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Impact of Flood Spreading on Infiltration Rate and Soil Properties in an Arid Environment

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Abstract Flood spreading (FS) is one of the suitable methods for flood management and water harvesting that increases the groundwater recharge, makes soil more fertile and increases nutrients in soil. It is also a method for reusing sediment, which is usually wasted. The purpose of this paper is to investigate the impact of flood spreading on physical and chemical soil properties (soil texture, infiltration rate, pH, EC, Na, P, K, Ca, Mg, Cl, HCO_3, and SO_4). It is examined that the soil properties change in the flood spreading projection area (FSP). The physico-chemical properties of soil and infiltration rate were measured in different soil depths at both flood spreading and control area. For the 20 cm of top soil, the amount of clay increased after the flood spreading implementation especially in the first and second dikes. Increasing clay was accompanied by decreasing soil infiltration and sand percentage. The mean differences of the clay, sand and infiltration rate between FSP and the control area were statistically significant ($P < 0.01$). A significant difference was not observed in 20–30 cm of the depth. Soil pH, Mg, HCO_3, Cl and SO_4 in different soil layers did not show any significant difference between the control and FSP. Soil EC in 0–20 cm depth of FSP and control area was showed a significant difference ($P < 0.05$) but no significant differences were found in deeper layers ($P < 0.05$). K, Na and Ca were remarkably different between 0 and 10 cm depths ($P < 0.05$) whereas no significant differences were found in deeper layers ($P < 0.05$). Comparison of the physico-chemical properties and infiltration rates between the dikes in the FSP shows that there are the significant differences between the medians of dike 1 with dikes 2, 3, 4 and 5, but the differences were not observed between dikes 3, 4 and 5. Our results show that the flood spreading operation can be influenced by the area that is under

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this operation. This study allowed us to investigate the mechanisms that regulate the infiltration rate and chemical soil properties throughout a seasonally flooded area.

Keywords Flood spreading · Soil properties · Infiltration rate

1 Introduction

In the arid and semi-arid regions of the world, water resources are limited, and under severe and increasing pressure due to population growth, increasing per capita water use and irrigation. The management of water resources has become an increasingly pressing issue in this arear (Al-Qudah and Abu-Jabe 2009). In these areas, the quantity of rainfall is worthless, but the distribution of rainfall in time and space is uneven (Reij et al. 1988). The rainfall regime in arid areas is characterized by low, irregular and unpredictable precipitation, often concentrated in a few rainstorms, creating humid conditions in the soil for a short period and over a limited area (Fengxiang 2007). The high intensity and short duration convective of rainfall cause the extensive overland flow. This overland flow, concentrated by the topography, converges on the result that a flood flows. In this area, floods are infrequent, but extremely damaging, and the threat from floods to lives and infrastructure is increasing due to urban development (Osborn and Hickok 1968; Osborn et al. 1979). Furthermore, there are many inconvenient effects of flooding on human settlements and economic activities. However, with a suitable management, floods can be attributed our benefits specially in the arid and semi arid area (Kowsar 1992).

Water harvesting technologies, which concentrate precipitation through runoff and storage for beneficial use, have probably been in use since 9,000 BC (Oweis et al. 2001) and it is now widely practiced in the world. There are several techniques for implementation of water harvesting based on farming and watershed management policy. Some of water harvesting methods for water collection into especial tanks for livestock water supply was used in Australia (Reij et al. 1988).

Flood spreading is one of the suitable methods for flood management and water harvesting that increases the groundwater recharge, makes soil more fertile and provides the soil nutrients (Dhruva Narayana et al. 1990; Unger et al. 2009). Floodwater spreading is also a method for harvesting water and reusing the sediment, which is usually wasted (Kowsar 1992).

It has been widely recognized that infiltration of ephemeral flows into alluvial channel beds is a characteristic feature of the hydrology in arid areas (Pilgrim et al. 1988) and is important with respect to flood propagation (Renard and Keppel 1966) and groundwater recharge (Wallace and Renard 1967). Flood-water can transfer a great amount of sediment to the spreading area. The quantity and quality of this sediment depend to rainfall intensity, flood quantity and geological condition of catchments (Parissopoulos and Wheater 1992). The presence of fine sediment within the alluvium was shown to have the important effects on surface infiltration as well as subsurface redistribution (Parissopoulos and Wheater 1990). Fine sediments intrude into the interstitial spaces, and get strained within the pores (Boulton 2000; Schälchli 1992). Usually both clogging mechanisms (gravity driven sedimentation and particle intrusion by infiltration) superpose each other and create a dense layer through which the filtrate has to pass (Brunke and Gonser 1997; Boulton et al. 1998). The degree which the infiltration will be reduced is dependent to the particle size of the suspended materials, total sediment load, and the pore geometry of the underlying materials. The study of a flood harvesting system shown that infiltration rate has been reduced 5.3 times in FSP as compared to the control area (Arabkhedri et al. 1997). A research in Argentina showed that infiltration rate had a direct and positive relation with vegetation cover and a negative relation with sandy cover of soil while sediment production has a negative relation with density, plant species and sandy cover properties (Rostagno 1989). The flood spreading operation can also influence the vegetation cover in the area that is under of this operation (Toda et al. 2005).

Because of population growth during the last few decades, groundwater has become an important source of freshwater throughout the world, especially in arid and semi arid region. It is also an important component of the hydrological cycle (Rejani et al. 2008; Thomas et al. 2009). The exchange between groundwater and surface water bodies in the floodplain can influence both the water quality and groundwater level variation. Floodwater temporally can influence groundwater flow level after a recharge event. Surface water may interact with the neighbouring aquifer during flood events when the groundwater is closed to land surface. Stream water levels that rise in response to runoff may result in lateral water flow into the neighbouring floodplain (Todd 1995; Kondolf et al. 1987; Peterjohn and Correll 1984).

Percolation of flood waters into the bed and banks of ephemeral streams provides one of the key mechanisms responsible for transmission loss. Flood affects not only river geomorphology but also the transport of other fundamental materials such as organic materials and nutrients. Therefore, sediment-associated nutrient transport during the flood event must be investigated in order to understand the role of flood flow in river environments. The motivation of this research was to investigate the impact of the flood spreading on the physical and chemical soil properties (Soil texture, infiltration rate, pH, EC, Na, P, K, Ca, Mg, Cl, HCO_3, and SO_4). We examined the soil properties change in the flood plain area and potential of flood sediments for improving the soil. Field observations were conducted to determine the effects of flood flow on the geometrical and chemical characteristics of flood plain soil.

2 Study Site and Data Monitoring

2.1 Study Site

The study site named Hajitahere (latitudes 28°52′28″ N, longitudes 54°41′30″ E) located in a catchment 25 km west of Darab, Fars, Iran. Darab has been located in arid and semi-arid zone with hot and dry summer and cold and dry winter.

Local meteorological data were measured in Darab city. The area has a mean annual rainfall of 290 mm of which 85% was occurred in the autumn–winter period, 13% in the spring and only 2% in the summer (Fig. 1). The mean annual air temperature is 22°C, ranging from 9.6°C in January to 34°C in July.

The main study area, which FSP located there, has 2.2 km length and 1.5 km wide. General slope in the flood plain is between 1% and 5%. In some parts of the slopes, there are sediment formations in shape of marl and silt that can be source of river sediment in this area. The most area in Hajitahere was formed from alluvial sediment with too much boulders and also shallow soil. The Flood spreading area was located

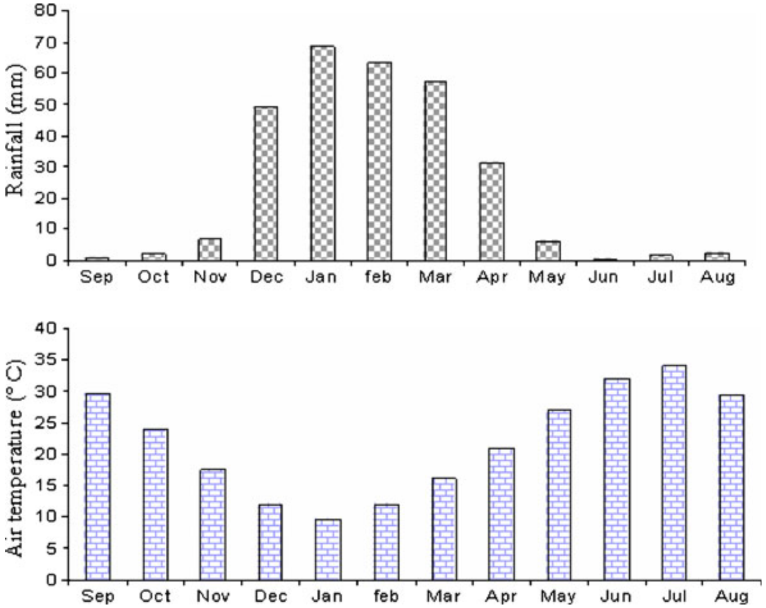


Fig. 1 Monthly means of rainfall and temperature at local meteorological station of Darab. Average of 30 years (1976–2006)

in piedmont and flood plain area. According to the observation wells, in the study period, groundwater depth in the area was between 30 and 45 m. The groundwater surface level was deeper in the end of summer and raised with increasing of rainfall. The groundwater depth was deeper also in the area with higher elevation.

2.2 Data Monitoring

The field observations were performed in the Hajitahere in Darab, Iran, during September 2005 to August 2006. The research was conducted at two close areas: control and flood projection area (Fig. 2). The FSP was initiated in 2000 utilising the flow of Hajitahere river. So dikes were active for 5 years at the time of study. Before flood spreading project, the FSP and control area had the same condition in view of soil and plant covers. A control area was selected which located more distinct from the stream channel, but with same topography condition. In the flood projection area, some dikes have been made on isoaltitude lines. There are some overflows for leading extra floodwater to the other dikes. The distance of overflow spacing is about 50 m. Immediately after each dike, a settlement basin (spreading channel) was made for water relaxation and suitable time for more penetration (Fig. 2a). Water spreading designed as the water was transported by transition channel to the first diffusion channel and separated behind of the first dike (Fig. 2b). After inflowing of water to this basin, water will reach to a particular level (0.2 m) for spreading inside the FSP region. When the level of water behind of the first dike reaches to a level that all soil surfaces were irrigated, water will be transferred to the second diffusion channel by the overflows. Before the project, both control and FSP area had the

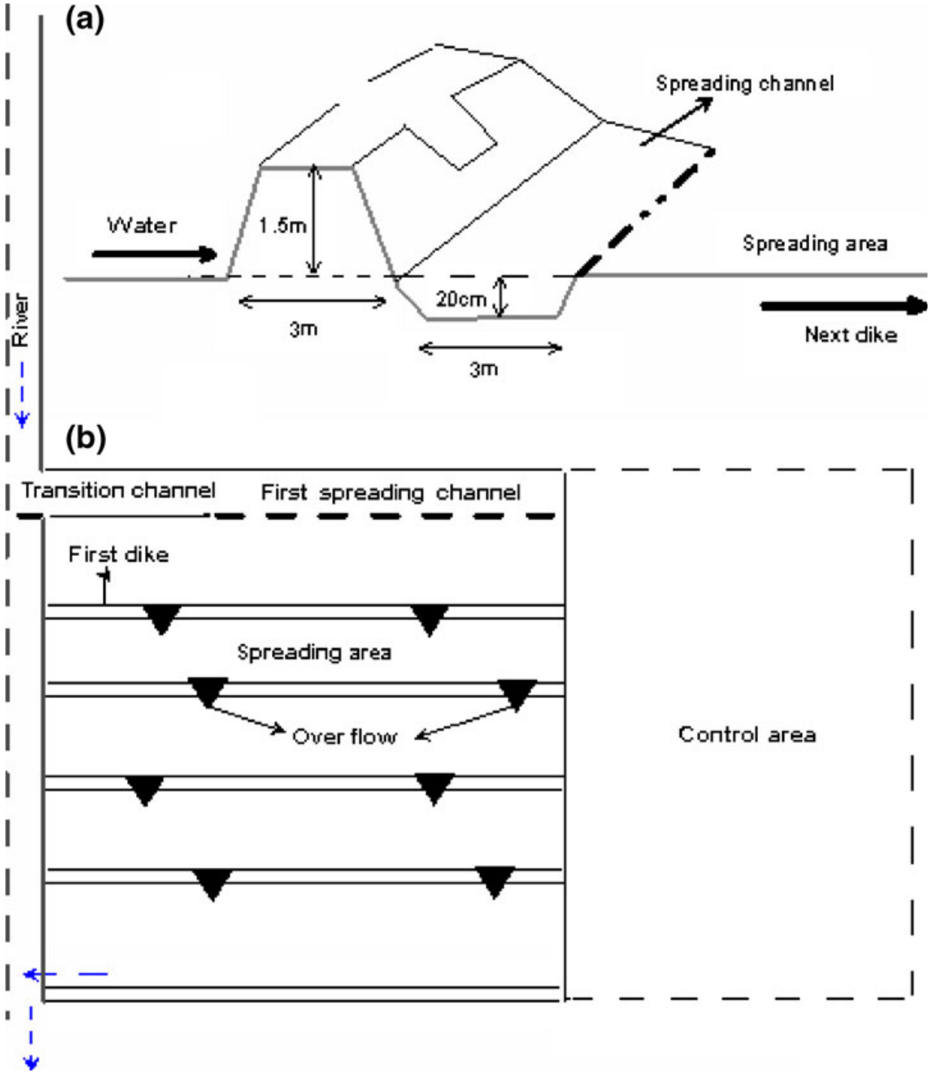


Fig. 2 Schematic of the studied area

same flooding condition. Hajitahere is an ephemeral river that its flow (about ten yearly peak flows) distributes on FSP area. The mean yearly flood water of this river is about one million cubic meters. Local direct runoff is the only water recourses in control area.

For the exact comparison between, before and after the FSP implementation, sampling operation and measurement were done in control land around the project area wich is exactly similar to primary situation of areas.

To measure the infiltration rates, 30 points in FSP (six points after any dike) and 30 points in the control area were selected. The infiltration measurements were done in triplicates with double ring method (Haise et al. 1956).

Soil sampling was conducted within the FSP and control area based on grid sampling system and also by auger from soil surface. Soil samples were taken in the neighbor of point that infiltrations were measured. The depths of sampling were 0–10, 10–20, and 20–30 cm. Recognition between the transferred sediment and base topsoil in area was capability of auger applying in the soil. Control area does not have transferred sediment (except in waterways). The samples were analyzed for selection of Calcium, Magnesium, Bicarbonate, Phosphorous, Potassium, EC, pH, and Soil texture. Selecting of these elements was done based on the assumption that changing of them will be effective in improvement or degradation of soil situation. For statistical analysis of the data, the MINITAB statistical package (Minitab 14 Statistical Software) and Excel (Microsoft Office Excel 2003) were used.

3 Results

3.1 Impact of Flood Spreading on Soil Physical Properties and Infiltration Rate

3.1.1 Comparison of Changes Between FSP and Control Area

A two-sample *t* test analysis was used to compare the soil properties of the FSP and the control areas. This test was carried out in MINITAB.

The results of particle size distribution analysis are shown in Table 1. The percent of clay in the 30 cm of topsoil in control area is <3%. This indicates a light texture

Table 1 Physical soil properties in FSP and control area in different soil layers with their standard divisions (below them)

Soil characteristics	Depth (cm)	FSP	Control	ANOVA
Clay (%)	0–10	8.17	1.96	**
		2.34	0.44	
	10–20	4.55	2.01	**
		1.04	0.56	
	20–30	2.67	2.12	ns
		0.78	0.95	
Silt (%)	0–10	30.05	27.83	ns
		4.41	2.39	
	10–20	29.43	25.77	ns
		3.84	2.69	
	20–30	26.72	25.17	ns
		3.59	3.18	
Sand (%)	0–10	62.05	70.22	**
		5.44	2.41	
	10–20	66.00	72.22	**
		4.06	2.90	
	20–30	70.74	72.71	ns
		3.95	3.60	
Infiltration rate (mm/h)	0–10	1.15	4.99	**
		0.11	0.42	
	10–20	3.99	7.45	**
		0.22	0.47	
	20–30	31.28	31.80	ns
		0.77	1.01	

ns treatment effect not significant (ANOVA results)
$^{**}P < 0.01$ (ANOVA results)

for topsoil in the study area that is a positive factor for the flood spreading area. The results of analyses show that the amount of clay increased after the flood spreading implementation especially in the first and second dikes. The clay content in the 30 cm of topsoil in FSP area is between 2.67% and 8.17% with a mean of 5.13. Increasing clay was accompanied by decreasing sand percentage. After 5 years that dikes were active, for the 20 cm of top soil, the mean difference of the clay and sand between the FSP and the control area was statistically significant ($P < 0.01$), while for 20–30 cm of depth, the mean difference between the FSP and control was not significant ($P < 0.05$). The results show that the amount of silt increased a little after the flood spreading implementation, but the mean difference between the FSP and control area is not significant ($P < 0.05$).

The vertical variation of the infiltration indicated that the permeability increased with increasing depth at both control and flood spreading area. The results of analyses show that the infiltration rate has been decreased after the flood spreading implementation companied with the previous condition of area (control area). This increasing is more important in the first 10 cm of the topsoil. The infiltration rate between 0 and 10 cm depths in the control area was about 4.5 times higher as compared with the FSP. The mean difference between the FSP and control area is significant for 20 cm of topsoil but significant different was not observed in deep soil (20–30 cm).

3.1.2 Comparison of Changes Between the Dikes

A one-way ANOVA with multiple comparisons was used to test the equality of means and to assess the differences in means between the dikes in the FSP.

Table 2 indicates the results of the Analysis of Variance for clay, silt and sand. This test shows that the amount of clay has been increased in some dikes and difference between the medians is significant ($P < 0.01$). Comparison of clay percentage between dikes in the FSP shows that there are a significance differences between medians of dike 1 with dikes 2, 3, 4 and 5, but the differences were not observed between dikes 3, 4 and 5.

Percentage of silt was changed in the FSP but it did not change from top to bottom significantly (Table 2). In the first dike, the percentage of sand was decreased with

Table 2 Physical soil properties and infiltration rate between dikes in FSP in 30 cm of topsoil layer with their standard divisions (below them)

Soil characteristics	Dike 1	Dike 2	Dike 3	Dike 4	Dike 5	ANOVA
Clay (%)	8.73a	7.07b	3.89c	3.28c	2.77c	**
	2.27	2.11	1.35	0.64	0.52	
Silt (%)	31.22a	29.41a	29.98a	30.60a	30.75a	ns
	4.11	4.31	3.39	3.80	3.62	
Sand (%)	60.04b	64.52a	66.13a	66.12a	66.48a	*
	5.50	5.42	3.51	4.06	4.09	
Infiltration rate(mm/h)	10.78d	11.23c	12.59c	17.53b	19.58a	*
	2.36	2.35	2.40	2.49	2.44	

Mean value with the same letter within the physical soil properties do not differ significantly between dikes

ns treatment effect not significant (ANOVA results)

$^{*}P < 0.05$, $^{**}P < 0.01$ (ANOVA results) increasing clay. A significant difference was observed between first dike and other ones. Infiltration rates were increased significantly from the top to the down in the FSP (Fig. 2; Table 2). Due to flood sedimentation; it is possible that with time the clay content of all dikes increase. If clay content increasing reduces the infiltration rate of all dikes, we have to use the mechanisms that regulate the infiltration rate.

3.1.3 Comparison of Changes Between FSP and Control Area

There were very few differences in chemical soil properties between FSP and control area (Table 3). Soil pH, ranging from 7.91 to 8, Mg, ranging from 1.18 to 1.84, HCO_3 ranging 2.63 to 3.1, Cl ranging from 1.7 to 1.40 and SO_4 ranging from 0.63 to 1.38 in different soil layers did not show any significant difference between the control and FSP. Soil EC in 0–20 cm depth of FSP and control area was different but no significant differences were found in deeper soil layers ($P < 0.05$). K, Na and Ca

Table 3 Chemical soil properties in FSP and control area in different soil layers with their standard divisions (below them)

	Depth (cm)	FSP		Control		ANOVA
		Mean of 30 samples	SD	Mean of 30 samples	SD	
EC	0–10	0.59	0.10	0.51	0.10	*
	10–20	0.48	0.10	0.41	0.06	*
	20–30	0.44	0.11	0.42	0.06	ns
PH	0–10	7.91	0.06	7.94	0.07	ns
	10–20	7.97	0.06	8.00	0.06	ns
	20–30	7.99	0.06	7.99	0.07	ns
K	0–10	0.16	0.02	0.14	0.01	*
	10–20	0.15	0.03	0.15	0.02	ns
	20–30	0.13	0.02	0.12	0.02	ns
Na	0–10	0.78	0.20	0.57	0.13	*
	10–20	0.71	0.21	0.71	0.20	ns
	20–30	0.74	0.27	0.71	0.20	ns
Ca	0–10	4.29	1.08	3.65	1.06	*
	10–20	3.31	1.12	2.58	0.42	ns
	20–30	3.03	0.69	2.38	0.42	ns
Mg	0–10	1.18	0.44	1.84	0.43	ns
	10–20	1.21	0.48	1.33	0.45	ns
	20–30	1.21	0.26	1.37	0.37	ns
HCO_3	0–10	2.85	0.41	3.10	0.30	ns
	10–20	2.71	0.33	2.79	0.36	ns
	20–30	2.66	0.30	2.44	0.23	ns
Cl	0–10	2.40	0.42	1.99	0.42	ns
	10–20	1.90	0.43	1.72	0.32	ns
	20–30	1.93	0.28	2.04	0.50	ns
SO_4	0–10	1.38	0.75	1.21	0.88	ns
	10–20	0.99	0.83	0.40	0.22	ns
	20–30	0.63	0.32	0.39	0.15	ns

ns treatment effect not significant (ANOVA results)
*$P < 0.05$ (ANOVA results)

Table 4 Chemical soil properties between dikes in FSP in 30 cm of topsoil layer with their standard divisions (below them)

Dikes	EC	PH	K	Na	Ca	Mg	HCO_3	Cl	SO_4
1	0.49a	8.02a	0.17a	0.86a	3.27a	1.78a	2.99a	1.97a	0.47a
	0.05	0.05	0.03	0.16	0.39	0.22	0.18	0.49	0.15
2	0.51a	8.01a	0.17a	0.85a	3.41a	1.76a	3.01a	2.01a	0.44a
	0.12	0.06	0.01	0.15	0.32	0.34	0.33	0.53	0.20
3	0.56a	7.98a	0.12b	0.86a	3.31a	2.09a	3.11a	1.97a	0.48a
	0.12	0.04	0.03	0.10	0.32	0.35	0.40	0.33	0.16
4	0.33b	7.89a	0.13b	0.56b	2.03b	2.02a	3.01a	1.96a	0.48a
	0.13	0.05	0.02	0.35	0.66	0.50	0.18	0.22	0.14
5	0.33b	7.81a	0.12b	0.54b	2.11b	1.79a	3.03a	2.05a	0.48a
	0.06	0.02	0.03	0.21	0.61	0.34	0.24	0.22	0.15
ANOVA	**	ns	**	**	**	ns	ns	ns	ns

ns treatment effect not significant (ANOVA results)
$^{*}P < 0.05$, $^{**}P < 0.01$ (ANOVA results)

were different between 0 and 10 cm depths whereas no significant differences were found in deeper soil layers ($P < 0.05$).

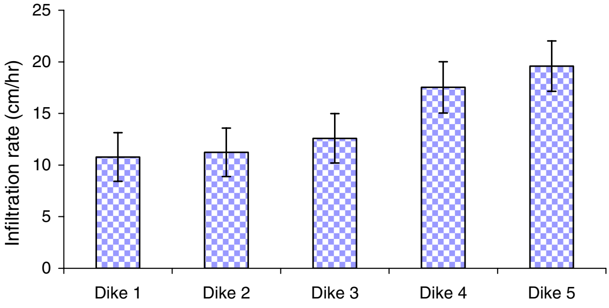
3.2 Impact of Flood Spreading on Chemical Soil Properties

3.2.1 Comparison of Changes Between the Dikes

This test has been carried out for investigation of the impact of flood-spreading project between dikes. The results showed that the amount of EC, Na, K, and Ca were significantly different between the dikes whereas no significant difference was observed for PH, Mg, HCO_3, Cl, and SO_4 (Table 4).

Amount of EC, Na, K, and Ca decreased from the top to bottom (Fig. 3). The results show that the amount of EC ranging between 0.56 and 0.33 ds/m increased slightly after the flood spreading implementation in dikes 1–3 in comparison to the dikes 4 and 5. The same results obtained for Na (ranging from 0.86 to 0.54), K (ranging from 0.17 to 0.12), and Ca (ranging from 3.41 to 2.03).

Fig. 3 Infiltration rates between dikes from top (dike 1) to down (dike 5) in the FSP



4 Discussion

The results of particle size distribution analysis indicate a significant difference in the percentage of clay and sand among flood spreading and control sites specially in 10 cm of topsoil. In the flood spreading area, the lowest value of clay (2.77 ± 0.52%) obtained in the fifth dike and the highest (8.73 ± 2.27) in the first dike. The results of our research indicate that sedimentation had a great impact on surface permeability decreasing. This decreasing was more important in 10 cm of topsoil where maximum increasing of clay sedimentation was observed. No significant different was observed in 30 cm depth for clay percentage and infiltration rate. The direct conclusion of these results is also that FSP may reduce groundwater recharge, but it increase water intensity and time of infiltration before the dikes and so increases the amount of the accumulated infiltration. Infiltrating surface water is gradually converted into artificial groundwater. Increasing of groundwater recharge can used to avoid groundwater depletion, store and recover groundwater and provide seasonal and long-term storage (Artimo et al. 2008).

The rate of infiltration decrease was depended on the particle size distribution of the suspended materials of the floodwater, total sediment load, the pore geometry of the underlying materials. As a result, infiltration rate was negatively correlated to the fine fraction of the soil (silt + clay) in the flooding zone. Several studies have reported the interaction of infiltration rate and soil texture (Boulton 2000; Schälchli 1992). Study of infiltration and sediment production in a shrubland of Patagonia showed that infiltration rate has a direct and positive relation with vegetation cover and a negative relation with the percent of clay (Rostagno 1989). If maintenance of the system would not be done well, it could be very dangerous after several years and soil infiltration will be decreased and thus the vegetation cover will be destroyed. In order to decrease the adverse effects of sedimentation in the flooded basin, removing the recent sediment, plowing the top 10 cm of the natural surface below the removed sediment, and plowing can be effective. In the light texture soil, increasing clay can also improve soil texture and soil moisture storage capacity. These changes can be useful to increases the vegetation cover (Gupta et al. 1995).

Statistically no significant differences were observed in the soil pH, Mg,HCO_3, and SO_4 in 0–30 cm of soil layers between the FSP and control area, whereas significant increase in the soil EC, K, Na, Ca, and Mg have been found specially in 0–10 cm depth.

The main reason for the increasing of soil EC, K, Na, and Ca in 0–10 cm depth in the flood spreading area compared to the control area might be the flood and sediment quality related to differences to previous soils condition of watershed in upslope. Related to flood quality, different research indicates increasing of pH (Ponnamperuma 1972), decreasing of EC (Gambrel and Patrick 1978) and a change in the composition and activity of soil microbial communities (Magnunsson 1992, 1994).

Our results show that the majority of flood spreading effects were useful for soil properties. K, Na, and Ca were increased in the flood spreading area. Those elements can improve the physical characteristics of soils and consequently a better vegetation cover will be installed in the flood spreading area. The crops planted in FSP area less suffer from moisture stress. Flood water spreading is also an effective mechanical land treatment that increases plant production and reduces flood peaks and sediment loads to downstream areas. Flood spreading can use for change in land use due to increasing soil water storage and fertility. Land cover and land use changes alter the hydrological cycle of a catchment by modifying infiltration and runoff, particularly in small catchments (Cao et al. 2009).

The production potential in FSP area is relatively high, though to varying degrees impeded by stresses related to flooding and drainage (Nebel 2001). Gupta et al. (1995) showed that water harvesting increased in total biomass compared with the control, doubled the root mass, and also has increased tree height by 20%, and water use efficiency from 4.78 (in the control) to 39.6 kg cm^{-1} ha^{-1}. This research indicates that benefit of water harvesting is high, and that is useful for increasing of vegetation cover.

Water storage behind the dikes can control floods event and increases the time of infiltration, in consequence the floodwater penetrates soil profile and recharges the aquifer. Willis et al. (1997) reported that under a flood irrigation system, groundwater recharge significantly and rising of groundwater were dependent on the weather conditions.

5 Conclusions

Physico-chemical soil properties under a flood spreading area were studied in comparison with a control area. The results show that sediment depth, infiltration rate, EC, Na, K, and Mg changed significantly in the flood spreading area. Significance differences for some of these soil properties were observed between the dikes. Generally, these changes can improve soil texture. Flood spreading operation can influence all of the area that is under this operation. Soil properties, vegetation cover, water levels and water quality and even socio-economic factors can be changed after implementation of floods. This study allows us to suggest a number of hypotheses concerning the mechanisms that regulate the infiltration rate and chemical soil properties throughout a seasonally flooded area. Future investigations should combine measurements of groundwater quality and dynamic, microbial biomass, organic matter contents and enzymatic activity under flooding area.

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References

Artimo A, Sami S, Ylander I (2008) Methods for integrating an extensive geodatabase with 3D modeling and data management tools for the Virttaankangas Artificial Recharge Project, Southwestern Finland. Water Resour Manage 22(120):1723–1739

Al-Qudah KH, Abu-Jabe N (2009) A GIS database for sustainable management of shallow water resources in the Tulul al Ashaqif Region, NE Jordan. Water Resour Manag 23(3):603–615

Arabkhedri MA, Sarreshtehdari A, Kamali K (1997) The long time effect of flood harvesting on infiltration rate. In: Proceedings of the 8th international conference on rainwater catchment system, vol 2. Ministry of Jihad-e-Sazandegi, Tehran, pp 1157–1158

Boulton AJ (2000) River ecosystem health down under: assessing ecological condition in riverine groundwater zones in Australia. Ecosyst Health 6(2):108–118

Boulton AJ, Findlay S, Marmonier P, Stanley EH, Valett HM (1998) The functional significance of the hyporheic zone in streams and rivers. Ann Rev Ecolog Syst 29:59–81

Brunke M, Gonser T (1997) The ecological significance of exchange processes between rivers and groundwater. Freshw Biol 37:1–33

Cao W, Bowden WB, Tim Davie T, Fenemor A (2009) Modeling impacts of land cover change on critical water resources in the Motueka river catchment, New Zealand. Water Resour Manag 23:137–151

Dhruva Narayana VV, Sastry G, Patnaik US (1990) Watershed management. Indian Council of Agricultural Research, New Delhi, p 176

Fengxiang XH (2007) Biogeochemistry of trace elements in arid environments. Springer, Netherlands, p 355

Gambrel RP, Patrick WH (1978) Chemical and microbiological properties of anaerobic soils and sediments. In: Hook DD, Crawford RMM (eds) Plant life in anaerobic environments. Ann Arbor Science, Mich pp 375–423

Gupta GN, Bala N, Choudhary KR (1995) Effect of run-off harvesting and conservation techniques on growth and biomass production of Prosopis cineraria. Indian For 121:702–710

Haise HR, Donnan WW, Phelan JT, Lawhon LF, Shockley DG (1956) The use of cylinder infiltrometers to determine the intake characteristics of irrigated soils. Publ ARS 41-7, Agricultural Research Service and Soil Conservation Service, USDA, Washington DC

Kondolf GM, Maloney LM, Williams JG (1987) Effects of bank storage and well pumping on base flow, Carmel River, Monterey County, California. J Hydrol 91:351–369

Kowsar A (1992) Desertification control floodwater spreading in Iran. Unasylva 43:27–30

Magnunsson T (1992) Studies of the soil atmosphere and related physical site characteristics in mineral forest soils. J Soil Sci 43:767–790

Magnunsson T (1994) Studies of the soil atmosphere and related physical site characteristics in peat forests soils. For Ecol Manag 67:203–224

Nebel G (2001) Sustainable land-use in Peruvian flood plain forests: options, planning and implementation. For Ecol Manag 150:187–198

Osborn HB, Hickok RB (1968) Variability of rainfall affecting runoff from a semiarid rangeland watershed. Water Resour Res 4(1):199

Osborn HB, Renard KG, Simanton JR (1979) Dense networks to measure convective rainfall in the Southwestern United States. Water Resour Res 15(6):1701

Oweis T, Prinz D, Hachum A (2001) Water harvesting. In: Indigenous knowledge for the future of drier environments. International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo

Parissopoulos GA, Wheater HS (1990) Numerical study of the effects of layers on unsaturated saturated two-dimensional flow. Water Resour Manag 4:97–122

Parissopoulos GA, Wheater HS (1992) Experimental and numerical infiltration studies in a wadi stream bed. Hydrol Sci J 37:27–37

Peterjohn WT, Correll DL (1984) Nutrient dynamics in agricultural watershed: observations on the role of a riparian forest. Ecology 65:1466–1475

Pilgrim DH, Chapman TG, Doran DG (1988) Problems of rainfall–runoff modelling in arid and semi-arid regions. Hydrol Sci J 33(4):379–400

Ponnamperuma FN (1972) The chemistry of submerged soils. Adv Agron 24

Reij C, Mulder P, Begemann L (1988) Water harvesting for plant production 0-8213-1142-5. The World Bank, Washington

Rejani R, Madan KJ, Panda SN, Mull R (2008) Simulation modeling for efficient groundwater management in Balasore Coastal Basin, India. Water Resour Manag 22(1):23–50

Renard KG, Keppel RV (1966) Hydrographs of ephemeral streams in the southwest. J Hydraul Div 92:33–52

Rostagno CM (1989) Infiltration and sediment production as affected by soil surface condition in a shrubland of Patagonia, Argentina. J Range Manag 27:382–385

Schälchli U (1992) The clogging of coarse gravel riverbeds by fine sediment. Hydrobiologia 235/236:189–197

Thomas TR, Jaiswal K, Galkate R, Singh S (2009) Development of a rainfall–recharge relationship for a fractured basaltic aquifer in Central India. Water Resour Manag 23(15): 3101–3119

Toda Y, Ikeda S, Kumagai K, Asano T (2005) Effects of flood flow on flood plain soil and riparian vegetation in a Gravel River. J Hydrol Eng 131:950–960

Todd GK (1995) Groundwater flow in relation to the flooding stream. Proc Am Soc Civ Eng 81(628):20–28

Unger IM, Motavalli PP, Muzika RM (2009) Changes in soil chemical properties with flooding: a field laboratory approach. Agric Ecosyst Environ 131:105–110

Wallace DE, Renard KG (1967) Contribution to regional water table from transmission losses of ephemeral stream beds. Trans Am Soc Agric Eng 10:786–789

Willis TM, Black AS, Meyer WS (1997) Estimates of deep percolation beneath cotton in the Macquarie Valley. Irrig Sci 17:141–150