INTERNATIONAL JOURNAL OF PLANT, ANIMAL AND ENVIRONMENTAL SCIENCES

IJPAES

Volume-3, Issue-1, Jan-Mar-2013 ISSN 2231-4490

Coden : IJPAES www.ijpaes.com

Received: 11th Jan-2013 *Revised: 23rd Jan-2013* *Accepted: 23rd Jan -2013*

Research article

COMPARATIVE EFFICIENCY OF RAINWATER HARVESTING BY SOME TYPES OF MICROCATCHMENTS

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ABSTRACT: The efficiency of three structures of rainwater harvesting namely: terraces, quadrangular and semi-circular bunds was investigated in Al Souda National Park (southwestern Saudi Arabia, 18° 17′ 59′′ N 42° 21 47′′ E). The study area was dominated by *Juniperus procera* Hochst. ex Endlicher trees. Terraces, quadrangular and semi-circular bunds significantly reduced runoff (8.6, 12.3 and 8.8 L/ha, respectively) as compared to control (19.6 L/ha). Also terraces, semi-circular and quadrangular bunds significantly reduced soil erosion (87.1, 75.3 and 31.0 kg/ha, respectively) as compared to control (109.6 kg/ha). Porosity percent was significantly higher in quadrangular, and semi-circular bunds and terraces (38.9, 38.8, and 37.4%, respectively) than in control (26.3%). Similarly, soil bulk density was maximum in control (1.90 g/cm³) as compared to repaired terraces (1.62 g/cm³), quadrangular and semi-circular bunds (1.69 and 1.66 g/cm³, respectively). Soil moisture content percent (MC %) significantly increased in all microcatchments compared to control. The increase in soil MC % was maximum at 5 cm soil depth, moderate at 15 cm and least at 30 cm soil depth. Improvement of soil and water conservation by microcatchments caused significantly more growth and survival of seedlings of *J. procera* as compared to control (7.0 and 4.8 cm in diameter; 46.3 and 24.8 cm in height; and 86.8 and 55.4% survival rate in seedlings in microcatchments and control, respectively).

Key Words: Juniper: Runoff; Soil erosion; Bulk density; Porosity; Soil moisture content

INTRODUCTION

Juniperus procera Hochst. ex Endlicher is the dominant tree species at 1600 m.a.s.l. or higher in southwestern Saudi Arabia. It occupies approximately 95% of the natural forest area [1]. These forests provide construction wood, firewood, grazing, beekeeping, reduction of water runoff in the mountainous areas thus protecting watersheds, reduce soil erosion on steep slopes, as well as reduce silting and damage to dams at the foothills [2]. In addition, they are important carbon sinks in their biomass and soil [3]. Due to the mountainous topography of the region, terraces are the main form of rainwater harvesting [4]. Most terraces in the juniper ecosystem have been destroyed and abandoned [5]. A widespread die-back and general deterioration of *J. procera* have been reported [6] [7] [8] [9] [10] [5]. This decline was associated with soil erosion, and surface runoff. Most juniper forests are fragile and with inadequate regeneration [11]. The frequency of abandoning agricultural land in the Middle East has been increasing. Abandoned fields in semi-arid areas are more subjected to gully erosion. Soil compaction and the limited vegetation cover caused the formation of soil crusts which were characterized with low infiltration and runoff [12]. In southwestern Saudi Arabia national parks are characterized with severe soil compaction that reduced water infiltration into the soil. Soil depth decreases dramatically with increasing distance from Juniper trees [7]. Terraces are important tools for rainwater harvesting in southwestern Saudi Arabia, whereas their destruction increased soil loss, surface runoff, bulk density and reduced infiltration. Junipers growing along intact terraces showed better performance [5]. The conversion of sloping lands to terraces in China, had significantly reduced soil erosion, bulk density and nutrient loss [44]. Terraces cover an area of approximately 13,200,000 ha in China [13]. In southeastern Spain terraces increased plant growth by reducing runoff [14].

Middle East and North Africa are the driest regions on Earth, containing only 1% of the world's freshwater resources. Countries in this region ran out of renewable freshwater decades ago, caused them unable to meet their requirements using the available water resources [15]. In arid and semi-arid areas the high rate of evaporation usually happens in growing seasons, and characterized by heavy rain-storms which made the soil unable to absorb the large amount of water in such a short period of time which resulted in high surface runoff [16]. This problem can be minimized by utilizing the limited amount of rainfall as efficiently as possible, by using the surface runoff through water harvesting [16]. Water harvesting is a method of collecting surface runoff from catchment areas and storing it in surface reservoirs or in the root zone of a cultivated area, and it is an ancient art practiced in the past in many parts of the world [17]. Terrace is one of several types of mechanical methods to control erosion, in the form of earth embankment constructed across the slope to intercept surface runoff, convey it to a stable outlet at a non-erosive velocity and shorten slope length [18]. Terrace alters topographic surface because its primary purpose is to create stable flat surfaces for agriculture on steep terrain otherwise unsuitable for sustained farming [19]. Terracing has been reported as causing positive effects by reducing runoff coefficient and soil loss, and maintaining soil moisture content. Runoff and soil loss in terraces in Likhu Khola drainage basin, Middle Hills, Nepal in the majority were lower than the rates that commonly perceived in other areas in the Middle Hills of the Himalaya [20]. The study was conducted in Al Souda National Park (southwestern Saudi Arabia: 18° 17′ 59′′ N 42° 21 47′′ E) during the period March 2011-March 2012. The study area (4 ha) was demarcated and fenced by iron poles and wire mesh. Al Souda National park (Aseer region) was chosen because it is characterized by heavy yearly traffic including both vehicles and humans especially in summer time (June-September). Apparently there is severe soil compaction, little or nil regeneration of *J. procera*. It also contains abandoned terraces and a wide spread mortality of Juniper trees. As such it represents a good site for intervention and improvement of rainfall harvesting which is the core objective of the current study. Most locations in the study area contained old, abandoned and damaged terraces.

The present study aimed at determining the comparative efficiency of terraces, semi-circular and quadrangular bunds as tools to harvest rainwater and their effect on growth performance and survival of 2-year-old seedlings of J. *procera*.

MATERIALS AND METHODS

Meteorological data

A Vantage pro2 weather station (solar operated) was installed in the study area and the console was connected to a laptop via data logger. Collection of meteorological data started in March 2011. It included rainfall, minimum, maximum, and mean temperature, humidity, solar radiation and wind speed.

Repair of damaged terraces

A total of 10 damaged terraces which have slope angles less than 10º were selected, hence slope is not a major factor influencing water runoff and soil erosion [20]. The selected terraces were treated as follows:

1. Six were repaired by maintenance of the terrace wall (using stones in the study area), sub-soiled and ploughed.

2. Four were left damaged (control).

Construction of semicircular bunds

Four semi circular soil bunds [21] around groups of juniper trees (5-10 trees) were constructed from earth. The radius of the bund was 3-5 m and 0.5-1 m high. Each bund was left open against the direction of the slope to allow entrance of rainwater. Excess water will overflow on the sides when the bunds are fully filled with water. The soil hard crust was broken mechanically. Dead and dying branches of *J. procera* were removed.

Construction of quadrangular bunds

Quadrangular bunds (1 x 1 m) were constructed inside semi-circular bunds. A total of 60 two-year-old *J. procera* seedlings were planted in quadrangular bunds in such a way that the depth of the bund after planting was 20 cm to act as a small catchment. A similar number of seedlings were planted in control area. The seedlings were monitored for one year by the measurement of height, diameter and survival.

The study plots

Two x one m plots [22] [23] [24] were prepared from galvanized iron and inserted 10 cm deep into the soil in terraces and semi-circular bunds. They were connected to a plastic container via a plastic hose for the collection of runoff and sediment and measurements of infiltration and bulk density (Fig. 1). The plots were replicated thrice/treatment [24]. Rain intensity, infiltration and soil physical properties could be affected by the plot parameters [25]. However, the results from small plots (1 m^2) were comparable to larger plots (30-40 m^2) and small plots are recommended for exploratory soil erosion studies [22]. Treated and control plots (terraces and semi-circular bunds) were monitored during March 2011-March 2012 and the following parameters were measured/plot:

Fig. 1 The study plot

Total rainfall

Total rainfall in mm was measured by a Davis pro 2 weather station installed at the study area.

Runoff and erosion

After every rain the sediment and water running off from the plot were collected in the plastic containers attached to the plot via a hose. A well-mixed sample of the suspended sediment was collected, filtered, dried and weighed. In this way runoff and soil loss were determined in each plot [24].

Infiltration rate

The infiltration rate was measured in mm per 15 minutes, later converted to one hour, using a double ring infiltrometer. The infiltrometer had an inner ring of 30cm and outer ring of 50cm diameter and a height of 30cm above the ground [26].The infiltration rate was measured after every rain event.

Soil moisture content

Soil moisture content was measured inside each study plot by using a soil moisture meter (Delta-T Devices Ltd Type HH2). Soil moisture content was measured at 5 cm depth on oven dry basis initially before the onset of rains in all types of microcatchments. Soil moisture content was then measured after every rain at 5, 15 and 30 cm soil depth using a soil moisture meter.

In addition, bulk density and soil porosity were measured periodically every three months.

Soil Bulk Density

The bulk density was calculated as the ratio between the mass of dry soil to the total volume for each sample [27] as follows:

$Pb = Ms / Vt = Ms / (Vs + Va + Vw)$

Where :

Pb = Bulk density(g/cm3)

Ms = Mass of soil

Vs = Volume of soil

Va = volume of air

Vw = volume of water

Statistical analysis

Data were analyzed by ANOVA (GLM, general linear model) and means were compared at P=0.05, and T-test using SAS statistical package [28].

RESULTS AND DISCUSSION

Meteorological data

Fig. 2. summarizes the rainfall in the study area (March 2011-March 2012). A dry spell was recorded in the period March-June 2011. However, the rain onset started in July and increased gradually through August – Nov. This was followed by a dry spell from Dec-March 2012. No considerable fluctuations in temperature were recorded. Maximum temperature recorded was below 25 °C and can go down to approximately 10 °C at night (Fig. 3). Generally, temperature was mild over the study period. The lowest temperature was recorded during Nov. - Jan. and the maximum occurred in May-Aug. The results of humidity and solar radiation were summarized in table 1. Humidity % ranged from 19.8 to 60.42% and solar radiation 131.18-264.7 (W/m^2). The results of wind speed were summarized in Fig. 4. Relatively wind speed was maximum in Oct., Jan, Feb. and March as compared to Apr.-Aug. The dry spell that occurred during March-June 2011 was characterized by no rains and consequently no runoff or soil erosion was recorded.

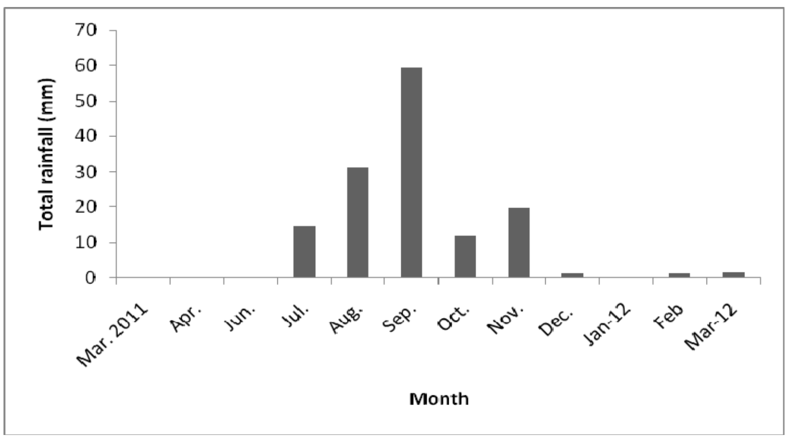

Fig. 2. Rainfall (mm) in the study area (2011)

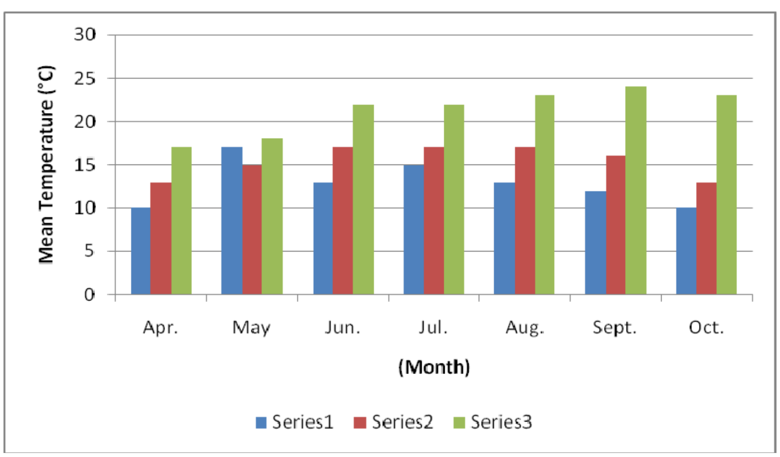

Fig. 3. Temperature in the study

Rainwater harvesting

All types of microcatchments were very successful in harvesting a good deal of rainwater i.e. repaired terraces, semi-circular and quadrangular bunds as compared to damaged (control) terraces (Fig. 5-6). As a result trees were flourished and rich ground vegetation was recorded in different types of microcatchments (Fig. 7) as compared to damaged terraces (Fig. 8) which showed poor ground vegetation. These results are in agreement with those of El Atta and Aref [5] who reported that repaired terraces in Abha and Al Namas (south western Saudi Arabia) have caused significant increase in infiltration rate and reduced runoff, soil loss and soil bulk density. Rainwater harvesting, plays an important role in reducing negative impacts on the environment [29]. Despite the fact that many areas have experienced water scarcity but paradoxically, rainwater is mostly considered as a risk [30] rather than as a valuable resource. The role of microcatchments on water harvesting has been reported globally. In Balukhistan which is a mountainous and dry province bunds are constructed across the slopes to force the runoff to infiltrate. The situation is similar in China with its vast population [31]. Most countries in the Middle East fall in the arid and semi-arid climates with very limited water resources [32].Water shortage in the Arab World may be indicated by the fact that more than 650 dams of variable size have been constructed in Saudi Arabia, Qatar, Oman and United Arab Emirates [33] [34]. Therefore, rainwater harvesting is crucial for present and future needs.

Series 1= Minimum temp.; Series2= Mean temp.; Series3= Maximum temp.

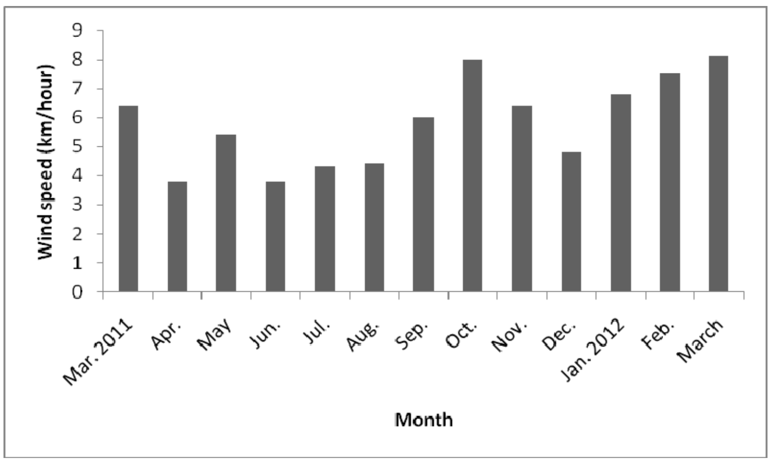

Fig. 4 Wind speed in the study area

Fig. 5 Rainwater harvested in a repaired terrace

Fig. 6 Rainwater harvested in a semi-circular bund

Fig. 7. Rainwater harvesting in a quadrangular bund

Fig. 8. Dense ground vegetation on a repaired terrace.

Fig. 9. Damaged terrace with poor ground vegetation.

Measurement of runoff and soil erosion

All microcatchments had highly significant (P=0.0001) effect on runoff. Repaired terraces significantly reduced runoff by 56% (9.5 L/ha) as compared to damaged terraces (21.6 L/ha). Similarly, quadrangular and semi-circular bunds significantly reduced runoff. The lowest runoff occurred in semi-circular bunds and repaired terraces (8.7 and 9.5L/ha, respectively). The highest runoff occurred in damaged terraces (21.6 L/ha) (Table 2). Also microcatchments significantly (P=0.001) reduced soil erosion as compared to damaged terraces (Table 2). The highest erosion was recorded in damaged terraces (120.2 kg/ha) as compared to repaired terraces (82.5 kg/ha), whereas erosion was minimum in quadrangular bunds (27.0 kg/ha) (Table 2). These results are in line with those of Hammad et al. [35] who reported that terrace conservation system reduced the negative effect of intense rainfall, resulting in a lower amount of runoff and erosion than in the non-terraced system under Mediterranean conditions. Similarly, Barth and Strunk [7] reported that soil erosion was evident in the abandoned terraces where soil depth decreases dramatically with increasing distance from Juniper trees in Al Souda National Park. El Atta and Aref [5] who investigated water harvesting by terraces in the same region (Aseer), found similar results. They reported that maintained terraces served as important means for rainwater harvesting, whereas abandoning of terraces resulted in increased soil loss, surface runoff, and soil bulk density and reduced infiltration rates. When surface runoff occurs it means that the infiltration rate is less than the intensity of rainfall. Infiltration rate was correlated to the bulk density, total porosity, air-filled porosity and capillary porosity [37].

It has been well established that runoff from a watershed had a significant effect on soil erosion.

Soil bulk density and porosity

Soil bulk density was significantly (P=0.01) different in various microcatchments. Soil bulk density was significantly (P=0.01) higher in damaged terraces (1.96 g/cm³) than in repaired terraces (1.58 g/cm³) and quadrangular and semi-circular bunds (1.68 and 1.7 g/cm³, respectively) (Table 2). Damaged terraces had significantly (P=0.01) the least porosity percent as compared to other microcatchments (Table 3). The least porosity percent occurred in damaged terraces (26.3 %) as compared to repaired terraces (37.4%) (Table 3). However, the highest porosity percent was recorded in quadrangular; semi-circular bunds and repaired terraces (38.9, 38.8 and 37.4%, respectively) (Table 3). It is apparent that as the soil bulk density increased, the soil porosity decreased which limited the depth of water flowing through the soil and thereby increasing the depth of water flowing on the surface as runoff [38]. Soil compaction is a serious problem for plant growth. Compacted soils are characterized by poor root growth and root zone aeration, poor drainage that results in less soil aeration, less oxygen in the root zone, and more losses of nitrogen from denitrification [39].

Table 1. Meteorological data in the study area (March 2011-March 2012)

Month	Humidity (%)	Solar Radiation (W/m^2)
Mar. 2011	46.96	131.18
Apr.	50.19	160.96
May	53.30	185.38
June	41.78	255.77
July	60.42	150.40
Aug.	49.29	238.09
Sep.	54.25	180.45
Oct.	34.5	160.2
Nov.	38.2	243.5
Dec.	25.6	264.7
Jan. 2012	19.8	257.6
Feb.	45.6	245.5
Mar.	35.6	255.8
Mean	42.7	210.0
Range	19.8-60.42	131.18-264.7

It is evident that increased soil compaction breaks down aggregates and lead to decreased soil water content due to reduction of air-filled capillary porosity [36]. Yang and Zhang [37] reported that as the bulk density increased, infiltration rate and air-filled pores decreased. Therefore, runoff coefficients were high in such compacted soils. Consequently Juniper trees growing in maintained terraces showed better growth compared to those in abandoned terraces [5].

Table 2. Water and soil conservation in microcatchments

Runoff	L/ha
Damaged terraces	21.6 a
Quadrangular bunds	11.4 b
Semi-circular bunds	8.7 c
Repaired terraces	9.5 c
Soil erosion	kg/ha
Damaged terraces	120.2a
Repaired terraces	82.5 b
Semi-circular bunds	75.3 b
Quadrangular bunds	27.0 c
Soil bulk density	g/cm^3
Damaged terraces	1.96 a
Quadrangular bunds	1.68 b
Semi-circular bunds	1.70 cb
Repaired terraces	1.58 c

Means followed by the same letter are not significantly different at P=0.05

Infiltration rate

Highly significant (P=0.0001) differences in infiltration rate in microcatchments were recorded. Infiltration rate was maximum in quadrangular (179.0 mm/hr) and semi-circular bunds (157.5 mm/hr). The least infiltration rate occurred in damaged terraces (87.7 mm/hr). Repaired terraces recorded a significantly (P=0.05) higher infiltration rate (122.7 mm/hr) than damaged terraces (Table 3). This might be attributed to the higher soil porosity in both quadrangular and semi-circular bunds as compared to terraces. These results are in line with other investigators. Terracing has been the main approach for water conservation in Loess Plateau (China) and it increased rain infiltration and reduced soil erosion (Lu et al. 2009). Soil infiltration significantly affects the quantity of runoff and the soil water content [40]. Hence, soil infiltration rate was considered as a critical index that reflects the ability of soil for water management [41]. Low infiltration leads to runoff which accelerates the process of soil erosion and flooding downstream [26] and this is the case in the control site in the study area which is part of Al Souda National Park that receives about 2-3 million visitors annually with their vehicles. This situation explains the high bulk density, low infiltration, high runoff and the consequent soil erosion in control.

Table 3. Porosity (%) and infiltration rate in microcatchments

Porosity	Mean porosity (%)
Quadrangular bunds	38.9 a
Semi-circular bunds	38.8 ab
Repaired terraces	37.4 b
Damaged terraces	26.3 c
Infiltration rate	Mean infiltration rate (mm/hr)
Quadrangular bunds	179.0 a
Semi-circular bunds	157.5 a
Repaired terraces	122.7 b
Damaged terraces	87.7 c

Means followed by the same letter are not significantly different at P=0.05

Soil moisture content

After the rain onset and at 5 cm soil depth the maximum mean MC % was recorded in repaired terraces (35.8%) which was more than double as compared to damaged terraces (14.5%) (Table 4). The minimum MC % was recorded in quadrangular bunds (8.4%). At 15 cm soil depth also significant (P=0.001) differ rences in MC % were recorded. No significant differences were found in MC % between repaired terraces, semi-circular bunds and damaged terraces (11.5- 16.4%) (Table 4), nevertheless quadrangular bunds recorded the least MC % (5.7 %) (Table 4). Similarly at 30 cm soil depth significant (P=0.05) differences in soil MC % were recorded though not as significant as at 5 and 15 cm. Terraces whether repaired or damaged and semi-circular bunds recorded more or less similar MC % (8.0-9.7%), whereas the least MC % occurred in quadrangular bunds (Table 4).

Table 4. Soil moisture content (%) in microcatchments

5 cm soil depth	Mean MC (%)
Repaired terraces	30.8 a
Semi-circular bunds	15.3 bc
Damaged terraces	11.8 bcd
Quadrangular bunds	8.6 d
15 cm soil depth	
Repaired terraces	16.4 a
Semi-circular bunds	13.4 a
Damaged terraces	11.5 a
Quadrangular bunds	5.7 b
30 cm soil depth	
Repaired terraces	9.5 a
Damaged terraces	9.2 a
Semi-circular bunds	8.0 ab
Quadrangular bunds	4.6 b

Means followed by the same letter at a soil depth are not significantly different at P=0.05

It is evident that MC % was maximum at 5 cm soil depth and decreased dramatically with soil depth. Taking the MC % at 5 cm soil depth as an example, it is clear that all types of microcatchments resulted in highly significant increase in MC % (Table 5). This might be attributed to reduced runoff and bulk density and increased infiltration as compared to control. Terraces have played an important role in the conservation of soil and water in the Ethiopian Highlands [42]. It has been reported significant increase in soil moisture and a reduction in the frequency of supplemental irrigation of fruit trees as a result of terracing and semi-circle bunds in Jordan [43].

Table 5. Soil MC% at 5 cm depth before and after the onset of rains

Microcatchment	Mean MC (%)	
	Before rains	After rains
Repaired terraces	0.98 a	30.8 b
Semi-circular bunds	1.0 c	15.3 d
Damaged terraces	0.93 e	11.8 f
Quadrangular bunds	0.92 g	8.6 h

Means followed by the same letter in a row are not significantly different at P=0.05

Seedlings performance and survival

Growth parameters and the survival rate of *J. procera* seedlings planted in quadrangular bunds constructed inside semi-circular bunds improved significantly (P = 0.0001) as compared to those planted in the control sites (Table 6) and the values were 7.0 and 4.8 cm for diameter, and 46.3 and 24.8 cm for height, respectively. Also the survival rate of seedlings was 86.8 and 55.4% in seedlings grown inside semi-circular bunds and in control sites, respectively (Table 6). These results are in line with those of Bastida et al. [14] who reported a better growth of plants in repaired terraces in Spain. This might be attributed to improved soil and water conservation in microcatchments.

Table 6. Growth performance and survival of *J. procera* seedlings

Location	Mean diameter (cm)	T-value	P
QSCB*	7.0	11.0	0.0001
Control	4.8		
	Mean Height (cm)		
QSCB	46.3	7.4	0.0001
Control	24.8		
Seedlings survival (%)			
QSCB	86.8		
Control	55.4		

*Quadrangular inside semi-circular bunds

CONCLUSION

Microcatchments in the form of terraces, quadrangular and semi-circular bunds played an important role in water harvesting in the study area. They increased significantly soil porosity and moisture content and infiltration rate, and significantly reduced soil bulk density, runoff and soil erosion. In conclusion microcatchments significantly improved soil and water conservation. This was indicated by the better performance and survival of *J. procera* seedlings. Therefore, construction of microcatchments especially in mountainous terrains is recommended to improve water management and to conserve the soil against erosion which in turn created better growth conditions for plants.

ACKNOWLEDGEMENT

The authors are much indebted to the National Plan for Sciences Technology and Innovation for sponsoring this study as part of Project No. 09-WAT 668-02. Special thanks to Prof. Ahmed Al-Khazim, Director of the programme, King Saud University, Kingdom of Saudi Arabia.

REFERENCES

[1] Aboulfatih H, Emara A and Hashish A. 1989. The influences of grazing on vegetation and soil of Asir highland. Arab Gulf J. Sci. Res. 7b (1): 69-78.

[2] Gorashi A. 2005. Sustainable Management of the Vegetal Cover in the Kingdom of Saudi Arabia. FAO project document.

[3] El-Juhany LI, Ibrahim MA and Al-Ghamdi MA. 2009. Effects of different pretreatments on seed germination and early establishment of the seedlings of Juniperus procera trees. World Appl. Scis. J. 7(5):616-624.

[4] Anonymous. 2006. The management plan for conservation of Juniper woodlands. JICA. 32.

[5] El Atta HA and Aref IM. 2010. Effect of terracing on rainwater harvesting and growth of Juniperus procera Hochst. ex Endlicher. Int. J. Environ. Sci. Tech. 7 (1):59-66.

[6] Fisher M. 1997. Decline in the juniper woodlands of Raydah reserve in southwestern Saudi Arabia: A response to climate change. Glob. Ecol. Biogeo. Let.

[7] Barth H J and Strunk H. 2000. The dieback phenomenon of *Juniperus procera* at the Al Souda family park. Report to Deutsche Forschungs Gemeinschaft (DFG), National Commission for Wildlife Conservation and Development (*NCWCD*), Riyadh.

[8] Fisher M. 2000. Dead or alive? The uncertain future of the Arabian Juniper woodlands. *Eur. Trop. For. Net*.

[9] El Atta H A. 2003. Decline of *Juniperus procera* in the Kingdom of Saudi Arabia. A report to the Ministry of Agriculture. Kingdom of Saudi Arabia.

[10] El Juhany L I, Aref IM and Al-Ghamdi MA. 2008. The possibility of ameliorating the regeneration of Juniper trees in the natural forests of Saudi Arabia. *Res. J. Agri. Biol. Sci.* 4 (2): 126-133.

[11] Ciesla WM. 2002. Protecting plantations from pests and diseases. Forestry Department. Food and Agriculture Organization of the United Nations. Forest Plantations Thematic Papers.

[12] Lesschen JP, Cammeraat LH and Nieman T. 2008) Erosion and terrace failure due to agricultural land abandonment in a semi-arid environment. Earth Surf. Proc. Land. 33 (10): 1574 – 1584.
[13] Wu S, Yin Y, Zheng D and Yang Q. 2003) Climate change in the Tibetan plateau during the last three decades. Science in China (Series D, Earth Sciences) 35. pp. 276–283.
[14] Bastida F, Moreno JL, Hernández T and García C. 2007. The long-term effects of the management of a forest soil on its carbon content, microbial biomass and activity under a semi-arid climate. Appl. Soil Ecol. 37 (1-2): 53-62.
[15] Qadir M, Bahri A, Sato T and Al-Karadsheh E. 2010. Wastewater production, treatment, and irrigationin Middle East and North Africa. Irrig. Drain. Syst. 24:37–51.
[16] Anschutz J, Kome A, Nederhof M, Neef Rd and Ven T van de. 2003. Water Harvesting and Soil Moisture Retention. Agromisa – CTA.
[17] Abrisqueta JM, Plana V, Mounzer OH, Mendez J and Ruiz-Sanchez MC. 2007. Effects of soil tillage on runoff generation in a Mediterranean apricot orchard. Agri. Water Manage. 93: 11-18.
[18] Morgan RPC. 2005 (ed.). Soil erosion and conservation. John Wiley and Sons. New York. USA. pp. 109-128.
[19] Zuazo VHD, Ruiz JA, Raya AM and Tarifa DF. 2005. Impact of erosion in the taluses of subtropical orchard terraces. Agr. Ecosyst. Environ. 107:199-210.
[20] Gardner RA and Gerrard AJ. 2003. Runoff and soil erosion on cultivated rainfed terraces in the Middle Hills of Nepal. Appl. Geog. 23:23-45.
[21] FAO AGL. 2000. Water resources, development and management services
[22] Hudson NW. 1993, Field measurement of soil erosion and runoff. Soils Bulletin 68, FAO, Rome.
[23] Battany MC, Grismer ME. 2000. Rainfall runoff and erosion in Napa Valley vineyards: effects of slope, cover and surface roughness. Hydro. Process. 14 (7):1289–1304.
[24] Thomaz EL. 2009. The influence of traditional steep land agricultural practices on runoff and soil loss. Agric. Ecosys. Environ. 130, 23-30.
[25] Phillips JD. 1999. Earth Surface Systems: Complexity, Order, and Scale. Blackwell, Oxford.
[26] Bassey E, Devalsam I and Comfort O. 2011. Evaluation of the infiltration capacity of soils in Akpabuyo Local Government Area of Cross River, Nigeria. J. Geog. Geol. 3(1):189-199.
[27] Chapman HD and Pratt PF. 1961. Methods of analysis of soils, plants and water. University of California Div. Agric. Sci. 1 – 312.
[28] SAS. 1997. SAS Institute Inc., Cary, North Carolina.
[29] El-Sayed M, Mahgoub NP, Van der Steen K, Abu-Zeid K and Vairavamoorthy B. 2010. Towards sustainability in urban water: a life cycle analysis of the urban water system of Alexandria City Egypt. J. Clean Prod. 18 (10–11), 1100–1106.
[30] Domènech L and Saurí D. 2011. A comparative appraisal of the use of rainwater harvesting in single and multi-family buildings of the Metropolitan Area of Barcelona (Spain): social experience, drinking water savings and economic costs. J. Clean Prod. 19 (6-7):598-608.
[31] Sivanappan R K. 2006. Rain water harvesting, conservation and management strategies for urban and rural Sectors. National Seminar on Rainwater Harvesting and Water Management 11-12 Nov. Nagpur.
[32] Al-Salaymeh A, Issam A, Al-Khatib H and Arafat H. 2011. Towards Sustainable Water Quality: Management of Rainwater Harvesting Cisterns in Southern Palestine. Water Resour. Manage. 25:1721–1736.
[33] Al Rashid MF and Sherif MM. 2000. Water resources in the GCC countries: an overview. Water Resour. Manage. 14: 59-75.
[34] Murad AA, Al Nuaimi H and Al Hammadi M. 2007. Comprehensive assessment of water resources in the United Arab Emirates (UAE). *Water Resour. Manage.*21: 1449-1466.
[35] Hammad AA, Borresen T and Haugen L E. 2006. Effects of rain characteristics and terracing on runoff and erosion under Mediterranean. Soil Till. Res. 87 (1): 39-47.
[36] Yang, J.L.; Zhang G.L.; Yuan, D.G., (2008) Characteristics of water infiltration in urban soils of Nanjing City. Chinese. J. Appl. Ecol. 19(2): 363–368.
[37] Yang JL and Zhang GL. 2011. Water infiltration in urban soils and its effects on the quantity and quality of runoff. J. Soils Sed. 11:751–761.

[38] Adekalu KO, Okunade DA and Osunbitan JA. 2006. Compaction and mulching effects on soil loss and runoff from two southwestern Nigeria agricultural soils. Geoderma. 137(1-2): 226-230.
[39] Johnson BS, Erickson AE and Smucker AJM. 1986. Alleviation of compaction on a fine textured soil ASAE Paper No. 86-1517. St. Joseph, MI: ASAE.
[40] Alaoui A and Goetz B. 2008. Dye tracer and infiltration experiments to investigate macropore flow. Geoderma. 144: 279–286.
[41] Liu DP, Chen SX, Zhang JC, Xie L and Jiang J. 2007. Soil infiltration characteristics under main vegetation types in Anji County of Zhejiang Province. Chinese. J. Appl. Ecol. 18(3):493–498.
[42] Aynsau J and de Graaff A. 2007. Determinants of adoption and continued use of stone terraces for soil and water conservation in an Ethiopian highland watershed. Ecol. Econ., 61 (2–3). 294-302.
[43] Al-Seekh SH and Mohammad AG. 2009. The effect of water harvesting techniques on runoff, sedimentation, and soil properties. Environ. Manage. 44(1):37-45.
[44] Li YY and Shao MA. 2006. Change of soil physical properties under long-term natural vegetation restoration in the Loess Plateau of China. J. Arid Environ. 64 (1): 77–96.