Available online at www.elixirpublishers.com (Elixir International Journal)

Pollution

Elixir Pollution 36 (2011) 3316-3319

ISSN: 2229-712X

The viability of base cations as tracers in sediment sources studies

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ARTICLE INFO

Article history:

Received: 9 May 2011;

Received in revised form: 21 June 2011;

Accepted: 30 June 2011;

Keywords

Base cations,
Sediment source,
Management,
Iran.

ABSTRACT

Recently the sediment tracing has been increasingly employed as a means of establishing sediment source information. The first step of this approach is the selection of diagnostic properties, which distinguish potential sediment sources in an unequivocal manner. However the selection of the most effective properties is required in the design of cost-effective catchment management strategies. This contribution reports an attempt to address this issue by testing the discrimination of sediment source within two small drainage basins in Iran using four base cations (Na, K, Ca and Mg). By field investigation, 10 representative samples were collected from each sediment sources per catchments. Several statistical methods were applied to the data including the Kruskal-Wallis, discrimination function analysis (DFA) and multivariate stepwise selection algorithm. The results indicate that in the case of the Amrovan basin, K is the most sensitive discriminator of source type (65 %), followed in decreasing order by Na (60 %), Mg (55 %) and Ca (45 %). In the case of the larger and more complex Atary drainage basin, Na and Mg are the best individual properties which successfully classify 54% of source material samples into the correct categories, followed in decreasing order by Ca (52 %) and K (45 %).

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Introduction

Sediment-related environmental problems pose a serious threat to land management sustainability and water resource utilization in many developing countries, including Iran. In such areas, efforts to conserve soil and water are frequently hampered by a complex interaction of physical, socioeconomic, political and technical factors. As a result, sediment management strategies must be targeted, in order to ensure effective deployment of the limited resources available. Such targeting is, however, frequently constrained by the paucity of detailed information on catchment sediment sources. The fingerprinting approach has been increasingly employed as a means of establishing such information (e.g. Walling and Collins. 2000). Sediment fingerprinting relies upon the premise that the physical and chemical properties of suspended sediment will reflect its source. The application of this approach comprises two basic steps. These involve, first, the selection of diagnostic properties that distinguish potential sediment sources in an unequivocal manner, and secondly, a comparison of suspended sediment and catchment source samples using these properties, in order to establish sediment provenance. Many different physical and chemical properties have been successfully used to discriminate potential sediment sources in drainage basins, including mineral magnetism (Caitcheon, 1993; Feiznia and Kouhpeima, 2010; Feiznia et al., 2009; Kouhpeima et al., 2010), clay minerals (Feiznia and Kouhpeima, 2010; Kouhpeima et al., 2010; Feiznia et al., 2009), environmental radionuclides (Wallbrink and Murray, 1996), base cations (Feiznia and Kouhpeima, 2010; Kouhpeima et al., 2010; Feiznia et al., 2009), acid extractable metals (Collins and Walling, 2002; Kouhpeima et al., 2010; Feiznia and Kouhpeima, 2010), particle size (Walling et al., 2008), organic constituents (Collins and Walling, 2002; Walling et al., 2008; Feiznia et al., 2009; Kouhpeima et al., 2010; Feiznia and Kouhpeima, 2010), trace elements and a variety of isotopic in stage one is very important in the design of cost-effective catchment management strategies. Sediment sourcing studies have proven successful in distinguishing individual source types, such as surface soils beneath different land uses and subsoil/channel banks (Walden et al., 1997); 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 & Woodward, 1995); and in reconstructing recent changes in sediment provenance using sediment cores (Collinset al., 1997b, c; Owens et al., 1999). This contribution addresses the viability of base cations for sediment source differentiation.

The study areas are two drainage basins in Semnan Province of Iran, Amrovan and Attary (Fig. 1). These catchments are representative of a range of geology formations, physiographic conditions and size and should therefore provide a meaningful basis for a general assessment of the degree of sediment source discrimination afforded by a range of organic constituents. Land use in the two drainage basin is homogenous, comprising rangeland. Table 1 provides more information on the two catchments.

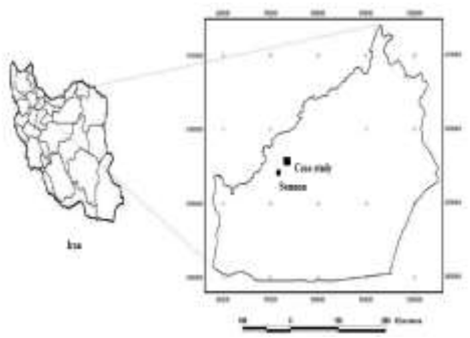

Fig 1 The location map of the study areas

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Methodology

Field sampling involved the collection of representative samples of the main potential sediment sources identified within each study catchment. Potential sediment sources were categorized surface soils from different geological formations and eroding gullies. Ten representative samples were collected from each of the primary sediment sources in each catchment. All source material samples were collected using a stainless steel spade, which was regularly cleaned to avoid inter-sample contamination. Care was taken to ensure that only materials likely likely to be mobilized by erosion (maximum depth of 2 cm) were collected.

Laboratory analysis of source material samples was undertaken at the University of Tehran, Faculty of Natural Resources. The samples were air-dried, gently disaggregated using a pestle and mortar and dry sieved through a 63 µm sieve. The concentrations of four base cations (Na, K, Ca and Mg) in these samples were measured using procedures described in Qui and Zhu (1993).

The discrimination of potential sediment sources was tested statistically. First the Kruskal-Wallis test was used to eliminate redundant parameters (fingerprint properties).Then discriminant 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 function coefficients reflecting the explanatory power of the included variables and this procedure were employed in two 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 fingerprint properties. In combination, these two procedures, which involved forcing a particular property or groups of properties into the analysis, provided a rigorous means of testing the assumption that composite fingerprints afford more powerful source discrimination than individual fingerprint properties.

Results

Table 2 summarizes the descriptive statistics for the Amrovan and Atary Drainage Basins and the corresponding Kruskal-Wallis Statistics. According to this table, all fingerprinting properties yield test statistics below the critical value ($p < 0.05$) and so survive the elimination process. 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. These results indicate that in the case of the Amrovan Basin, K concentration is the best source discriminant, correctly identifying 65 % of the samples, followed in decreasing order by Na (60 %), Mg (55 %) and Ca (45 %). In the case of the Atary drainage basin, Na and Mg concentrations are the best individual discriminants, successfully classifying 54% of source material samples into the correct categories, followed in decreasing order by the fingerprints Ca (52 %) and K (45 %).

The results of using DFA to test the discriminatory power of the composite of four base cations are represented in Figures 2 and 3 for the Amrovan and Atary basins, respectively. These scatterplots are a useful means of examining the relationship between the source categories and of identifying misclassification resulting from using four properties passing the Kruskal-Wallis elimination procedure. In these figures there are a few symbol groups that each symbol group is representative of each sediment source. A composite fingerprint based on four base cations provides more robust discrimination of the sources than those individual fingerprinting properties. For example this composite fingerprinting (Na, K, Ca and Mg) provide 72 % of source type samples classified correctly in the Amrovan drainage basin (Fig. 2) Similarly, for the Atary drainage basin, that classifies 68 % of the source type samples correctly (Fig. 3).

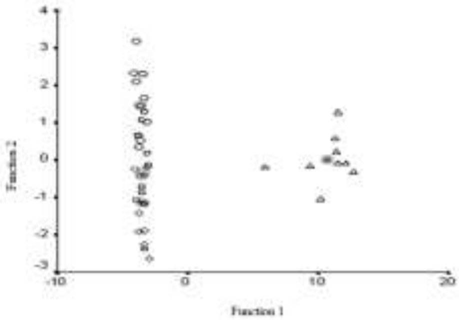

Fig.2. Scaterplots constructed from DFA to test the power of fingerprint property groups for distinguish potential sediment sources in the Amrovan catchment

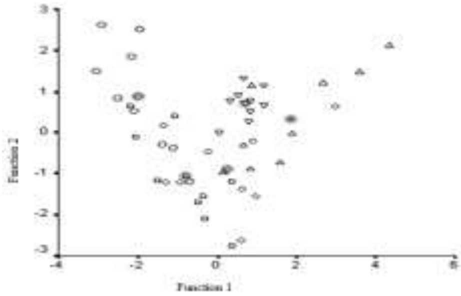

Fig.3. Scaterplots constructed from DFA to test the power of fingerprint property groups for distinguish potential sediment sources in the Atary catchment

Discussion

The results of the statistical analysis demonstrate that no single or composite property is capable of classifying 100% of the samples into their correct source categories for any of the study basins. 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. The discriminatory power of both single and composite fingerprinting properties was higher in Amrovan drainage basin than that in Atary drainage basin. In Atary drainage basin, due to the higher slope and rainfall the sediments have been mixed together so that discrimination of sediment source is more difficult than in Amrovan drainage basin, as the lower slope and rainfall would lead to less sediment mixing. The existence of four sediment sources in Amrovan drainage basin against five sediment sources in Atary drainage basin cause more discriminated sediment sources in Amrovan drainage basin than that in Atary drainage basin. Using composite fingerprinting properties nevertheless improves the discrimination of sediment sources in Atary drainage basin as well. The results presented clearly indicate that the use of a composite signature consistently enhances the level of sediment source discrimination over that afforded by any one of its constituents. These results overlap with results of Collins and Walling (2002). For example the highest proportion of source samples from the Amrovan catchment correctly classified by an individual property from the group of base cations is 65% (K), whilst the combined use of a number of properties in the group correctly classifies 70 % of the source material samples. Similarly, for the Atary Catchment, the best single property (Mg and Na) correctly classifies 54 % of the source samples, whilst this increases to 68 % for a set of properties from the group. Although a composite fingerprint based on base cations provides more discrimination of the sources, the corresponding scatterplot presented in Figures 2 and 3 also shows considerable overlap between the source categories and show that the discrimination functions calculated are characterized by considerable overlap between the samples representing surface soils beneath different geological formation and those under eroding gully walls.

Based on the results of this study, it is suggested that using a composite index that includes base cations would improve sediment source discrimination. This is in agreements with Collins and Walling (2002), who suggested that measurements of a combination of base cations, acid and pyrophosphate-dithionite extractable metal and organic constituents should provide an effective basis for establishing composite fingerprints for discriminating individual sediment source types.

Conclusion

The ability of base cations to discriminate sediment sources was undertaken by laboratory analysis and statistical procedures. A great number of fingerprinting properties have been used in previous studies. The greater the number of fingerprinting properties that are used, the better the discrimination of sediment sources would be expected, but laboratory costs would increase as well. This study shows a comparatively low-cost way to make a first estimate of sediment sources. The viability of such fingerprinting properties especially in different regions is required in cost-effective planning of natural resource management. Although this study has produced reasonable results overall, there are still limitations to the method: source-sediment comparisons could be refined by generation of season-specific composite signatures for individual source types, based on source material sampling in different seasons, This would help to represent potential seasonal fluctuations in fingerprint parameter values. Initial selection of fingerprint properties, prior to objective statistical verification, could be guided by the establishment of “general rules” choice of parameters with differing environmental behaviour, or according to catchment mineralogy. This would help to rationalise fingerprint property lists and maximize the use of available laboratory resources.

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Table1. The characteristics of catchments

Drainage basin	Area (Ha)	High elevation (m)	Low elevation (m)	Mean slope (%)	The mean annual rainfall (mm)	The mean annual temperature (o^C)
Amrovan	102.35	1925	1795	11.4	174.5	12.5
Attary	627.96	2220	1750	15.95	180.4	12.5

Table 2.The descriptive statistics and the corresponding Kruskal-Wallis and DFA Statistics

Catchments	Fingerprinting properties	Minimum (ppm)	Maximum (ppm)	Mean (ppm)	Std. Deviation	P-value[a]	% source type samples classified correctly
Amrovan	Na	0.03	0.4	0.21	0.12	0.00	60
	k	0.51	1.03	0.72	0.17	0.00	65
	Ca	16.05	26	21.67	3.20	0.00	45
	Mg	0.55	1.52	1.03	0.30	0.00	55
Atary	Na	0.17	0.51	0.36	0.11	0.00	54
	k	0.34	1.19	.907	0.26	0.00	48
	Ca	11.70	21.80	16.42	3.14	0.00	52
	Mg	0.84	1.95	1.43	0.38	0.00	54

a: Critical P-value = 0.05