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Original Research Article

Effects of type, level and time of sand and gravel mining on particle size distributions of suspended sediment

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ABSTRACT

Monitoring the sediment transport behavior induced by different interventions, particularly sand mining from rivers, is needed to adaptively manage the watersheds. The particle size distribution of the suspended sediment in up and downstream of rivers is one of the main indicators to know about fate of sediments, which may be varied in different conditions. We investigated the effect of some types of sand and gravel (i.e., manual and low, semi-heavy, and heavy machinery) mining on particle size distribution of suspended sediment in the Vaz-e-Owlya, Vaz-e-Sofla and Alesh-Roud riverine mines located in Mazandaran Province, northern Iran. The study was conducted on a monthly basis from February, 2012 to January, 2013. Laser granulometry was used to analyze the particle size distribution of suspended sediment samples taken from up and downstream sections of the study mines. The results revealed that the level and intensity of mining activity affected particle size distribution of suspended sediments. Further statistical assessments in up and downstream sections of the mines proved that sorting, D50, mean, D90, kurtosis, skewness and D10 of the suspended sediment were not significantly influenced by mining activities at levels of 0.09, 0.11, 0.12, 0.15 to 0.69, 0.15–0.69, 0.77, 0.87, 0.97, respectively. While it was not statistically significant, we found that the type of mine and the level of the exploitation changed the particle size distribution of the suspended sediment.

1. Introduction

Watersheds health plays a decisive role in earth system balance, as the knowledge of those led to provide the human well-being and ecosystem health (Adhami, Sadeghi, & Sheikhmohammady, 2018; Hazbavi & Sadeghi, 2017). Riverine sediments are a key component of the watersheds which determines a watershed health (Adhami & Sadeghi, 2016). Suspended sediments (SS) is the most important and ratio of riverine total sediments (Sadeghi & Kheirfam, 2015). They are suspended for a considerable time due to flow turbulence and transported by the flow. The SS are transported in a very long distance by water flow and finally deposited in the base level (Kheirfam & Vafakhah, 2015) affecting downstream landforms and geomorphology (French Burningham, Thornhill, Whitehouse, & Nicholls, 2016a). Nevertheless, the SS behavior and characteristics in rivers may be varied by different factors consisting of climatic (Li et al., 2016), temporal and hydrological (Kheirfam & Sadeghi, 2017; Papenmeier, Schrottke, & Bartholomä, 2014; Ryan & Dixon, 2007; Sadeghi & Singh, 2017; Sadeghi, Kheirfam et al., 2015), geomorphologic (Brunier, Anthony, Goichot, Provansal, & Dussouillez, 2014) conditions and human intervention (Kheirfam & Sadeghi, 2017; Li et al., 2016; Monsalve, Yager, Turowski, & Rickenmann, 2016; Qi & Liu, 2017).

In this regards, increasing of human activities in watersheds and particularly sand and gravel mining from gravel-bed rivers to secure their structural needs influence SS behavior in rivers

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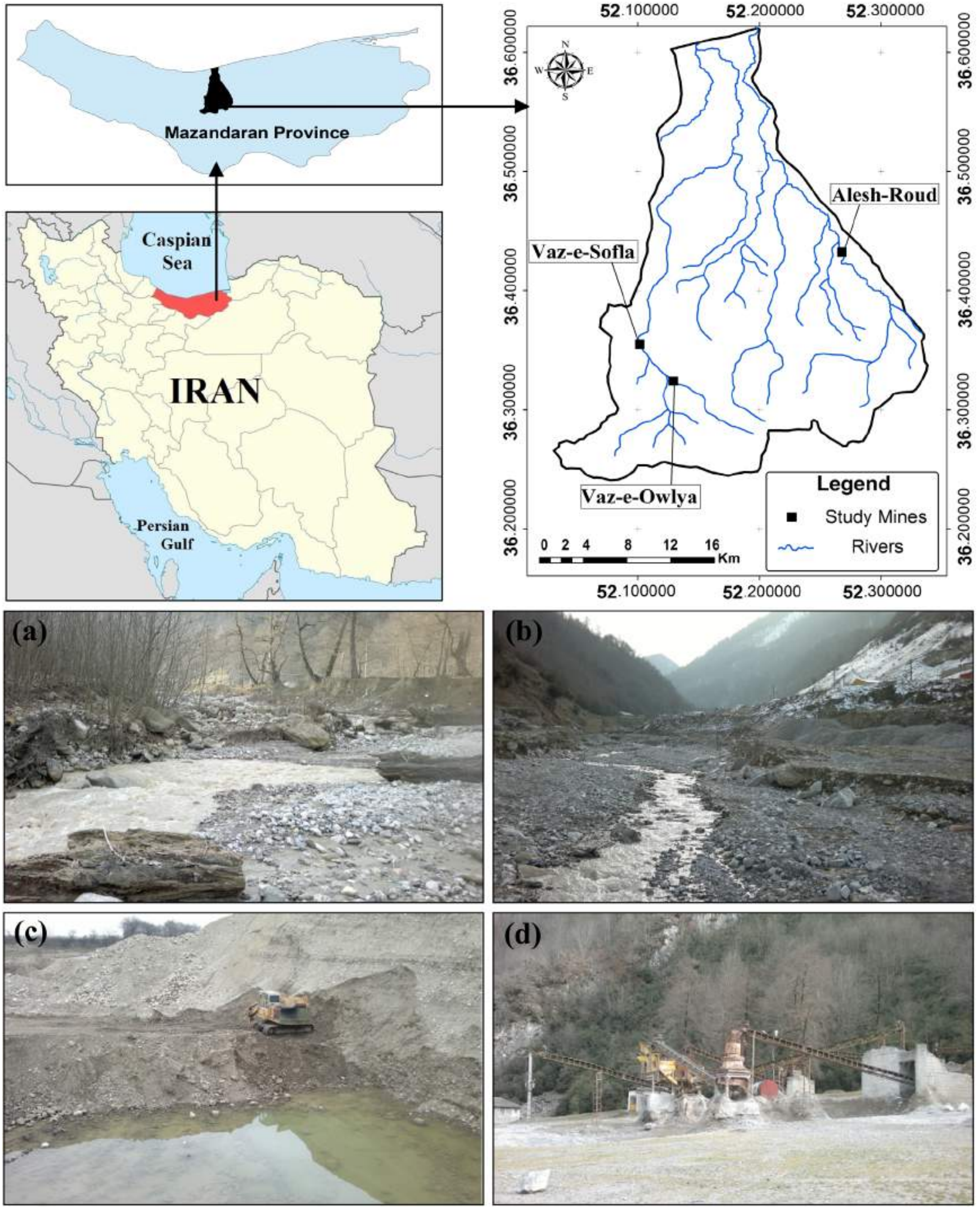

Fig. 1. General location and view of the study mines; Vaz-Sofla mine with semi-heavy mining (a), Vaz-Oulia mine with light and traditional mining (b) and Alesh-Roud mine with intensive harvesting by heavy machinery mining (c and d), located in Mazandaran Province, Iran.

(Kondolf, Piégay, & Landon, 2002; Li et al., 2016; Sadeghi, Kheirfam et al., 2015; Wyss et al., 2016). River gravel and sand are desired resources of river materials, since their fine particles are carried by water flow, and durable sediments with suitable granulometry are deposited (Sadeghi & Zakeri, 2015). In addition, it changes the amount of turbidity and type of transported sediments (Ashraf, Maah, Yusoff, Wajid, & Mahmood, 2011; Liu, Chen, Ma, & Zhang, 2015; Sadeghi, Kheirfam et al., 2015). In turn, sand and gravel mining could change the amount of transported sediment load and river-bed erosion by changing the flow regime (Baratelli, Flipo, & Moatar, 2016; Kheirfam & Sadeghi, 2017; Sadeghi, Kheirfam et al., 2015; Walling & Fang, 2003). However, there is no comprehensive information on the role of active and non-active mines on SS behavior.

Mining from upstream of gravel-bed rivers influences on bank and bed river erosion (Kheirfam & Sadeghi, 2017; Kondolf et al., 2002), hydraulic and geometric traits (Sadeghi, Kheirfam et al., 2015), urban and coastal morphological changes (Brunier et al., 2014) in downstream. In addition to sediment yield rates (Sracek et al., 2012), physical characteristics of SS may be varied by sand and gravel mining from rivers (Papenmeier et al., 2014; Sadeghi & Kiani Harchegani, 2012; Sadeghi & Zakeri, 2015; Sracek et al.,

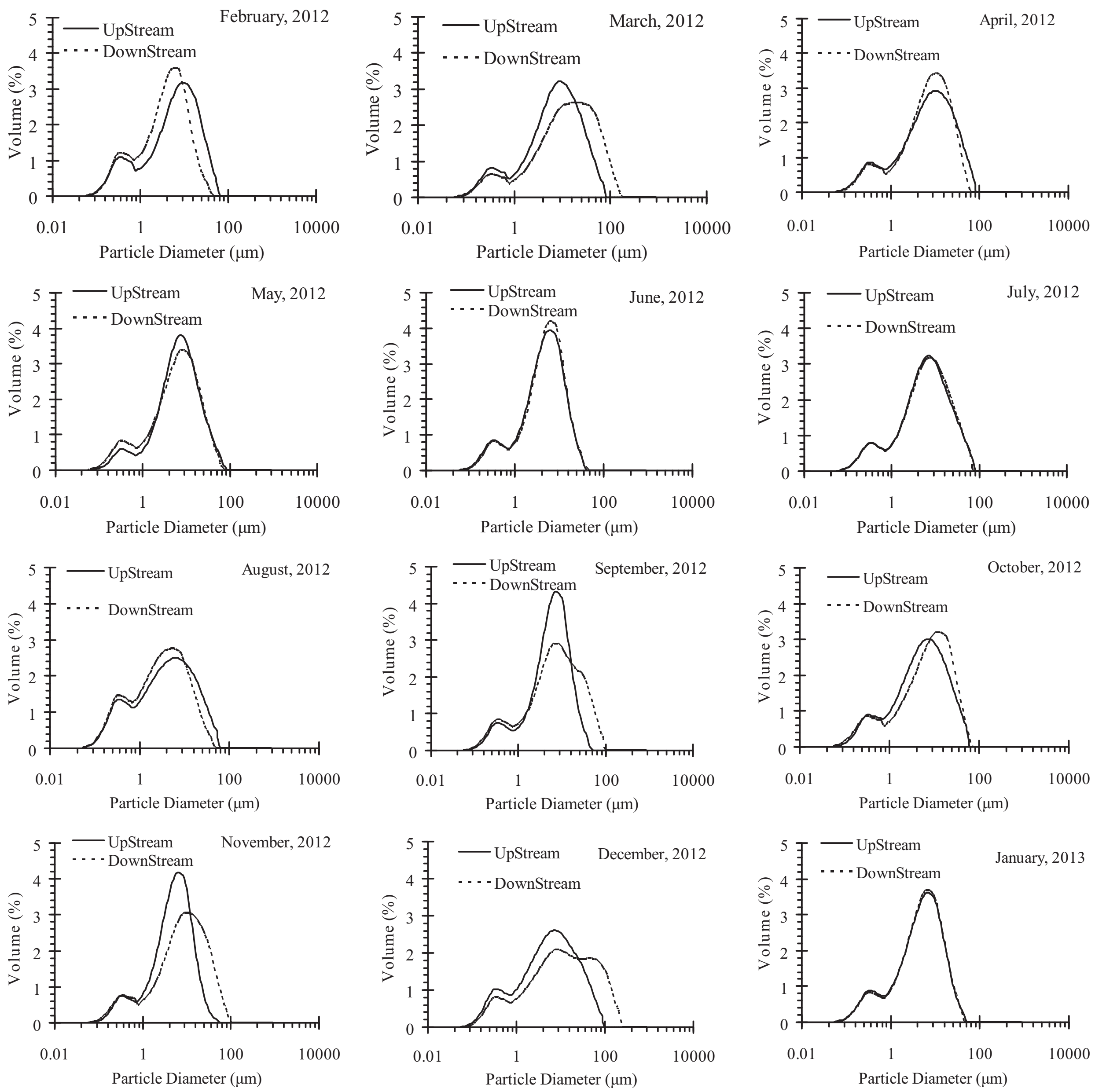

Fig. 2. Results of laser granulometry for particle size distribution of monthly collected suspended sediment samples from up-and downstream of the Vaz-e-Owlya mine during February 2012 to January 2013.

2012; Thompson, Sattar, Gharabaghi, & Warner, 2016; Walling, Owens, Waterfall, Leeks, & Wass, 2000; Williams, Walling, & Leeks, 2008). The changes in SS rates and particularly its particles size and other characteristics can therefore be influenced on urban and deltas landscapes (Brunier et al., 2014; Schwartz & Smith, 2016), aquatic habitats (Abarca et al., 2017), water quality (Baer, Barbour, & Gibson, 2016), and rivers and coastal morphology (French, Payo et al., 2016).

Accordingly, the knowledge about physical characteristics and behavior of SS in different conditions is necessary to use in water use policy (Abarca et al., 2017), conceptualization of the coastal morphological changes modeling (French, Burningham et al., 2016a; Zhang et al., 2016) as well as managing mining policies and techniques (Karimnia & Bagloo, 2015; Liu et al., 2015). In this regard, applying proper analysis methods with the help of appropriate software and high-tech instruments for instance the GRADISTAT software and laser particle size analyzer (Kheirfam & Sadeghi, 2017) are inevitable to achieve reliable results for characterizing the SS particle size (dos Santos, Martinez, Filizola, Armijos, & Alves, 2017; Walling et al., 2000).

A deep insight to the literatures reviewed from various parts of the world (e.g., Walling et al., 2000; Ryan & Dixon, 2007: Williams et al., 2008; Sracek et al., 2012; Sadeghi & Kiani Harchegani, 2012; Papenmeier et al., 2014; Karimnia & Bagloo, 2015; Liu et al., 2015; Abarca et al., 2017; Kheirfam & Sadeghi, 2017) shows that the fluvial behavior of the rivers is differently influenced by sand and gravel mining as one of the common human interferences. The accurate temporal and spatial management of sand and gravel mining and other human interference inside the river is therefore necessary for appropriate utilization of watershed resources. Besides that, particle size distribution is one of the most fundamental traits of sediments, which affects their transport and sedimentation processes. So that, analysis of particle size distribution provides important information about sediments origin, transport

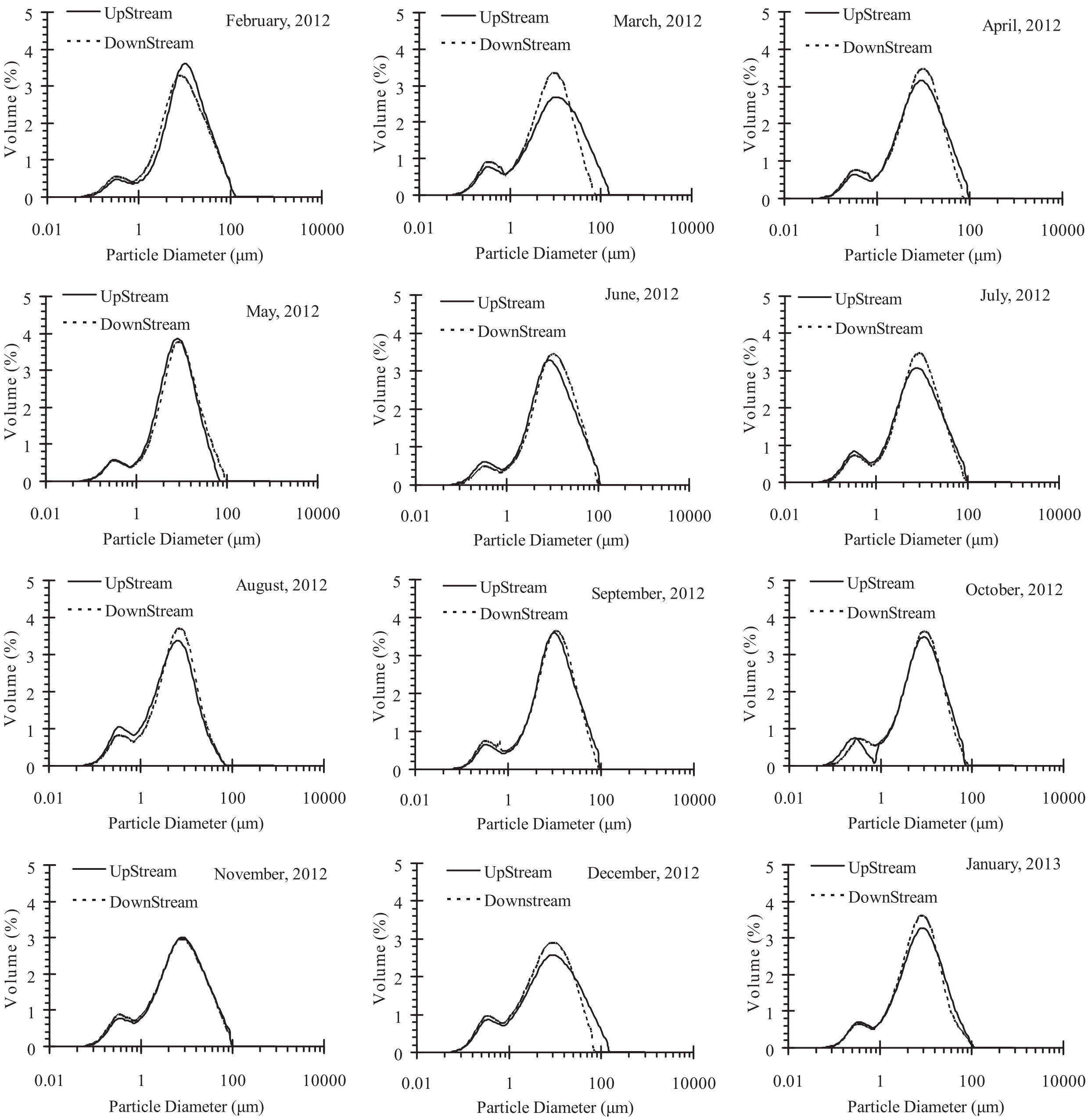

Fig. 3. Results of laser granulometry for particle size distribution of monthly collected suspended sediment samples from up-and downstream of the Vaz-e-Sofla mine during February 2012 to January 2013.

history and their sedimentation conditions. Analyzing particle size distribution of SS and corresponding temporal and spatial variability and consequences of sand and gravel mining is a key task leading to optimal management of watershed resources. Accordingly, our study was aimed to assess the variability of SS particles size induced by (i) type, (ii) level, and (iii) time of sand and gravel mining. However, our hypothesis is that the time of mining (due to variation of hillslopes contribution in SS production) can change the influence of the aforementioned factors on SS particles size variations. For this purpose, we selected three types of sand and gravel mining (by using manually, semi-heavy, and heavy machinery) with three level of mining (low, normal and intensive) in Mazandaran Province, Iran to understand the effect of them on SS particle sizes in downstream of mines. The monthly basis SS sampling in up and down-streams of mines was considered to describe the role of time on the studied variable.

2. Materials and methods

2.1. Study mines

In order to investigate the SS granulometry influenced by exploitation of various gravel and sand mines, the Vaz-e-Owlya mine (with low intensity and manual mining), the Vaz-e-Sofla mine (mining by semi-heavy equipment), and the Alesh-Roud mine (with fully industrial mining by heavy machinery) were selected as study sites. The Vaz-e-Owlya and the Vaz-e-Sofla mines are located in the Vaz watershed (with an area of 14102 ha; 51° 55' 15'' to 52° 12' 15'' E, 36° 12' 30'' to 36° 12' 13'' N). The Alesh-Roud mine with fully industrial extraction by heavy machinery is located in the Alesh-Roud watershed (with an area of 2415 ha; 5152° 18' 30'' to 52° 15' 00'' E, 36° 25' 25'' to 36° 20' 50'' N). Both watersheds entirely are located in central part of Mazandaran Province, northern Iran, and drained to the Caspian Sea through respective

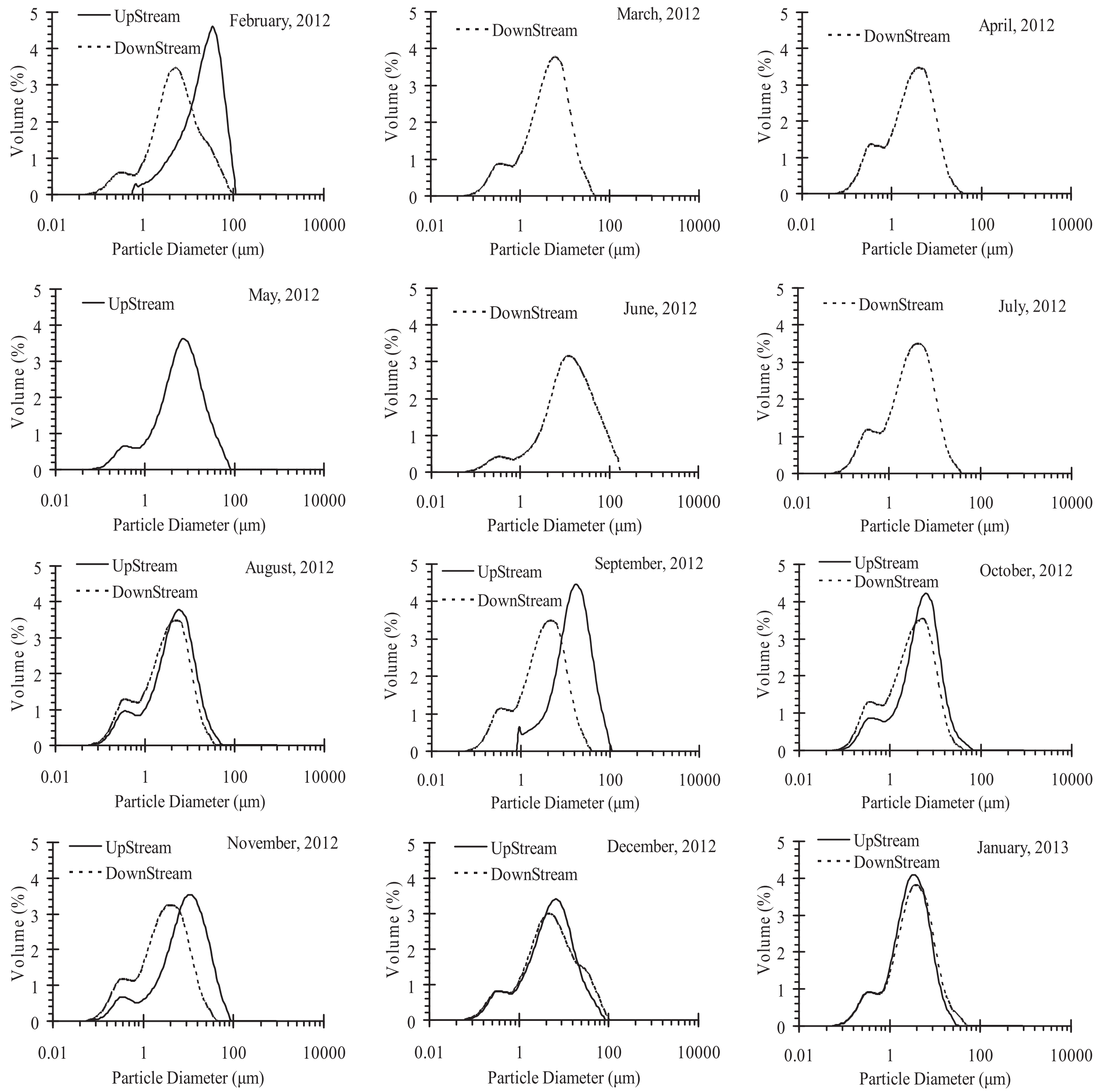

Fig. 4. Results of laser granulometry for particle size distribution of monthly collected suspended sediment samples from up-and downstream of the Alesh-Roud mine during February 2012 to January 2013 (granulometry for particle size distribution of upstream in March, April, June and July 2012 and downstream in May (2012) was not detectable).

65 and 60 km-length rivers. The average gradient slope of the Vaz- and Alesh-Roud watersheds are 40% and 20%, respectively. The mean annual precipitation and temperature (1978–2010) of the Vaz- and Alesh-Roud watersheds are 600 and 827.4 mm and 15 and 15.7 °C, respectively. Accordingly, the Vaz- and Alesh-Roud watersheds are semi-humid and humid, respectively based on the De Marton's climate classification.

A large part of geological formations of the Vaz- and Alesh-Roud watersheds belong to the second, and second-third geological era, respectively. Dolomite, limestone, shale, clay, silt, sandstone, limestone chile, conglomerate, alluvial deposits (sand, gravel, and rubble) are the most important geologic formations in the study areas. The soil of both watersheds categorized as Rendzina type overlaid limestone, limestone marl and calcareous sandstone formations. The soil texture was clay, and clay-loam with fine to coarse granular structure and the pH of the both watersheds soil were ≈ 7.2–7.7. The area has been mainly covered by Hyrcanian forests (*Carpinus sp.*, *Quercus*^{sp}., *Parrotia persica*, *Diospyros lotus*) and ranglands.

The study mines were selected due to accessibility and history of the mine utilization and research history. A general view of the study mines and their geographical situation has been shown in Fig. 1.

2.2. Research methodology

The SS granulometry variations were considered in one-year period through monthly measurement of the mentioned traits from February 2012 to January 2013. For SS sampling, at first, one-liter plastic sampling containers were washed (Fernández, Villanueva, de Diego, Arana, & Madariaga, 2008). Sampling was then conducted by deep integration method and in the vertical length of the river (Edwards & Glysson, 1999; Rovira & Batalla, 2006; Sadeghi, Kheirfam et al., 2015). The SS samples were

Table 1
Descriptive statistics of suspended sediments granulometric results for the study period in upstream and downstream sections of the Vaz-e-Owlya sand and gravel mine, Iran.

Month	Morphometric characteristics in study sections													
	Upstream							Downstream						
	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)
February 2012	1.02	−0.32	4.64	4.76	25.75	6.68	0.43	1.002	−0.29	3.79	3.19	14.12	4.18	0.42
March 2012	1.14	−0.25	4.19	6.41	30.90	7.65	0.59	1.10	−0.24	4.89	11.45	63.94	13.41	0.92
April s, 2012	1.06	−0.25	4.56	6.28	33.96	7.75	0.55	1.13	−0.29	3.92	6.24	26.50	7.68	0.61
May 2012	1.27	−0.18	3.43	6.51	25.39	7.03	1.12	1.13	−0.26	3.97	5.43	24.45	6.95	0.57
June 2012	1.19	−0.28	3.35	4.20	15.22	4.97	0.55	1.24	−0.29	3.21	4.53	15.39	5.32	0.63
July 2012	1.16	−0.18	4.08	5.75	28.52	6.45	0.62	1.14	−0.21	4.08	5.86	28.46	6.68	0.62
August 2012	0.88	−0.17	4.92	3.35	22.70	4.12	0.35	0.88	−0.18	4.30	2.65	15.10	3.24	0.34
September 2012	1.29	−0.30	3.20	5.28	17.46	6.20	0.73	1.08	−0.19	4.62	6.59	37.78	7.53	0.58
October 2012	1.04	−0.21	4.19	4.84	24.88	5.73	0.53	1.06	−0.32	4.41	5.97	28.93	7.87	0.51
November 2012	1.22	−0.27	3.11	4.65	15.41	5.33	0.75	1.12	−0.25	4.28	7.36	35.95	8.73	0.67
December 2012	0.98	−0.18	4.98	4.97	33.24	5.95	0.46	0.94	−0.13	6.38	10.08	90.47	11.15	0.64
January 2013	1.11	−0.27	3.65	4.28	17.50	5.21	0.52	1.14	−0.27	3.53	4.47	17.47	5.32	0.57

Table 2
Descriptive statistics of suspended sediments granulometric results for the study period in upstream and downstream sections of the Vaz-e-Sofla sand and gravel mine, Iran.

Month	Morphometric characteristics in study sections													
	Upstream							Downstream						
	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)
February 2012	1.29	−0.17	3.70	9.98	42.47	10.53	1.61	1.22	−0.15	3.98	8.49	40.58	8.91	1.18
March 2012	1.08	−0.19	5.01	8.03	50.25	9.39	0.64	1.13	−0.29	4.24	5.69	27.21	7.26	0.51
April s, 2012	1.17	−0.19	4.08	7.43	35.81	8.22	0.89	1.18	−0.27	3.92	6.53	28.29	7.87	0.65
May 2012	1.27	−0.21	3.35	6.88	25.38	7.48	1.20	1.31	−0.19	3.54	7.86	31.27	8.45	1.29
June 2012	1.24	−0.17	4.07	8.46	40.56	9.02	1.01	1.23	−0.18	3.67	9.86	41.09	10.49	1.61
July 2012	1.17	−0.19	4.36	6.55	34.90	7.37	0.59	1.23	−0.21	3.84	7.14	31.20	7.95	0.83
August 2012	1.07	−0.24	3.94	4.01	18.94	4.96	0.47	1.18	−0.25	3.62	4.96	20.32	5.86	0.62
September 2012	1.29	−0.21	3.87	8.71	37.90	9.62	1.05	1.26	−0.28	3.94	7.88	33.68	9.45	0.75
October 2012	1.29	−0.25	4.01	6.99	30.13	7.93	0.72	1.21	−0.26	3.73	6.62	27.13	7.77	0.78
November 2012	1.11	−0.19	4.42	6.34	34.91	7.27	0.63	1.08	−0.20	4.56	5.82	33.28	6.89	0.55
December 2012	1.03	−0.17	5.21	6.69	46.24	7.84	0.54	1.01	−0.25	4.58	5.23	29.08	6.56	0.48
January 2013	1.16	−0.19	4.005	6.66	31.55	7.51	0.79	1.21	−0.21	3.63	6.32	25.96	7.13	0.92

Table 3
Descriptive statistics of suspended sediments granulometric results for the study period in upstream and downstream sections of the Alesh- Roud sand and gravel mine, Iran.

Month	Morphometric characteristics in study sections													
	Upstream							Downstream						
	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)
February 2012	1.04	−0.29	2.81	20.95	63.59	24.87	4.39	1.21	−0.08	3.76	5.45	27.18	5.50	0.88
March 2012	Not detectable by laser fraction							1.11	−0.25	3.38	3.84	14.63	4.55	0.56
April s, 2012								0.96	−0.23	3.47	2.41	10.13	2.93	0.38
May 2012	1.20	−0.19	3.63	6.01	25.49	6.73	0.87	Not detectable by laser fraction						
June 2012	Not detectable by laser fraction							1.23	−0.16	4.46	12.36	60.96	13.09	1.68
July 2012								1.02	−0.22	3.42	2.71	11.06	3.22	0.42
August 2012	1.12	0.97	−0.25	3.54	2.65	11.18	3.27	0.97	−0.25	3.54	2.65	11.18	3.27	0.40
September 2012	1.12	1.02	−0.22	3.46	2.86	11.77	3.41	1.02	−0.22	3.46	2.86	11.77	3.41	0.43
October 2012	1.21	0.97	−0.24	3.50	2.63	10.95	3.24	0.97	−0.24	3.50	2.63	10.95	3.24	0.40
November 2012	1.20	1.003	−0.19	3.65	2.67	12.02	3.16	1.003	−0.19	3.65	2.67	12.02	3.16	0.39
December 2012	1.12	1.09	−0.08	4.33	4.84	29.58	4.98	1.09	−0.08	4.33	4.84	29.58	4.98	0.58
January 2013	4.14	−0.19	2.92	2.82	9.41	3.11	0.53	1.13	−0.18	3.16	3.11	11.53	3.46	0.53

Table 4
Significance level of difference resulted from application of paired *t*-Test for studying the effect of study sand and gravel mines on the measured variables of suspended sediments.

Variable	Vaz-e-Owlya					Vaz-e-Sofla					Alesh-Roud				
	Significance Level	t	df	Standard Error Mean	Standard Deviation	Significance Level	t	df	Standard Error Mean	Standard Deviation	Significance Level	t	df	Standard Error Mean	Standard Deviation
D_{10} (mm)	0.87	0.16	11	0.20	1.53	0.97	−0.03	11	0.07	0.27	0.30	1.08	11	0.44	0.06
D_{50} (mm)	0.11	−1.70	11	2.53	8.44	0.51	0.67	11	0.31	1.08	0.42	0.82	11	2.43	0.73
D_{90} (mm)	0.15	−1.53	11	20.28	17.96	0.35	−0.96	11	168.23	582.87	0.24	1.22	11	5.18	5.85
Mean (mm)	0.12	−1.64	11	2.19	7.40	0.29	1.09	11	0.33	1.14	0.45	0.76	11	2.13	0.63
Sorting	0.28	−1.12	11	0.79	2.18	0.03	2.36	11	0.09	0.33	0.09	−1.83	11	0.62	0.22
Skewness	0.77	0.29	11	0.05	0.16	0.02	2.61	11	0.01	0.04	0.63	0.48	11	0.04	0.01
Kurtosis	0.18	1.41	11	0.08	0.72	0.69	−0.40	11	0.01	0.05	0.32	−1.02	11	0.20	0.02

Table 5
Significance level of different resulted from applying GLM test to study the difference of the mean value of measured variables of suspended sediments in difference seasons and study mines.

Variable	Statistic					
	Factor	Mean Square	df	Type III Sum of Squares	Significance level	F- Value
D_{10} (mm)	Season	0.80	1.27	1.02	0.62	0.33
	Mine	0.55	2	1.10	0.48	0.82
	Season × Mine	1.21	2.54	3.08	0.65	0.51
D_{50} (mm)	Season	26.46	1.24	32.92	0.53	0.50
	Mine	15.22	2	30.45	0.62	0.50
	Season × Mine	21.57	2.48	53.67	0.71	0.41
D_{90} (mm)	Season	225.94	1.44	326.30	0.50	0.62
	Mine	888.78	2	1777.56	0.14	2.66
	Season × Mine	115.78	2.88	334.42	0.80	0.32
Mean (mm)	Season	15.66	1.23	19.40	0.60	0.37
	Mine	15.64	2	31.28	0.51	0.73
	Season × Mine	17.94	2.47	44.46	0.70	0.42
Sorting	Season	2.50	2.42	6.06	0.14	2.16
	Mine	15.02	2	30.05	0.01	8.38
	Season × Mine	0.91	4.84	4.44	0.56	0.79
Skewness	Season	0.01	1.59	0.01	0.26	1.51
	Mine	0.02	2	0.04	0.20	2.07
	Season × Mine	0.01	3.19	0.04	0.21	1.79
Kurtosis	Season	0.10	1.83	0.18	0.56	0.57
	Mine	0.60	2	1.21	0.07	4.18
	Season × Mine	0.20	3.66	0.75	0.38	1.14

simultaneously taken from the immediate upstream and downstream sections of the study mines. Besides those, no changes has been reported in between of up and downstream of the study reaches except sand and gravel mining. So that, any changes in between could be simply attributed into mining activities. Therein to, the study mines were temporarily inactive.

Flow discharge and other soft information were also recorded before and after mines at the time of monthly samplings to ascertain no drastic change in transport capacity of the current. A homogenized volume of 120 cm^3 was then provided and appropriately prepared to be injected laser master sizer device of Malvern Instruments Ltd. Worcestershire-WR14 1XZ, UK, with ability to measure particle size with diagonal range of 0.055–878 μm (http://www.malvern.com). The GRADISTAT software package (Blott & Pye, 2001; Sadeghi & Zakeri, 2015) was then used to extract diffident granulometric components of the SS samples viz. mean, standard deviation, skewness, D_{10}, D_{50} and D_{90} stretched by graphical and geometric method of Folk and Ward and reported in Blott and Pye (2001). To investigate difference of the measured variables, and to assess the impact of gravel and sand mines in different months, seasons and rivers on the study factory of SS, the paired *t*-test and the general linear model (GLM) and repeated measures test (Elliott & Woodward, 2007) were applied. The entire statistical analyses were adopted in SPSS 19 software package and necessary conclusions ultimately were drawn.

3. Results and discussion

The results of granulometry in upstream and downstream cross sections of three study sand and gravel mines of the Vaz-e-Owlya, the Vaz-e-Sofla and the Alesh-Roud by laser device have been shown in Figs. 2 to 4. Variations of morphometric traits values of SS, which have been obtained from laser granulometry using GRADISTAT in upstream and downstream of the study mines during the research period, have also been summarized in Tables 1 to 5.

According to the results (Figs. 2 to 4), it is seen that all distribution curves are bimodal. The first portion can be attributed to organic matters containing colloids with diameter below one

Table 6
Downstream relative changes (%) in suspended sediments granulometric results of the Vaz-e-Owlya sand and gravel mine, Iran.

Month	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)
February 2012	1.76	9.38	18.32	32.98	45.17	37.43	2.33
March 2012	3.51	4.00	−16.71	−78.63	−106.93	−75.29	−55.93
April s, 2012	−6.60	−16.00	14.04	0.64	21.97	0.90	−10.91
May 2012	11.02	−44.44	−15.74	16.59	3.70	1.14	49.11
June 2012	−4.20	−3.57	4.18	−7.86	−1.12	−7.04	−14.55
July 2012	1.72	−16.67	0.00	−1.91	0.21	−3.57	0.00
August 2012	0.00	−5.88	12.60	20.90	33.48	21.36	2.86
September 2012	16.28	36.67	−44.38	−24.81	−116.38	−21.45	20.55
October 2012	−1.92	−52.38	−5.25	−23.35	−16.28	−37.35	3.77
November 2012	8.20	7.41	−37.62	−58.28	−133.29	−63.79	10.67
December 2012	4.08	27.78	−28.11	−102.82	−172.17	−87.39	−39.13
January 2013	−2.70	0.00	3.29	−4.44	0.17	−2.11	−9.62

Table 7
Downstream relative changes (%) in suspended sediments granulometric results of the Vaz-e-Sofla sand and gravel mine, Iran.

Month	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)
February 2012	5.43	11.76	−7.57	14.93	4.45	15.38	26.71
March 2012	−4.63	−52.63	15.37	29.14	45.85	22.68	20.31
April s, 2012	−0.85	−42.11	3.92	12.11	21.00	4.26	26.97
May 2012	−3.15	9.52	−5.67	−14.24	−23.21	−12.97	−7.50
June 2012	0.81	−5.88	9.83	−16.55	−1.31	−16.30	−59.41
July 2012	−5.13	−10.53	11.93	−9.01	10.60	−7.87	−40.68
August 2012	−10.28	−4.17	8.12	−23.69	−7.29	−18.15	−31.91
September 2012	2.33	−33.33	−1.81	9.53	11.13	1.77	28.57
October 2012	6.20	−4.00	6.98	5.29	9.96	2.02	−8.33
November 2012	2.70	−5.26	−3.17	8.20	4.67	5.23	12.70
December 2012	1.94	−47.06	12.09	21.82	37.11	16.33	11.11
January 2013	−4.31	−10.53	9.36	5.11	17.72	5.06	−16.46

Table 8
Downstream relative changes (%) in suspended sediments granulometric results of the Alesh-Roud sand and gravel mine, Iran.

Month	Kurtosis	Skewness	Sorting	Mean (μm)	D_{90} (μm)	D_{50} (μm)	D_{10} (μm)
February 2012	−16.35	72.41	−33.81	73.99	57.26	77.89	79.95
March 2012	Not detectable by laser fraction						
April s, 2012							
May 2012							
June 2012							
July 2012							
August 2012	13.39	125.77	1516.00	25.14	−321.89	70.75	87.77
September 2012	8.93	121.57	1672.73	17.34	−311.54	71.03	87.39
October 2012	19.83	124.74	1558.33	24.86	−316.35	70.41	87.65
November 2012	16.42	118.94	2021.05	26.85	−350.19	73.71	87.66
December 2012	2.68	107.34	5512.50	−11.78	−511.16	83.16	88.35
January 2013	72.71	5.26	−8.22	−10.28	−22.53	−11.25	0.00

micron and transported from the surface of upstream watershed of the forest region considering its diagonal. Accordingly, the second part with larger size is associated with watershed SS resulted from eroded soils (mineral soils), which have been either washed from the watershed surface or contributed from the manipulated areas and have arrived to the sampling points. Generally, it can be inferred that, a major part of the SS ($\geq 97\%$) is characterized as watershed or washed load. This finding is consistent with the results reported by Sadeghi and Zakeri (2015) about high percentage of washed load ($\geq 96\%$) in producing the sediment load of the Educational and Research Forest watershed of Tarbiat Modares University (Kojour) located very close to the study watersheds. At the downstream of the Vaz-e-Owlya mine in December 2012, the graph had an extra mode at end part that can be due to local removal of sand and gravels in the upstream of sampling season. At the downstream of the Vaz-e-Owlya, particle size distribution of SS in September, November and December 2012 and March 2012 extended towards coarser sediment. This is associated with intensification of mining activities especially in the river bed and increase of transport power (Sadeghi, Kheirfam et al., 2015) due to snow melting in upper areas of the study reach in March 2012. In June, July and January, particles size distribution curves in upstream and downstream sections are coincident. This can be exacerbated due to mining activities particularly in the river bed and changing the carrying capacity (Ashraf et al., 2011; Sadeghi, Kheirfam et al., 2015; Wyss et al., 2016). In addition, in April, May and August 2012, granulometic curves of SS for both the sections were almost coincident and followed the same trend due to falling loose and deep sidewalls of this cross section of the river triggered by rainfall or runoff made by snow melting as well as increasing mining activities despite of greater volumetric percentage of sediment after the mine.

Granulometric variations in the Vaz-e-Sofla mine were not considerable during the study period due to inactivity of the mine at the time of sampling. But, in the Alesh-Roud mine, SS particles distribution was finer in most of months except in January and December 2012. The reason was releasing finer particles due to eliminating armoring effect of coarser particles (Sadeghi & Kiani Harchegani, 2012; Sadeghi, Kheirfam et al., 2015; Wyss et al., 2016) as a result of mining and machinery activities. In addition, some conditions such as slope reduction (Karimnia & Bagloo, 2015), cross section broadening (Sindelar, Schobesberger, & Habersack, 2017) and pits creation caused to deposit coarser particles and transportation of finer particles from the upstream to the downstream section of the study mines. However, rainfall characteristics at monthly scale can be supposed as the dominant factor contributing temporal variation of SS size distribution through ascribing sediment sources from the upland areas. Similar findings have been reported by Sadeghi & Singh in connection with effects of climatic factors on designation of sediment sources in the States. Whilst, the effects of human manipulation such as mining in a very short distance in the study rivers has been reported by the present research as the dominant factor on the spatial variation of SS size distribution. The impact of time of sand and gravel mining on SS size distribution has also been separately discussed in each mine to avoid mixing the effect of rainfall temporal variation.

The results of analyses given in Tables 1 to 3 proved variability of SS traits in study mines and months. So that, D_{10} varied from 0.35 to 4.39, D_{50} from 2.93 to 24.87 and D_{90} from 9.41 to 63.94 μm. This is consistent with Williams et al. (2008) who similarly reported the high variability of particle size distribution of SS in Tweed and Humber Rivers in UK. According to the results, it also could be implied that most of fine SS was classified as wash load (≤ 63 μm) or organic matter induced mainly draining from the upper area of the study watersheds. Considering the above mentioned implication and variability of descriptive statistics of study variables, it was inferred that the upstream surface of the study watersheds was the main source of SS production (Sklar et al., 2017) during the study period as reported by Sadeghi and Kiani Harchegani (2012) and Sadeghi and Zakeri (2015) for neighboring Kojour watershed.

The mean particle size of SS samples varied between 2.41 and 20.95 μm. Besides that, sorting, skewness and Kurtosis were also tuned from 2.61 to 6.38, −0.08 to 0.32 and 0.88–1.31 μm, respectively. Mean particle size of SS of downstream section of the Vaz-e-Owlya was often greater than that for the upstream due to intensification of mining activities particularly in the river bed and increasing transportation power of the flow. It was more serious in December 2012 and March 2012 due to snow melting and contributing in runoff generation. Though, the difference was not statistically significant (Table 4). Mean particle size of the SS in downstream of the Vaz-e-Sofla and the Alesh-Roud mines showed a reduction compared to those of the upstream sections. It could be caused due to semi-heavy and heavy mining and creation of mining pits because of which coarser particles got deposited into the pits and finer particles have been washed out or released from armored coats (Orrú, Blom, Chavarrías, Ferrara, & Stecca, 2016). According to the results, the SS particles had a suitable sorting and therefore extended within a narrow range limited particle size range. According to the results represented in Tables 1 to 3, the SS particle were left skewed and had a small kurtosis due to the processes governed study mines and explained before.

The results of paired *t*-test of the data collected during the research period (Table 4) did not show any significant difference among measured variables of SS except the Vaz-e-Sofla mine and in case of sorting and skewness with respective level of significant of 0.03 and 0.02. However, the results of GLM test (Table 5) clearly verified the significant difference ($p < .01$) for sorting, kurtosis in the study mines. In addition, significant changes were recognized for sorting, skewness and D_{90} in season as well as D_{90} and D_{10} in mines ($p < .05$), and other variables at level of 10%. The kurtosis and skewness of the SS particles were also significantly ($p < .05$) influenced by combined effect of season and mine. However, contemplation in sorting data of SS approved the lack of significant difference among study variables at downstream sections and upstream of the mines, which also proved impressibility of the variables due to mining activities. Scrutinizing values of significant levels implied different effectiveness of mining activities on sorting, D_{50}, mean, D_{90}, kurtosis, skewness and D_{10} of SS particles with respective level of significant of 0.09, 0.11, 0.12, 0.15–0.69, 0.77, 0.87 and 0.97. Discontinuing mining activities and consequently lack of long-time influence of the interference resulted from mining the gravel and sand mines (Hagos, Sisay, Alem, Niguse, & Mekonen, 2016) were found as the major cause of the lack of significant difference among the study components ($0.07 < P < .97$). It is consistent with Sadeghi and Zakeri (2015) in Kojour watershed with similar general conditions. Also, distance of sampling places from the study mines and effectiveness of mines extraction in limited distance (Jiménez-Moreno et al., 2016) also could be attributed as another main reason of the lack of significant difference between two sections of each study rivers.

Despite reporting no significant statistical differences (Tables 4, 5), the relative changes between the SS granulometric properties in up and downstream of the study mines were calculated whose results have been given in Tables 6 to 8. The results of Tables 6 to 8 showed that the relative changes of SS granulometric properties in the downstream were considerable enough to distinct the significant effect of mining. For instance, relative changes in D_{10} between up and downstream in the Vaz-e-Owlya mine due to mining activities varied from −55.93 (March 2012) to +49.11% (May 2012). Though no differences was statistically proved between most studied variables of SS size distribution in up and downstream of the mines due to the nature and quiddity of the granulometric data.

4. Conclusions

Our observation and results somewhat demystified the effects of different types, levels and times of sand and gravel mining activity on particle size distribution of SS. From the results, it can be concluded that the type and times of mining could significantly affect study variables at different mining levels. However, there was not found significant difference between the particle size distribution in up and downstream of mines due to monitoring situations of low flow discharge, manner of mining and obstacle mining activities and even governing climatic and hydrologic conditions. By and large, it could be obviously concluded that the type and level of mining have affected particles size distribution of SS among three study mines. However, the differences between morphometric characteristics of the SS of up and downstream of the study mines were not statistically significant. Our findings can be accordingly used for watersheds modeling and river mining manages. Though, broader researches with longer period and real time monitoring are needed to allow drawing comprehensive conclusion.

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Conflict of interest

The authors have declared no conflict of interest.

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