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Impact of Land-Use Practices on Sediment Yield in the Dhrabi Watershed of Pakistan

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Abstract: Soil erosion by water is one of the most important land degradation processes in the sloping rainfed lands in Pakistan. A study was conducted in the Dhrabi watershed of Pakistan to evaluate sediment yield associated with rainfall-runoff under various land-use practices. Five sub-catchments with sizes varying from 1.5 to 350 ha were selected for measurement of rainfall, runoff and sediment yield. Soil conservation techniques were also introduced to reduce the soil erosion. All runoff events occurred in the summer especially during monsoon season (July-September). Sediment yield of two small gully catchments ranged from 4.79 to 8.34 t/ha/yr in 2009, a relatively dry year. In 2010, the annual sediment yield was 8.15 to 12.31 t/ha. Terraced catchment with arable crops produced annual 4.1 t/ha of sediment as compared to 12.31 t/ha by the adjacent gully catchment showing high potential of terraces in reducing erosion. Runoff coefficients calculated for these catchments vary from 0.09 to 0.75. The macro and micro nutrients present in the sediment indicate that these nutrients are being depleted due to soil erosion.

Key words: Soil erosion, sediment yield, rainfall, runoff, vegetative cover, soil conservation structures.

1. Introduction

Globally, erosion by water and wind affected 1094 and 549 million hectares (Mha), respectively [1, 2]. The soil erosion rates are the highest in Asia, Africa and South America averaging 30-40 t/ha annually where it is the lowest in the United States, Europe and Australia, averaging 5-20 t/ha/yr [3, 4]. It is estimated to be severe in south Asia with water erosion as the most serious problem in the region.

In Pakistan several factors accelerate soil erosion, which include deforestation, overgrazing, urbanization, low organic matter, improper tillage practices, fallow lands, competing land uses, small and fragmented land holdings, land-tenure system and overall poverty [5].

This continuous and rapid loss of nutrient rich top soil can eventually lead to desertification. Soil erosion causes not only onsite degradation of agricultural land but also offsite problems such as downstream deposition of sediment in fields, floodplains and water bodies. Along with various problems that arise due to land degradation, it also causes tremendous loss to the economy. Estimate of global productivity loss in dry lands ranges from US$13 billion to $28 billion per year [6]. A study conducted by FAO, UNDP and UNEP in South Asia revealed that the countries in this region are losing at least US$10 billion annually as a result of land degradation. This was equivalent to 2% of the region's gross domestic product, or 7% of the total agricultural output. This is probably an underestimate, as only on-site effects were considered [7].

In Pakistan, about 16 Mha out of a total geographical area of 80 Mha, are exposed to soil erosion, especially by water about 11 Mha was affected. In Pothwar

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Plateau, the largest contiguous drylands, 1.21 Mha out of 2.2 Mha, is affected by gully erosion and only 0.61 Mha is cultivated. High intensity rainfall, steep slopes and fragile soils in the absence of appropriate preventive measures have led to extensive soil erosion. The consequences are devastating including loss of fertile soil, loss of vegetation, depletion of reservoirs capacity due to sedimentation and eutrophication and contamination of surface and ground water [5].

Annual soil loss in the middle Yellow River basin of China amounts to 3,700 t/km^2, the largest sediment carrying river in the world. The Indus River in Pakistan ranks third in the world with an annual sediment load of 435 million ton. According to an estimate, the Indus River is adding 500,000 tones of sediment to the Tarbela Reservoir every day, due to which the dam has lost about 35% of its reservoir capacity in 24 years [8].

It is important to quantify and monitor soil erosion in order to assess and evaluate the magnitude of problem [9]. An understanding of the links between soil erosion and sediment yield and sediment transportation to the fluvial system is an important component of the environment [10].

Inspite of a substantial soil loss and negative impacts on agricultural lands and terrestrial environment, in Pakistan little work has been done to address this issue. Nasir et al. [11] carried out a study using Revised Universal Soil Loss Equation (RUSLE) and GIS at small mountainous watershed of Rawal Lake near Islamabad. The predicted soil loss ranged from 0.1 to 28 t/ha/yr. Similarly, Ahmad et al. [12] reported annual soil loss rates of 17-41 t/ha under fallow conditions, and at annual rate of 9-26 t/ha under vegetative cover in the Fateh Jang watershed having slope of 1%-10%. More recently, Sarah [13] estimated soil erosion risk using Coordination of Information on the Environment (CORINE) model in the Rawal lake watershed. The annual soil loss ranged between 24-28 t/ha with high erosion risk (26%) in areas with steep slope and small vegetative cover. These studies however were confined to the areas of relatively high rainfall (> 1,000 mm). This study was conducted in the medium rainfall areas of Chakwal, Pakistan to study the impact of land-use practices on sediment yield, nutrients depletion and runoff.

2. Material and Methods

The study was conducted in the watershed area of Dhrabi reservoir, located between latitude 32°42′36″ to 32°55′48″ and longitude 72°35′24″ to 72°48′36″ in Chakwal District. It comprised 196 km^2 having one lake, two medium reservoirs and 12 small reservoirs. The watershed drains through a perennial stream known as Dhrab Kass which is a tributary of the Soan river. The Soan river drains into the Indus river at Kalabagh. Rainfall is the main source of freshwater in the watershed with some small springs. The topography varies from shallow to deep gullies, small to large terraces and mounds to hillocks. The study was conducted from 2007 to 2010. The location map of the area is shown in Fig. 1.

The sediment yield was measured from the five sub-catchments of watershed. These catchments consisted of gully land-use and terraced land-use systems. The selection was based on the following criteria: (1) the catchments have well defined boundaries; (2) the sites are representative of the area; (3) the access to the catchment and its outlet is relatively easy and (4) the equipment can be protected. The salient features of the catchments are given in Table 1 and topographic maps are shown in Figs. 2-6. The textural and soil chemical analyses are given in Tables 2 and 3, respectively. The soil is predominantly sandy-loam, low in organic matter and calcareous in nature.

One automatic weather station, four recording rain gauges and nine automatic water-level recorders were installed at different locations to cover the spatial variability in rainfall and runoff. The automatic rain gauges and water-level recorder were installed for measurement of rainfall and water level at different location in the sub-watersheds. Sharp-crested weirs

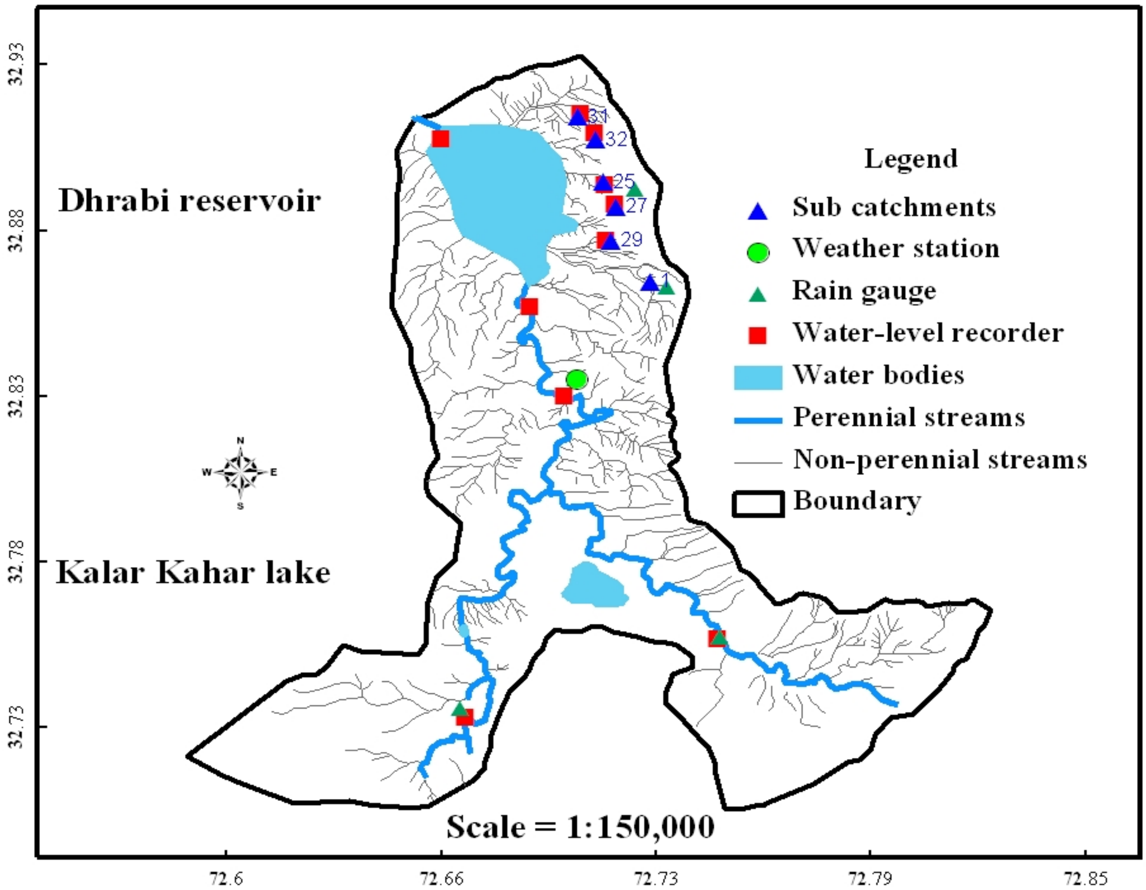

Fig. 1 Map of Dharbi watershed with locations of instrumentation.

Table 1 Salient characteristics of selected catchments.

Catchment No.	Catchment type	Land-use system	Vegetation/crop detail	Area (ha)	Average slope (%)
25	Generally deep gully with wide gully bed	Scrub trees, bushes and grasses on gully tops and slopes used for grazing	Phulahi (*Acacia modesta)* trees, grasses and shrubs saroot (*Saccharum bengalensis*), dab (*Desmostachya bipinnata*), khavi, khabbal (*Cynodon dactylon*)	2.0	10.5
27	Deep gully with terraces in the gully bed, average vertical interval is about 0.5 m	Scrub trees, bushes used for grazing	Scrub trees of phulahi, kikar (*Acacia nilotica)*, sheesham (*Dalbergia sissoo)*, arable crops and grasses at terraces in gully bed	3.0	5.7
29	Gentle sloping land, deep and wide gullies, terraces with strong bunds (dikes)	Cultivated fields with grass cover, terraces used for arable crops and controlled grazing	Wheat, brassica in winter; groundnut and sorghum/millet mixed fodder in summer, phulahi, kikar, bushes and grasses	350	2.2
31	Slightly deep gully with vertical gully walls near catchment outlet	Grasses on gully slopes used for grazing	Dab, creen (*Capparis deciduas*) and khabbal grasses on gully bed and slope, saroot in gully bed. Few scrub trees of phulahi	1.5	10.0
32	Slightly gully with bed modified to terraces	Terraces on gully bed; used for arable crops	Sorghum and millet mixed fodder in terraces except few abandoned terraces, wheat crop during winter at gully top fields, usually single cropping system	3.3	7.6

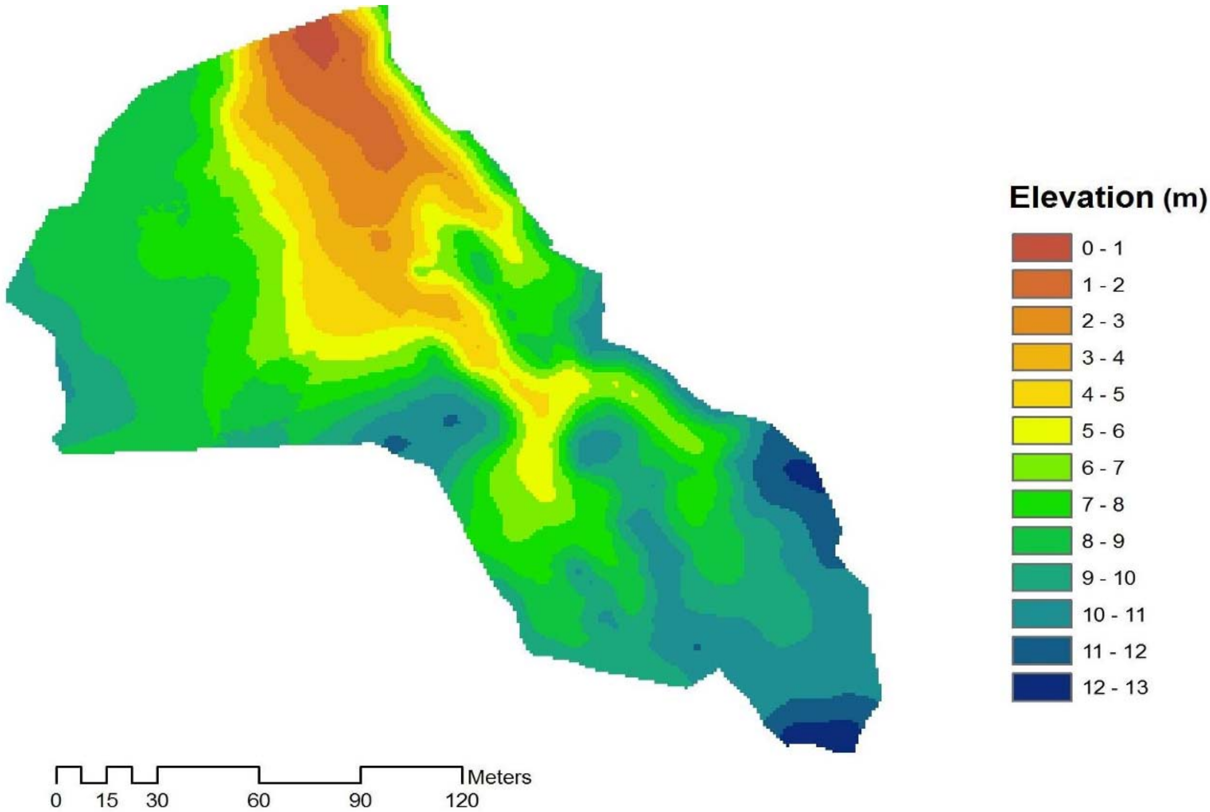

Fig. 2 Topographic map of the catchment No. 25.

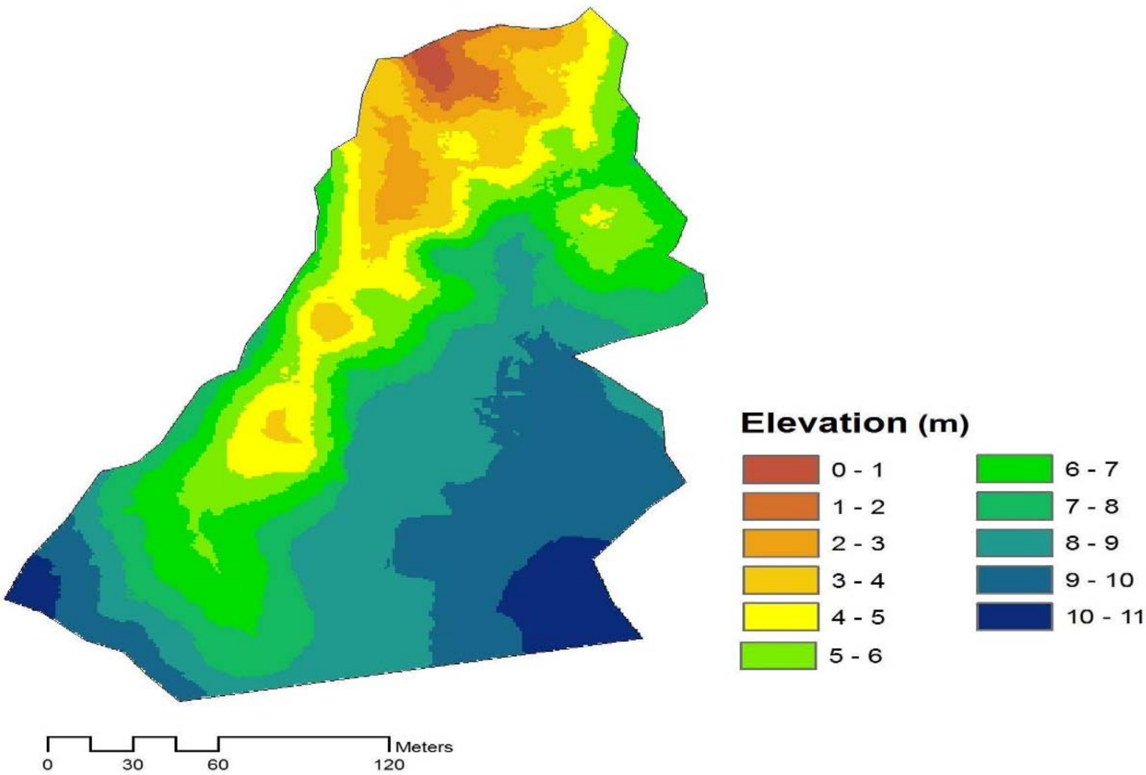

Fig. 3 Topographic map of the catchment No. 27.

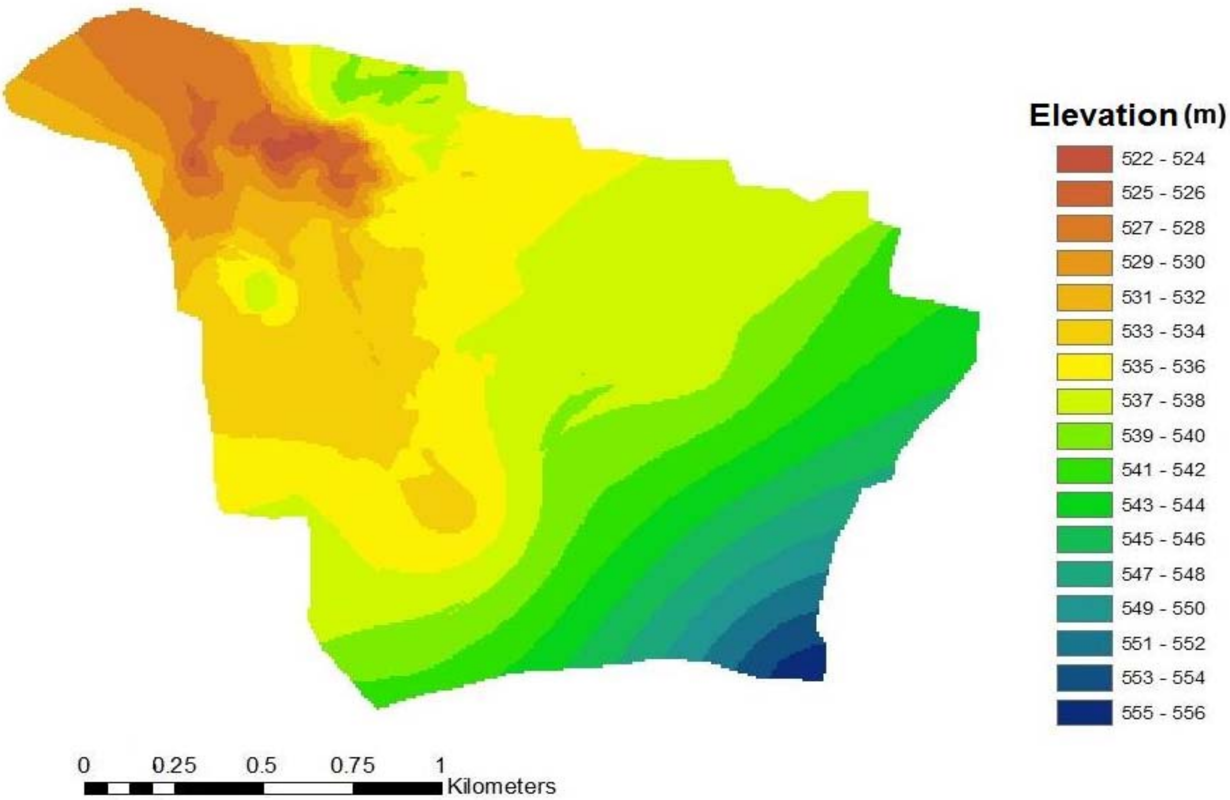

Fig. 4 Topographic map of the catchment No. 29.

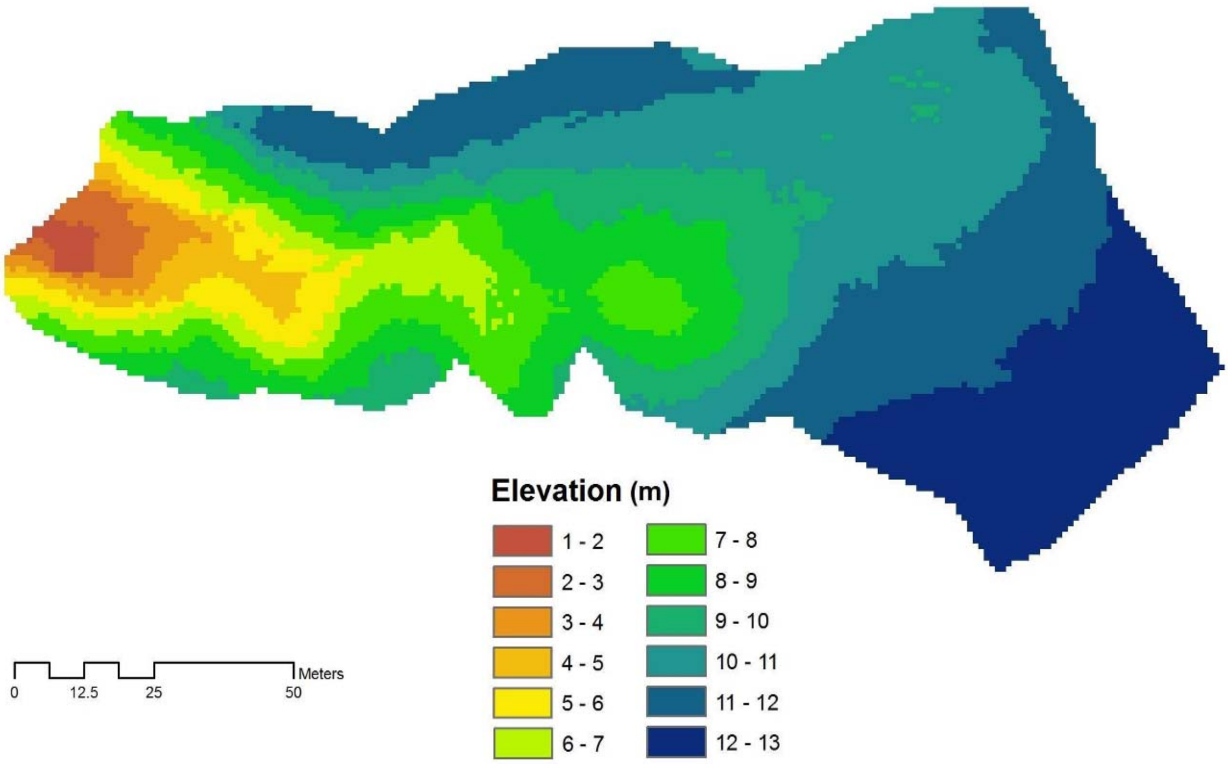

Fig. 5 Topographic map of the catchment No. 31.

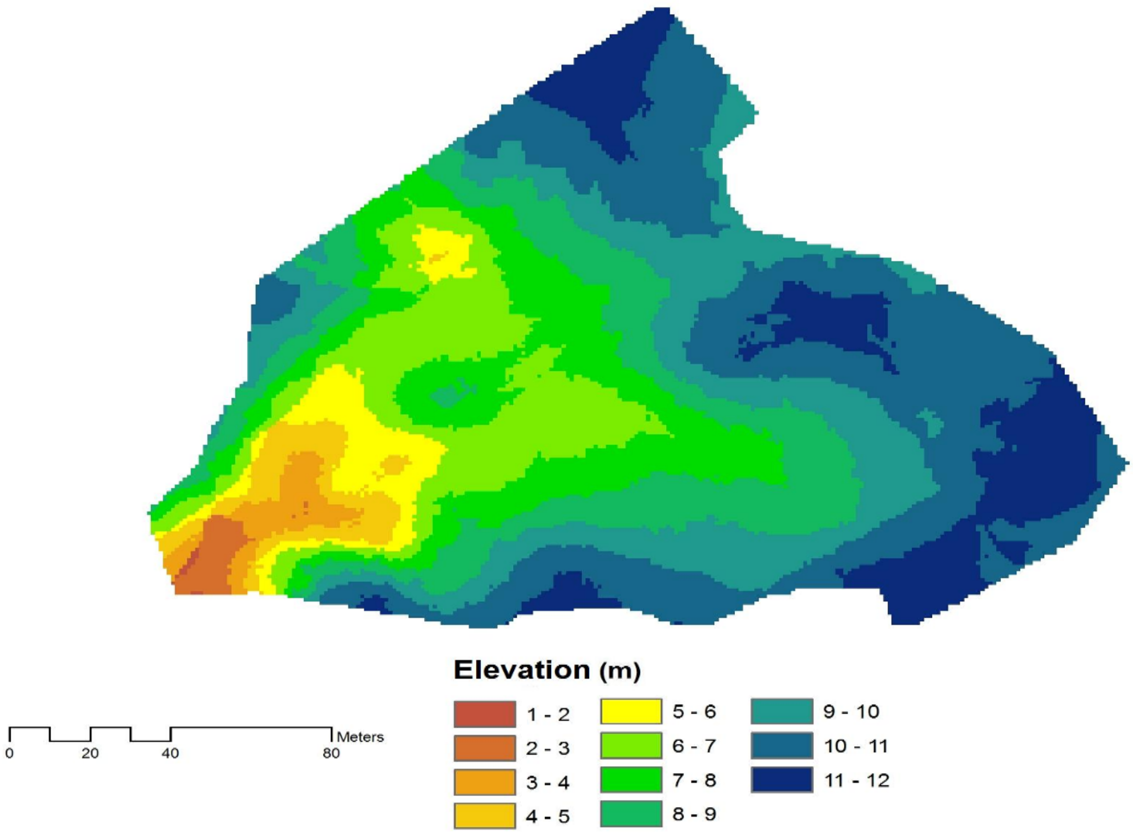

Fig. 6 Topographic map of the catchment No. 32.

Table 2 Soil textural analysis of the sub-catchments.

Catchment	Textural class	Sand(%)	Silt(%)	Clay(%)
25	Sandy loam	67	19	14
27	Sandy loam	72	15	13
29	Sandy loam	71	17	12
31	Sandy loam	68	22	10
32	Sandy loam	74	14	12

Table 3 Average soil chemical analysis of the sub catchments.

Parameter	Catchment				
	25	27	29	31	32
ECe (dS/m)	0.44	0.89	0.63	0.49	0.39
pH	7.62	7.78	7.74	7.81	7.74
Av P (mg/kg)	4.7	3.5	4.8	3.9	3.5
Ex K (mg/kg)	96	135	105	90	121
OM (%)	0.80	0.21	0.53	0.63	0.44
$CaCO_3$ (%)	15.67	16.17	17.18	15.67	15.42
Zn (mg/kg)	1.50	1.84	1.53	1.61	2.15
Cu (mg/kg)	0.06	0.13	0.11	0.02	0.00
Fe (mg/kg)	4.72	3.04	2.15	1.70	2.33
Mn (mg/kg)	26.63	44.74	29.39	16.11	12.48

were constructed at the catchment outlet and were used to determine the discharge (runoff) passing over the weir. Stage hydrograph was converted to discharge using the equation:

$$Q = C\,B\,H^{3/2} \quad (1)$$

where Q = discharge in $m^3 \cdot sec^{-1}$, C = constant, B = width of weir (m), H = height (m) of water passing over the weir. C was taken as 1.48. The locations of the rain gauges and the water-level recorder installed in the watershed are given in Fig. 1.

Coarser sediments were trapped in the stilling basin during the runoff event (Fig. 7). This was considered as bed load. After each runoff event, the standing water from the stilling basin was drained off through the drain pipe and the wet sediments were collected and weighed. A representative sample of wet bed load was collected after mixing five to six sub samples from the stilling basin. Part of the sample was over dried for determining its moisture contents. The moisture contents were deducted from the wet weight to determine the dry weight of the sediment. Steel pins were installed at the catchment outlet, in the stilling basin, pins height was measured at the end of the season to determine the bed load.

Finer sediments in the runoff water passing the weir were sampled using vertical sampling tubes with holes. Following runoff events, samples present in the container were collected and analyzed. The sediment collected was also analyzed for determining the nutrients such as available P, extractable K, organic matter, Zn, Cu, Fe and Mn.

3. Results and Discussions

3.1 Rainfall Characteristics

As rainfall intensity and duration has a profound impact on soil erosion, the analysis of the long-term data (1977-2010) from SAWCRI Chakwal was conducted; it shows that 63% of the annual rainfall (632 mm average) occurred in summer from June to September (Fig. 8). During 2008, and 2010, the rainfall was 14% higher than the average. In 2009, the total

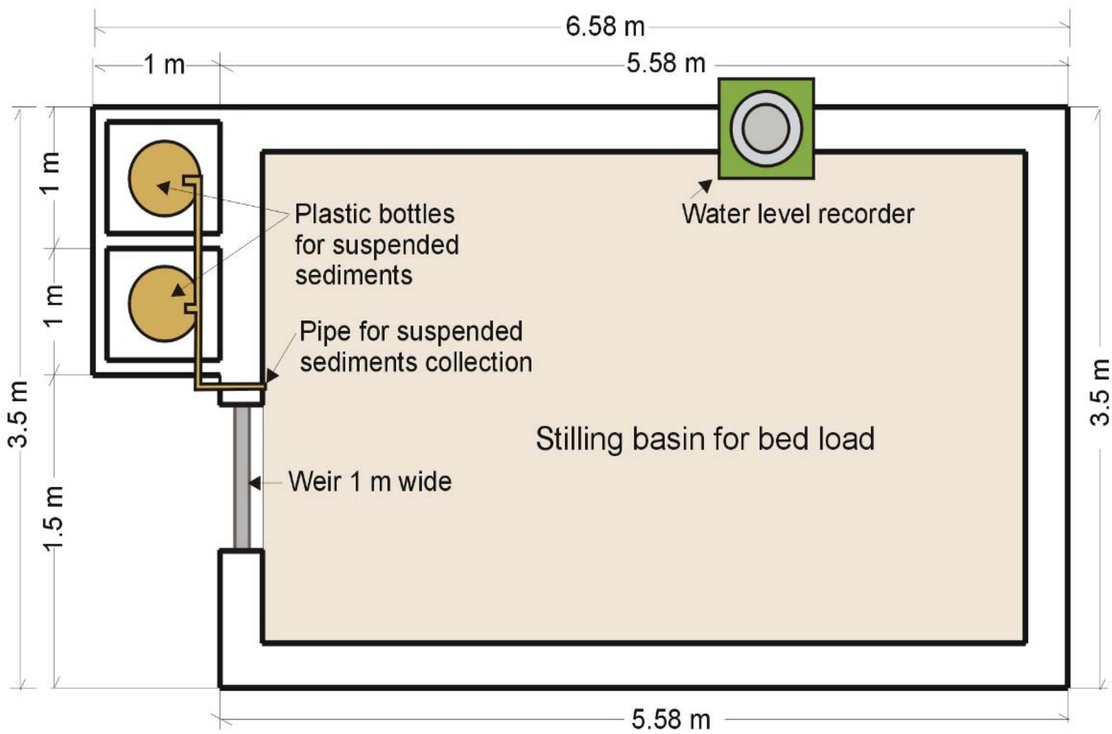

Fig. 7 A schematic showing the arrangement for the collection of sediment samples.

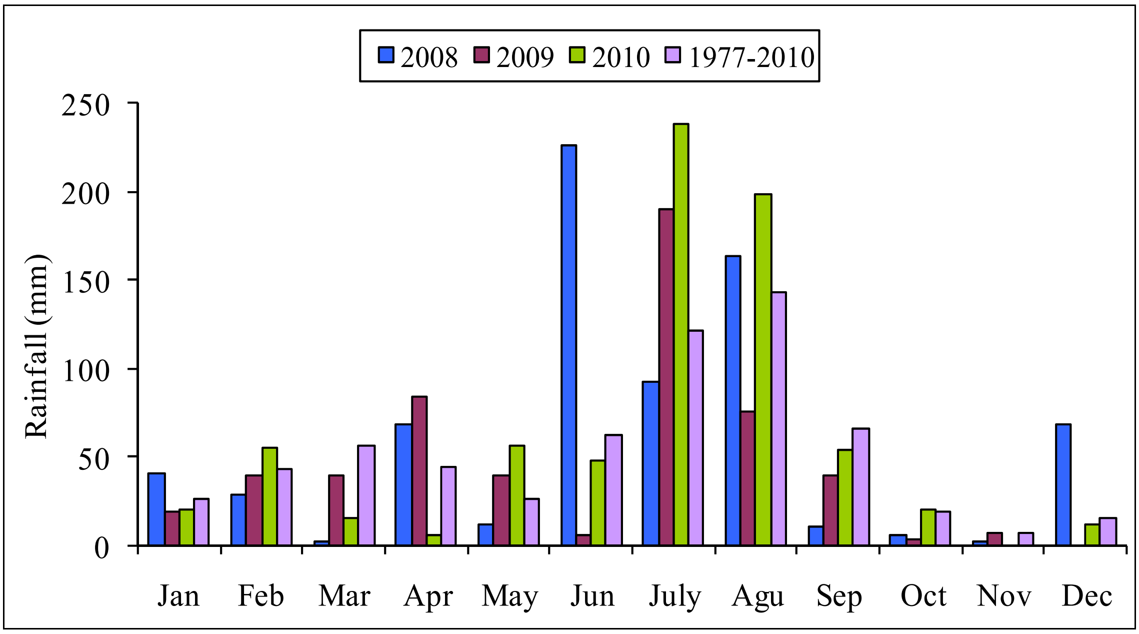

Fig. 8 Rainfall at SAWCRI, Chakwal.

rainfall (547 mm) was 14% less than the normal, out of which 49% (265 mm) occurred during the months of July and August.

3.2 Total Sediment Yield

Annual sediment yield (t/ha) is the total quantity of sediments that left the watershed divided by the watershed area. Sediment load includes bed load as well as suspended load [10]. The sediment yield data for small catchments over two years is presented in Table 4. Most of the runoff events occurred in the summer season from April to September. The year 2009 was dry compared to 2010. The sediment yield of gully catchments No. 25 and 31 in 2010 was about 1.5 times more than 2009. Terraced catchments No. 27 and 32 showed substantially low sediment yield as compared to gully catchments. Marston and Dolan [14] found that hill slope gradient, vegetation density, and soil texture were the most critical factors in determining sediment yields in semiarid Wyoming.

McCormack et al. [15] defined SLTL (soil loss tolerance limit) as the maximum rate of annual soil erosion that will permit a level of crop productivity to be obtained economically and indefinitely. In India, a sediment yield of 11.2 t/ha/yr is followed as default SLTL value [16] assuming a soil formation rate of 2.5 cm in 30 years. USDA-Natural Resources Conservation Services [17] has proposed a range of SLTL from 2.5 to 12.5 t/ha/yr. Considering the SLTLs, it appears to be difficult to maintain long-term productivity of the gully system. So there is need for interventions to reduce the soil loss. The terracing in catchment 32 and 27 has shown its potential to reduce soil erosion.

Table 4 Annual Sediment yield (t/ha) of small catchments at Dhrabi watershed.

Catchment	2009			2010		
	Coarser sediments	Finer sediments	Total sediment yield	Coarser sediments	Finer sediments	Total sediment yield
25	3.13	1.66	4.79	0.92	7.23	8.15
27	0.77	-	-	0.11	2.67	2.78
31	1.96	6.38	8.34	3.95	8.36	12.31
32	0.81	-	-	1.47	2.62	4.09

For catchment No. 25, all the runoff events of 2009 were received during the summer. In this year, two main runoff events i.e. 46 and 43 mm occurred in early June and late July, respectively which caused most of the erosion. The maximum 30-minutes intensity (I30) reflects prolonged peak rates of detachment and runoff [18]. I30 of these events was 81 and 85 mm/hr, respectively which produced the highest peak discharge of 0.38 and 0.41 m^3/s, respectively. Similarly, during 2010, there were four runoff events, resulting in sediment yields of more than 0.7 t/ha/yr (Table 5). Most of the erosion was caused by a few high intensity rainfall events as has also been reported by Toy et al. [19] and Ramos et al. [20]. Since the catchment was a natural gully system with no engineering or vegetative protection by the farmers, there was no obstacle to the overland flow. As a result, nearly all the catchment contributed to the runoff during most of the storms. The I30 for initiating runoff at small catchment scale (size 2.0 ha) was 29 mm/hr. Hudson [21] reported that 25 mm/hr storm was the threshold intensity for initiating erosion in the tropical climate of Zimbabwe at a runoff plot scale. In temperate climate however, erosion has been reported to start at much lower intensity. Lower threshold values of 6 and 10 mm/hr have been identified in Germany and Great Britain [22]. Most of the sediments were transported as finer sediments (Table 5).

Similar to the adjacent catchment No. 25, the catchment No. 27 was a single gully that has been converted to terraces by the farmers. There was a dike in the middle of the catchment that resisted rainfall event of 60 mm during summer. One reason for lesser runoff was due to cultivation of sorghum and millet crops. No runoff occurred during winter season from December 2008 to March 2009 and October to December 2009 (Table 6). The lower part of the catchment contributed all the runoff. Similar to catchment No. 25, only two rainfall events produced substantial runoff with peak discharge lower than of catchment No. 25 due to dikes and smaller contributing area. Decrease of peak discharge with terracing has also been reported by Huang et al. [23]. Similarly, the bed load of this catchment was also less than the gully catchment. Bunds helped decrease the runoff from the catchment by storing water in the soil profile.

Table 5 Main runoff events with sediment yield at catchment No. 25.

Date	Rainfall (mm)	Peak discharge (m^3/sec)	Coarser sediments trapped (kg)	Finer sediments passing over weir (kg)	Sediment yield (kg/ha)
6-4-09	46	0.38	1985	901	1343
28 & 29-7-09	23, 43	0.41	3724	1832	2778
7-5-10	60	0.44	554	3695	2125
20-7-10	60	0.44	304	7017	3661
27-7-10	21	0.15	172	1013	592
29-7-10	42, 64	0.12, 0.16	226	1197	711

Table 6 Main runoff events with sediment yield at catchment No. 27.

Date	Rainfall (mm)	Peak discharge (m^3/sec)	Coarser sediments trapped (kg)	Finer sediments passing over the weir (kg)	Sediment yield (kg/ha)
6-4-09	26	0.15	16	-	-
6-4-09	46	0.14	216	-	-
28/29-7-09	23, 43	0.16	449	-	150
20-7-10	60	0.16	22	1461	1483
27-7-10	21	0.03	13	150	163
29-7-10 am	42	0.05	-	405	405
29-7-10 pm	64	0.08	9	157	166
24-8-10	50	0.06	4	179	183

Since 2009 was comparatively dry year, with no extraordinary rainfall events, runoff occurred only at the lower part of the catchment and, most of the rainfall was retained in the terraces. In 2010, the same trend was observed and no dike was broken in the catchment.

The catchment No. 29 was comparatively larger (350 ha) than others. It contained gullies and terraces and measurement of coarser sediment yield was rather on annual basis. Total sediment yield was obtained by adding the coarser and finer sediments. The annual sediment yield for the two consecutive years 2009 and 2010 was 123 and 416 kg/ha, respectively. In 2010 annual sediment yield was 3 times higher than 2009, probably due to double number of rainfall events occurred in 2010.

In catchment No. 31, ten runoff events produced a soil loss of more than 18 t/ha. The sediment yield of these storms is presented in Table 7. The sediment yield was closely related to peak discharge. Higher sediment yield observed for this gully system compared to catchments No. 25 and 27 was due to less vegetative cover and steeper slope. Comparatively lesser catchment area may also be the reason for higher sediment yield as the sediment delivery ratio of smaller catchments is higher.

The terraces of catchment No. 32 have gentle slopes with no bunds. The peak discharge of the events was lower in this catchment. The maximum rainfall of 56 mm occurred in late July (Table 8). In 2010, six runoff events occurred, in the catchment No. 32 which produced 2.7 t/ha sediments.

3.3 Nutrient Analysis of Sediments

Farmers in the rainfed areas at the watershed rarely use micro and macro nutrients. Micro nutrients that are naturally available in the soil are exposed to depletion due to soil erosion. Tables 9-13 show the nutrients analysis of the sediment collected at the outlet of the catchments. Generally, the organic matter (OM) is low in the cultivated lands of the areas (less than 1%). The organic mater contents of sediments were relatively high which explains the low OM in the soils. Up to 2.17% OM was recorded in the sediments of a single rainfall event.

Table 7 Main runoff events with sediment yield at catchment No. 31.

Date	Rainfall (mm)	Peak discharge (m^3/sec)	Coarser sediments trapped (kg)	Finer sediments passing over weir (kg)	Sediment yield (kg/ha)
22-7-09	21	0.15	748	1948	1797
29-7-09	56	0.27	1370	4322	3795
18-8-09	32	0.06	263	553	544
02-9-09	25	0.14	362	2448	1873
07-5-10	32	0.18	826	1002	1219
20-7-10	55	0.29	1148	4357	3670
21-7-10	36	0.09	1335	1209	1696
29-7-10	39, 16, 38	0.08	801	2602	2268
24-8-10	42	0.08	117	1294	941
10-9-10	44	0.15	260	913	782

Table 8 Main runoff events with sediment yield at catchment No. 32.

Date	Rainfall (mm)	Peak discharge (m^3/sec)	Coarser sediments trapped (kg)	Finer sediments passing over weir (kg)	Sediment yield (kg/ha)
29-7-09	56	0.39	224	-	-
18-8-09	32	0.06	194	-	-
02-9-09	25	0.15	108	-	-
20-7-10	55	0.31	1426	4334	1745
21-7-10	36	0.09	352	1097	439
29-7-10	39, 16, 38	0.10	462	1337	545

Table 9 Nutrients present in the sediments of catchment No. 25.

Date	Rainfall (mm)	Av P* (mg/kg)	Ext K** (mg/kg)	OM (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
6-4-09 pm	46	6.1	674	0.31	3.3	1.01	22.0	69.2
28 & 29-7-09	23, 43	18.7	230	0.74	2.3	0.50	-	78.8
7-5-10	60	-	-	-	-	-	-	-
20-7-10	60	0.17	155	0.22	-	-	-	-
27-7-10	21	0.03	149	0.64	-	-	-	-
29-7-10	42, 64	0.10	163	-	-	-	-	-

*Available phosphorous; ** Extractable potassium.

Table 10 Nutrients present in the sediments of catchment No. 27.

Date	Rainfall (mm)	Av P (mg/kg)	Ext K (mg/kg)	OM (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
6-4-09	26	6.6	302	0.49	3.3	1.15	7.6	90.8
6-4-09	46	9.5	631	0.49	2.1	0.53	2.1	54.8
28 & 29-7-09	23, 43	10.8	295	0.76	2.8	0.13	29.2	91.3
20-7-10	60	0.15	215	1.39	-	-	-	-
27-7-10	21	0.14	257	0.64	-	-	-	-
29-7-10 am	42	-	-	-	-	-	-	-
29-7-10 pm	64	0.24	221	2.17	-	-	-	-
24-8-10	50	0.49	254	-	-	-	-	-

Table 11 Nutrients present in the sediments of catchment No. 29.

Year	Av P (mg/kg)	Ext K (mg/kg)	OM (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
2009	6.7	137	0.45	2.5	2.1	7.0	9.38
2010	7.9	156	0.51	1.9	2.5	5.9	7.14

Table 12 Nutrients present in the sediments of catchment No. 31.

Date	Rainfall (mm)	Av P (mg/kg)	Ext K (mg/kg)	OM (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
22-7-09	21	11.4	262	0.46	2.5	0.37	25.3	68.1
29-7-09	56	8.0	154	0.99	1.8	0.55	21.6	65.5
18-8-09	32	9.5	295	1.02	3.1	0.14	17.8	69.6
02-9-09	25	9.7	-	0.65	1.9	0.30	7.00	65.2
7-5-10	32	-	110	1.31				
20-7-10	55	0.00	99	1.62				
21-7-10	36	0.00	88	0.91				
29-7-10	93	0.00	69	0.10				
24-8-10	42	0.02	83	-				
10-9-10	44	-	97	-				

Table 13 Nutrients present in the sediment of catchment No. 32.

Date	Rainfall (mm)	Av P (mg/kg)	Ext K (mg/kg)	OM (%)	Zn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)	Mn (mg/kg)
29-7-09	56	6.6	153	0.87	1.4	0.42	14.6	66.2
18-8-09	32	12.4	245	0.43	2.6	0.20	7.1	82.2
02-9-09	25	10.7	-	0.31	1.8	0.10	5.8	37.6
20-7-10	55	0.00	97	0.79	-	-	-	-
21-7-10	36	0.00	110	1.01	-	-	-	-
29-7-10	93	0.00	110	0.70	-	-	-	-

The concentration of Zn, Cu, Fe and Mn in the sediments trapped in the stilling basins was higher as compared to those present in the soil. Particularly, available K was high in these sediments. On one hand, the removal of these nutrients from top soil, results in the deficiencies affecting the crop yield. On the other hand, these nutrients play an important role in the water quality deterioration and eutrophication of downstream reservoirs. Further research should be conducted to study the depletion of macro and micro nutrients from the soil and their impact on reservoir capacity and quality.

3.4 Runoff Coefficients

An analysis of runoff coefficients provides insight in catchment response, especially if a range of catchments and runoff events are compared by a single indicator [24]. The runoff coefficient is the ratio of rainfall and runoff and is used to calculate runoff from a given storm. It depends on the catchment characteristics and the rainfall intensity and duration. Unfortunately, in Pakistan runoff coefficients have not been determined and estimates are based on similar conditions. This study, however, provides an opportunity to present runoff coefficients for a range of small catchments.

The rational method is used for runoff estimation from small watersheds. The rational method of predicting a design peak runoff rate is expressed by the Eq. (2) [25].

$$Q = 0.0028\ CIA \qquad (2)$$

where, Q is the design peak runoff rate (m^3/s), C is the runoff coefficient, I is the rainfall intensity (mm/h) for the design return period and for a duration equal to the time of concentration (Tc) of the watershed and A is the watershed area (ha). In the present work, the runoff coefficient C was calculated from the runoff data of small watersheds. On the basis of measured data, the calculated values for runoff coefficients are presented in Table 14. Calculated runoff coefficients for these catchments vary from 0.09 to 0.75.

Runoff coefficients depend in addition to rainfall on soil type, slope, vegetative cover and land-use systems. The basic assumption for application of rational method is that rainfall occurs at relatively uniform intensity over the entire area of the watershed [25]. However, the monsoon rainfall events are known for their extreme non-uniform intensity over few hectares. These phenomena also affect the runoff coefficients.

3.5 Prediction of Sediment Delivery to Dhrabi Reservoir

The soil erosion and associated soil particles suspended sediments are carried by streams to the reservoir downstream when larger solids move along the stream bed as bed load. When sediment-laden water reaches a reservoir, the velocity and turbulence are greatly reduced. The large suspended particles and most of the bed load (having high specific weights) are deposited at the upstream of the reservoir. However, the smaller particles remain in suspension and are deposited farther down the reservoir and may pass the dam through the sluice gate or over the spillway.

The sediment yield from small catchments of a watershed may be used to determine the total sediment flowing into the reservoir. To transfer the sediment yield directly, the drainage areas should not be

Table 14 Calculated values of runoff coefficient (*C*) in the Dhrabi watershed.

Catchment	Area (ha)	*C* for rainfall intensity (mm/hour) equal to *Tc*		
		50	100	150
25	2.0	0.09	0.21	0.41
27	3.0	0.10	0.23	0.40
29	350	0.12	0.30	0.40
31	1.5	0.23	0.48	0.75
32	3.3	0.11	0.26	0.34

Table 15 Sediment trapped behind the structures.

Year	Village Name	Structure	Cost per structure (Rs)*	Cost of installation (Rs)	Cost of repair (Rs.)	Average sediment trapped (t/ha)
2008	Dhoke Mohri	22	3995	87890	15900	-
	Rehna	8	3625	29000	-	-
	Chak Khushi	24	4000	96000	-	-
	Khokharbala	12	4667	56004	-	-
2009	Dhoke Mohri	22	-	-	-	2.2
	Rehna	31	5761	132515	-	1.1
	Chak Khushi	24	-	-	-	3.1
	Khandua	16	3500	56004	-	-
	Khokharbala	13	5600	5600	1000	2.3
2010	Dhoke Mohri	22	-	-	-	125.4
	Rehna	31	-	-	-	365.8
	Chak Khushi	24	-	-	-	231.8
	Khandua	16	-	-	-	204.8
	Khokharbala	13	-	-	-	184.6

*Rs = Pakistani Rupee, 1 US$ = Rs 72 (2008-9).

different in size by a factor greater than two. For drainage areas that differ by a factor greater than two, the United States Soil Conservation Service recommended that the following relationship for humid areas of the Rocky Mountains be used to transfer sediment yield estimates [22]:

$$Se = Sm\,[Ae/Am]^{0.8} \quad (3)$$

where *Se* = sediment yield of the unmeasured watershed, *Sm* = sediment yield of measured watershed, *Ae* = drainage area of unmeasured watershed, *Am* = drainage area of measured watershed.

The annual 2009 sediment yield of the 350 ha catchment (catchment No. 29) was established at 123 kg/ha. Using the above equation, the predicted sediment yield of Dhrabi watershed (19,100 ha) is about 1,056 t/yr. Using the annual sediment yield of catchment No. 25 and No. 27, i.e. 4.7 and 8.34 t/ha/yr, the predicted sediment yield of Dhrabi watershed may be 24,055 and 14,359 t/yr, respectively. Similarly, the sediment yield of 350 ha catchment (catchment No. 29) was 416 kg/ha during 2010. The predicted annual sediment yield of Dhrabi watershed (19,100 ha) is about 3,570 t. Using the annual sediment yield of catchment No. 25 and No. 31, i.e. 8.15 and 12.31 t/ha, the predicted sediment yield of Dhrabi watershed may be 24,055 and 35,514 t/yr, respectively. There is large variation in these estimates due to inaccuracies in quantification of sediment delivery ratio and problems of large extrapolation. The measurement of sediment yield from plots or small catchments cannot be directly extrapolated to large catchments, since the effect of the sediment delivery ratio is not easily quantifiable [26].

3.6 Impact of Interventions on Soil and Water Conservation

Rainfall, soil and topography tend to have major influences on soil erosion processes. Land management practices can be manipulated to control the magnitude and extent of these processes [27]. Interventions that reduce runoff and conserves soil moisture usually reduce soil erosion. Conservations structures reduce the runoff, help conserve soil and moisture and also trap the sediments (Table 15). The sediment trapped behind the structure in the long term reduces the elevation difference between the head and tail of a field. These sediments are rich in micro nutrients (Tables 9-13) and enhance crop yield. They also contribute to the sustainability of the downstream water bodies by reducing the accumulation at sediments.

4. Conclusions

Erosion process in the watershed gullies is rapid which makes it difficult to sustain long-term fertility of the soil. The macro and micro nutrients present in the sediment indicate that these nutrients are being depleted due to soil erosion. More production of sediments will eventually decrease the life of the reservoir. Practice of terracing for arable crops inside the gully has shown potential in reducing the soil erosion. As soil erosion is the highest during monsoon (July-August) permanent vegetation cover needs to be maintained in the watershed, for sustainable crop-production systems.

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