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Downstream Enrichment in the Transport and Storage of Sediment Fingerprint Properties

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ABSTRACT Today fingerprinting techniques are increasingly adopted as an alternative and more direct and reliable means of assembling sediment source information. One of the principal assumptions of sediment fingerprinting is that potential watershed sediment sources can be distinguished on the basis of their physical, geochemical and biological properties or fingerprint properties. However, while the source fingerprinting approaches necessarily assume conservative behaviour of the fingerprint properties, some in-stream alteration of these properties during both transport and short-term storage is probably inevitable. This potential limitation must be judged in the context of the problems associated with the use of sediment fingerprinting techniques. Samples of sediment source and reservoir sediment collected during the present study have been used to determine the conservative behavior of fifteen fingerprint properties. Comparison of fingerprinting property concentrations of intensive properties used in fingerprinting indicates there is an increase in content of the N, P, C, Co, Cr, clay minerals (smectite, illite, kaolinite), Low Frequency Magnetic Susceptibility (XLF) and Frequency Dependent Magnetic Susceptibility (XFD) and decrease in clay mineral chlorite and base cations Ca, Mg, Na and K. The results indicate that N, Na and smectite properties have no significant difference in reservoir sediment samples than that in sediment source samples and therefore are useful for fingerprinting investigations in these watersheds.

Key words: *Conservative behavior, Fingerprinting properties, Reservoir sediment, Sediment sources*

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1 INTRODUCTION

Today fingerprinting techniques are increasingly adopted as an alternative and more direct and reliable means of assembling sediment source information (Walling *et al.,* 2008). Source fingerprinting techniques provide a relatively simple and cost-effective basis for assembling spatially- and temporally-integrated data for watersheds of different scales (Collins and Walling, 2002; Walling, 2005). Many different physical and chemical properties have been used to discriminate potential sediment sources in watersheds, including mineralogy, color (Grimshaw and Lewin, 1980; Martínez-Carreras *et al.,* 2010), mineral magnetism (Caitcheon, 1993; Kouhpeima *et al.,* 2010), clay minerals (Kouhpeima *et al.,* 2010, 2011), environmental radionuclides (Wallbrink and Murray, 1996),

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geochemical composition (Foster and Walling, 1994), organic constituents (Collins and Walling, 2002; Kouhpeima *et al.,* 2010), acid extractable metals (Collins and Walling, 2002; Kouhpeima *et al.,* 2010) and particle size (Stone and Saunderson, 1992). However, although the source fingerprinting approach necessarily assumes conservative behavior of the fingerprint properties (Walling *et al.,* 2008), some in-stream alteration of these properties due for example to adsorption or desorption or to biological uptake during both transport and short-term storage is probably inevitable. This potential limitation is the most important uncertainty associated with the source fingerprinting studies and however, must be judged in the context of the numerous and probably, problems associated with the use of sediment fingerprinting techniques. Most of the previous studies were suggested to do the particle size and organic matter correction factors because of sediment downstream enrichment (Walling *et al.,* 2008; Collins *et al.,* 2010). According to the goals of the study and the review of literature, this contribution addresses sediment downstream enrichment of some fingerprint properties and the particle size and organic matter correction factors using samples of source area and reservoir sediment.

2 MATERIALS AND METHODS

2.1 Study area

The study area is situated in northernmost Iran and contains five small watersheds ranging in size from about 100 to 600 ha, each with a reservoir at its outlet (Figure 1). The climate is semi-arid, with sparse vegetation. Precipitation is largely in the form of rain during the winter months. Present land use is confined largely to grazing rangeland. The source areas represent a range of geological formations, and should provide a meaningful basis for a general assessment of enrichment of some fingerprint properties in the source and reservoir sediment. Table 1 represents characteristics of study watersheds.

Table 1 Characteristics of study watersheds.

Watershed	Area (ha)	Mean annual rainfall (mm)	Mean slope (%)	Low elevation (m)	High elevation (m)
Amrovan	102.35	174.5	11.4	1795	1925
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
Royan	538.83	184	23.95	1855	2070

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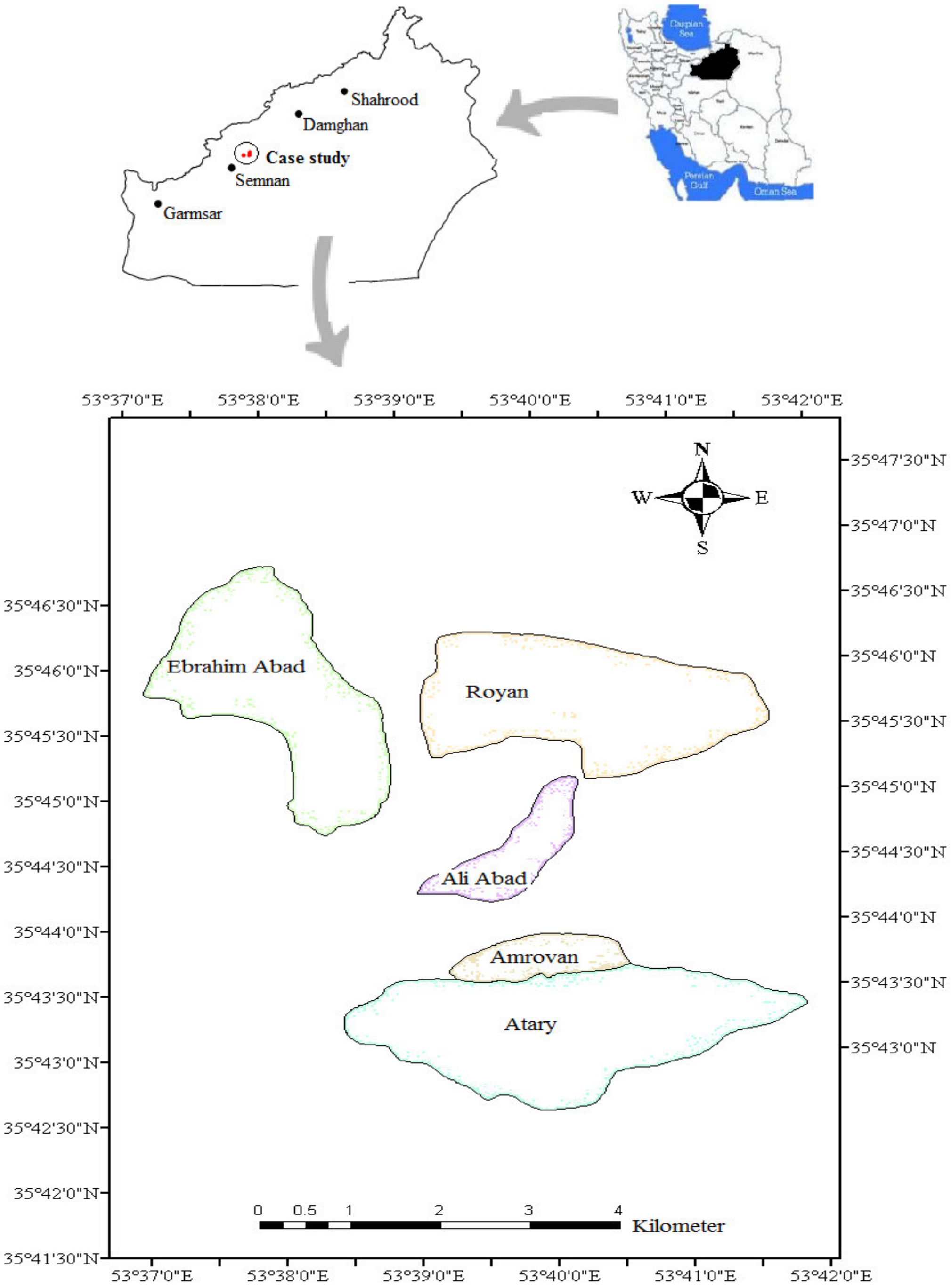

Figure 1 Location map of the study areas and five small watersheds.

3 METHODS

By field monitoring, 130 representative samples of both source area and sediments deposited in reservoir dam constructed in the outlet of watersheds were collected using a stainless steel spade. All source material samples were air-dried and subsequently dry-sieved to<63 µm to facilitate direct comparison with sediment samples. The samples of both source area and the sediments deposited in reservoir were analyzed in the laboratory for five groups of fingerprinting properties, including organic matter (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 Spectrophotometry, after extraction with perchloric acid (Olsen and Dean, 1965). Ammonium acetate was used to extract Na, Mg, Ca and K (Qui and Zhu, 1993). Cr and Co were extracted using direct acid digestion (Allen *et al.,* 1989). Mineral magnetisms were determined using a Bartington meter and MS2B dual frequency sensor (Caitcheon, 1998) and clay minerals were determined using X-ray diffraction (Garrad and Hey, 1989). Statistical analysis was performed by Kruskal Wallis non-parametric test (SPSS for windows sub-program (cf. Nie *et al.*, 1995) for values of each fingerprinting property to determine the signification of the differences between source area materials as well as sediment source samples and reservoir sediment samples. This procedure is the non-parametric equivalent of analysis of variance and is a distribution-free test for contrast between two or more different groups. If the values of Kruskal Wallis exceed the critical value, the measurements of fingerprinting property exhibit no significant differences between different group samples. A non-parametric test was used because fingerprinting properties data set rarely satisfy the main condition for adapting parametric equivalents that data are normally distributed and have equal variance (Collins *et al.,* 1998). An analysis on the properties of the fine fractions (sand, silt and slay particles) of the sediments from these sources (with a grain size contribution to the grain size of the reservoir sediments) was determined. A particle size and organic matter correction factor was used, because it is well known that particle size and organic matter exert a major influence upon element concentrations (Horowitz and Ehick, 1987). To calculate such a factor, specific surface area (m^2g^{-1}) was chosen as a surrogate measure (Horowitz, 1991).

4 RESULTS AND DISCUSIONS

Figure 2 shows a comparison between the average of each fingerprinting property contents of source samples and of sediment samples. The increase in the contents of N, P, C, Co, Cr, smectite, illite, Kaolinite, XLF and XFD can be related to the downstream increase in the concentration of fingerprinting properties due, for example to adsorption or to biological uptake during both transport and short-term storage (Walling *et al.,* 2008). The enrichment in the content of clay minerals can be related to particle size and specific areas of these particles as well. Clay minerals are tiny particle with high specific area. These characteristics cause clay minerals suspend for a long time no trapped in the way and more transport to output watershed, therefore the content of clay minerals increase in reservoir sediment. XLF, Co, and Cr show profound differences in source and sediment samples. Therefore they are not suitable for this purpose. Results also indicate the mean values of all base cations are decrease in sediment samples. For example the mean value of Ca is 13.67% in source sediment samples whilst it is 12.35% in reservoir sediment samples. Similarly the mean value of Mg is 2.87% in source sediment samples whilst it is 2.08% in reservoir sediment samples. However this surprising result can be related to high trap efficiency of these properties in time of transportation and must investigate exactly in future studies.

Figure 3 compares the particle size contribution for source material with that for the sediment samples in each watershed. For the Ebrahim Abad, reservoir sediment is enriched in silt and slightly enriched in clay particles but depleted in sand particles compared to source material samples. In the four other watersheds, reservoir sediments are markedly enriched in silt; this is the important finding that shows the high credibility of silt particles in these watersheds. In these four watersheds however reservoir sediments depleted in clay and sand particles compared to the surface soils from source areas. These comparisons clearly demonstrate the need for a particle size correction factor.

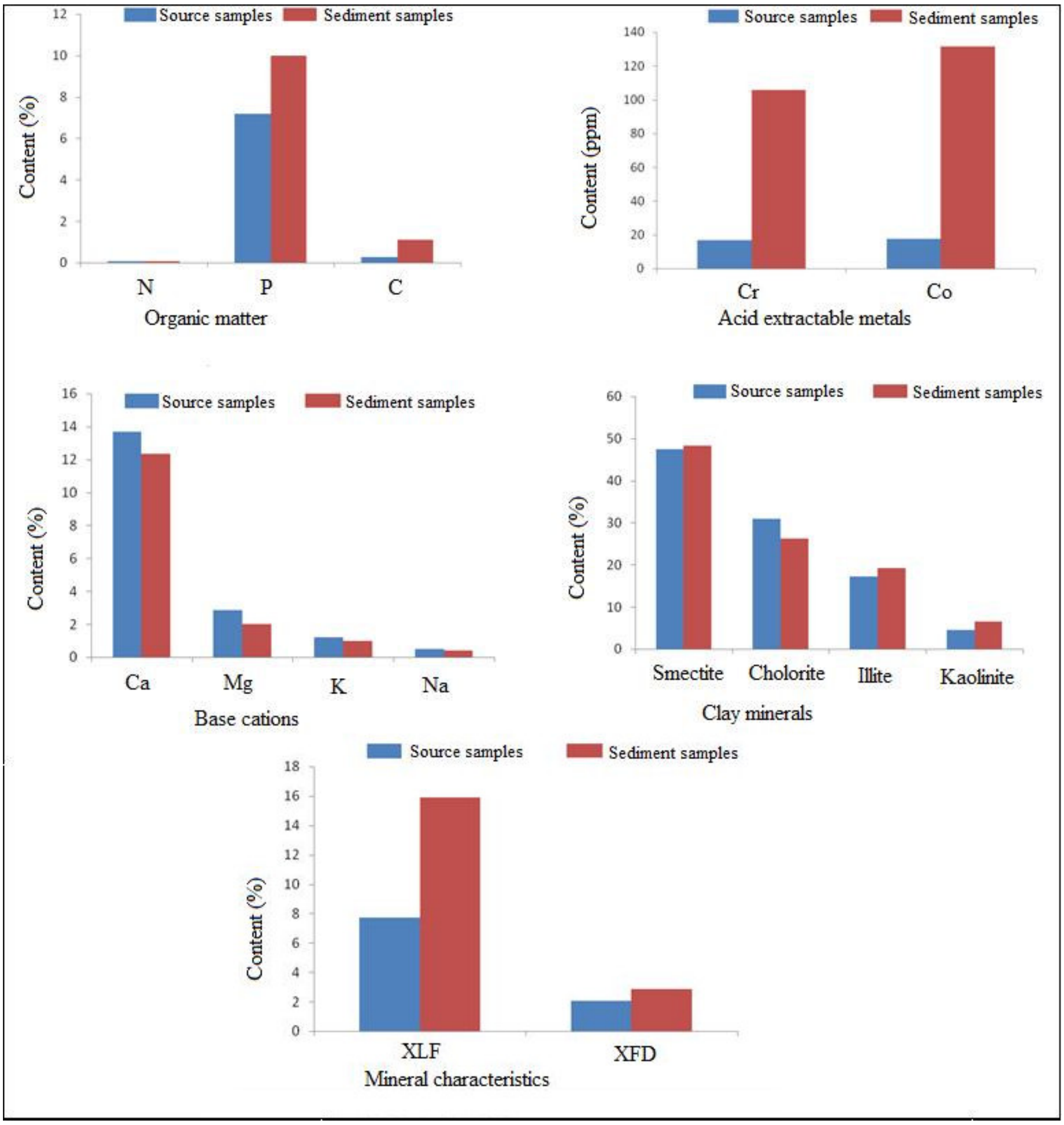

Figure 2 Comparison between the average of each fingerprinting property contents of source samples and of sediment samples.

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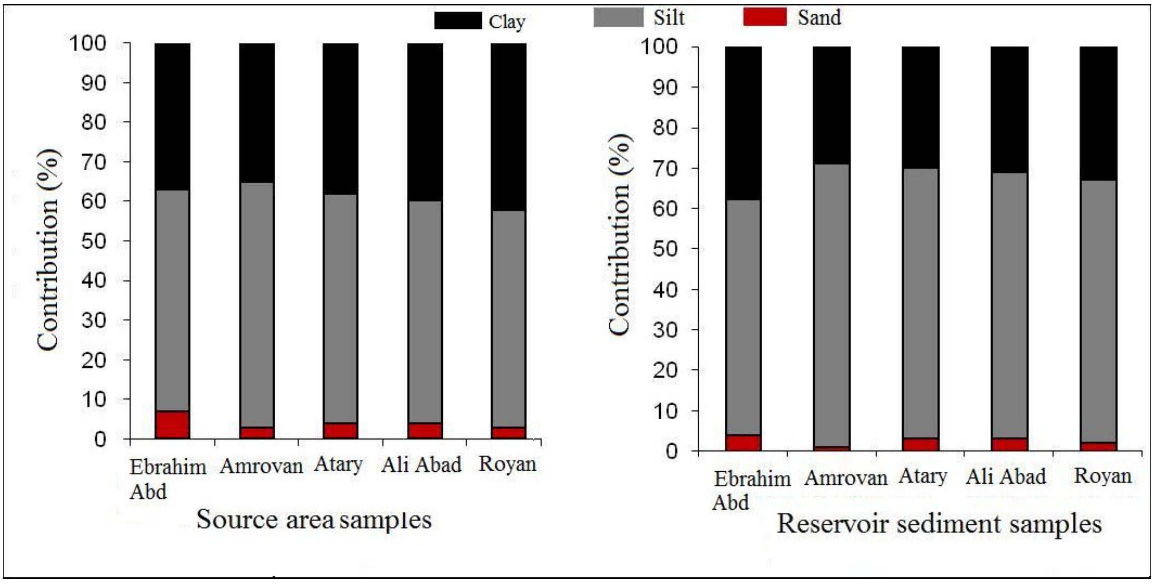

Figure 3 Results of particle size contribution for source material with that for the sediment samples.

The ratio of the specific surface area of each individual sediment sample to the specific surface area of each individual source area was used to represent particle size correction factor and the results are presented in Table 2. These correction factors range from 1.14 to 1.24. The content of N, P and C was selected as a surrogate measure for organic matter content. The data presented in Figure 2 however show reservoir sediments are enriched in three organic maters and emphasize the need for a correction factor to be incorporated into the fingerprinting technique. This correction factor was calculated in the same manner as that for particle size and values are given in Table 2. According to this table, the highest N correction factor is related to the Atary watershed (1.05) while the lowest N correction factor is associated with the Amrovan watershed that shows no difference in the sediment source and reservoir sediment samples. The same results were obtained for the P correction factor. However Atary and Royan watersheds represent the highest P correction factor (1.27) and Amrovan represents the low P correction factor (1.2). The C correction factor ranges from 1.99 to 2.84. This results show the C correction factor is higher than three other correction factors.

Table 2 Mean particle size and organic matter correction factors.

Watershed	Particle size	N	P	C
Ebrahim Abad	1.14	1.03	1.22	2.23
Amrovan	1.23	1.00	1.20	2.17
Atary	1.24	1.05	1.27	2.84
Ali Abad	1.17	1.02	1.23	1.99
Royan	1.17	1.03	1.27	2.78

It is important to recognize that use of a mean concentration value to represent the individual sources introduces uncertainty, since the representativeness of the mean value obtained will clearly be dependent on the representativeness of the source material collected samples. Since the concentration of a particular fingerprint property in sediment derived from a specific source will reflect the mixing of sediment mobilized from many different areas within the portion of the watershed associated with that source, use of

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the mean value is physically meaningful. However, the mean value will be sensitive to the number of source material samples collected and the extent to which those samples adequately characterize the natural variability of the fingerprint property within the area covered by the source. The combined use of correction factors ensured more direct comparability between the source type and sediment samples. However, the simultaneous incorporation of these correction factors into the mixing model may result in the over-correction of tracer parameter values For example, during the summer, a low energy flood event could result in the mobilization of fine sediment heavily enriched in organic matter. The higher concentrations of many tracer parameters which could be expected to exist in such a sample could reflect either the enrichment in fines or in organic matter, or both. Differing levels of precision associated with measurements of each individual tracer parameter can also present problems in the use of composite signatures. It is preferable for the parameter providing the greatest precision to exert the greatest influence upon the mixing model solutions.

5 CONCLUSION

The ability to pre-select potentially successful properties in the fingerprinting techniques would clearly be an important advantage in sediment source investigation to provide a relatively cost-effective basis for assembling spatially- and temporally-integrated data. Many different physical and chemical properties have been used to discriminate potential sediment sources in watersheds, including mineralogy, color, mineral magnetism, clay minerals, environmental radionuclides, geochemical composition, organic constituents, acid extractable metals and particle size. However some in-stream alterations of these properties due, for example to adsorption or desorption or to biological uptake during both transport and short-term storage is probably inevitable and this potential limitation, was judged in the context of problems associated with the use of sediment fingerprinting techniques. Samples of sediment source and reservoir sediment collected have been used to determine the conservative behaviour of some fingerprint properties in the source and sediment output. Comparison of fingerprinting property concentrations for sediment source and reservoir sediment samples indicates there is an increase in content of the N, P, C, Co, Cr, smectite, illite, kaolinite, X_{LF}, and X_{FD} and decrease in chlorite Ca, Mg, Na and K. The results provide useful information on the importance of the fingerprinting properties to represent the difference of sediment source and reservoir sediment samples from the study watersheds, which can be used to support fingerprinting model validation and the targeting of management and control strategies. For example the results of this study indicate that N, Na and smectite properties have no significant difference in reservoir sediment samples than that in sediment source samples and therefore are useful for fingerprinting investigation in these watersheds. However further work is required to explore the factors controlling these variations.

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رفتار حفاظتی خصوصیات منشایاب رسوب در حین انتقال و رسوبگذاری

اصغر کوهپیما[1] و سادات فیض نیا[2]

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چکیده امروزه تکنیک‌های منشایابی به عنوان ابزارهایی قابل اعتماد، مستقیم و متفاوت به منظور کسب اطلاعات از منابع رسوبی به کار گرفته می‌شوند. یکی از فرضیات اولیه منشایابی رسوب این است که منابع بالقوه رسوب حوزه‌های آبخیز می‌تواند براساس خصوصیات فیزیکی، شیمیایی و بیولوژیکی رسوب یا خصوصیات منشایاب تفکیک گردد. اگرچه تکنیک‌های منشایابی رفتار خصوصیات منشایاب را ثابت و بدون تغییر فرض می‌کند ولی به هر حال بعضی تغییرات در حین انتقال یا رسوبگذاری کوتاه مدت در این خصوصیات اجتناب ناپذیر خواهد بود. این محدودیت‌های بالقوه به دلیل مشکلاتی که در هنگام بکارگیری تکنیک‌های منشایابی رسوب ایجاد می‌کنند باید بررسی گردند. نمونه‌های رسوبی که از منابع رسوب و رسوبات مخازن جمع‌آوری شد به منظور تعیین رفتار حفاظتی ۱۵خصوصیت منشایاب استفاده شده است. مقایسه غلظت‌های خصوصیات منشایاب مورد استفاده نشان دهنده افزایش در مقادیر نیتروژن، فسفر، کربن، کبالت، کروم، کانیهای رسی (اسمکتیت، ایلیت و کائولینیت)، X_{LF} و X_{FD} و کاهش مقادیر کانیهای رسی کلریت و کاتیونهای پایه کلسیم، منیزیم، سدیم و پتاسیم می‌باشد. نتایج نشان داد که نیتروژن سدیم و اسمکتیت تفاوت معنی‌داری در نمونه‌های رسوبات مخازن و رسوبات منابع رسوب نداشته و بنابراین برای بررسی‌های منشایابی در این حوضه‌ها مناسب می‌باشند.

کلمات کلیدی: رسوبات مخازن، رفتار حفاظتی، منابع رسوب، ویژگی‌های منشأیاب

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