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Appraisal of the Trend of Soil Infiltration Rate Changes in Flood Spreading Stations of Iran

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Abstract Flood spreading stations were constructed in Iran with different objectives such as groundwater recharge and vegetation recovery. Accumulation of sediment can be a major problem in flood spreading stations. According to generally accepted theories, floods and salt pollution can reduce gradually the infiltration rate. In order to investigate this issue, 13 flood spreading stations were selected across the country and infiltration rate changes were monitored over five years in the flood spreading areas. Non-parametric tests were used to analyze the abnormally distributed data. Based on the soil properties of the spreading stations, stations were first classified into three groups separately by cluster analysis; next, studies were conducted in three separate groups. Results in stations group 1 showed that, in the first year, the infiltration rate among spreading lines was not significantly different, but data for the second year showed a significant difference at $\alpha = 0.05$. For stations group 2, in the third year, the difference in the infiltration rate was significant at $\alpha = 0.05$. In addition, changes in the infiltration rate were significant at $\alpha = 0.05$ in stations groups 1 and 2 in the second spreading line. For stations group 3, significant changes among lines have been detected. Results also showed that changes in the infiltration rate in different years were somewhat different among the three groups of stations. Although infiltration rate changes were low, there was a general decreasing trend.

Key words: *Floodwater, Infiltration rate, Iran, Sediment*

1 INTRODUCTION

Worldwide, almost 90% of damages relating to natural disasters are caused directly or indirectly by floods. Floods are among the most frequent and costly natural disasters in terms of human hardship and economic loss. Floods that are eruption-caused can be more damaging than other natural disasters because they contain a large amount of salts and sediment. Flood spreading can be used as an appropriate solution to inhibit land degradation and desertification. As water is the most precious commodity in an arid environment, its shortage is an important cause of desertification while its temporary abundance results in flooding and soil erosion. Rehabilitation of a desert in an arid environment is a great challenge. Any plan to inhibit desertification should be based on its technical feasibility, financial viability, environmental soundness and social acceptability.

Flood spreading may be employed in flood mitigation, inhibition of desertification, artificial groundwater recharge and environmental rehabilitation (de Vries and Simmers, 2002).

Moreover, flood spreading represents an optimum approach for rural development by means of flood irrigation (Dahan *et al.*, 2007). Floodwater has different positive or negative effects on soil properties, e.g. infiltration rate.

Infiltration, defined as the vertical movement of water through the soil surface into the profile,

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is a complex phenomenon that has great practical importance in water management projects. Soil infiltration rate governs how much of the soil water holding capacity can be satisfied by irrigation water. Infiltration is affected by properties of the infiltrating fluid and soil factors, which include both soil hydraulic parameters and initial conditions of the soil profile. Charkhabi and Amiri (2003) reported that flood spreading in Kabudar Ahang Hamedan, Iran, led generally to a large reduction in the infiltration rate due to the sedimentation of fine particles including clay and silt. Funseca (2003) reported that sediment from run-off had a high fertility index and more potassium than soils of the area tested. Boroomand Nasab *et al.* (2004) showed that sedimentation decreased the surface infiltration rate significantly compared with data obtained from the control points. Mateosa and Giráldeza (2005) showed that the total sediment load decreases with successive irrigations and increases as it moves downstream. Sarreshtehdari and Skidmore (2005) showed that after the flood spreading project, sediment depth and infiltration rate increased significantly. Results indicated that, generally, soil conditions were improved. Soleimani (2006) indicated that the increase of the percentage of clay in a flood spreading area compared with the control points was not significant, but soil moisture saturation percentage significantly differed. Ghazavi *et al.* (2010) reported that an increase of clay content was accompanied by decreasing infiltration rate and sand percentage at the studied flood spreading station. Based on these results, mean differences of the clay, sand and infiltration rate between flood spreading and control areas were statistically significant ($P < 0.01$). Sokouti and Mahdian (2005) demonstrated a significant difference among some soil properties during four years of experiments. Compared with the first year, some soil parameters such as electrical conductivity, organic carbon and clay percentage increased whereas pH, sand and infiltration rate decreased. This means that flood spreading has had some positive and negative effects on soil properties (Devitt and Smith, 2002).

Some results indicated that the overall reduction of soil infiltration rate is due to the closing of soil pores by the suspended materials in the flood water (Allaire-Leung *et al.*, 2000). Considering the diverse and different ecological characteristics, climate, geology and soils, it can be concluded that the effects of flood spreading projects on soil properties vary according to area, and therefore further study is needed to determine the trend of these changes over time by monitoring the infiltration rate in flood spreading stations. Hence, this research was conducted with the aim of analyzing and monitoring the trend of infiltration rate changes over the flood spreading stations of Iran.

2 MATERIALS AND METHODS

2.1 The study area

Thirteen flood spreading stations were selected in the country, and the infiltration rate was measured during five years. Fig. 1 shows a typical flood spreading network.

The location of the selected stations is illustrated in Fig. 2. These stations are located in different parts of Iran, making a fairly uniform network for investigation.

2.2 Methods

In order to study trends in the infiltration rate changes among flooded lines, first, second and third lines of the spreading system were selected. Also, control measures at three points with three replications were performed.

Infiltration rate (cm/h) was measured in the spreading stations during five years after construction by the double ring method (ASTM D5093-02, 2008) in three flood spreading lines (Fig. 3). A circular radius of 4 m and base center was constructed. Selecting the first point (i1) on the circle, second and third points' replications (i2, i3) with a 90-degree angle on the circumference of the circle were selected. In later years, the influence of measurement points with a 45-degree change compared with previous years was determined.

In total, 585 measurements of the infiltration rate were investigated. Cluster analysis was conducted to classify floodwater spreading stations. The Kolmogorov-Smirnov test (Corder and Foreman, 2009) was used to determine the normality of data obtained. The data were analyzed and compared with non-parametric Kruskal-Wallis tests (Corder and Foreman, 2009) and cluster analysis (Hastie *et al.*, 2009). In order to determine factors affecting the infiltration rate, the stepwise multiple regression method was employed, using SPSS software (Levesque, 2007).

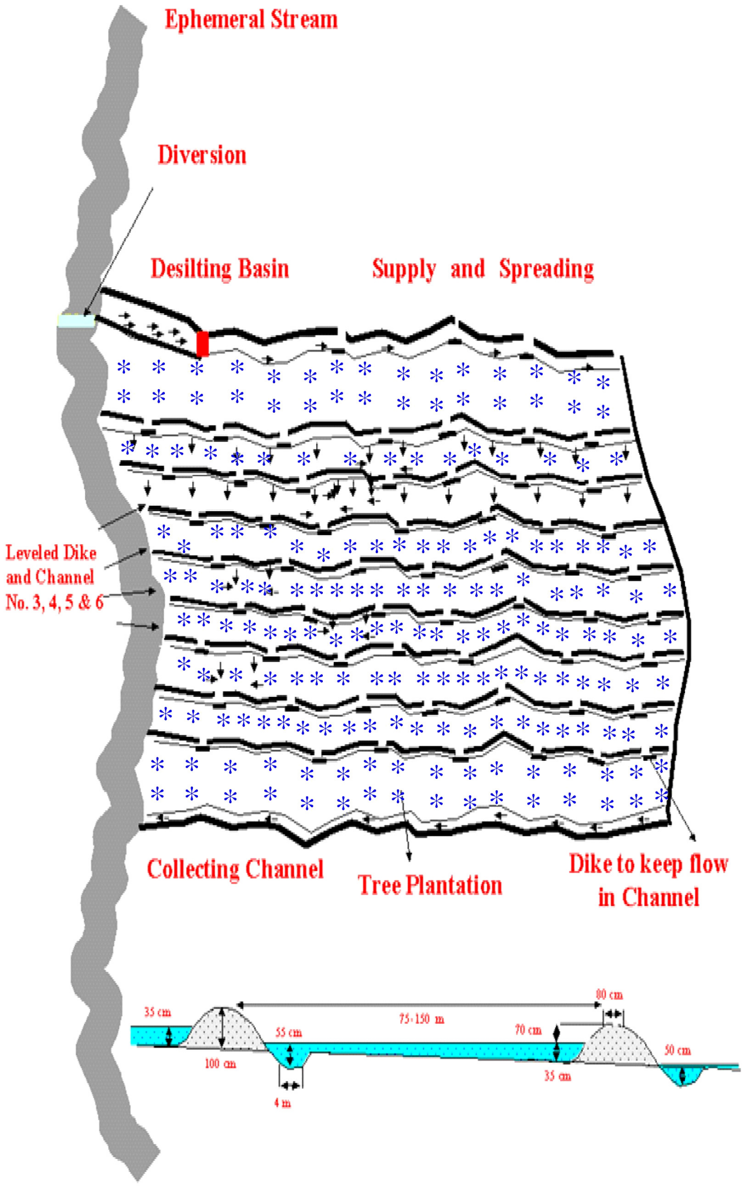

Fig. 1 A typical flood spreading network.

Fig. 2 Distribution of flood spreading stations over the country.

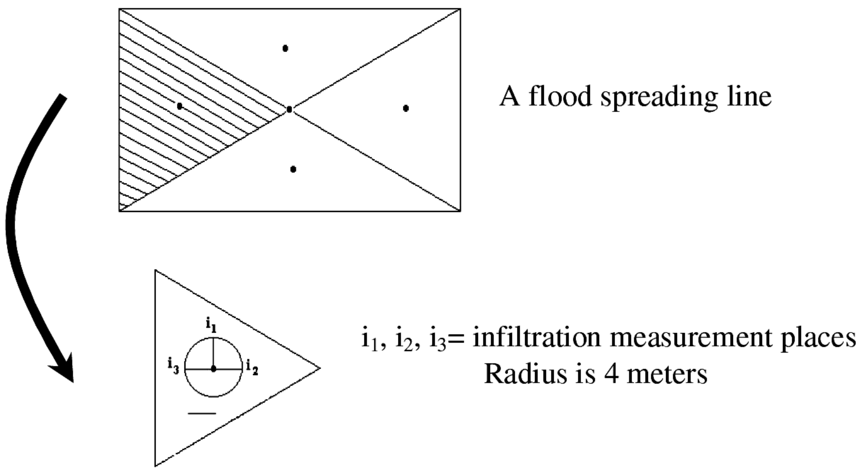

Fig. 3 Measurement of infiltration rate at a single point.

3 RESULTS

3.1 Cluster analysis

Cluster analysis was conducted to classify floodwater spreading stations based on infiltration rate data. Results are illustrated in Fig. 4. According to the dendrogram, spreading stations can be classified into two, three, or four classes. An important component of a clustering algorithm is the distance measured between data points. To select a suitable distance for classification of the data, a proximity matrix was used in which the entry in the table cell is

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some measure of the similarity or distance between the items (Table 1). These distances are based on the Squared Euclidean Distance. Based on Table I, an Eigenvalue above 1 was used to draw a scree plot. Results in Fig. 5 show clearly that the numbers of root axes as separable categories are based on an Eigenvalue above 1. Thus, floodwater spreading stations are classified into three groups as described in Table 2. For data analysis, the non-parametric Kruskal-Wallis test was used because none of the spreading stations infiltration rate data had a normal distribution.

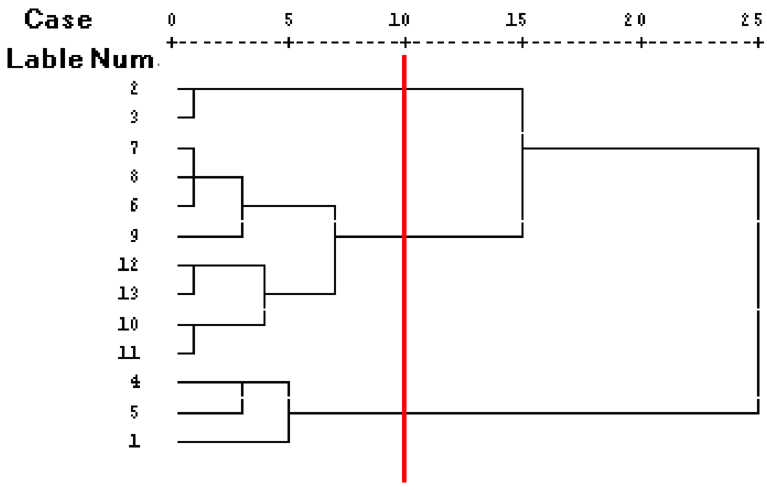

Fig. 4 Dendrogram of hierarchical cluster analysis using average linkage.

Table 1 Proximity matrix.

Case	Squared Euclidean Distance												
	1	2	3	4	5	6	7	8	9	10	11	12	13
1	0.0	118.2	121.0	20.6	16.2	90.4	129.7	133.2	198.0	126.0	127.3	209.0	225.9
2	118.2	0.0	1.0	59.2	117.9	23.5	26.3	38.7	49.6	81.0	112.3	102.1	124.2
3	121.0	1.0	0.0	56.1	112.7	16.5	17.3	27.7	36.6	65.9	95.2	83.1	103.1
4	20.6	59.2	56.1	0.0	10.1	26.0	48.4	49.4	91.9	46.9	52.3	99.8	112.9
5	16.2	117.9	112.7	10.1	0.0	60.3	90.3	86.3	141.2	64.9	59.4	129.8	139.0
6	90.4	23.5	16.5	26.0	60.3	0.0	3.5	5.2	21.2	17.9	33.2	37.7	49.9
7	129.7	26.3	17.3	48.4	90.3	3.5	0.0	1.2	7.61	17.8	35.8	25.0	36.4
8	133.2	38.7	27.7	49.40	86.3	5.2	1.3	0.0	6.8	10.1	24.6	16.0	25.0
9	198.0	49.6	36.6	91.9	141.2	21.2	7.6	6.8	0.0	24.7	44.3	13.8	22.4
10	126.0	81.0	65.9	46.9	64.9	17.9	17.8	10.1	24.7	0.0	3.2	11.1	14.5
11	127.3	112.3	95.2	52.3	59.4	33.2	35.8	24.6	44.3	3.2	0.0	18.2	18.6
12	208.9	102.1	83.1	99.8	129.8	37.7	25.1	16.0	13.8	11.1	18.2	0.0	1.1
13	225.9	124.1	103.1	112.9	138.9	49.9	36.4	25.0	22.4	14.5	18.6	1.1	0.0

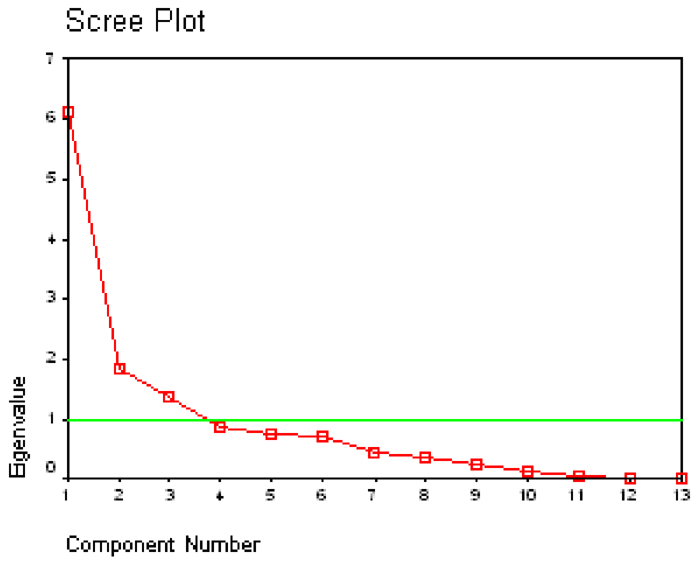

Fig. 5 Number of separable categories based on the Eigenvalue of the correlation matrix above 1.

Table 2 Grouping flood spreading stations based on cluster analysis.

Groups	Stations
1	East Azarbaijan, west Azarbaijan, Sabzevar, Yazd, Gonabad, Birjand, Ilam, Hormozgan
2	Kerman, Mazandaran, Fars
3	Balochestan, Bosher

3.2 Infiltration rate changes

The infiltration rate data of three groups do not have a normal distribution, and therefore a non-parametric Kruskal-Wallis test was used to compare and study the changes in the soil infiltration rate.

Fig. 6 shows the average infiltration rate between flood spreading strips in the experimental years in station group 1 separately, e.g. this varies between 5.6 and 9 cm/h. Statistical comparison of the results of soil infiltration rate changes in different years of implementation is presented in Table 3, and shows no significant difference among years except in year 1 and between the first and second strip. Table 4 demonstrates that there are significant differences in the second year between the first and second strip at $\alpha = 0.01$ and between the first and third strip at $\alpha = 0.05$, but there is no significant difference of infiltration rate among strips.

Fig. 7 shows the average infiltration rate of strips in stations group 2 during the years of experiments separately. Statistical comparison of soil infiltration rate in different years showed that it is significantly different at $\alpha = 0.05$ only in the third year between the first and third strip and between the second strip and third. Statistical comparison of soil infiltration rate in different strips showed that it is significantly different at $\alpha = 0.05$ only in the second strip between the second and third years. Fig. 8 shows the average infiltration rate of spreading strips in stations group 3 during the years of the experiments. Statistical comparison of soil infiltration rate data in different years showed that there are significant differences in the second year between the first and second strip at $\alpha = 0.05$ and between the first and third strip at $\alpha = 0.01$. The soil infiltration rate differed significantly at $\alpha = 0.05$ in the third year between the first and second strips.

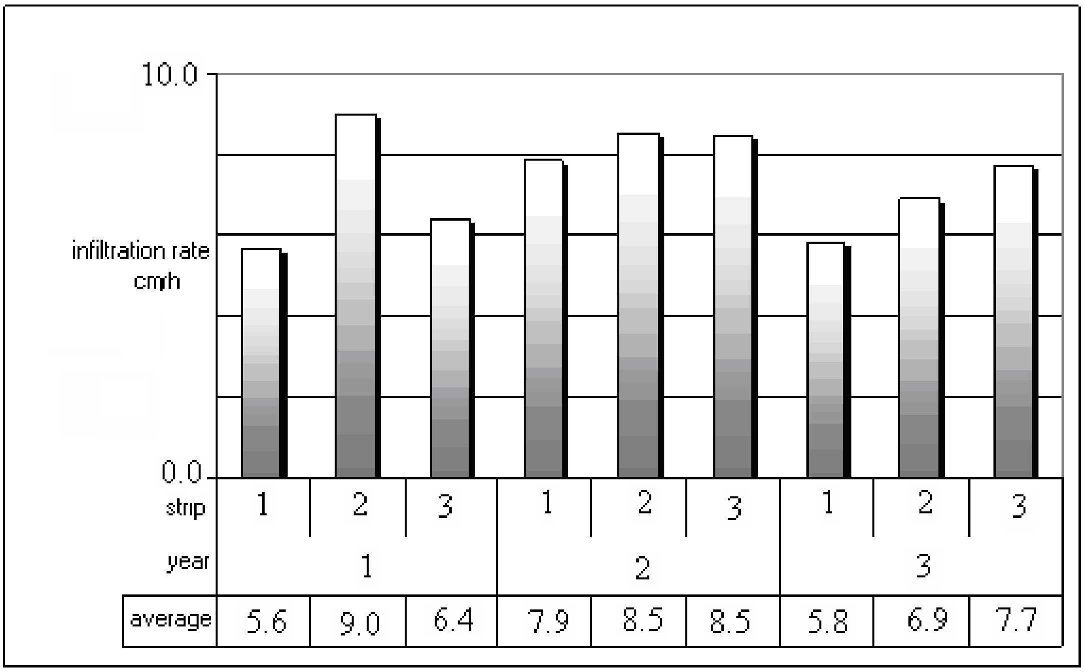

Fig. 6 Average infiltration rate in spreading strips during experiment years in group 1 stations.

Table 3 Statistical comparison of infiltration rates over the experiment years.

Experiment years	Compared samples	Statistical parameters	Infiltration rate index
Year 1	First and second strips	X^2	6.916
		probability	0.009
	First and third strips	X^2	0.588
		probability	0.443
	Second and third strips	X^2	3.722
		probability	0.054
Year 2	First and second strips	X^2	0.376
		probability	0.540
	First and third strips	X^2	0.161
		probability	0.688
	Second and third strips	X^2	0.100
		probability	0.752
Year 3	First and second strips	X^2	0.042
		probability	0.837
	First and third strips	X^2	1.086
		probability	0.297
	Second and third strips	X^2	0.336
		probability	0.562

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Table 4 Statistical comparison of infiltration rate over the experiment strips.

Experiment strips	Compared samples	Statistical parameters	Infiltration rate index
Strip 1	First and second strips	X^2	1.125
		probability	0.289
	First and third strips	X^2	0.000
		probability	0.988
	Second and third strips	X^2	0.912
		probability	0.340
Strip 2	First and second strips	X^2	0.007
		probability	0.936
	First strip with third	X^2	3.467
		probability	0.063
	Second and third strips	X^2	1.707
		probability	0.191
Strip 3	First and second strips	X^2	3.157
		probability	0.076
	First and third strips	X^2	0.330
		probability	0.566
	Second and third strips	X^2	0.448
		probability	0.503

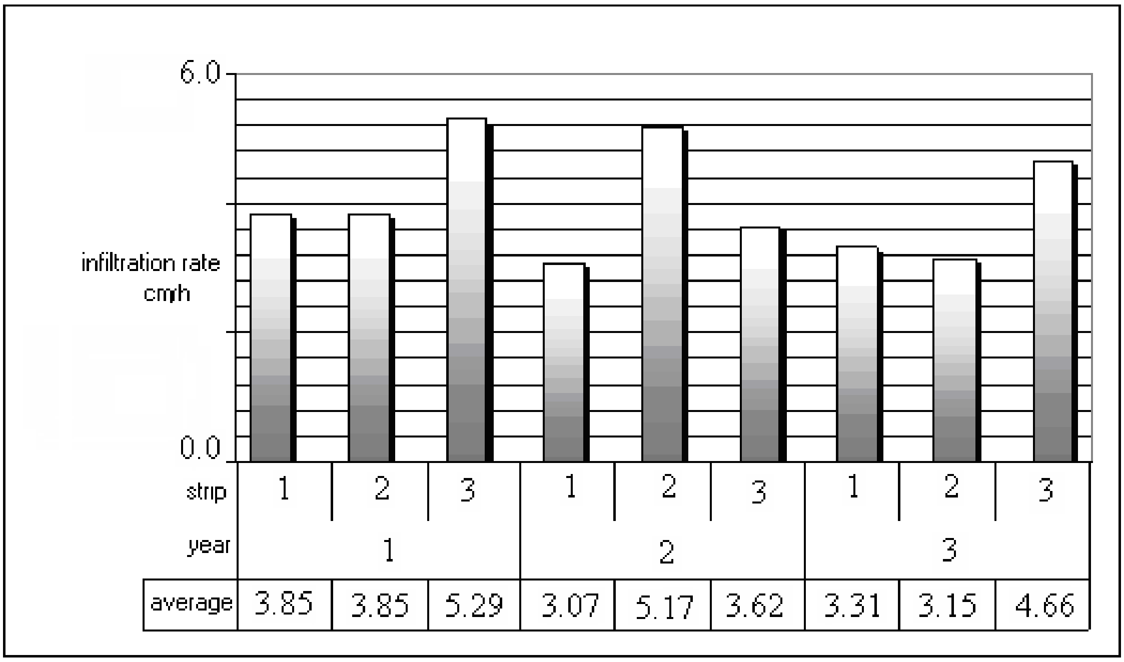

Fig. 7 Average infiltration rate in spreading strips during experiment years in group 2 stations.

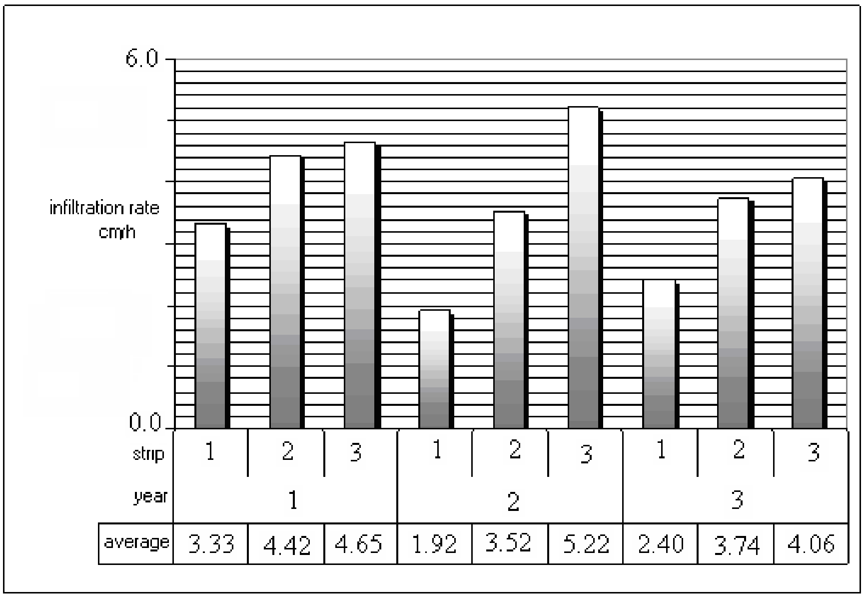

Fig. 8 Average infiltration rate in spreading strips during experiment years in group 3 stations.

4 DISCUSSION AND CONCLUSION

The experiment started on virgin land and results showed a clear decrease in the infiltration rate of flood spreading stations. This is mainly due to upstream sediment transport and accumulation of particles and thus fine soil pores are closed as reported by Ghazavi *et al.* (2010), Charkhabi and Amiri (2003) and Boroomand Nasab *et al.* (2004). Sokouti and Mahdian (2007) have also reported a relative reduction in soil infiltration rate in flood spreading stations due to the increase of sediment depth on flooded land.

However, floods that can carry a large amount of sediment also can contain nutrients and can increase soil fertility, as reported by Ghazavi *et al.* (2010), Funseca (2003) and Hirst and Ibrahim (1996).

Results from this research showed that infiltration rate changes in different years between the three groups of stations are somewhat different. In group 1 stations, the measured infiltration rates in the first, third and fifth years were 7.09, 8.24 and 6.76 cm/h, respectively. This means that if the third year of consideration is scarcely justified, the decreasing trend is generally what is expected. In contrast, in some cases infiltration rate of the third year compared to the first year increased. The main reason for this may be the nature of the infiltration rate variability that can influence the process in different locations when measured over two years.

For stations in group 2, the average infiltration rate was calculated as 6.96, 6.99 and 6.77 cm/h for the first, third and fifth years, respectively. The values for the stations in group 3 are less for the first, third and fifth years at 5.05, 4.18 and 4.27 cm/h, respectively. These results demonstrate that the infiltration rate changes at a slow rate, but overall has a decreasing trend.

Study of the mean infiltration rate of the first and third years for stations in group 1 and third and fifth years for stations in group 3 gave results contrary to what was expected. First, the differences were negligible; secondly, these differences can be compared to changes in spatial variability of the infiltration rate. This means that if the exact measurements were made at the same points previously measured, in those circumstances a decreasing trend was observed. Comparison of these results with results from a groundwater recharge project (Mousavi and Rezai, 1998) shows that the decrease in the infiltration rate is very slow.

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ارزیابی روند تغییرات نفوذپذیری در ایستگاه‌های پخش سیلاب ایران

محمد حسین مهدیان، رضا سکوتی اسکویی و کوروش کمالی

چکیده ایستگاه‌های پخش سیلاب با اهداف مختلفی ماتند تغذیه آب‌های زیرزمینی و احیای پوشش گیاهی احداث می-گردند. انباشته شدن رسوب معضل اساسی در شبکه‌های پخش‌سیلاب محسوب می‌گردد. ایده کلی این است که املاح در سیلاب و گل‌آلودگی آن، می‌تواند نفوذپذیری عرصه‌های پخش سلاب را کاهش دهد. به منظور بررسی این موضوع، ۱۳ ایستگاه پخش سیلاب در سطح کشور انتخاب و تغییرات نفوذپذیری در این ایستگاه‌ها در طی پنج سال در عرصه‌های پخش پایش گردید. برای تجزیه و تحلیل داده‌ها از آزمون‌های ناپارامتری استفاده شد. بر اساس ویژگی‌های ایستگاه‌های پخش سیلاب، ابتدا این ایستگاه‌ها با استفاده از روش خوشه‌بندی، در سه گروه مجزا دسته‌بندی شده و بررسی‌های بعدی در این سه گروه انجام گردید. نتایج بدست آمده در ایستگاه‌های گروه یک نشان دادند که در سال اول، بین نوارهای مختلف اختلاف معنی‌داری وجود ندارد، ولی داده‌های سال دوم اختلاف معنی‌داری را با احتمال ۰/۰۵ درصد نشان داد. برای ایستگاه‌های گروه ۲، در سال سوم، میزان نفوذپذیری با احتمال ۰/۰۵ درصد اختلاف معنی‌دار بود. به علاوه تغییرات در سطح عرصه ایستگاه‌های پخش سیلاب، برای ایستگاه‌های گروه ۱ و ۲، تغییرات در نوار دوم با احتمال ۰/۰۵ معنی‌دار بود. برای ایستگاه‌های گروه ۳، تغییرات معنی‌دار در سطح نوارها مشاهده نشد. هم‌چنین نتایج این تحقیق نشان داد که تغییرات نفوذپذیری در سال‌های مختلف بین سه گروه ایستگاه‌ها، تا حدی متفاوت است. هر چند تغییرات نفوذپذیری بطئی است، اما در مجموع از یک روند کاهشی برخوردار است.

کلمات کلیدی: سیلاب، نفوذپذیری، ایران، رسوب

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