Evaluation of scraping treatments to restore initial infiltration capacity of three artificial recharge projects in central Iran

Sayed-Farhad Mousavi · Vafa Rezai

Abstract A limiting factor in developing artificial recharge of groundwater is clogging of the soil surface and consequent reduction of infiltration rates. In order to evaluate the degree of improving infiltration rates by scraping away various amounts of the upper soil materials, a study was conducted at three artificial recharge sites (Kohrouyeh, Bagh-Sorkh, and Kachak) in Isfahan Province, central Iran. Five treatments (T1–T5) were considered. Infiltration was measured: T1, on deposited sediment layer; T2, after removing the sediments; T3, scraping of sediments and 5 cm of soil; T4, scraping of sediments and 10 cm of soil; and T5, removing sediments and 15 cm of soil. Initial soil-moisture content of the sites ranged from 1.0–2.87% for Kohrouyeh, 1.18–3.47% for Bagh-Sorkh, and 1.89–3.93% for Kachak. The main texture of the soils was sandy loam. Clay particles have penetrated to a depth of more than 40 cm in some of the recharge basins. A significant increase in final infiltration rate of T5 as compared to T1 treatment was observed for all recharge sites. The final infiltration rates of T1 and T5 treatments for Kohrouyeh, Bagh-Sorkh, and Kachak sites were 0.35, 7.9; 1.22, 12.3; and 0.93, 6.2 cm/h, respectively. The differences between infiltration rates of T2, T3, and T4 treatments were not statistically significant. It is concluded that on average, the infiltration capacity of the untreated recharge facilities have reached 20.3% of the original values, and that scraping the top sediment layer and 15 cm of topsoil could restore 68.3% of the initial infiltration capacity.

Résumé Un facteur limitant lorsqu'on développe la recharge artificielle d'une nappe est le colmatage de la surface du sol et la réduction concomitante des taux d'infiltration. Afin d'évaluer le degré d'amélioration de l'infiltration en grattant de différentes manières la surface du sol, une étude a été conduite sur trois sites de recharge artificielle (Kohrouyeh, Bagh-Sorkh et Kachak) dans la province d'Ispahan (Iran central). Cinq traitements (T1–T5) ont été testés et l'infiltration a été mesurée: T1, sur une couche de sédiments déposés; T2, après enlèvement du sédiment; T3, grattage des sédiments et du sol sur 5 cm; T4, grattage des sédiments et du sol sur 10 cm; et T5, enlèvement des sédiments et de 15 cm de sol. La teneur initiale en eau du sol sur les sites va de 1.0 à 2.87% à Kohrouyeh, 1.18 à 3.47% à Bagh-Sorkh, et 1.89 à 3.93% à Kachak. Les sols sonbt surtout des sols végétaux sableux. Les particules argileuses ont pénétré jusqu'à plus de >40 cm de profondeur dans certains bassins de recharge. Un accroissement significatif du taux final d'infiltration de la procédure T5 comparée à T1 a été observée sur tous les sites de recharge. Les taux finaux d'infiltration des procédures T1 et T5 à Kohrouyeh, Bagh-Sorkh et Kachak étaient respectivement 0.35 et 7.9, 1.22 et 12.3, et 0.93 et 6.2 cm/h. Les taux d'infiltration des procédures T2, T3 et T4 ne présentaient pas statistiquement de différences significatives. On en conclut donc qu'en moyenne la capacité d'infiltration de la recharge non traitée s'est accrue de 20.3 % par rapport aux valeurs initiales, et que le grattage du sommet du sédiment et du sol sur 15 cm peut améliorer 68.3 % de la capacité initiale d'infiltration.

Resumen Un factor limitativo en el desarrollo de los sistemas de recarga artificiales la colmatación de la superficie, con la consiguiente reducción en lacapacidad de infiltración. Para evaluar la mejora producida en la capacidadde infiltración por escarificado de diferentes espesores de la superficie, se llevó a cabo un estudio en tres zonas de recarga (Kohrouyeh, Bagh-Sorkh y Kachak) ubicadas en la Provincia de Isfahán, Irán. Se consideraron cinco tratamientos (T1–T5), de manera que se midió la infiltración: T1, en la capa de sedimentos; T2, tras eliminar los sedimentos; T3, tras escarificar los sedimentos junto con 5 cm de suelo; T4, tras escarificar los sedimentos con 10 cm de suelo y T5, tras eliminar los sedimentos junto con 15 cm de suelo. Los valores iniciales de humedad del suelo oscilaron entre 1.0 y 2.87% para Kohrouyeh, 1.18 y 3.47% para

Received, July 1998
Revised, April 1999, May 1999
Accepted, June 1999

Sayed-Farhad Mousavi (✉) · Vafa Rezai
College of Agriculture, Isfahan University of Technology,
Isfahan 84154, Iran
Fax: +98-31-8912254
e-mail: mousavi@cc.iut.ac.ir

Bagh-Sorkh y 1.89 y 3.93% para Kachak. Durante el proceso se vio que en varias de las zonas de recarga algunas partículas de arcilla procedentes del suelo habían penetrado más de 40 cm. Como resultado del estudio se observó un incremento significativo en la capacidad de infiltración tras el tratamiento T5 respecto a la correspondiente a T1 en las tres zonas de estudio. Así, los valores finales de infiltración tras T1 y T5 fueron de 0.35 y 7.9 cm/h (Kohrouyeh), 1.22 y 12.3 cm/h (Bagh-Sorkh) y 0.93 y 6.2 cm/h (Kachak). Las diferencias de infiltración tras T2, T3 y T4 no fueron estadísticamente significativas. Como conclusión, se observó que en media la capacidad de infiltración en las zonas en que no se hacía ningún tratamiento se había reducido hasta un 20.3% de los valores originales, y que el utilizar un escarificado de la capa de sedimentos removiendo los 15 cm más superficiales de suelo podía llegar a restaurar un 68.3% de la capacidad de infiltración inicial.

Key words groundwater recharge · arid regions · Iran

Introduction

The shortage of water in arid and semi-arid regions of the world is a factor in the development of sound economic and social structures. In these regions, where groundwater is often the only source of water supply (Wright and du Toit 1996), almost any development of the aquifers constitutes overdraft conditions (Bani-Hashemi 1995). Here, natural recharge is small, and artificial recharge can play an important role in conservation of water quality and quantity. Sukhija et al. (1996) conclude that the natural recharge rate in dry parts of India is 3–25% of local annual rainfall, and that the ever-increasing demands for development of groundwater resources for agricultural, industrial, and domestic uses necessitate proper water-resources assessment and management in arid and semi-arid regions.

Planned artificial recharge is carried out by various methods and includes such facilities as spreading grounds, infiltration ponds, or wells and galleries (Kashef 1987). During the operation of artificial-recharge facilities that use turbid water, infiltration rates decline quickly because of clogging (Al-Muttair et al. 1994). The decrease in infiltration rate and depth of clogging were evaluated for a sandy artificial recharge test basin during the application of water containing 51–61 mg/L suspended solids (Schuh 1990). Infiltration rate decreased by two orders of magnitude. Clogging tends to be more severe at the surface (Ripley and Saleem 1973). Physical measurements indicate that although much of the suspended material is filtered at the surface, some clay particles penetrate to greater depths (Schuh 1988). If clogging occurs at significant depths beneath the surface, the long-term use of the basins is seriously affected (Goss et al. 1973).

Maintaining a high infiltration rate for long periods of time is essential for the success of groundwater recharge. Soil-clogging factors are chemical, biological, and physical (Rice 1974). Among the various factors that reduce the rate of recharge with time in an artificial basin, the settling of suspended solids in the recharge water is usually the most important. Management techniques that have been developed to minimize clogging effects include basin stage management, use of an organic mat, silt removal and scratching, use of gravel filters, grass filtration of suspended solids, and scheduling of consecutive recharge and dry periods (Jones et al. 1981; Zomorodi 1990; Schuh 1991; Al-Muttair et al. 1994). Often, scraping and scratching of topsoil in recharge basins is the most efficient way of restoring the infiltration rate. Not much research has been done on the amount of topsoil removal that is needed to restore infiltration rates.

This article presents the results of experiments that were conducted at three artificial-recharge sites in central Iran, where initial infiltration rates had declined substantially. The experiments were intended to evaluate the effectiveness of various treatments at restoring the initial infiltration rates at the sites. The treatments involved removing the deposited sediments and various thicknesses of underlying topsoil and comparing the infiltration rates that were obtained with each successive treatment.

Background and Site Descriptions

The annual groundwater withdrawal in the central watershed of Iran is about 32.59 billion m^3 (Water Resources Research Center 1997). Overexploitation of groundwater in Isfahan Province, central Iran, has caused severe declines of the water table (1–2 m/year). Various artificial-recharge projects have been constructed to conserve the water contained in flash floods of ephemeral streams in this region. Three of the recharge sites – Kohrouyeh, Bagh-Sorkh, and Kachak, near the city of Shahreza – were selected for study. Locations of the sites are shown in *Figure 1*. Shahreza is 85 km south of Isfahan. Because of low annual precipitation (120 mm) and high evaporation (1200 mm/year), drought conditions exist throughout most of the year. The short-duration, high-intensity rains create flash floods of large volumes in normally dry streams. Usually four or five flood events, which last from less than 1 day to 2 or 3 days, occur each year. The concentration of suspended solids in the flood flows ranges from 0.05–5 g/L. Average annual minimum and maximum air temperatures in this region are –1.5 °C and 42 °C, respectively. The summers are very hot, and during 8–10 months of the year there is no rain. Most of the precipitation occurs during December to March.

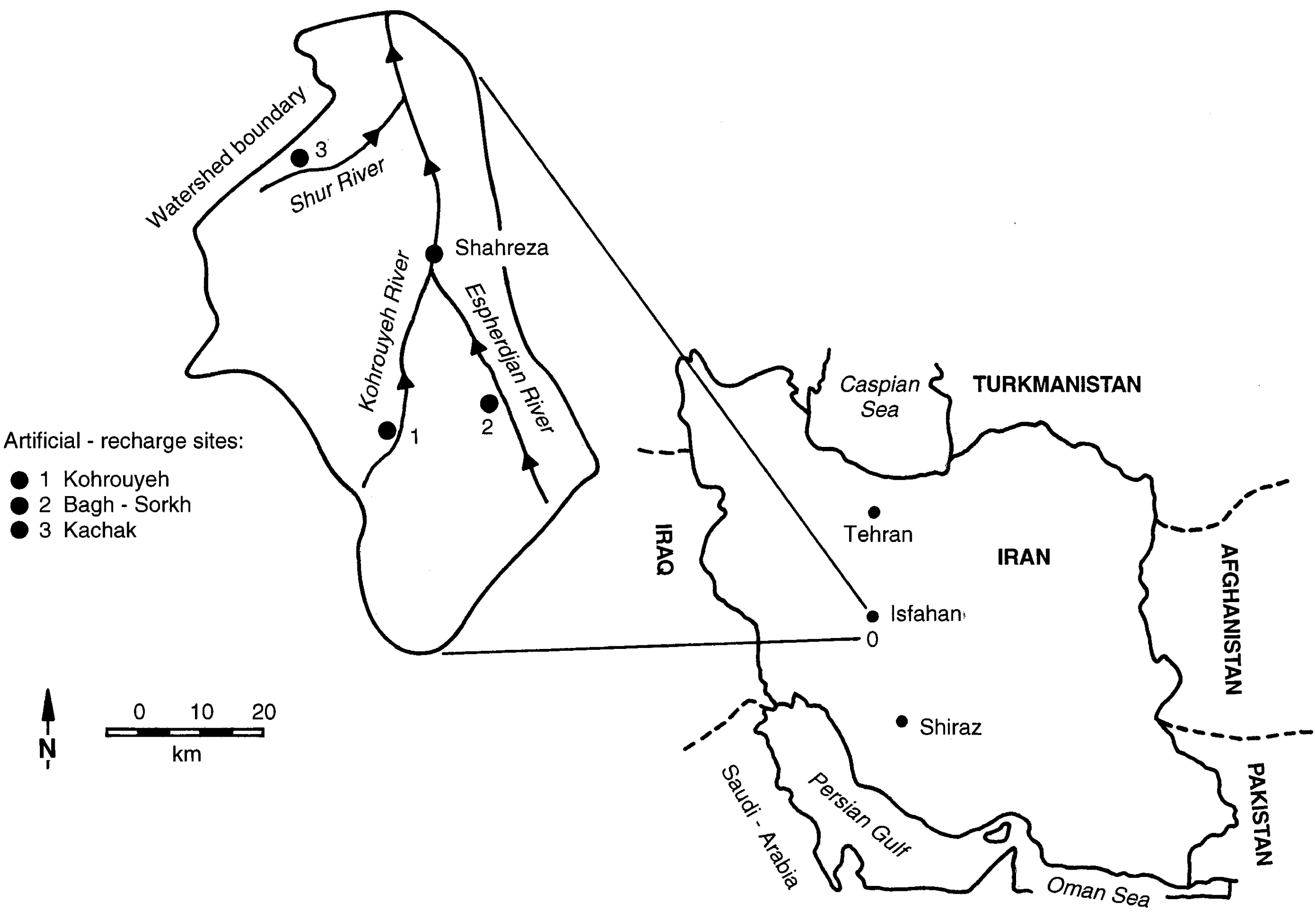

Figure 1 Location of artificial recharge sites of Kohrouyeh, Bagh-Sorkh, and Kachak, central Iran

The Kohrouyeh Project

The site at Kohrouyeh was constructed in 1993. It is located on the left bank of the ephemeral Kohrouyeh River, at a longitude of 51°56′ east and latitude of 31°50′ north. The watershed area of Kohrouyeh River above this point is 245 km^2. The water-table depth near this project ranges from 20–50 m in different locations. The recharge facilities consist of a diversion dam, 300 m of main canal, a desilting basin of 170×70 m, and four recharge basins of 170×70×4 m each. *Figure 2* shows a general view of the site.

The Bagh-Sorkh Project

The site at Bagh-Sorkh was constructed in 1988. It is situated 25 km south of Shahreza, on the west side of the ephemeral Espherdjan River, at a longitude of 52° east and latitude of 31°46′ north. The watershed area of the Espherdjan River above this point is 323 km^2. The water-table depth ranges from 30–40 m around this project. The recharge facilities consist of a diversion dam, 200 m of main canal, a desilting basin of 150×50 m, and five recharge basins of 150×50×3 m each. *Figure 3* shows a general view of this site.

The Kachak Project

The site at Kachak was constructed in 1985, 30 km northwest of Shahreza, on the north side of the ephemeral Shur River, at a longitude of 51°45′ east and latitude of 32°10′ north. The watershed area of the Shur River above this point is 50 km^2. The water-table depth near this project ranges from 30–50 m in various wells. The recharge facilities consist of a diversion dam, 50 m of main canal, a desilting basin of 150×50 m, and ten recharge trenches each having a length of 350–500 m, bed width of 10 m, and depth of 2.5 m.

Methods

The experimental treatments (T1–T5) were carried out by measuring infiltration rates under various conditions: T1, directly on the deposited surface sediments; T2, after the deposited sediments were removed; T3, after the deposited sediments and 5 cm of topsoil were removed; T4, after the deposited sediments and 10 cm of topsoil were removed; and T5, after the deposited sediments and 15 cm of topsoil were removed. The infiltration rate was measured by using a double-ring

Figure 2 Desilting basin and general setting of the Kohrouyeh recharge site

Figure 3 General view of the Bagh-Sorkh recharge site in operation

infiltrometer. A completely randomized design in a hierarchical classification (nested type) of treatments (Steal and Torrie 1982) with three replications was used at each site. This type of design was chosen because the basins (or trenches) were compared with each other within each site. Comparison of sites is not possible by this design. All the treatments, with their replications, were arranged randomly along a transverse line in the middle of each basin or trench. The Kostiakov equation (Kostiakov 1932) was used to fit the experimental infiltration data. This equation is written as:

$$F = B\,t^{-n} \quad (1)$$

where F is the infiltration rate (cm/h), t is the time since infiltration started (minutes), and B and n are constants that depend on the soil and initial conditions. The constants in this equation are evaluated from experimental data.

The soil texture of each site to a depth of 120 cm was classified according to USDA methods (Brady 1990), and initial soil-moisture content to a depth of 80 cm was determined by the gravimetric method. Sieve analysis was performed on samples of soil and deposited sediments collected from each basin or trench.

Results and Discussion

Initial Conditions

The initial moisture contents of the soils in the basins (for the Kohrouyeh and Bagh-Sorkh projects) or trenches (for the Kachak project) are shown in *Table 1*. This value ranges from 1.0–2.87% for the Kohrouyeh site, 1.18–3.47% for the Bagh-Sorkh site, and 1.89–3.93% for the Kachak site, indicating that the soil was very dry at all the recharge sites. The initial infiltration capacities of the Kohrouyeh, Bagh-Sorkh, and Kachak projects (before construction), measured in the vicinity of the sites, were 14, 13.5, and 7.5 cm/h, respectively.

The soil texture is shown in *Table 2*. The main texture of the soils is sandy loam. In all the sites, the percentage of soil particles larger than 2 mm increases with increased depth. For example, for Kohrouyeh, this value was 45% at depths of 0–20 cm in the topsoil and 77% at 100–120 cm. The corresponding values were 36 and 69% for Bagh-Sorkh and 51 and 75% for Kachak.

Table 3 shows the texture and thickness of deposited sediments in the basins or trenches. Thickness of sediments decreases and texture of sediments becomes finer from the beginning (desilting basin) to the end (last recharge basin or trench) of each recharge site. The reason is that water velocity decreases as it moves through the system. Therefore, coarse suspended solids deposit rapidly in the desilting basin and finer particles move to the recharge basins. Thus, more silt and clay occurs in the recharge basins (or trenches). These fine particles penetrate deeply into the soil and cause clogging problems. Schuh (1988) describes an initial period of clay penetration to a maximum depth of 23 cm in a sandy soil; Goss et al. (1973) show clay penetration to 15 cm on a tilled clay loam soil; and Kovenya et al. (1972) report sediment penetration to depths greater than 40 cm for a soil with large structural pores. In the

Table 1 Initial soil moisture content (% by weight) at the artificial recharge sites

Site	Basin or trench	Soil depth (cm)			
		0–20	20–40	40–60	60–80
Kohrouyeh	Desilting (part 1)	1.00	2.36	2.81	2.78
	Desilting (part 3)	1.23	1.49	1.87	2.68
	Recharge 1	1.32	2.59	2.87	2.67
	Recharge 2	1.20	2.30	2.50	2.70
Bagh-Sorkh	Desilting (part 1)	1.80	3.22	3.47	2.01
	Recharge 1	1.85	1.98	2.20	2.58
	Recharge 2	1.24	1.38	2.48	2.25
	Recharge 3	1.18	1.89	2.14	2.22
	Recharge 4	1.22	1.26	1.73	2.06
Kachak	Trench 1	3.64	2.98	1.90	1.89
	Trench 3	3.40	3.10	3.20	3.30
	Trench 5	3.93	3.24	3.30	3.58
	Trench 9	3.10	3.00	1.95	2.60

Table 2 Results of sieve analysis and description of soil texture at the recharge sites

Depth (cm)	Kohrouyeh				Bagh-Sorkh				Kachak			
	Sand	Silt (%)	Clay	Texture	Sand	Silt (%)	Clay	Texture	Sand	Silt (%)	Clay	Texture
0–20	58	22	20	Sandy clay loam	40	29	31	Clay loam	49	14	37	Sandy clay
20–40	70	12	18	Sandy loam	46	18	36	Sandy clay	69	10	21	Sandy clay loam
40–60	76	8	16	Sandy loam	58	11	31	Sandy clay loam	71	11	19	Sandy loam
60–80	80	8	12	Sandy loam	59	11	30	Sandy clay loam	76	8	16	Loamy sand
80–100	80	9	11	Sandy loam	69	11	20	Sandy loam	77	6	17	Loamy sand
100–120	78	10	12	Sandy loam	72	9	19	Sandy loam	80	4	16	Loamy sand

Table 3 Results of sieve analysis, texture, and thickness of deposited sediments

Site	Basin or trench	Sand (%)	Silt (%)	Clay (%)	Texture	Thickness of deposited sediments (cm)
Kohrouyeh	Desilting (part 1)[a]	6	45	49	Sandy clay	20.0
	Desilting (part 3)	4	38	58	Clay	15.0
	Recharge 1	3	37	60	Clay	3.0
	Recharge 2	2	38	60	Clay	1.5
	Recharge 3	1	33	66	Clay	0.2
Bagh-Sorkh	Desilting (part 1)	14	47	39	Sandy clay	18.0
	Recharge 1	1	29	70	Clay	7.5
	Recharge 2	0	31	69	Clay	3.0
	Recharge 3	0	28	72	Clay	1.5
	Recharge 4	0	27	73	Clay	0.2
Kachak	Desilting	8	48	44	Sandy clay	15.0[b]
	Trench 1	6	48	46	Sandy clay	28.0
	Trench 3	5	43	52	Sandy clay	25.0
	Trench 5	5	41	54	Sandy clay	23.0
	Trench 7	4	36	60	Clay	14.0
	Trench 9	3	34	63	Clay	10.0

[a] The desilting basin is divided by cross-levees into three parts
[b] Deposited sediments in the desilting basin had been scraped 2 years before conducting the experiments. Deposited sediments in Kohrouyeh and Bagh-Sorkh sites had not been disturbed since their first use prior to the experiments

Table 4 Mean values of final infiltration rate (cm/h) for different treatments in artificial recharge projects. Within rows, mean values followed by a *different letter* are significantly different at the 5% probability level, according to Duncan's Multiple Range Test

Site	Basin or trench	T1	T2	T3	T4	T5
Kohrouyeh	Desilting (part 1)	0.53 d	3.39 c	4.29 bc	5.24 b	7.90 a
	Desilting (part 3)	0.56 d	4.13 c	4.75 c	5.39 bc	7.79 a
	Recharge 1	3.80 b	5.02 b	5.06 b	5.54 ab	7.47 a
	Recharge 2	4.42 b	4.95 b	5.52 ab	7.43 a	7.32 a
	Recharge 3	3.79 c	6.10 b	7.40 ab	7.76 a	9.08 a
Bagh-Sorkh	Desilting (part 1)	1.22 b	2.54 b	3.22 b	10.87 a	12.30 a
	Recharge 1	1.38 c	1.87 c	3.04 c	7.45 b	9.74 a
	Recharge 2	4.49 d	5.88 cd	7.19 bc	9.14 ab	10.60 a
	Recharge 3	3.89 c	5.52 bc	7.01 ab	8.21 a	8.30 a
	Recharge 4	4.66 c	5.27 bc	5.45 b	6.30 ab	8.23 a
Kachak	Trench 1	0.93 d	2.41 c	4.48 b	5.07 ab	6.20 a
	Trench 3	1.05 d	2.23 cd	4.82 b	5.54 ab	5.93 a
	Trench 5	1.55 d	2.56 cd	3.66 bc	4.34 b	5.80 a
	Trench 7	1.10 d	2.64 bc	2.53 c	3.95 ab	5.18 a
	Trench 9	1.60 d	3.03 c	3.59 bc	4.68 ab	5.22 a

Table 5 Mean values of cumulative infiltration (cm) for different treatments in artificial recharge projects

Site	Basin or trench	T1	T2	T3	T4	T5
Kohrouyeh	Desilting (part 1)	4.2	12.1	15.6	23.4	36.3
	Desilting (part 3)	4.1	18.6	22.7	28.3	35.3
	Recharge 1	15.4	19.3	23.5	26.6	32.0
	Recharge 2	20.9	24.7	23.9	28.6	33.8
	Recharge 3	15.3	20.7	29.8	35.0	39.7
Bagh-Sorkh	Desilting (part 1)	5.7	10.5	12.9	41.1	44.3
	Recharge 1	6.1	7.8	13.2	26.5	34.7
	Recharge 2	15.7	22.5	32.2	40.7	45.6
	Recharge 3	12.8	23.8	33.3	34.5	33.2
	Recharge 4	19.9	22.8	24.8	25.2	29.5
Kachak	Trench 1	6.1	8.9	16.9	17.4	22.7
	Trench 3	5.1	9.3	18.0	19.5	20.5
	Trench 5	8.0	9.4	14.0	17.7	21.8
	Trench 7	6.2	10.3	11.6	20.0	20.7
	Trench 9	9.8	17.5	16.4	24.0	21.5

Table 6 Initial infiltration capacity and percent improvement of this value for some of the treatments in artificial recharge projects. The average of the particular treatment at every site is given

Site	Basin or trench	Initial infiltration capacity (cm/h)	Improvement (%)		
			T1	T3	T5
Kohrouyeh	Desilting (part 1)	14.0	4	31	56
	Desilting (part 3)	14.0	4	34	56
	Recharge 1	14.0	27	36	53
	Recharge 2	14.0	32	39	52
	Recharge 3	14.0	27	53	65
Average			22.8	38.6	56.4
Bagh-Sorkh	Desilting (part 1)	13.5	9	24	91
	Recharge 1	13.5	10	23	72
	Recharge 2	13.5	33	53	79
	Recharge 3	13.5	29	52	61
	Recharge 4	13.5	35	40	61
Average			21.4	38.4	72.8
Kachak	Trench 1	7.5	12	60	83
	Trench 3	7.5	14	64	79
	Trench 5	7.5	21	49	77
	Trench 7	7.5	15	34	69
	Trench 9	7.5	21	48	70
Average			16.6	51.0	75.6

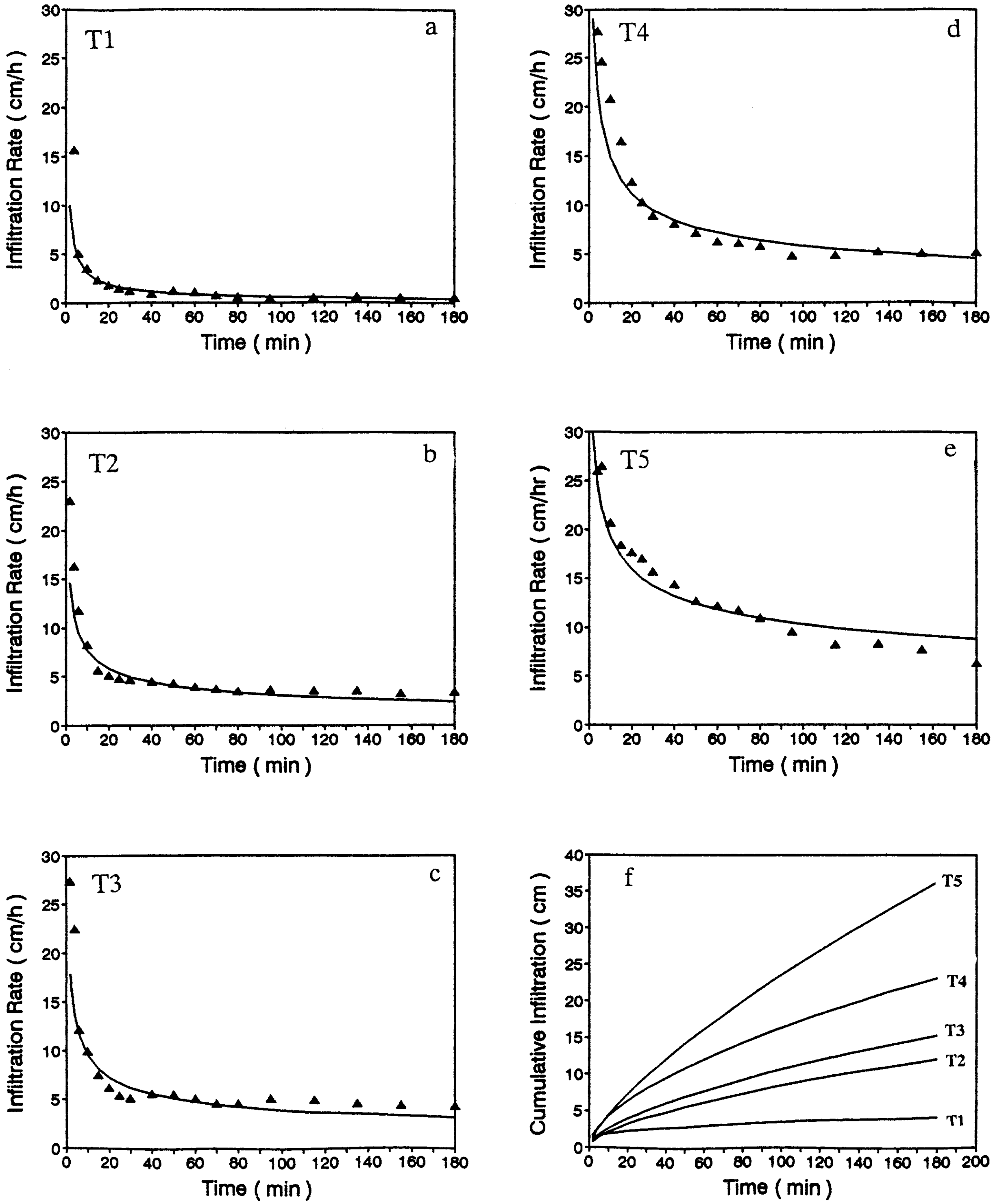

Figure 4 Infiltration rate and cumulative infiltration for part 1 of desilting basin at the Kohrouyeh site

present experiment, clay penetration to a depth of 10 cm in the desilting basins and occasionally more than 40 cm in the recharge basins was observed in the sandy loam soil of the sites. For example, at the Kohrouyeh site, clay percentage at a depth interval of 40–60 cm was 16% (*Table 1*), whereas it was 23% in part 1 of the desilting basin and 22% in the recharge basin number 1. Penetration of fine particles causes infiltration rates to decrease.

Infiltration Treatments

Table 4 shows mean values of final infiltration rates (for three replications in each treatment), and *Table 5*

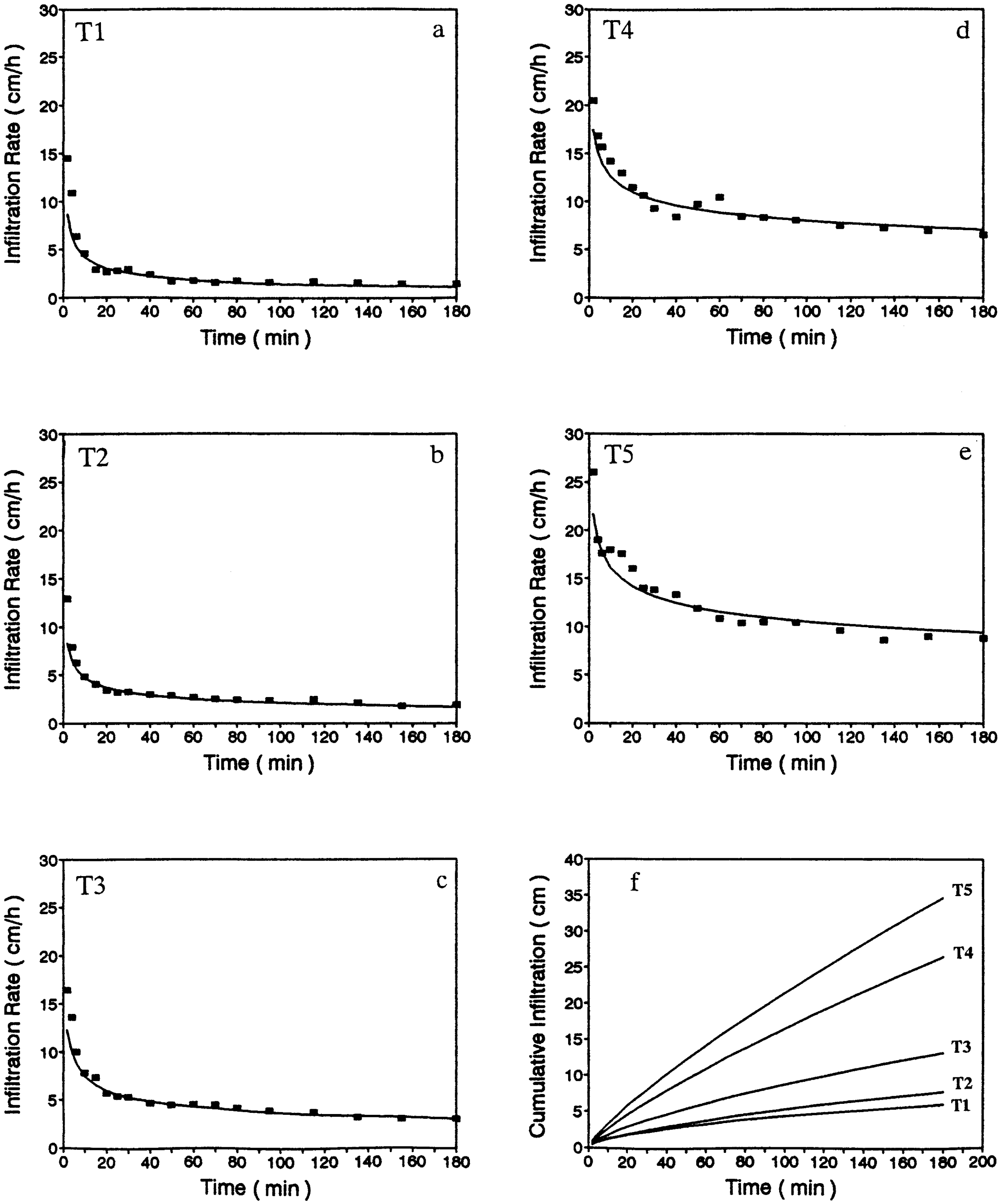

Figure 5 Infiltration rate and cumulative infiltration for recharge basin no. 1 at the Bagh-Sorkh site

shows cumulative infiltration depth (after 3 h) of different treatments in the recharge sites. At every site, final infiltration rate of treatment T1 is the least in the desilting basins and the maximum in the last two recharge basins (or trenches). Significant differences exist between treatments T1 and T5. For example, at the Kohrouyeh site, T1 had a final infiltration rate of 0.53 cm/h, whereas T5 had a value of 7.9 cm/h. In *Table 4*, within each row, mean values followed by a different letter are significantly different at the 5% probability level according to Duncan's Multiple Range Test (Steal and Torrie 1982). For example, at the Kachak site, the final infiltration rates of treatments T5 and T4 for trench no. 5 are 5.8 and 4.34 cm/h and,

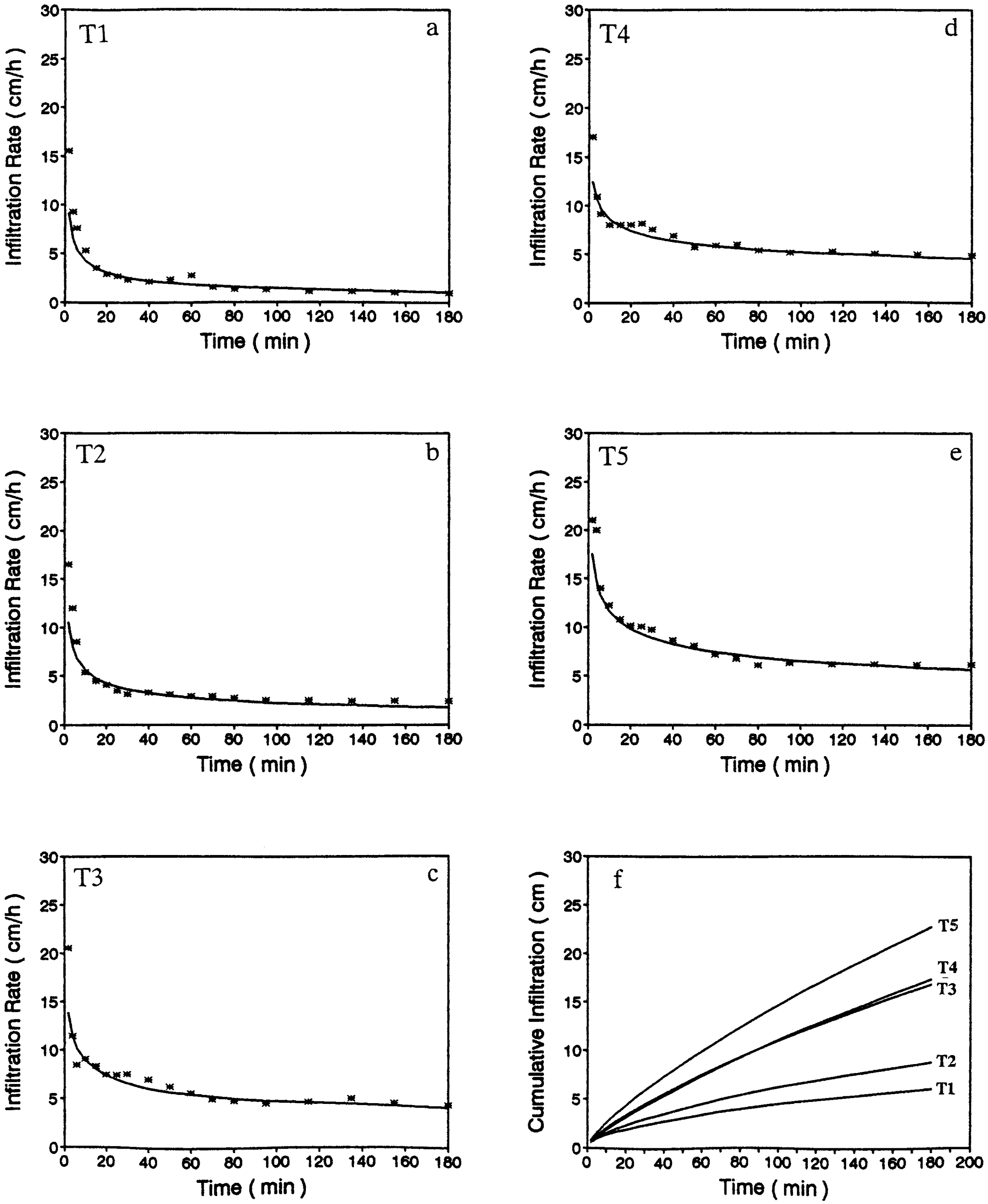

Figure 6 Infiltration rate and cumulative infiltration for recharge trench no. 1 at the Kachak site

hence, statistically different. In contrast, the infiltration rates for trench no. 1 are 6.2 and 5.07 cm/h and, hence, the difference is not statistically significant. The values in each column can be compared without regard to the letters accompanying them. Generally, the statistical difference between treatments T2 and T3 is significant, but between treatments T3 and T4 the difference is not significant (*Table 4*), although all the cumulative infiltration values in treatment T4 are greater than treatment T3 (*Table 5*).

Improvement of infiltration rates is indicated by data in *Tables 5* and *6*. In *Table 6*, the initial infiltration rates and percentage of infiltration improvement after conducting the tests are shown for treatments T1, T3,

Table 7 Infiltration equations by the Kostiakov model for some of the treatments in the artificial recharge sites (Kostiakov 1932)

Site	Basin or trench	Treatment		
		T1	T3	T5
Kohrouyeh	Desilting (part 1)	$I=16.52\ t^{-0.73}$	$I=23.38\ t^{-0.39}$	$I=35.96\ t^{0.27}$
	Desilting (part 3)	$I=16.13\ t^{-0.73}$	$I=23.20\ t^{-0.28}$	$I=28.57\ t^{-0.22}$
	Recharge 1	$I=20.48\ t^{-0.35}$	$I=24.42\ t^{-0.28}$	$I=36.13\ t^{-0.30}$
	Recharge 2	$I=21.26\ t^{-0.28}$	$I=25.78\ t^{-0.30}$	$I=36.69\ t^{-0.30}$
	Recharge 3	$I=18.10\ t^{-0.32}$	$I=30.40\ t^{-0.28}$	$I=44.17\ t^{-0.30}$
Bagh-Sorkh	Desilting (part 1)	$I=10.51\ t^{-0.45}$	$I=12.76\ t^{-0.27}$	$I=32.18\ t^{-0.19}$
	Recharge 1	$I=11.95\ t^{-0.46}$	$I=15.33\ t^{-0.31}$	$I=24.70\ t^{-0.18}$
	Recharge 2	$I=16.87\ t^{-0.29}$	$I=33.68\ t^{-0.28}$	$I=37.99\ t^{-0.23}$
	Recharge 3	$I=15.08\ t^{-0.32}$	$I=35.14\ t^{-0.29}$	$I=45.50\ t^{-0.35}$
	Recharge 4	$I=22.77\ t^{-0.30}$	$I=24.66\ t^{-0.29}$	$I=26.34\ t^{-0.24}$
Kachak	Trench 1	$I=12.67\ t^{-0.48}$	$I=16.68\ t^{-0.27}$	$I=20.80\ t^{-0.25}$
	Trench 3	$I=10.85\ t^{-0.49}$	$I=26.24\ t^{-0.30}$	$I=18.90\ t^{-0.25}$
	Trench 5	$I=15.86\ t^{-0.46}$	$I=18.85\ t^{-0.24}$	$I=25.96\ t^{-0.33}$
	Trench 7	$I=14.54\ t^{-0.51}$	$I=15.25\ t^{-0.35}$	$I=25.40\ t^{-0.32}$
	Trench 9	$I=21.19\ t^{-0.49}$	$I=19.85\ t^{-0.32}$	$I=24.10\ t^{-0.30}$

and T5. In treatment T1, the infiltration rate increased to 22.8, 21.4, and 16.6% of the original values in Kohrouyeh, Bagh-Sorkh, and Kachak projects, respectively. The average of these three values is 20.3%. Treatment T3 resulted in increases of 38.6, 38.4, and 51% of the initial infiltration capacity. Treatment T5 resulted in increases of 56.4, 72.8, and 75.6% (average 68.3%) in the above recharge sites.

Figure 4 shows infiltration rate (*Figure 4a–e*) and cumulative infiltration (*Figure 4f*) for part 1 of the desilting basin at the Kohrouyeh project. The difference between treatments T1 to T5 is demonstrated by the curves in *Figure 4f*. Treatment T1 has cumulative infiltration of 4.2 cm, whereas treatment T5 has a value of 36.3 cm, after 180 min of test. *Figure 5* shows infiltration curves for recharge basin no. 1 of the Bagh-Sorkh project, and *Figure 6* shows similar graphs for the first recharge trench of the Kachak site. Again, the effect of scraping the deposited sediment layer plus 15 cm of topsoil (T5) is shown to be better than just removing the sediment layer (T2). This is because fine silt and clay particles have penetrated to deeper depths, and removing the top 15 cm of soil restores most of the initial infiltration capacity of the recharge basins or trenches.

In *Table 7*, the Kostiakov infiltration equations (Kostiakov 1932) for some of the treatments in basins or trenches of the recharge sites are shown. In all the treatments, coefficients B and n of Kostiakov equation are determined from the experimental data.

Conclusions

Among the various factors that decrease the infiltration rates in artificial recharge projects, deposition of sediments in basins or trenches and the clogging phenomenon are the most significant. Scraping or scratching only the deposited sediments in these recharge facilities is not very efficient in restoring the initial infiltration rate. Three artificial recharge sites of Kohrouyeh, Bagh-Sorkh, and Kachak were evaluated by using five treatments. The dominant soil texture at the sites is sandy loam, and the initial soil moisture content was very low. The infiltration rates into the deposited sediments at these recharge sites had decreased to 22.8, 21.4, and 16.6% of their respective initial infiltration capacities. Removing the deposited sediment layer plus 15 cm of topsoil resulted in a restoration to about 68.3% of the original infiltration capacity.

References

Al-Muttair FF, Sendil U, Al-Turbak AS (1994) Management of recharge dams in Saudi Arabia. ASCE Water Resour Plan Manage 120(6):749–763

Bani-Hashemi SAR (1995) Natural groundwater recharge estimation and groundwater resources management. In: Mousavi SF, Karamooz M (eds) Proceedings of regional conference on water resources management, Isfahan University of Technology, Iran, 28–30 August, pp 79–87

Brady NC (1990) The nature and properties of soils, 10th edn. Macmillan, New York

Goss DW, Smith SJ, Stewart BA, Jones OR (1973) Fate of suspended sediment during basin recharge. Water Resour Res 9(3):668–675

Jones OR, Goss DW, Schneider AD (1981) Management of recharge basins on the southern High Plains. Trans ASAE 24(4):977–980, 987

Kashef AAI (1987) Groundwater engineering. McGraw-Hill, New York

Kostiakov AN (1932) On the dynamics of the coefficient of water-percolation in soils and on the necessity for studying it from a dynamic point of view for purposes of amelioration. Trans 6th Comm Int Soil Sci Soc, part A:17–21 (in Russian)

Kovenya SV, Melnikova MK, Fried AS (1972) Study of the role of mechanical forces and geometrical conditions in the movement of highly dispersed particles in soil columns. Sov Soil Sci 10:133–140 (English translation)

Rice RC (1974) Soil clogging during infiltration of secondary effluent. Water Pollut Control Fed 46(4):708–716

Ripley DP, Saleem ZA (1973) Clogging in simulated glacial aquifers due to artificial recharge. Water Resour Res 9(4):1047–1057

Schuh WM (1988) In-situ method for monitoring layered hydraulic impedance development during artificial recharge with turbid water. J Hydrol 101:173–189
Schuh WM (1990) Seasonal variation of clogging of an artificial recharge basin in a northern climate. J Hydrol 121:193–215
Schuh WM (1991) Effects of an organic mat filter on artificial recharge with turbid water. Water Resour Res 27(6):1335–1344
Steal RGD, Torrie SH (1982) Principles and procedures of statistics: a biometrical approach. McGraw-Hill, New York
Sukhija BS, Nagabhushanam P, Reddy DV (1996) Groundwater recharge in semi-arid regions of India, an overview of results obtained using tracers. Hydrogeol J 4(3):50–71
Water Resources Research Center (1997) Water resources bulletin. Ministry of Energy, Iran
Wright A, du Toit I (1996) Artificial recharge of urban wastewater, the key component in the development of an industrial town on the arid west coast of South Africa. Hydrogeol J 4(1):118–129
Zomorodi K (1990) Optimal artificial recharge in intermittent multibasin system. ASCE Water Resour Plan Manage 116(5):639–651