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Estimation of Stormwise Sediment Yield of Gully Erosion Using Important Rainfall Components in Different Land Uses of Zagros Forest, Iran

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Abstract. Erosion is one of the important social-economic problems in Iranian catchments that have been posed by surface water vastness and runoff production. So, the study of water resources, soil erosion and effective factors is of high importance. Gully erosion also extends in many parts of Iran and its study particularly in viewpoint of sediment yield is therefore very important and should be taken into account. In order to investigate the relationships between sediment yield of gully erosion and rainfall parameters such as amount, intensity and duration of them, the present study was conducted in Alashtar, Lorestan province, Iran. For this purpose, 18 digitalized linear and frontal gullies have been identified and morphological characteristics of the gullies were specified at the beginning and after five Storm Runoff productions in November 2007 to May 2008. Then, using matrix correlation and regression analysis, the most effective factor in the sedimentation of Gully erosion was determined. The results have showed that the most important climatic factors that can be pointed out with respect to the sedimentation of gullies were the maximum and average rainfall intensities. Results of regression analysis have also indicated that the maximum intensity of rainfall is the most important factor in the study area and has the ability to estimate sediment and erosion rates caused by the storms with the coefficient of determination as ($R^2=0.91$) and the standard error value of 18.8.

Introduction

Gully erosion of sediment production is more important than surface erosion so that the problems in the area of erosion create 50 times more sediment productions (Sundquist, 2000).

This type of erosion limits the land uses and can be a threat for the roads, buildings and agricultural lands (Zare Mehrjerdi *et al.,* 2006). According to Morgan (2000), gully is a relatively constant stream with vertical or inclined walls that may pass the temporary flow resulted from storm.

Considering the importance of gully erosion in the world, several important studies have been conducted worldwide. Bufalo and Nahon (1992) have studied the sedimentation process in three gullies in badland areas in France. They reported the annual precipitation and soil loss about 840 mm and 190 ton ha^{-1} and provided an equation to estimate the amount of sediment production on the basis of effective kinetic energy.

In another study done by Schmitt *et al.* (2006) concerning the gullies' losses in the south-east of Poland, it has been concluded that soil has been severely eroded during heavy rainfall and the huge amount of sediment has been accumulated in the gully areas and gully erosion has been developed because of the uncontrolled harvesting of iron and glass in these areas.

One of the most important characteristics of rainfall with respect to the soil erosion is rain erosivity (R), a factor that was introduced by Wishmeier and Smith (1978) and Capra *et al.* (2009). Cumulative 24-hour, 3-days and 5-days precipitation rates were introduced as the effective factors on soil erosion (Capra *et al.*, 2009). Their results in Italy indicated a close relationship between gully erosion and storm characteristics. They presented a rainfall threshold equal to 51 mm for a three-day rainfall event for the formation and development of gully in the semi-arid regions of Italy. It was determined that the average sediment production rate by the gullies was about 420 m^3 per year for an

annual precipitation rate of 415 mm. Gully formation and development in the semi-arid regions often occur in a single event due to high soil moisture and minimum vegetation cover (45%) at the time of precipitation (Capra *et al.*, 2009).

Vegetation cover can improve some physical-chemical parameters of the soil through both physical protection of the soil surface and the contribution of organic matter from the plant canopy and root system (Ruiz-Colmenere *et al*., 2013) as well as the increased structural stability of soil due to the increase in soil organic carbon and aggregation of it (Verchot *et al*., 2011). Vegetation cover also affects the soil water balance by promoting the formation of biological-produced macro-pores and improving structural stability of soil. Vegetation cover also increases the plant-derived carbon that may be essential to restore the degraded soils (Thomaz and Vestena, 2012). A number of studies have demonstrated a direct relationship between vegetation cover and soil water storage through the reduced evaporation and increased infiltration resulting from the increased vertical porosity created by the root of perennial plants (Novera *et al*., 2011).

In Iran, some extensive studies on factors affecting the ravine erosion were done in Bandar Genave (Rahi, 1998), Khouzestan Provinve (Tabatabaei, 2000), Fars Province (Samadnejhad, 2002), some parts of Zayandeh Rood Watershed (Sadeghi *et al.,* 2005b), Ghom Province (Gherli *et al.*, 2005) and Ilam Province (Nourmohammadi, 2007) but there has been no special study to determine major rainfall factors associated with the sedimentation of gully erosion during the storms.

The only study about the important rainfall characteristics of sediment production resulting from gully erosion in Darehshahr region has been done by Sadeghi *et al.* (2008) and their results have showed that time of precipitation is the

most important factor for the gully sedimentation.

Cheshmeh Sardeh region in Alashtar province, Lorestan has gully erosion features and its special erosion was estimated about 12.46 ton ha^{-1} y^{-1}. The aim of this study was to determine the roles of the main parameters of storms playing in the sedimentation of gully erosion.

Materials and Methods
Case study

Case study is a part of Alashtar region in Lorestan province, a western part in Iran located in N 33° 44' 01.06″ to 33° 44' 46.28″ and E 48° 11' 54.95″ to 48° 14' 03.36″ and its area is 2,040 ha and maximum and minimum altitudes are 3,500 and 1500 m above sea level. The case study and the distribution of the Gullies are shown in (Fig. 1).
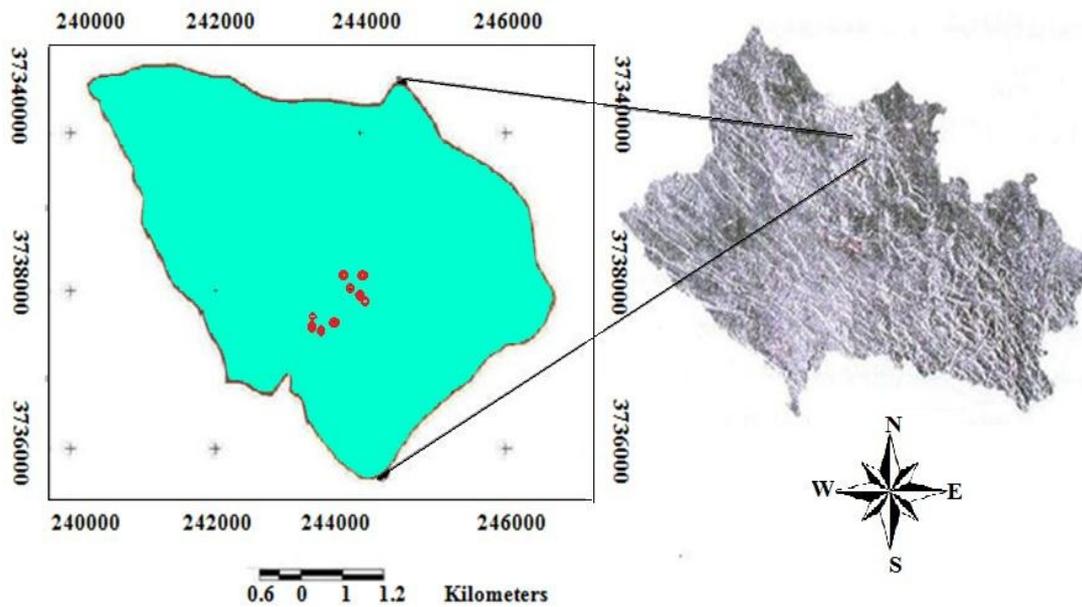

Fig. 1. Case study in Cheshmeh Sarde region, Lorestan province

Kashkan watershed is located in a part of Karkhe watershed with the annual precipitation rate of 554 mm that the maximum and minimum monthly rainfall rates computed as 99.11 and 0.16mm in the city have been observed in March and September, respectively. In general, much of annual rainfall (86%) occurs in Cheshmaeh Sardeh watershed, Alashtar during December-April. The mean annual temperature is 8.8°C in the Cheshmeh Sardeh. Maximum and minimum monthly rates in this city have been estimated as 3.20 and -4°C in August and February. In terms of tectonics, the geological structure of the region follows Zagros zone's structure. Total area of Cheshmeh Sardeh is 2040 ha while consisting of pastures, agricultural and forest areas as 421, 1222 and 397 ha, respectively (Agriculture

Office of Lorestan Province, 2005). Forests of the region according to national classification of forests is a semi-arid forest of Zagros. Forest vegetation types in the area are *Quercus brantii* and *Quercus brantii − Acer monspessulanum − Pyrus glabra*. with the type species of *Pistacia atlantica*, *Crataegus aronia*, *Amygdalus lycioides*, *Amygdalus haussknechtii* and *Astragalus spp*. Generally pasture species such as *Astragalus spp* and *Daphne mucronata* in the main areas and the species such as *Acantholimon sp*. and *Amygdalus sp*. have been developed in high lands (Agriculture Office of Lorestan Province, 2005).

Research Methodology

In order to study the sediment production resulting from storm events in the gullied regions of Lorestan province, spatial distribution of the gullies was determined by the experienced experts using the aerial photos on a scale of 1:40000. From this analysis, gullies were selected for a fieldwork that involved their monitoring and measurement. The gullies that had typical characteristics for climate, geological formation, vegetation and soil for each region were selected. Gullies were also selected with regard to their shape (Sadeghi *et al.*, 2008); in total, there were 18 gullies. For each gully, three sections from the upper, middle and lower parts of the channel at the distances of 1 and 2 m were determined. The sections were marked with wooden pegs on both sides (Ries Alves and Rodriguez, 2005). Different morphological factors of gullies were identified including upper and lower width, depth, distance between sections, head cut height, distance of head cut, gully length, and slope of banks which were measured using a thread scaled with 25 cm intervals tied to wooden pegs. The factors were measured for each gully before the rainfall in the questionnaires. These parameters were measured after each rainstorm. Each cross section was depicted and calculated using AutoCAD version 14. The next stage was a calculation of the difference of areas; it was calculated in Excel version, 2003 and multiplied to the length between the cross sections to compute the volume of gully erosion in each rainstorm (Fig. 2).

Rainfall characteristics of the research site were determined using the recorded data and the automatic rain gauges in Alashtar city (Table 2). The variables that were used in this study include amount and intensity of precipitation and maximum and mean rainfall intensities. The maximum and mean intensities and also precipitation rate were provided using cumulative rainfall curves. The duration of precipitation has been obtained using rain

fall graphs (Alizadeh, 1999). In the analysis of the relationships between climatic factors and gully erosion, the correlation matrix, regression analysis and the estimated error were used to reduce the variables, relationships and performance of models (Sadeghi *et al.*, 2005a).
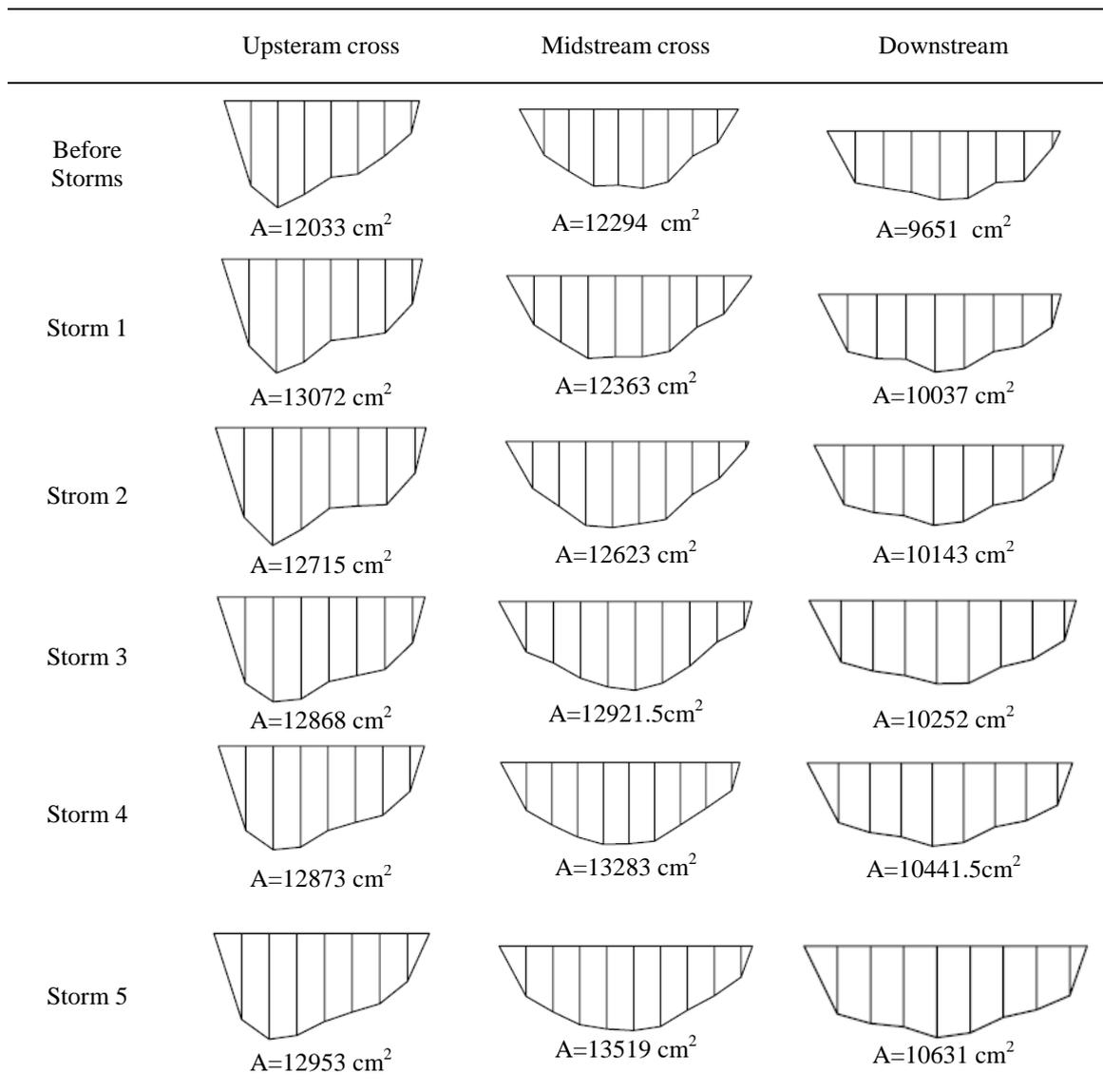
	Upsteram cross	Midstream cross	Downstream
Before Storms	A=12033 cm^2	A=12294 cm^2	A=9651 cm^2
Storm 1	A=13072 cm^2	A=12363 cm^2	A=10037 cm^2
Strom 2	A=12715 cm^2	A=12623 cm^2	A=10143 cm^2
Storm 3	A=12868 cm^2	A=12921.5cm^2	A=10252 cm^2
Storm 4	A=12873 cm^2	A=13283 cm^2	A=10441.5cm^2
Storm 5	A=12953 cm^2	A=13519 cm^2	A=10631 cm^2

Fig. 2. An example of the measured sections of gully (number 8) before and after storms

Results

Gullies of this watershed were formed in a semi-arid climatic zone and land uses including cropland, forest and rangeland. Gullies in the rangeland and forest were mostly located in hilly areas with the slopes higher than 10% while the gullies in croplands were located in the alluvial plain with the slopes between 2 and 5%. All the gullies were located on Marl and Quaternary formations (Table 1). Average gully developments for linear and digitized gullies were 0.091 and 0.024 m^{2}m^{-3}, respectively (Table 3). Maximum gully development occurred in the second and first rainstorms, respectively and the rate of development was decreased in the subsequent storms (Table 3).

In order to analyze the roles of rainfall parameters in sediment production by gullies, only five storms were investigated during the study period in November 2007 to May 2008 that may lead to the production of runoff and sediment transport. (Table 2), summarizes the information recorded in the storms and also sediment production volume of each gully during each storm is presented in (Table 3).

Table 1. Charetristics of gullies measured in Cheshmeh Sarde watershed

Gully	Type	Drainage Area(ha)	Slope (%)	Land Use	Formation	Length (m)
1	Linear	0.12	5	Agriculture	Quaternery	7
2	Linear	0.04	7	Range	Quaternery	6.7
3	digitated	0.168	22	Range	Quaternery	3.5
4	digitated	0.58	19	Range	Marl	3.2
5	Linear	0.042	14	Forest	Marl	3.3
6	Linear	0.006	22	Forest	Marl	2.5
7	Linear	0.001	15	Forest	Marl	6
8	Linear	0.001	14	Forest	Marl	5
9	Linear	0.001	12	Forest	Marl	5.3
10	Linear	0.062	15	Forest	Marl	2.8
11	Linear	0.12	9	Forest	Marl	8
12	Linear	0.075	21	Range	Marl	6
13	Linear	0.052	12.5	Range	Marl	5.18
14	digitated	0.52	5	Agriculture	Marl	5.08
15	Linear	0.25	2	Agriculture	Marl	2.32
16	Linear	0.012	6	Agriculture	Marl	9.3
17	Linear	0.46	4	Agriculture	Marl	5.85
18	Linear	0.22	3	Agriculture	Marl	4

Table 2. Charactristics of storms ocurred in November 2007 to May 2008 in Cheshmeh Sarde watershed, Lorestan Province

Storm	Year	Date of Percipitation	Amount (mm)	Duration (hr)	Average Intensity (mm hr^{-1})	Maximum Intensity (mm hr^{-1})
1	2007	November 20 to 23	40	22.09	1.81	5.25
2	2007	December 5 to 8	79	30.29	2.6	4.24
3	2008	February 27	38	21.42	1.77	3.22
4	2008	April 7 to 9	5	1.68	2.97	3.5
5	2008	May 9 to 10	5.9	2.04	2.89	3.19

Table 3. Spatial erosion rate for each gully (m^2 m^{-3}) per each storm

Gully	Storm 1	Storm 2	Storm 3	Storm 4	Storm 5
1	0.043935	-0.00403	0.10165	0.0161	0.01331
2	0.045539	0.02237	-0.00863	0.02854	0.01531
3	0.083854	0.015501	-0.01961	0.01788	0.00977
4	0.045032	0.02885	-0.3766	0.017882	0.00977
5	0.064618	0.01251	0.03672	0.008253	0.0139
6	0.013724	0.012447	0.00165	0.004964	0.00207
7	0.017478	0.034783	-0.00372	0.01044	0.0072
8	0.027541	0.003845	0.016434	0.01156	0.015368
9	0.011427	0.019987	-0.00781	0.01252	0.004187
10	0.016148	0.019987	0.00053	0.014873	0.004631
11	0.016132	-0.01825	0.03638	0.008	-0.02405
12	0.02523	0.01841	0.0049	0.006856	0.011124
13	0.02007	0.02043	0.00218	0.01065	0.01366
14	0.022839	0.034907	0.00417	0.01513	0.01747
15	0.091685	0.018357	0.03078	0.0026	0.007235
16	0.038653	0.008986	0.01685	0.01715	0.01855
17	0.12875	0.030274	-0.01297	0.03424	0.01546
18	0.003048	0.01543	0.00162	0.01001	0.003382
SUM	0.715703	0.294794	-0.17548	0.247648	0.158347

The changes happened in the gully 8 during five storms are presented in (Fig. 2). Correlation matrix between various parameters of storms and sedimentation are given in Table 4. As the correlation matrix table shows, the most important rainfall factor that affected the sedimentation resulting from gullies was maximum and average intensities of percipitaion in the study area.

Table 4. Correlation matrix between varous parameters of storms and sediment yield

Storm gully	Intensity(mm h⁻¹)		Duration (Min)	Amount (mm)
	Maximum	Average		
1	-0.163	-0.794	0.200	-0.056
2	0.789*	0.130	-0.021	0.013
3	0.902*	-0.226	0.146	0.081
4	0.487	0.558	-0.202	-0.039
5	0.667*	-0.878*	0.423	0.182
6	0.939**	-0.231	0.632	0.660*
7	0.601*	0.239	0.496	0.678
8	0.441	-0.616	-0.070	-0.317
9	0.554	0.453	0.175	0.37
10	0.712*	0.101	0.412	0.517
11	0.058	-0.749	0.205	-0.042
12	0.898*	0.102	0.381	0.413
13	0.756*	0.177	0.397	0.418
14	0.592	0.280	0.425	0.610*
15	0.500	0.900*	0.700*	0.7
16	0.665*	-0.528	0.000	0.203
17	0.921**	0.292	0.194	-0.113
18	0.123	0.541	0.244	0.488

* and **=significance at probability levels of 5% and 1%

Results of regression analysis of relationships between the independent variables of rainfall and the volume of sediment produced in gullies were assesed and the only result obtained by stepwise method was established with the respective coefficient of determination and the estandard error as 0.91 and 0. 18.8, respectively (Equation 1).

$V = -0.039 + 0.015X$ $R^2 = 0.91$ RE= 18.8% (Equation 1)

V is volume of sediment production (cm^3) and X is the maximum intensity of rainfall ($mm.hr^{-1}$).

Discussion

Total rainfall factors were studied during this research and according to the results of correlation matrix, maximum intensity has more importance for Gully erosion in the region (Equation 1). According to the recorded storms, the minimum amount of rainfall to begin runoff and sediment production during the study opportunities (November 2007 to May 2008) was 5 mm that is not in agreement with the declared value about 7.9 mm by Sadeghi *et al.* (2008) for the initiating the runoff in Darehshahr city of Ilam Province. This difference was due to poor vegetation and greater soil sensitivity in the study area.

The results showed that among the various factors of rainfall, maximum rainfall intensity had the highest correlation with the gully erosion and the minimum intensity necessary to begin runoff and erosion was 3.19 ($mm.hr^{-1}$) during the study peiod. In addition, the lowest amount of rainfall to produce the runoff and erosion according to the recorded storms was 5 mm andMaximum rainfall intensity of this storm was 3.5 mm hr^{-1} during the study period while the erosion caused by it was much more than the storm with 38 mm percipitation (maximum intensity: 3.22 $mm.hr^{-1}$). The results have indicated that the maximum rainfall intensity had an important role in the sediment production of gully erosion in this area as the storm with the low amount and high maximum intensity can produce much sediment as compared with the storm with high amount, long duration and low intensity. The maximum gully development occurred in the first and second rain storms (Table 3). This result supports the research results of Capra *et al.* (2009) which demonstrated the maximum sediment that occurred from the first rainstorms in the semi-arid regions. Rainfall intensity recorded in Cheshmeh Sardeh (2.4 $mm.hr^{-1}$) was not similar to the

result obtained by Capra *et al.* (2009) in a research in Italy with an intensity of 0.7 $(mm.hr^{-1})$.

Moreover, the results showed that the maximum amount of gully erosion has occurred by storms with the average intensity about 3.19 mm hr^{-1} that is in agreement with the results reported by Sadeghi *et al.* (2008) and Valcarcel *et al.* (2005) about the role of the storms with low intensities in the initiation of ephemeral gullies in the agricultural lands in Spain while Rahi (1998) explained that the 90% of the storms that occurred in gullies' area in Bandar Genaveh had more than 10 $(mm.hr^{-1})$. On the other hand, Samadnejhad (2002) showed that 91% of gullies in Fars Province have occurred in the area with the intensity of 42 to 60 mm hr^{-1}. Resultes obtaianed from this study also has no agreement with those presented by Rose (Alizadeh, 1999) that explained that 68% of soil losses during the storms with the intensity about 15 to 60 $(mm.hr^{-1})$ may be a good reason for different responses of watersheds under the same conditions. The results of this study also have a good agreement with those reported by Valcarcel *et al.* (2005) who claim that ephemeral gullies were formed in the seasons with low intensity by tillage in the agricultural lands in Spain. In addition, the gullies that were linear in Cheshmeh Sarde watershed and formed on quaternary formation have a gradient ftom 5 to 22% and had more sediment.

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چکیده. مساله فرسایش در حوزه‌های آبخیز ایران به دلیل هدر رفت آب‌های سطحی از موضوعات مهم اقتصادی و اجتماعی کشور محسوب می‌شود. از این رو مطالعه منابع آب، فرسایش خاک و عوامل موثر بر آنها و پیامدهای مربوطه از اهمیت زیادی برخوردار است. فرسایش آبکندی در ایران به دلیل شرایط مختلف حاکم بر نقاط متفاوت، گستره زیادی را به خود اختصاص داده و لذا مطالعه ویژگی‌های مختلف آن و خصوصاً تولید رسوب ناشی از آنها در آبخیزهای مرتعی به عنوان یکی از معمول ترین کاربری‌های اراضی در کشور بسیار مهم است. در این تحقیق با توجّه به اهمیت فرسایش آبکندی در شهرستان الشتر واقع در استان لرستان، رابطه بین رسوب دهی فرسایش آبکندی و خصوصیات مختلف زودیافت بارش شامل مقدار، شدت و مدت مورد بررسی قرار گرفت. برای این منظور ۱۸ آبکند خطی، پنجه‌ای و جبهه‌ای شناسایی و خصوصیات مورفومتریک آنها در قبل و بعد از ۵ رگبار منجر به تولید رواناب از آبان ۱۳۸۶ تا اردیبهشت ۱۳۸۷ اندازه‌گیری و ثبت گردید. سپس با استفاده از ماتریس همبستگی و آنالیز رگرسیون مهمترین فاکتورهای موثر بر تولید رسوب آبکندها تعیین شد. نتایج نشان داد که از مهمترین عوامل اقلیمی موثر در تولید رسوب آبکندها، شدت حداکثر بارندگی بوده است. نتایج تحلیل رگرسیون نیز نشان داد که شدت حداکثر بارش، مهمترین عامل موثر در منطقه مورد مطالعه بوده و توانایی تخمین رسوب ناشی از فرسایش آبکندی را با ضریب تبیین ۰/۹۱ و خطای استاندارد ۱۸/۸ درصد دارا می‌باشد.

کلمات کلیدی: فرسایش آبکندی، تولید رسوب، عوامل موثر، چشمه سرده