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Study of the Temporal Distribution Pattern of Rainfall Effect on Runoff and Sediment Generation Using Rain Simulator (Case Study: Alvand Basin)

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Abstract: One of the important and effective, but ignored variables on runoff and sediment generation is the temporal distribution pattern of rainfall. In this research, initially temporal rainfall variability patterns were determined in Alvand Watershed (located in the realm of cities of Ghasr-e-shirin and Gilan-e-qharb from Kermanshah province environs using pilgrim's average variability or ranking method. After determining and comparing local patterns with the American soil conservation service(SCS) type patterns, the effect of One hour, first quartile pattern on generation of runoff and sediment is examined for formations of Fars Group(Agajari, Mishan and Gachsaran). Based on the results, groups of continuous 1-3 hours and 3-6 hours storms displayed fourth and first quartile patterns, respectively and first quartile pattern being determined for total precipitation with various temporal bases. Comparing regional patterns with SCS type patterns showed no similarities among them. Then 1-hour storm with first quartile pattern on formations of Fars group was simulated using a non-pressure rain simulator, with the same conditions in terms of slope, direction, plant cover, Antecedent Moisture Condition (A.M.C) and Land use. Data obtained from the results of these simulations was analyzed using appropriate statistical distributions. Comparing the effect of temporal pattern within formations showed that correlations between variables of sediment, runoff, as well as runoff coefficient change as the rainfall patterns change within all formations, confirming the effect of temporal pattern on generation of runoff and sediment within formations. Overall result of these tests shows that Mishan marl has more sensitivity to the temporal pattern.

Key words: Rainfall · Temporal pattern · Runoff and Sediment Generation · Alvand-Fars group

INTRODUCTION

Soil erosion is one of the problem and phenomena caused by human's improper and irrational interferences with nature. The first step taken to combat erosion is to study and estimate the type and rate of erosion in watershed which is made possible with the help of field data and experimental model.

Considering complexity of nature, many different variables are involved in erosion quantity and quality. One of the most important of which is precipitation. From the water erosion point of view, rainfall is the most important and major type of precipitation. Temporal rainfall distribution is one of significant features of rainfall affecting the quantity and quality of erosion, unfortunately attracted less attention. Temporal rainfall distribution means the amount of rainfall volume per temporal periods of precipitation [1]. To study the effect of this factor on generation of runoff and sediment, it is initially necessary to determine the pattern of temporal rainfall distribution within studied region, then to simulate rainfall patterns determined on the soil of that region. This task can be done by using rainfall simulator device. With the aim of evaluating the effect of temporal rainfall distribution pattern on generation of runoff and sediment, this research seeks to get answers to following questions:

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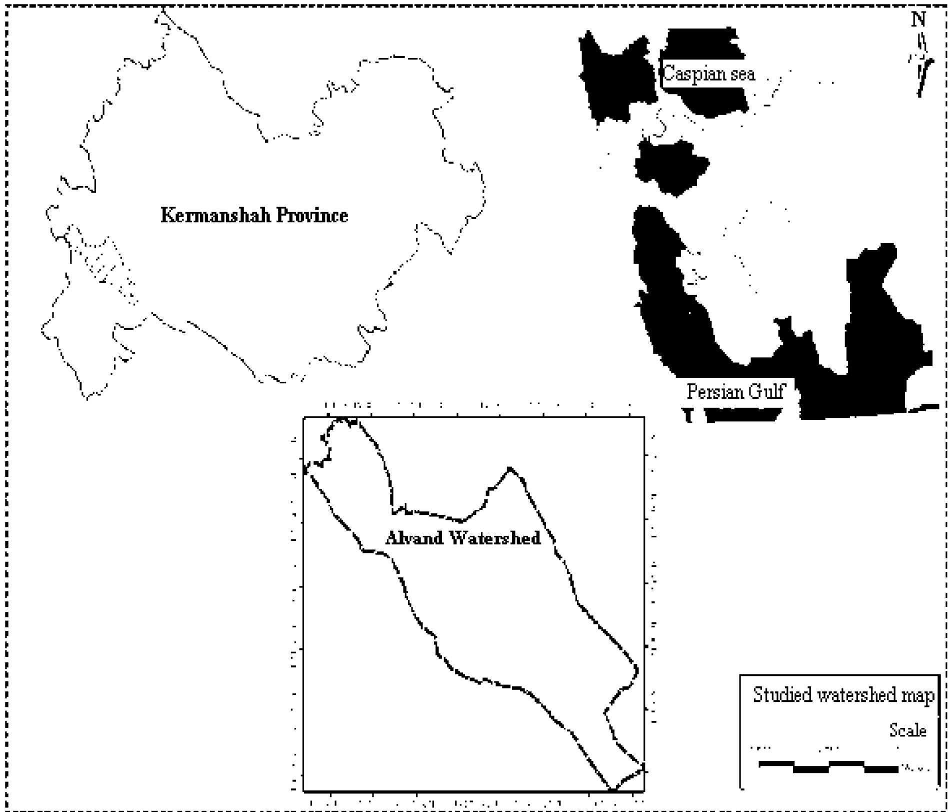

Fig. 1: Alvand Watershed

- What is the temporal distribution pattern of rainfall like in the studied region? Does this pattern match those of type SCS?
- How dose rainfall pattern affect the generation of runoff and sediment within Fars group formations?

The study area is located in the realm of cities of Ghasr-e-shirin and Gilan-e-qharb from Kermanshah province of Iran (Fig. 1). There are all formations of Fars group (Agajari, Mishan and Gachsaran) in this basin.

In the field of research done, following items can be referred to determining temporal distribution pattern.

Telvari *et al*. [2], for northern part of country have determined temporal rainfall patterns using different descriptive and computational methods. Numerous studies have been performed around the world in the field of determining temporal pattern of rainfall distribution and researchers have attempted to determine such patterns by using different methods like Huffs and pilgrim's methods. Most performed studies had the aim of determining regional pattern and comparing it with SCS type pattern and referred to here in the field of using rain-simulators for natural resources research. Moloodi [2]; Mohammadzadeh [2]; Sheklabadi, Khademi and Charkhabi, Sharifi, Saffarpur, Vakili and Ayyoobzadeh [2]; Razavi, Raissiyan, Sadeghi and Razavi on Karoon and Zayanderood basins [2]; and finally, research project under heading of comparing runoff and sediment rate within Lahbari formation in sub-basin "Golalmort" by using rain-simulator performed by experts from the watershed management research center of Khuzestan province [3],1998. Many studies have been done about the effect of rainfall intensity on runoff and sediment generation. Orsham [3] has studied runoff and sediment on different geological formations within Abulfaress watershed, Ramhormoz, Khuzestan, using rain-simulator. He has done simulations of ten-minute storms on Agajari and Mishan formations for the 2.5%, 7.5%, 15% and 30% slopes and concluded that Mishan formation has less permeability but more erodibility than Agajari formation dose.

Heshmati [4] has studied marl formations in Ghasr-e shirin and Naftshahr in terms of geology and erosion. He has concluded that Agajari, Gachsaran and Pabadeh (marl formations) fall in high erodible class; and formations of Asmari, classic part of Imam-hassan from Gourpey formation fall in low-to-medium erodible class. Haeri [5] has classified stones of Kermanshah province, in terms of erodibility, into 10 classes, with class 1 having the loosest lithology and class 10 having the most stiff or permanent lithology.

In present research, formations of Agajari and Mishan fall in erodible class 6 and formation of Gachsaran in class 7.

MATERIALS AND METHODS

In the first phase of this research, temporal rainfall distribution patterns were defined for continuous 1-3, 3-6 and 6-12 hours groups using Pilgrim's average variability or Ranking method. Also all continuous groups were determined and compared with type SCS patterns. After determining regional temporal rainfall distribution patterns, in the second phase of research, 1-hour storms with 1st-quartile pattern were simulated on under study formations using a rain simulator.

Pilgrim's Average Variability Method: Pilgrim's and his coworkers' *descriptive method* was based on dimensionless cumulative curves, but because this method was not a suitable and actual indication of all storms, they introduced another method, means *Average variability* or *Ranking method* by which they extracted temporal rainfall distribution patterns of storms with various durations for Sidney pluviograph station. This method is based on breaking down heavy rainfalls into rainfall blocks or segments and counting the occurrence frequency of the biggest segment of rainfall in different temporal states during rainfall period of time. This task is done repeatedly for remaining blocks and the mean of occurrence frequency of varied blocks or segments during rainfall period is defined eventually. During the last phase, temporal rainfall distribution pattern is obtained [6].

Table 1 presents, using Pilgrim's average variability method, temporal distribution patterns of studied watershed storms with 1-3h duration.

The Effect of Temporal Pattern on Generation of Runoff and Sediment Within Formations: In this phase, the degree of correlation between measured amounts of *runoff coefficient*, *runoff amount* and *sediment* was examined separately for each variable and each formation with considering the pattern of temporal rainfall distribution and without considering this pattern states at 0.01 or 0.05 level of significance.

RESULTS

Determining the Regional Temporal Distribution Patterns: As observed on the last row of the Table 1, temporal distribution patterns of 1-3h storms in Alvand watershed are represented, respectively, as follows:

4th-quartile events with 48.34%; 2nd-quartile with 27.88%; 3rd-quartile with 15.94%; and 1st-quartile with 8.13%. In other words, 1-3h events within basin are of the type of fourth quartile, thus the highest volume of 1-3-hour duration storms occurs within fourth quartile or fourth 25% of storm duration.

Storms with different durations are of the first-quartile type and 45.49% of total precipitation volumes with different temporal bases occur in the first quartile or 25% of events duration followed by second (28.19%),third (17.35%),and fourth(8.81%) quartiles, respectively.

Comparing Regional Temporal Distribution Patterns with SCS Type Patterns: The U.S.A. soil conservation service has provided some patterns for suburbs and urban areas in some parts of this country known as I, Ia, II and III [7]. These patterns have been designed and extracted on the basis of data on rainfalls in certain parts, so it is obvious that using them for other parts without being studied results in an increase in the rates of error and risk [8]. In Iran, using type patterns by users is partly justified due to not studying temporal rainfall distribution pattern in many watersheds, but the truth is that using such regional and local meteorological patterns and behaviors for other parts and with no study, has no scientific justification at all, unless they are compared carefully with regionally existing patterns before being applied, then in the case of pattern agreement with regional conditions and patterns they can be applied carefully and cautiously. With this aim, present research compares 24-hours rainfall pattern for studied region with that for 4-fold SCS types shown in Table 3.

Rainstorms Simulation: After determining regional temporal rainfall distribution pattern, because of limitations of water supply, costs and time, just 1 hour events over Fars group formations were simulated using a non-pressure rain simulator. Test plots were chosen on their size equal to 1m^2. Simulations with 3 repetitions were done on each formation twice, once with considering temporal rainfall pattern (first quartile) and once without considering it.

Table 1: Method of Average Variability for 1-3 hours storms in Alvand watershed

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Rain (mm)	*Rank*	*Rain in each period(mm)*				*Rank of each period's rainfall period*				*% of rain in period of each rank*			
28	1	0.8	8.1	18.1	1	4	2	1	3	65	29	4	3
10.7	2	0.8	3.05	2.9	3.95	4	2	3	1	37	29	27	7
8.1	3	1.5	3.5	0.3	2.8	3	1	4	2	43	35	19	4
9.3	4	1.75	3.05	1.6	2.9	3	1	4	2	33	31	19	17
11	5	2.7	0.3	0.3	7.7	2	3	3	1	70	25	3	3
8.8	6	3.2	2.65	0.75	2.2	1	2	4	3	36	30	25	9
10	7	0.3	0.4	2.85	6.45	4	3	2	1	65	29	4	3
4.8	8	0.65	2.15	0.4	1.6	3	1	4	2	45	33	14	8
27.1	9	6.85	4.8	2.35	13	2	3	4	1	48	25	18	9
14	10	0.5	6.2	4.7	2.6	4	1	2	3	44	34	19	4
12.5	11	3.3	1.3	4.65	3.25	2	4	1	3	37	26	26	10
22.5	12	13.3	1.75	1.5	5.95	1	3	4	2	59	26	8	7
6.4	13	1.2	3.8	0.45	0.95	2	1	4	3	59	19	15	7
18.9	14	4	2.8	4.1	8	3	4	2	1	42	22	21	15
13.8	15	1.95	2.80	6.1	2.95	4	3	1	2	44	21	20	14
9.6	16	0.95	1.2	3.05	4.4	4	3	2	1	46	32	13	10
		Average				2.8	2.31	2.81	1.94	48.3	27.8	15.9	813
		Standard Deviation				1.09	1.08	1.22	0.85	11.58	4.72	7.78	436
		Assigned Rank				4	2	3	1				
		Period				1	2	3	4				
		Final pattern (% of total rainfall)				8.13	27.88	15.94	48.34				

Table 2: Method of Average Variability for studied storms in Alvand watershed

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*
Rain (mm)	*Rank*	*Rain in each period(mm)*				*Rank of each period's rainfall period*				*% of rain in period of each rank*			
19	1	7.8	6	2.65	2.55	1	2	3	4	41.05	31.58	13.59	13.42
28.2	2	9.3	9.6	6.7	2.6	2	1	3	4	34.04	32.98	23.76	9.22
32.9	3	13.6	15.1	2.55	1.65	2	1	4	3	45.90	41.34	7.75	5.02
20.6	4	8.25	3.35	2.8	6.2	1	3	4	2	40.05	30.10	16.26	13.59
17.1	5	5.5	4.8	1.3	5.5	1	2	3	1	32.16	32.16	28.07	7.60
15.9	6	2.7	5.15	3.75	4.3	4	1	3	2	32.39	27.04	23.58	16.98
16.2	7	4.05	1.35	6.6	4.2	3	4	1	2	40.74	25.93	25.00	8.33
33.6	8	1.8	9.4	13.85	8.55	4	2	1	3	41.22	27.98	25.45	5.36
20.4	9	1.5	2.8	10.1	6	4	3	1	2	49.51	29.41	13.73	7.35
13.2	10	9.3	0.1	1.75	2.05	1	4	3	2	65.33	13.67	12.67	8.33
30	11	4.1	3.8	2.5	19.6	2	3	4	1	65.23	12.46	8.76	6.95
31.2	12	2.45	5.7	18.8	4.25	4	2	1	3	60.26	18.27	13.62	7.85
34.5	13	11.6	15.35	4.8	2.75	2	1	3	4	44.49	33.62	13.91	7.97
28.4	14	2.65	6.15	10.4	9.2	4	3	1	2	36.62	32.39	21.65	9.33
10.3	15	3.5	0.5	1.25	5.5	2	4	3	1	53.40	33.98	12.14	4.85
		Average				4.47	2.40	2.53	2.40	45.49	28.19	17.35	8.81
		Standard Deviation				7.99	1.12	1.19	1.06	11.12	7.89	6.57	3.41
		Assigned Rank				4	2	3	1				
		Period				1	2	3	4				
		Final pattern (% of total rainfall)				8.81	28.19	17.35	45.49				

Table 3: Comparing regional 24 hours storm patterns with SCS types

	Pattern			
Type	*First quartile*	*Second quartile*	*Third quartile*	*Fourth quartile*
SCS(type I)	12.6	55.6	20	11.8
SCS(type IA)	20.4	46	19.4	14.2
SCS(type II)	8	25.9	58.3	7.8
SCS(type III)	7.2	42.8	42.9	7.1
Ghasre-shirin	17.6	21.68	28.7	32.02

Table 4: Comparing Fars group formations sensitiveness to temporal pattern of rainfall

	Correlation in 2 states (With considering and non considering temporal Pattern) Confidence level=0.05		
Formation	*Correlation of Runoff coefficient*	*Correlation of Runoff*	*Correlation of Sediment*
Aghajari	0.822**	0.819**	0.634*
Mishan	0.674*	0.686*	0.683*
Gachsaran	0.079*	0.076*	0.042*

**Correlation is significant at the 0.05 level(2-tailed)*

***Correlation is significant at the 0.01 level(2-tailed)*

Experiments were carried out under the same conditions of plant coverage, soil moisture (A.M.C.), slope and direction of amplitude in order to reduce the number of independent variables and the effect of temporal distribution pattern of rainfall were examined. Following conclusions were obtained based on measuring runoff and sediment as well as on the results of statistical analysis. Analysis of variance was used to test the statistical significance.

As the Table 4 indicates, the effect of temporal pattern on generation of runoff and sediment within formations is significant. The correlations of 0.822 and 0.819 were observed for the rates of runoff coefficient and runoff, respectively in both considering and non considering rainfall pattern states within Agajari formation.

Dependent variable of the amount of sediment for considering and none considering states of rainfall pattern showed correlation of 0.634 at 0.05 significance level.

For the Mishan, these correlations were 0.674, 0.686 and 0.683 respectively for runoff coefficient, runoff amount and sediment.

For Gachsaran formation and in both targeted states, runoff coefficient, runoff and sediment correlations were 0.079, 0.076 and 0.042, respectively, which are close to zero. In other words, in this formation and in both studied states, a highly weak correlation is observed for the studied variables. Table 4 shows these correlations for three studied formations.

DISCUSSION AND CONCLUSION

As seen in the Table 3, none of type SCS patterns is in agreement, or even close to, temporal distribution pattern of 24h rainfalls of Qasre-shirin station. Only type II pattern within the second 25% of rainfall duration (25.9) is a bit close to the amount of this temporal precipitation quarter (21.68) in Qasr-e-shirin station, but no similarity exists in the case of other temporal patterns and quarters. So, it can be concluded that applying 24h rainfall SCS type patterns to Alvand watershed isn't allowed and recommended at all. Applying this pattern- and of course, other patterns- to other parts of Kermanshah province isn't recommended too.

Fars group formations are generally sensitive to chemical destruction and water erosion [9]. Detrital Agajari formation, as the newest formation of Fars group in studied region, is predominantly located on flat areas and plains. This formation is vulnerable to water erosion because of having marl structure and all kinds of water erosion are observed on this formation, including rill, stream, surface, gully (greatly in farming and plowed lands) and river erosions.

Different types of soil have formed on Agajari formation, but soil texture is loam-clay within this formation. Major factor of erosion on this formation is the material of formation since it stretches over low-steep surfaces of the region. Of course, land use is considered as the major erosion factor on Gully erosion. In this formation, as shown in Table 4, a significant correlation of

0.634(p=5%) is observed between dependent variable of sediment in both states of considering and non-considering the pattern of temporal rainfall distribution. This not so much strong correlation is indicative of the effect of temporal rainfall distribution pattern on generation of runoff and sediment. On the whole, the less the degree of correlation, the more the difference in sediment generation.

Like Agajari, Mishan formation consists of marl formations, but with less stickiness. One difference between Mishan and Agajari is a considerable lack of plaster in Mishan formation. Mishan's marl is greatly calcic. Considering the role of plaster in reducing erosion, more sensitivity the calcic marl have than plaster marl is justified.

Based on the results of analysis done, for both considering and non-considering the pattern of rainfall, the rates of runoff correlation (0.686), runoff coefficient (0.674) and sediment generation (0.683) in Mishan are weaker than those for Agajari. This represents more sensitive to temporal rainfall distribution pattern for this formation. In sum, it can be stated that compared to Agajari marl, Mishan marl has more sensitivity as the pattern of temporal rainfall distribution changes. Gachsaran formation showed less sensitivity to the temporal pattern changes.

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