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Soil and water loss from natural and cultivated slopes in Dharabi watershed

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Abstract

Land use is one of the main factors affecting erosion. Present study was carried out at runoff plots in the Dharabi watershed in Chakwal Pakistan for two years. Soil and water loss from a cultivated slope use and an undisturbed slope having natural cover was evaluated to ascertain the impact of conversion of natural slopes into cultivated sloping terraces. A relatively steep slope and a gentle slope having natural vegetation were compared with a gentle slope on cultivated terrace with existing cropping pattern. Significance was checked by Kruskal-Wallis test and pair wise comparisons of water loss from all land uses were done using Mann-Whitney U and Wilcoxin tests. Cultivated slope produced highest soil loss (8.96 Mg ha^{-1}) annually as compared to both undisturbed gentle and steep slopes, viz., 2.08 and 4.66 Mg ha^{-1} respectively. Cultivated slope produced 107 mm of average annual runoff as compared to 89.7 mm from natural steeper slope and 56.5 mm from gentle natural slope. Annual runoff coefficient increased from 13.9% to 16.7% with conversion of steeper grassland into cultivated land use. Soil and water losses from cultivated slope were higher despite the fact that cultivated slope had lesser slope gradient than undisturbed natural slope. This suggested that cultivated land use i.e. cropland is capable of producing more soil and water loss as compared to natural grassland. The outcome of the study would help making policy decisions regarding the land use change and its downstream impacts.

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Introduction

Climate, topography, vegetative cover and land use are main factors affecting erosion as incorporated in USLE (Wischmeier and Smith, 1978). From agricultural point of view, cultivated slopes and slopes with natural vegetation are two major land uses. Among these two, croplands has been reported by many researchers to be more erodible than other land uses. Tiwari *et al.* (2008) established runoff plots on outward sloping agricultural terraces. Here agricultural land produced more soil loss i.e. 1.3 Mg ha^{-1} yr^{-1} as compared to forested areas i.e. 0.3 Mg ha^{-1} yr^{-1}. Moreover, reduced tillage treatment minimized soil and water loss by 18 to 28 percent and 7 to 11 percent respectively which indicated that cultivation was the main cause for enhanced soil loss. Navar and Synnott (2000) also observed the highest runoff and soil loss from agricultural lands. Tillage operations were believed to be the most important factor for controlling these processes. Similar results were achieved on loess hilly area of China, where Wei *et al.* (2007) compiled the 14 years of data and reported that mean runoff coefficients and erosion modulus amongst the five land use types were in the order of cropland > pastureland > woodland > grassland > shrubland. High intensity, short duration and high frequency caused the greatest proportion of runoff and soil loss. One reason for higher soil loss or erosion is the high soil detachment capacity which was recorded by Li *et al.*(2015). He observed that croplands on red loess soils and yellow red soils had 34 and 34 times higher soil detachment capacity than natural grasslands. Perennial grasses are also known to decrease erosion. In a study by Jankauskas *et al.* (2008), perennial grasses prevented water erosion completely in Lithuania on undulating slopes, and increased the % age of clay-silt and clay fractions in arable soil horizons. Similar results were reported by Yueqiang *et al.* (2015) when he found that soil erosion rate in each sub-watershed of his study in China increased when the cover of natural vegetation decreased. In present area of study, Dharabi watershed, farmers cultivate sloping lands through decreasing the slope and by growing crops on sloping terraces. This decline in slope gradient decreases the soil erosion; however, tillage promotes the soil loss (Wischmeier and Smith, 1978). However, no study has been conducted in Dharabi watershed Chakwal, Pakistan to ascertain soil and water losses on these land uses. Therefore, present study was conducted to measure the soil loss from undisturbed and cultivated sloping land uses at plot scale in Dharabi watershed.

Materials and methods

Study area

Study was carried out at Dharabi Watershed Site which is located between the latitude 32º 42′ 36″ to 32º 55′ 48″ and longitude 72º 35′ 24″ to 72º 48′ 36″ in Chakwal District in Pakistan with elevation from 445 to 898 meters asl. Sloping lands exist as flood plains or piedmont plains having slope gradient about 10%. These slopes consist of grasses and shrubs. May, June and July are the hottest months with daily maximum temperatures rising above 40 ºC. Monsoon rainfall season is spread from July to September which is followed by autumn. December to February are winter months with night temperatures decreasing to -1 to -2 ºC for a few days. Average annual rainfall ranges from 440 to more than 600 mm (on spatial scale) with higher rainfall in northern parts of the watershed. However, most of the rainfalls are received during monsoon season extending from July to September. At slopes, dominating grass species are *Heteropogon contortus (Sariala), Cenchrus ciliaris* (Dhaman), *Desmostachya bipinnata* (Dab grass), and *Cynodon dactylon* (Khabbal) (Oweis and Ashraf, 2012). Natural vegetation is used for grazing and as a source of fire and timber wood for local people. At slopes, generally *taramira* is grown during winter and but usually remain fallow during summer. Grazing usually occurs from March to October.

Layout of runoff plots

Experiment was laid out at piedmont hillslope, a part of which had been converted to a sloping field terrace about 5 years ago (Fig 2 a). Runoff plots were established on natural slopes and cultivated slope

(Location of the experiment is N=32° 53' 22.24", E=72° 42' 13.32"). The length and width of the plots was 10 meters and 2 meters respectively. A plot length of 10 meter was used to make it relevant to existing field situation because longer length automatically converts fields into gullies if not terraced. Three set of runoff plots were within a distance of about 50 meter from each other on the same plain with the experimental slopes facing north-east. These experimental plots were about 200 meters away from the recording rainguage installed in Rahna Sadaat. Nine runoff plots were built in Dharabi watershed at farmers' fields and used for comparing two land use systems and two slope angles in triplicate. The runoff plots enabled us to explore whether the decrease in slope accompanied with cultivation has resulted in decreasing the soil loss. LS2 and LS3 were added to ascertain whether the change in soil and water loss is due to decrease in slope or due to cultivation. Experimental data were collected from January 2010 to December 2011. Runoff plots were established on following slopes:

LS1: Undisturbed slope having natural grasses and shrubs – 11.2%

LS2: Undisturbed slope having natural grasses and shrubs – 6.1%

LS3: Cultivated slope on terrace with existing cropping pattern -5.8%.

Undisturbed natural slopes

Plots were delimited with bricks and cement which were 15 cm high above surface on an average. These boundaries were at least 8 cm deep in the soil in order to stop leakage of water in/out of plot. Runoff was collected in drums (200 liters capacity) at the bottom of the slopes. Cemented trough was made at the bottom of the slopes to receive the eroded soil which was added to the soil loss. Water was led to these drums through a multislot divisor (12 slots) and a plastic pipe (Figure 1). This design was originally reported by Pinson (2004) and later on the detailed field testing was reported by Bonilla *et al.* (2006). The multislot divisor for the present experiment had a combination of plastic bucket and galvanized steel sheet crown with silicone gel used for sealing. Whole system was covered with plastic cover at the farmers' field.

Cultivated slopes

Cultivated slope boundaries included plastic boards which were 15 cm above soil and 8 cm inserted into the soil. Joints were fitted tightly together. The runoff water was conducted to the drum through multislot divisor (procedure mentioned above). The plastic board boundaries were removed during cultivation. Farmer practice cropping pattern was adapted at cultivated slope viz. *Taramira* (*Eruca sativa*) without fertilizer addition during winter and fallow during summer.

Rainfall, runoff and sediments

Study was conducted during the years 2010-2011 in a watershed located upstream of the Dharabi reservoir. Rainfall data were recorded at Rahna Sadaat rainguage. Other data were recorded at SAWCRI Chakwal few kilometers away from the site. Total runoff was measured by dipping the meter rod in the runoff drum and reading the level. The runoff volume in the drum was multiplied with twelve (12 slots in multislot divisor) and added to the runoff volume of multislot divisor bucket to get the total runoff volume of the event as under.

$$R = V_m + (12 \times V_d)$$

Where R = total runoff volume (m^3) of event, V_m is volume of multislot divisor bucket and V_d is the volume of runoff in drum.

Total sediments mass for each runoff event was calculated as

$$S = (V_m \times C_1) + (12 \times V_d \times C_2).$$

Where S is the total sediment in kg, C_1 and C_2 are total concentration of solids in multislot divisor and drum respectively. Same formula was used for calculating the yield of OM (organic matter) and clay in sediments.

To measure sediment yield and analysis, samples were collected in 10 liter plastic cans from drums and 1500 ml bottles from the bucket. Before taking sample, the multislot divisor bucket was stirred. Coarser sediments deposited on trough were mixed in the multi slot divisor bucket.

Samples were brought to the lab and analyzed. However, the quantity of sediments obtained was very small for smaller events. Therefore, sediments from some smaller events had to be mixed to get enough weight of sediment for analysis. Electrical Conductivity and pH was measured by methods described by Handbook 60 (Rhoades 1996), extractable phosphorus by method of Olsen and Sommers (1982) and available potassium by ammonium acetate (1N) extraction method (Ryan *et al.* 2001).

Statistical analysis

Normality of soil and water loss data were tested with Kolmogorov-Smirnov tests which showed that the data were not having normal distribution. Non parametric test Kruskal-Wallis mean rank test was used for testing significance, whereas pair wise comparisons of soil and water loss data were done using non parametric tests of Mann-Whitney U and Wilcoxin Signed Rank tests. Its significance was checked using Z test. High mean rank indicated higher surface runoff.

Results and discussion

Soil and rainfall characteristics

Soil analysis of experimental site is presented in table 1. Soil was alkaline with pH ranging between 7.9 and 8.0; having electrical conductivity range of 2.0-2.5 dS m^{-1}. Texture was sandy loam. Organic carbon was low and ranged from 0.33 to 0.97% with the lowest value in cultivated slope.

Table 1. Soil characteristics of experimental site at Rahna Sadaat.

Parameters		Undisturbed steeper slope (LS1)	Undisturbed gentle slope (LS2)	Cultivated gentle slope (LS3)
ECe	dS m^{-1}	2.00	2.20	2.50
pH		8.07	7.97	7.87
Organic carbon	%	0.79	0.97	0.33
Sand	%	75.9	74.5	75.3
Silt	%	13.4	14.3	14.1
Clay	%	10.7	11.2	10.6
Textural class		Sandy loam	Sandy loam	Sandy loam
Slope gradient	%	11.2	6.1	5.8

Table 2. Rainfall (mm) at experimental site at Rahna Sadaat.

Year	J	F	M	A	M	J	J	A	S	O	N	D	Total
2010	4	49	20	4	71	81	288	162	39	0	0	0	718
2011	4	36	20	65	24	31	192	127	59	14	7	0	580

During two study years i.e. 2010 and 2011, 718 mm and 580 mm of rainfall occurred respectively at experimental site (Table 2) which was 13.2 % higher and 8.5 % lower respectively than the long term average rainfall (623 mm) of Chakwal. During two years, sixty seven percent of total rainfall occurred during monsoon months of July, August and September while rest occurred during other months.

Most of the water and soil loss occurred during monsoon months. Twenty five runoff event days were observed during these two years i.e. 12 during the year 2010 and 13 during 2011 respectively. Data of rainfall event days are presented in Table 3. Maximum rainfall intensity (I_{30}) was 89.4 mm h^{-1} with median figure of 36 mm h^{-1}.

Table 3. Rainfall characteristics of runoff event days at runoff plot site during 2010-2011.

Parameter	Rainfall duration (minutes)	Average intensity	Max rainfall intensity I_{30}	Daily rainfall (mm)	Main event rainfall (mm)
	minutes	-----------mm h^{-1}-------		-----------mm---------	
Mean	149	18.1	38.9	33.4	28.8
Median	106	15.0	36.1	25.4	24.5
Min	38	03.6	08.1	11.4	11.4
Max	408	40.8	89.4	132.6	64.3

Surface runoff

Average annual runoff was 89.7, 56.5 and 107.9 mm from LS1, LS2 and LS3 respectively (Table 4). It indicated that cultivated gentle slope (LS3) produced 1.2 times more runoff than undisturbed steeper slope (LS1) and 1.9 times more runoff than undisturbed gentle slope (LS2). This meant that cultivation was responsible for increased runoff despite the fact that slope gradient had been reduced from 11.2 to 5.8 percent. Same trend was observed during both of the years (Table 5). Average annual runoff coefficients (mm of average annual runoff ÷ mm of average annual rainfall) of land uses LS1, LS2 and LS3 were 14, 9 and 17 percent respectively (Table 4).

Table 4. Annual average runoff and soil loss from different land uses 2010-2011.

Land use type	Annual average runoff	Average annual runoff coefficient	Annual average soil loss
	mm	%	Mg ha^{-1}
Undisturbed steeper slope (LS1)	89.7	14	4.66
Undisturbed gentle slope (LS2)	56.5	9	2.08
Cultivated gentle slope (LS3)	107.9	17	8.96

Pair wise comparisons of water loss from all land uses were done using Mann-Whitney U and Wilcoxin signed rank tests. Pair wise analysis indicated that event wise runoff from LS1 & LS2 and LS2 & LS3 was significantly different from each other (Tables 6) which meant that runoff was less at lower slope gradients having natural vegetation. Similarly, at similar slope gradient (about 5%), runoff was higher at cultivated slope than undisturbed slope. Annual runoff from LS1 and LS3 was statistically similar which indicated that cultivated slope, despite having lower slope gradient produced water loss equal to steeper natural slope.

Table 5. Annual runoff and soil loss under different land uses.

Year	Total rainfall (mm)	Cumulative daily rainfall (mm)*	Land use type	Annual runoff coefficient (RC %)**	Annual runoff depth (mm)	Annual soil loss (Mg ha^{-1})
2010	718	533	LS1	13.4	96.4 (±2.36)	6.97 (±0.194)
			LS2	9.7	69.3 (±6.6)	3.47 (±0.059)
			LS3	16.2	116.2 (±2.51)	12.86 (±0.144)
2011	580	396	LS1	14.3	83 (±2.76)	2.35 (±0.284)
			LS2	7.5	43.7 (±2.2)	0.68 (±0.078)
			LS3	17.2	99.6 (±2.55)	5.07 (±0.282)

*Total rainfall of runoff event days; **Runoff depth (mm) as percent of total annual rainfall.

Median figures of all 75 event wise runoff values from LS1, LS2 and LS3 were 4.48 mm, 2.22 mm and 7.59 mm respectively. Third quartile of all 75 event wise runoff values was 9.7 mm, 5.7 mm and 14.5 mm from LS1, LS2 and LS3 respectively. This showed that individual rainfall events produced highest runoff at cultivated land use (LS3) followed by undisturbed steep slope (LS2). Undisturbed gentle slope (LS1) produced the lowest runoff. If various parameters like runoff figures, runoff coefficients, results of parametric tests and quartile analysis are taken into consideration, it can be inferred that cultivated slope is capable of producing runoff which is equal to or more than undisturbed steeper slope in Dharabi watershed. Girmay *et al* (2009) also found that land use significantly change runoff generation and, cultivated land produced significantly higher runoff coefficient (i.e. 23– 39%) as compared to the other land uses including grazing land.

Table 6. Kruskal-Wallis mean rank test and Mann-Whitney U Test Ranks for water loss from three land uses.

Land Use	N	Mean Rank	Sum of Ranks	Test	Test statistics value
LS1	69	79	5446	Mann-Whitney U	1730
LS2	69	60	4145	Wilcoxon W	4145
Total	138			P-Value	0.01
LS1	69	66	4526	Mann-Whitney U	2111
LS3	69	73	5066	Wilcoxon W	4526
Total	138			P-Value	0.25
LS2	69	59	4082	Mann-Whitney U	1667
LS3	69	79	5509	Wilcoxon W	4082
Total	138			P-Value	0.01

Soil loss

Results indicated that soil loss at all the runoff plots was higher during 2010 as compared to 2011 due to higher rainfall in 2010. Cultivated slope (LS3) produced the highest average annual soil loss which was 8.96 Mg ha^{-1} (Table 4). It was followed by undisturbed steeper slope with 4.66 Mg ha^{-1}. Undisturbed gentle slope produced the lowest soil loss equal to 2.08 Mg ha^{-1}. Statistical analysis is presented in Table 7 which indicated that the differences in soil loss from three land use were significant.

Table 7. Kruskal-Wallis mean rank test and Mann-Whitney U Test Ranks for soil loss from three land uses.

Land Use	N	Mean Rank	Sum of Ranks	Test	Test statistics value
LS1	75	65	4852	Mann-Whitney U	2002
LS2	75	86	6474	Wilcoxon W	4852
Total	150			Z	-3.05*
LS1	75	62	4675	Mann-Whitney U	1825
LS3	75	89	6650	Wilcoxon W	4675
Total	150			Z	-3.71*
LS2	75	69	5197	Mann-Whitney U	2347
LS3	75	82	6128	Wilcoxon W	5197
Total	150			Z	-1.95**

*Significant at P<0.05, **Significant at P<0.10.

Though the runoff depth from cultivated slope (LS3) was higher by 1.2 times from undisturbed steeper slope (LS1) but increase in soil loss was much higher i.e. 1.9 times. Higher value of soil loss from cultivated slope (LS3) as compared to undisturbed natural slope (LS2) indicated that cultivation was the main reason for increased runoff and soil loss. Decrease in slope from 11.2 to 5.8 percent could not compensate the erosion supporting effect of cultivation. Similar results were reported by Liu *et al.* (2004) who reported that erosion rates from farmland were higher and in order of farmland > disturbed grassland > undisturbed grassland > forestland in hilly and mountainous area. Shrestha *et al.* (2004), while working in Nepal, also observed higher soil losses where rainfed crops were grown at sloping terraces. He observed a maximum soil loss of 32 Mg ha^{-1} yr^{-1} at sloping terrace and minimum with dense forest. Wei *et al.* (2007) also observed the same results and found that mean erosion modulus and runoff coefficient were in the order of cropland > pasture land > woodland > grassland > shrubland while working in China. Similar results have also been reported by Neil and Fogarty (1991), Erskine *et al.* (2002) in Australia. However, reduced tillage treatment may reduce soil and water loss by 18 to 28 percent and 7 to 11 percent respectively showing the role of cultivation in erosion enhancement (Tiwari *et al.,* 2008). Zhu and Zhu (2014) also found the same results with grassland producing only 6.9% of soil loss as compared to farmland in China.

Conclusions

Slope cultivation enhanced soil and water loss. Decreasing the slope gradient from 11 to 6% failed to compensate the erosion caused by cultivation. Therefore, undisturbed slopes with natural grass and shrub system are less prone to erosion as compared to cultivated sloping terraces.

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