impact of selective delivery and enrichment on sediment geochemistry. A weighting to reflect within-source variation of individual properties is incorporated to ensure that the property with the smallest standard deviation exerts the greatest influence on the optimised solutions. This weighting has been shown to help constrain the uncertainty ranges in predicted source contributions (Collins et al., 1997; 2010).

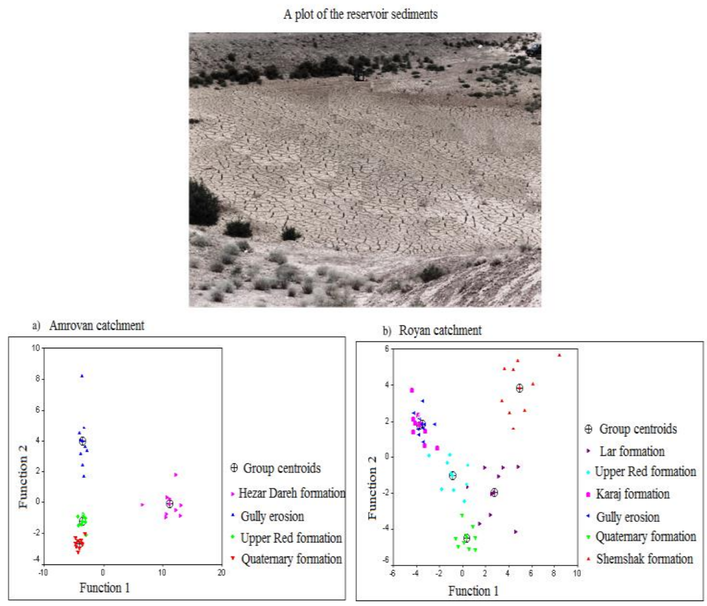

Fig 2. A plot of the reservoir sediments and scatterplots constructed from the first and second discriminant functions calculated using DFA in association with the stepwise selection of the optimum composite fingerprint for the Amrovan and Royan catchments

The overall goodness-of-fit of the optimized mixing model was also performed using the Mean Relative Error (MRE) statistic. This involves a comparison of the actual fingerprint property concentration measured in sediment sample with the corresponding values predicted by the model, based on the optimized percentage contribution from each source group. 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 therefore that the relative contributions of the potential sources estimated by the mixing model are likely to be reliable. All of the 100 mixing models calculated in this study met this criterion. A Monte Carlo approach was used to quantify the uncertainties associated with the optimized sediment source contributions predicted by the mixing model (Rowan et al., 2000; Wallbrink et al., 2003; Motha et al., 2004; Collins et al, 2010). Cumulative Normal distributions were constructed on the basis of the mean and standard deviation of the measurements for each fingerprint property for each source type using a random number generator. The mixing model was repeatedly solved by randomly sampling values for each property included in a composite fingerprint from their corresponding Normal distributions. 95% confidence limits for the relative contribution from each source type to each fine sediment sample were estimated using the standard error of the mean associated with the results of the repeat iterations.

Results and discussion

Sediment and source tracer values

All reservoir sediment and sediment source samples were measured for 15 tracers. For each tracer the mean and the standard deviation of the source and sediment samples are presented in Table 1. Values for source samples collected at different monitoring sites were compared to determine the spatial variability of fingerprinting parameters. The Std. Deviation values presented in Table 1 show there are considerable variation between different sediment sources. C, P and N have the highest relative standard deviations with variances up to 50% of the mean value. Similarly Cr, smectite and X_{LF} have among the lowest relative standard deviations. The highest variability in different sediment sources was not unexpected. As such, the observed variability in sediment sources can probably be attributed to soil heterogeneity of different sediment sources.

Source type discrimination

In order to test the capability of fingerprinting parameters to discrimination of the sources types at Amrovan catchment, source materials were classified according to the four source type found in the area: surface materials from Quaternary, Hezar-Dareh and Upper Red Formations and sub-surface materials from gully walls. Table 2 shows the ability of each fingerprinting property to discriminate between the source types by using Kruskal–Wallis H-test. The H- value and p-value parameters in this table show the ability of each tracer in discrimination of sediment sources. The higher H-value associated with each fingerprinting properties, the higher ability of that properties in sediment source discrimination. According to this table the majority of tracer parameters exhibit p-values well below the significance value of 0.05, indicating that they can strongly discriminate between the source types. In the case of Amrovan catchment these successful properties generate test statistics ranged from 0.00 to 0.35. Three parameters (N, Cr and Co) were however found to be not significant in making the discrimination (Table. 2), and were therefore removed at this stage. The source materials collected from the Royan Catchment were also classified into surface material from different geological formations (Upper Red, Karaj, Lar, Shemshak and Quaternary) and material from gully walls. The results of the Kruskal–Wallis test are shown all of the 15 properties provided a clear discrimination between the six source types. However these successful properties generate test statistics ranged from 0.00 to 0.03. The low P-values obtained for some of the tracer parameters however suggest that these parameters could be used for this purpose successfully. Table 2 also includes the results of employing DFA to assess the percentage of source material samples classified correctly by each individual property passing the Kruskal-Wallis test for two catchments. In the case of Amrovan catchment the most powerful individual fingerprint property is organic constituent C, which successfully classifies 70% of source material samples into the correct categories. Ca, Illite and X_{FD} are the weakest individual fingerprint property, correctly distinguishing only 45% of the source samples. No individual property classifies 100% of the source samples correctly. In the case of Royan catchment also no single fingerprint property correctly classifies the entire set of source samples. However, Mg correctly classifies 83% of the samples.

According to the obtained results it seems that the best looking individual fingerprints are excluded from the optimum composite fingerprint. For example Mg can classify 83% of the samples correctly, yet it is excluded from the Royan catchment with no other base cation (Na, K nor Ca) present in the fingerprint; similarly P is capable of 80% classification yet this is excluded in favor of another organic constituent C which only provides 64% capability. Therefore it is important to know that an individual property with high discriminatory power may not include in the optimum composite fingerprint because of intergroup differences between different tracer properties. The high intergroup differences the more discriminatory power of optimum composite fingerprint. Table 3 shows the results of optimum composite fingerprints and their discriminatory power on the basis of minimising Wilks' lambda during stepwise selection. With addition of each property Wilks'lambda was decreased and Cumulative source samples Classified correctly was increased. For the Amrovan catchment results indicate that the optimum multicomponent fingerprint, comprising C, P, Kaolinite and K was able to distinguish correctly 100% of the source material samples. This composite fingerprint includes tracer properties from several different Property groups (i.e. Organic constituents, base cations and clay minerals). In this composite fingerprint C as the first entered property has the high sample classified correctly (66.7%). Although with entering of third property (Smectite) the percent of sample classified correctly has a little decreased, however it has been improved the difference of inter groups because of decreasing Wilks'lambda. A multicomponent signature containing Chlorite, X_{FD}, N and C was selected as the optimum fingerprint in the Royan catchment capable of classifying 92.9% of the source material samples correctly (Table 3), and the addition of further tracer properties to the composite fingerprint does not increase the success of the classification. The first entered property in the composite fingerprint classified 57.10% of samples correctly. The fact that discriminate function analysis were not classified 100% of the samples correctly into the appropriate source groups indicate that however there is some overlap between the samples collected to represent source groups because of source similarity.

In order to examine existing differences between sediment sources, scotterplots obtained from DFA was presented in fig 2 for two catchments. From Fig. 2a, it can be seen that the samples from this catchment tend to occur in four distinct clusters, and as such can be differentiated. There is no overlap between the four sediment sources. Fig. 2b shows a similar plot for the Royan catchment. In this catchment there is a little overlap between sediment sources.

The results of the statistical analysis clearly demonstrate that no single property is capable of classifying 100% of the source material samples into the correct source categories for any of the study catchments. Levels of sediment source discrimination afforded by individual properties can, however, be used as a potential indication of the likelihood of correctly classifying all source samples using composite signatures. It is more valuable to attempt to identify the most useful groups of fingerprint properties. Such an approach recognizes the fact that a single extraction procedure can frequently be used to provide several potential properties for inclusion in a composite fingerprint. The results from the stepwise DFA clearly indicate that the optimum composite fingerprint comprising constituents selected from a number of properties generally affords the most robust discrimination of the sediment sources within the study catchment. For example, the final composite fingerprint identified for the Amrovan catchment, correctly classifies 100% of the source material samples, whereas the maximum discrimination afforded by an individual properties is 70%. Likewise, for the Royan catchment, the optimum fingerprint provided by stepwise DFA correctly classifies 92.90% of the source material samples; whereas the best performance for fingerprints based on single properties is 84%. This result reflect the likelihood that the different groups of properties tested are influenced by contrasting environmental controls and therefore characterized by a substantial degree of independence. Consequently, when used in combination (for example to construct a composite fingerprint) the different types of property afford a more robust means of discriminating catchment sediment sources (Walling et al., 1999; Collins et al., 1997a, 1998, 2001). The ability to pre-select potentially successfully fingerprint properties would clearly be an important advantage in sediment source investigation. Although composite fingerprints based on several properties improve the level discrimination over that afforded by their individual constitutes, some single properties offer more robust discrimination than other properties. The results of this study, for example, demonstrate that organic constituent properties consistently provide more source discrimination than many other individual properties. It can therefore be suggested that these properties represent the more potentially useful properties tested by this study and are selected in two final composite fingerprints, suggesting that this group of properties is extremely useful for sediment source discrimination in the study area and similar catchments.

Source type contribution

Table 4 Presents information on the overall mean relative contribution from each sediment source type to the sediment samples collected from the reservoir of each catchment. These results relate to the overall means of the repeat mixing model solutions with 95% confidence limits. A high relative contribution may not necessarily reflect a high contribution in terms of the actual mass of sediment; therefore it is important to take account of the proportions of the catchment area supplying these contributions and calculate the amount of specific sediment yield from each sediment source. The area of each source type was calculated by GIS software and the results presented in table 4. This table also represents the amount of specific sediment yield of each sediment source calculated by actual sediment survey. The data presented in table 4 exhibit important contrasts in the relative contributions from each individual source type between the catchments. In the case of Amrovan catchment the mean contribution from the Upper-Red Formation (36%) is most important, followed in descending order by the Hezar-Dareh Formation (28%), Gully erosion (21%) (This subsurface is from the gully walls) and Quaternary units (15%). It is important to know all of the gullies are within the Upper-Red formation, this means that 57% of the contribution is coming from 31.33ha of land which is under one third of the catchment area. Based on the area of the catchment occupied by Upper Red, Hezar Dareh Quaternary formations and gully erosion (see table 4), the specific sediment yields from these four geological formations are shown in table 4. According to specific sediment yield result Quaternary units and Upper Red formation is more important sediment source in this catchment. Field evidence also confirms this subject. Quaternary Units are located downstream and along the main drainage and its sediments enter the drainage directly and are not trapped in the way, therefore, this sediment source has the high specific sediment yield. Upper Red Formation consists of evaporated (haliferous and gypsiferous) marls. It is hilly and deprived of vegetation. The fact that this sediment source approximately supplies higher than 36% of the sediment while only occupying the small area (Table 4) may reflect higher rates of erosion and sediment supply associated with the Upper Red Formation. This finding is consistent with that obtained for another Iranian river (Hakim khani et al., 2007). Furthermore one of the main catchment river branches, a cross from parts of this formation with high slope, erodes the materials of this formation. (See the slope map in fig 1). Hezar-Dareh Formation consists of conglomerate with sandstone and little claystone, it has medium erodibility and the relatively high contribution from this sediment source is probably due to high surface areas of this geological formation, exist of till erosion in the formation and the close proximity of this source to the channel network. 21% sediment sources are derived from Gully erosion and this sediment source is the third contribution. Although all of the gullies located in Upper red formation, the larger one located down parts of river that the slop is low. Carter et al., 2003 believe gully erosion could be expected to be more important in larger catchments with well-developed gullies, whilst smaller catchments (such as Amrovan) provide greater opportunity for a particular land use or geological formation to be dominant and to therefore dominate the source contribution. Therefore the less contribution of Gully erosion than that Upper-Red and Hezar-Dareh Formations can be related to presence of undeveloped gullies in this catchment. Although the close proximity of Quaternary formation to reservoir, the relatively small contribution from the area of Quaternary units is in accordance with the small area that these rocks occupy in the catchment (c. 7.79 ha), while the contribution from the other formations is larger than expected on the basis of their areal extent (Table 4). These results are similar that Collins et al, 1997 presented. In this formation the river bed erosion is active (see erosion feature map in fig 1). The Relative Error, associated with mixing models calculated, was change from 4.5% to 21.18% for each sediment sample and the Mean Relative Error for all samples was 12. Walling and Collins (2000) reported that relative errors <15% indicate that the mixing model provides an acceptable prediction of the fingerprint property concentrations associated with a sediment sample. Uncertainty for each sediment source was also changed from 0 to 4. These results indicate the relative contributions of the potential sources estimated by the mixing model are likely to be reliable. Table 4 examines again the results of the mixing model calculations for the relative contribution from each sediment source to the reservoir sediment sampled and specific sediment yield at Royan catchment. The results presented in Table 4 indicate that the contribution of Karaj formation (33%), Quaternary units (32%) and Gully erosion (28%) is dominated and the results of specific sediment yield also clearly provide this subject. This three sediment sources overall approximately supplies higher than 80% of the sediments. In this catchment 60% of the contribution comes from over two thirds of the catchment area. The increased importance of Karaj formation reflects the existence of large areas occupied by this geological formation (Table 4) and location of this formation close proximity to the channel network more than 90% stream network across from this formation. Quaternary units that affected by surface erosion and 10-20% slope (see fig 1) is located downstream and along the main drainage and its sediments enter the drainage directly and are not trapped in the way. The high contribution of sediment from gullies in the Royan catchment is firstly due to severe eroded gullies in the reaches of the catchment spatially downstream, where gullies are often big and secondly it also reflects the downstream location of the sampling sites, and thus the distal location of some other sources, particularly Upper-Red and Lar Formations, which are mainly located in upstream areas. Due to their distal location, the opportunity for conveyance losses is greater. There was insufficient sediment supplied by Shemshak, Upper-Red and Lar formations for their contribution to be detected by the mixing model. This reflects both the limited extent of these sources in the catchment and the lack of erosion from such sources. Looking in general at the results presented in Table 4, Surface sources, as taken together, are the dominant source in both Amrovan and Royan catchments, accounting for 79 and 73% of the sediment yield respectively. The Relative Error calculated for each sediment sample from 2.2% to 11.34% and the Mean Relative Error 7 for all samples as well as the uncertainty of 0-2 represents the acceptable results. According to the geological formation and erosion feature maps, in the Amrovan catchment, gully erosion is almost identical to erosion from the Upper Red formation, while in the Royan catchment, the gullies are well distinguished from the Karaj formation. The samples collected from gully walls were distinguished clearly from corresponding formation. It is a surprising result that the gully sediment reflects gully deepening whereas the surface erosion from the corresponding formation represents headward extension of the gullies. So far insufficient and less reliable sediment source data have been collected for many regions of Iran. However available sediment deposition rates in reservoirs makes the use of reservoir sediments very attractive for regional-scale studies of sediment source fingerprinting. A further problem associated with the sediment sampling procedures commonly used in suspended sediment is the need to obtain the collect of large volumes of water to sufficient dry mass of sediment and to permit analysis of a wide range of fingerprinting properties (Walling, 2005) whereas reservoir sediment are free from these significant problems. There is clearly a need to provide guidance on the initial selection of fingerprint properties, in order to reduce the number of properties analyzed. The source fingerprinting approach relies heavily on the assumption of conservative behavior of the fingerprint properties during sediment mobilization and transport. This assumption was addressed by selecting fingerprint properties that the values measured in the sediment were not higher than the ones measured in the sources. However, further work is undoubtedly required to explore this problem further and to verify empirically the assumption of conservative behavior for a range of fingerprint properties. The study reported by Motha et al. (2002), which involved use of a rainfall simulator in the field, to simulate the mobilization of sediment from the land surface and permitted direct comparisons between the properties of the mobilized sediment and the in situ source material, provides one potential approach for addressing this issue.

Conclusions

Statistically verified composite fingerprints of source materials and a multivariate mixing model have been used to identify the main sources of the reservoir sediment transported by the rivers of Amrovan and Royan catchments, Semnan Province, Iran. The results provide important information on the relative importance of the contributions from different geological formations and gullies to the reservoir sediments, which can be used to support model validation and the targeting of management and control strategies. In addition, the availability of information on sediment from different sources adds to existing understanding of the relative importance of surface and subsurface sources and of surface sources under different geological formation to sediment in similar catchments. The optimum composite fingerprint was selected by DFA comprising constituents selected from a number of the different groups of properties generally affords the most robust discrimination of the sediment sources within the study catchment. The optimum composite fingerprint identified for the Amrovan catchment (C, P, Kaolinite and K), correctly classifies 100% of the source material samples. For the Royan catchment, the optimum fingerprint provided by stepwise DFA (Chlorite, X_{FD}, N and C) correctly classifies 92.9% of the source material samples. If fingerprint properties used in combination (for example to construct a composite fingerprint) the different types of property afford a more robust means of discriminating catchment sediment sources. (Walling et al, 1999; Collins et al, 1998, 2001, 2002). The contribution of each sediment source obtained by multivariate mixing model varied at two catchments. For Amrovan catchment Upper Red Formation is the main sediment sources as this sediment source approximately supplies 36% of the reservoir sediment whereas the dominant sediment source For the Royan catchment is from Karaj formation that supplies 33% of the reservoir sediments. But that both Quaternary units and gully erosion also represent important sources (32% and 28% respectively). The mean (average for all properties within each composite fingerprint) relative errors for the mixing model calculations were typically around 10%, confirming that the relative contributions from the individual source types generated by the mixing model were meaningful. The clear discrimination between the potential source materials provided by the source fingerprint properties, the relatively high levels of correct classification demonstrated by the stepwise discriminate function analysis and the limited divergence between the observed and predicted values for the sediment properties associated with individual suspended sediment samples, demonstrated by the RME analysis and the low amount of uncertainty indicate that the source fingerprinting approach appears to work well in the study catchments and to generate reliable results.

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