ESTIMATION AND RAPPORT BETWEEN RAINFALL-RUNOFF AND SEDIMENT LOAD AS SOIL LOSS FROM RAWAL SUB-WATERSHED (SATRAMEEL)

A. G. Mangrio[1], M. Aslam[2] and M. Z. Ikram[2]

[1]Senior Scientific Officer, and [2] Principles Scientific Officers, Water Resources Research Institute, National Agricultural Research Centre, Park Road, Islamabad, Pakistan

ABSTRACT

A research was conducted to evaluate a three year field data of rainfall-runoff and sediment load at Rawal sub-watershed (Strameel), Islamabad. The water samples were taken during the monsoon seasons of years 2006, 2007 and 2008. The total runoff was measured as 115, 191 and 241 mm during monsoon as per recorded events out of 282, 557 and 512 mm rainfall in 2006, 2007, and 2008 years respectively. The total sediment load as 0.944, 2.417 and 2.517 tons/ha during the recorded events of monsoon for the years 2006, 2007 and 2008 respectively. The maximum sediment load 0.331 (35% of total), 0.734 (30% of total) and 0.960 (37% of total) was observed on 28.7.2006, 24.8.2007 and 8.7.2008 respectively in single rainfall storm, and further 65, 70 and 63% sediment load was observed in remaining runoff events during monsoon season of the years 2006, 2007 and 2008 respectively. The maximum sediment load as total (2.517 tons/ha) against the runoff of 241 mm out of 512 mm rainfall with 190 lit/sec/ha maximum peak unit discharge was observed during the monsoon season of 2008. It was observed that maximum peak unit discharge was 136.69, 177.38 and 189.63 lit/sec/ha in month of July, August and July with an average peak unit discharge were 66.59, 56.41 and 76.90 lit/sec/ha for the years 2006, 2007 2008 respectively. However, the peak unit discharge data were needed to design the hydraulic structure for the control of erosion/sediment for sub-watershed management.

Keywords: Erosion watershed, rainfall, runoff, sediment load

INTRODUCTION

Out of total geographical area of 79.61 Mha, the suitable area for agriculture in Pakistan is about 29.37 Mha while 50.24 Mha is uncultivated (GoP, 2009). The 19.22 Mha (24.14% of the total area) is affected by soil erosion, out of this 13.05 Mha (16.39% of the total area) is affected by water erosion (Zia & Arshad, 2006).

Corresponding author: mangrioghafoor@yahoo.com

The Indus River carried the fifth largest load of sediment (4.49t/h) in the world in year 1990 and estimates the Indus is adding 500,000 tons of sediment to the Tarbela Reservoir every day, reducing the life of the dam by 22% and the capacity of reservoir by 16% (Zia and Arshad, 2006). The Indus River has annual sediment load of 435 million tons and an average sediment concentration of 2.4 kg m^{-3} (Belaud *et al*., 1998). Average annual water inflow at Tarbela is 64 MAF, which brings along a huge quantum of sediments estimated at 200 million tons per year from a catchments area of more than 169,000 sq.kms, and Tarbela Lake has gone down to 6.77 MAF from its original storage capacity of 9.68 MAF, recording 30% decrease during the last 36 years (Pakissan, 2011) http://www.pakissan.com/english/news (Lahore, May 17, 2011). Nearly 4.95 million hectares or 25% of the total cultivated area of the country is under rain-fed which depends on rainfall for crop production (Alam, 2000). The rainfed area is concentrated in Pothwar Plateau, northern mountains and northeastern plains of the country forming the largest contiguous block of dry land farming in Pakistan. The pothwar spreads over 2.2 Mha and the total cultivated area is about 1.0 Mha. Geographically, it is located on the watershed of the Soan river, which is one of the main tributaries of the Indus River.

The Warsak and Khushdil Khan Reservoirs have almost silted up. Another example of the same situation is shahpur dam, Fateh Jhang as reported by Ashraf *et al.* (2000). Similarly, the Kallar Kaahar Lake has lost almost half of capacity due to unwanted vegetation. The watershed in scrub forests of the pothwar are degraded due to overgrazing and illegal cutting (Shafiq *et al.* 1998). Ahmad *et al.* (1990) reported that for a slope of 1-10%, soil is being lost at a rate of 17-41 t/ha/yr under fallow conditions, and at a rate of 9-26 t/ha/yr under vegetative cover in the Fateh Jang watershed. About 4.2 billion cubic meter (BCM) of water is lost from *Pothwar* plateau as surface runoff annually reported by Bhutta (1999). Soil erosion has major consequences on the terrestrial environment, which affects both cultivable and forest lands. Soil erosion creates serious problems in agriculture and water resources management due to removal of fertile soil as degradation and aggregation.

There is a considerable variation in rainfall within a year and that on a year-to-year basis. Despite these variations, the data derived from flume and sediment dried; show an excellent correlation with the input parameters. Using the parameters presented by Nasir *et al.* (2002), it is possible to predict the soil loss with the application of RUSLE for verification. A comparison of predicted soil loss with measured monsoon soil loss shows that in Satrameel sub watershed, soil loss is up to 18.6 ton/ha/yr by (Shafiq *et al.*, 1998 and Nasir *et al.* 2002). The surface runoff and soil loss depends upon rainfall and catchment characteristics. The amount, duration, intensity and aerial distribution are the important parameters of rainfall which affect runoff and soil loss. Rainfall intensity influences both the velocity and volume of runoff. An intense storm exceeds the infiltration capacity by a greater margin than does a gentle rain; thus the total volume of runoff is equal for the intense storm even though total rainfall is the same. Gifford and Hawkins (1978) indicated that heavy grazing tends to reduce infiltration and increases storm runoff and erosion by removing protective plant

28

cover and compacting soil. Further, revealed that effects from light and moderate grazing are difficult to differentiate, and although highly variable, tends to be intermediate between heavy grazing and no grazing. Also no single system proved superior in improving range or watershed conditions.

In contrast, the differences in storm runoff quantity from watershed that contains wetlands appear to be related to total precipitation during study period of each year. The wetlands and ponding areas likely retain the load of sediment and, subsequently, lower the amount of storm-runoff loading exposed from a watershed. A research study is, therefore, designed for the estimation of rainfall, runoff and soil loss and its relationship at Strameel watershed area to address the issues of runoff and soil loss and to develop management guidelines for sustainable watershed management of Pakistan.

The research study will be useful for planning and management of the selected watersheds as well as other area of country to estimate the potential runoff volume and soil loss and peak unit discharge. This would help measure the runoff control structures, conservation strategies, storage (ponding) and its utilization to minimize the poverty elevation of the country. The Satrameel sub-watershed emerges from the southern parts of Margalla hills, Islamabad. These hills generally bring in flashy floods of shorter and longer duration with high peaks of runoff. Due to steep gradients of drainage network and cutting of vegetation, the resulting flow velocities are usually high. Consequently, these runoff volumes causing soil loss as sediment load (loss of fertile soil), ultimately reducing channel carrying capacity and reservoir capacity associated with considerable soil erosion. Therefore, the runoff and silt load problems need attention to optimize conservation of watersheds for sustainable agriculture and crop production.

MATERIALS AND METHODS

The Rawal sub-watershed is stretched in twin districts of Islamabad and Rawalpindi. The Rawal sub-watershed feeds Rawal Dam, which is a strategic asset and meet primarily the drinking water requirements alongside some agricultural allocations in twin cities. The major issues being faced by the Rawal sub- watershed area are urbanization, sewage discharges without treatment, active erosion, non-existent of any cooperative communal structure and reduced livelihood opportunities. The mountain watershed called Strameel is situated in the watershed of Rawal lake near Islamabad in southern part of the Margalla hills, between latitude 33^0 45' 90" to 33^0 46' 16"N and longitude 73^0 12' 44" to 73^0 12' 81"E with 625 to 723 meters elevation above mean sea level. The drainage area of the satrameel watershed is 12.64 ha. The area falls is one of the hilly areas having deforestation problems of natural vegetations, over grazing and cutting of trees. The degraded scrub forest of satrameel sub-watershed drains into Rawal Lake as surface runoff (Fig.1).
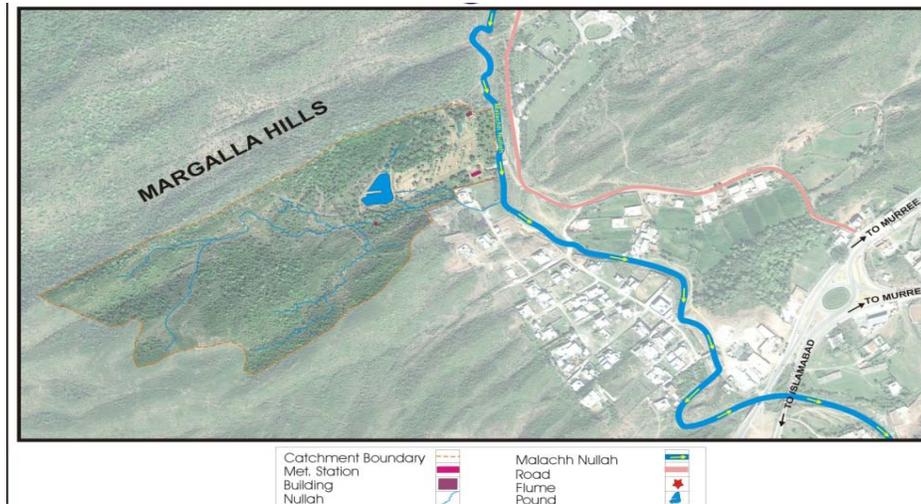
Figure 1. Location map and Ariel view of satrameel, watershed area

Figure 2.   H-flume installed at sub-rawal watershed satrameel

The climate of Pothwar as well as Strameel area ranges (from semi-arid to sub-humid subtropical continental. As distance from the mountains increases, rainfall decreases steadily. Mean annual rainfall at Strameel is 1326 mm, out of which 798 mm (i.e. 60 % (2006-2008) rainfall is generally received during monnsoon season (July to September). June and July are the hottest months of the year, with mean maximum temperature ranging from 36º to 42ºC with extremes sometimes as high as 48ºC. Contrarily, December and January are the coldest months, with mean minimum temperatures of about 3º to 5.5º C. Occasionally;

the lowest minimum temperature may drop to -4ºC. Usually, frost occurs for some days of November to February, with conducive conditions (i.e., clear sky, calm wind and temperatures close to or below freezing points). Concentrated rainfall and undulating topography are the main causes of erosion in Pothwar.

Rainfall measurements

A meteorological observatory was established at the Rawal sub-watershed, Satrameel. The rainfall was measured using of manual rain-gauge of 8 inches size. The volume of rainfall was measure with a graduated cylinder in milli-liters (ml), which was converted into depth of water in milli-meter (mm) by dividing the volume of water with x- sectional area (8 inch dia) of rain gauge.

Surface runoff measurements

The H- type flume (4.5 ft size) was installed at the drainage outlet with measuring gauge to measure the flow depth (Fig. 2). The flow depth verses time was recorded and the data was analyzed for flow discharge by using following formula.

$$\text{Log } Q = A + B \text{ Log } H + C \text{ (Log } H)^2 \qquad (1)$$

where,

Q = discharge, $m^3 \sec^{-1}$.
H = flow depth, m

A, B, C are the coefficients based on the flume size, the value of A, B and C are 0.0588, 2.3032 and 0.2547 respectively for 4.5 ft above flume size.

The flume data was analyzed for flow volume (m^3), flow depth (mm) and peak unit discharge (lps per hectare).

Measurement of sediment load

The water samples were collected during the runoff period for analyzing the sediment load. The bottles were air tightened and shifted to laboratory. The settled sediment in bottle along with water was completely mixed by thorough shaking and passed through filter paper (watman sheet). The watman paper was dried at 60- 65 ^{0}C for 24 hrs and weighted before its use. The sediment collected on filter paper was dried in 3-4 hrs on same funnel. Later on the filter paper along with sediment was shifted to oven for complete drying at 60-65 ^{0}C for 24 hrs. The filter paper alongwith sediment was weighted again after drying. The difference in weight (grams per sample) was multiplied with total runoff volume to determine have a total soil loss in storm runoff.

Peak unit discharge measurement

The runoff discharge against average flow depth between the two time intervals in storm runoff was divided by total watershed area using below formula.

$$\text{Unit Discharge (lps/ha)} = Q (1000)/A \qquad (2)$$

where,

Q = Discharge, m^3/sec,

A = Area, hac

RESULTS AND DISCUSSION

Distribution of rainfall

The annual rainfall during 2006-2008 varied considerably within the sub-watershed of Satrameel area. It was observed that the annual rainfall was 1204, 1360 and 1409 mm during the years 2006, 2007 and 2008, respectively. During the year 2008 the 6 % more rainfall occurred than the average rainfall. Whereas, during the year 2006 about 15 % lesser rainfall occurred than average rainfall. About 51 % to 65 % of the total rainfall was received during monsoon season and the remaining occurred during rest of the year. The rainfall during the monsoon (July- September) also varied among the years under report. July was the wettest month during 2006 and 2008 with rainfall of 489 and 390 mm respectively, while the wettest month during 2007 was August with 403 mm rainfall. Contrarily, the driest months observed were November in 2006 with 17 mm, October in 2008 with 13 mm for and in January and October (2007) with Zero rainfall (Fig..3).
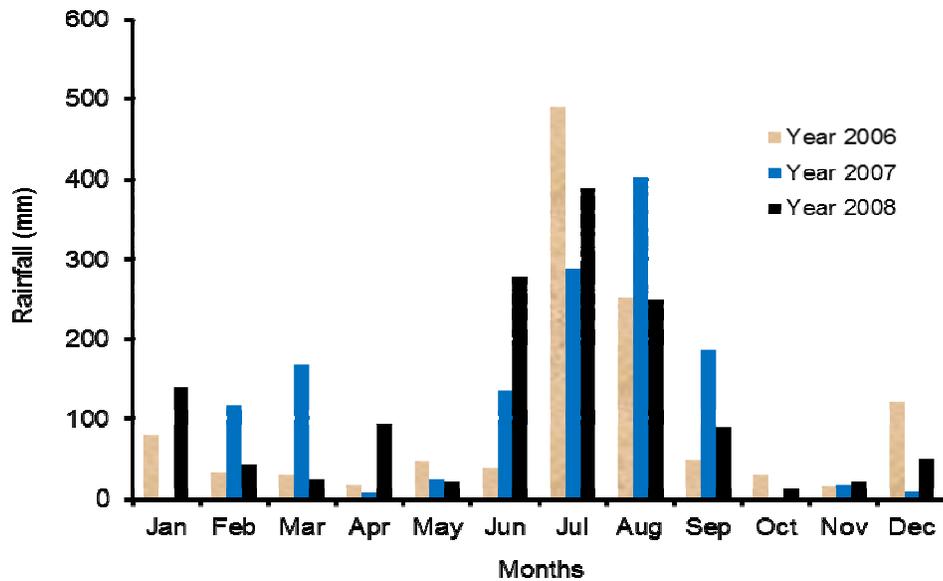

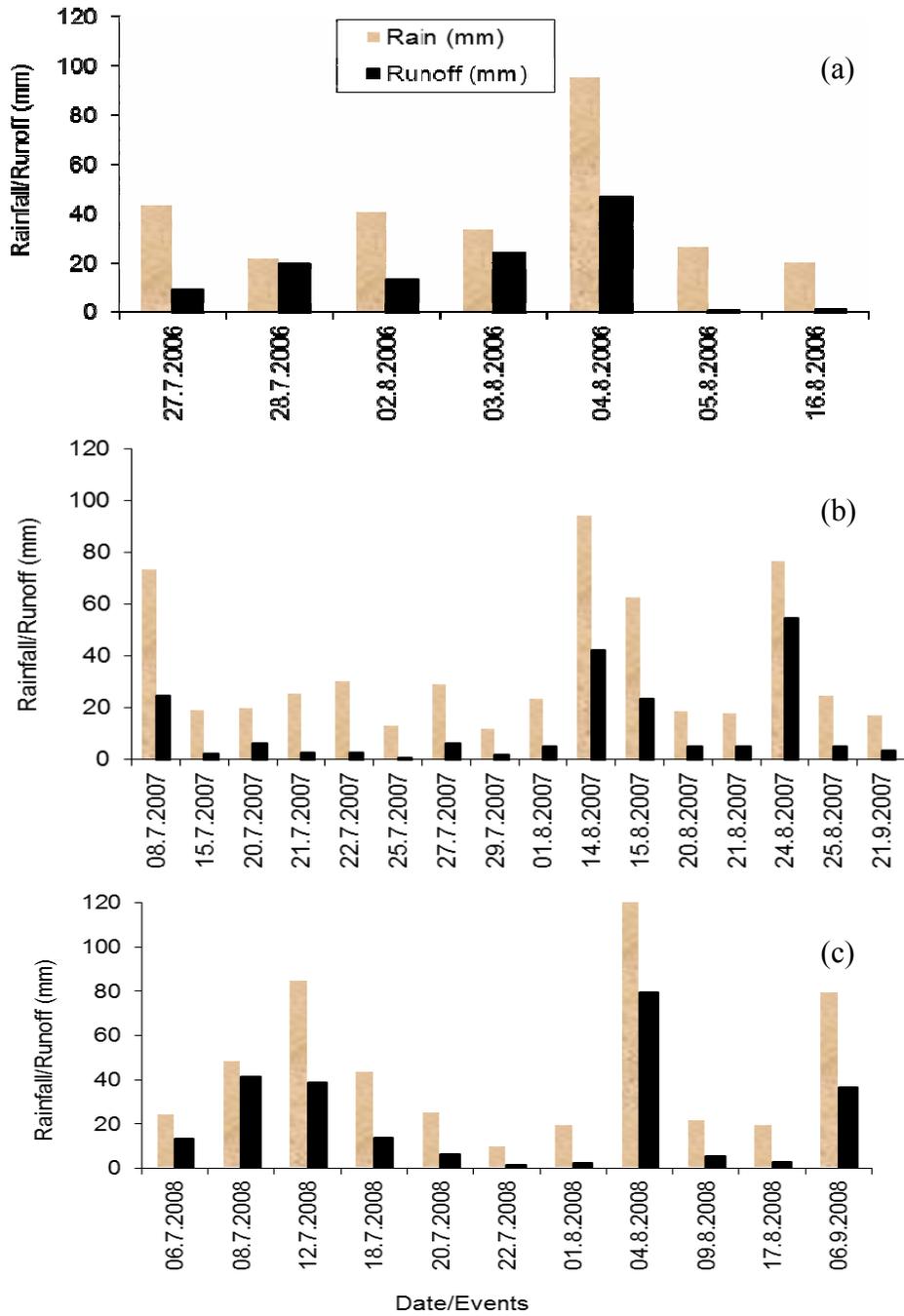Figure 3. Month-wise distribution of rainfall during the study period

Figure 4. Distribution of event wise rainfall/runoff (mm) during monsoon season (2006-2008)

The total number of events of rainfall occurred during the 2006, 2007 and 2008 were 77, 75 and 90, respectively. The data showed that 33, 37 and 34 events were recorded in monsoon during the years of 2006, 2007 and 2008, respectively. Also it was observed that 65, 64 and 52 % of total rainfall occurred during 2006, 2007 and 2008 respectively (Table 1 and 2).

Surface runoff analysis

The surface runoff was measured for the monsoon seasons during 2006, 2007 and 2008 and has been plotted in Figure 3a, 3b and 3c respectively. The total runoff was measured 115, 191 and 241mm with 7, 16 and 11 rainfall events. The maximum runoff of 91, 72 and 84 mm was recorded during the months of July, August and July, and the minimum runoff of 3, 4 and 11 mm was observed during the months of August, July and August for the years 2006, 2007 and 2008, respectively. The 41, 34 and 47 % rainfall-runoff coefficient was determined for 7, 16 and 11 rainfall events during the years 2006, 2007 and 2008, respectively (Table 3). It was observed that maximum rainfall occurred in the month of August for 2006 and 2007 years, and in July for 2008 period (recorded events), and maximum runoff generated in percentage was 91, 72 and 85 on 28. 7. 2006, 24. 8. 2007 and 8. 7. 2008, respectively during single event basis due to high intensity of rainfall and presented in Figure 4a, 4b and 4c, respectively.

Table 1. Month wise distribution of rainfall events during the study period (2006-2008).

Months	Rainfall events	Months	Rainfall events
	2006	Jan.	2006
Jan.	6	Feb.	6
Feb.	5	Mar.	5
Mar.	5	Apr.	5
Apr.	2	May.	2
May.	4	Jun.	4
Jun.	5	Jul.	5
Jul.	15	Aug.	15
Aug.	9	Sep.	9
Sep.	9	Oct.	9
Oct.	4	Nov.	4
Nov.	6	Dec.	6
Dec.	7		7

Table 2. Distribution of yearly, monsoon rainfall (Jul-Sep) and events during the study period (2006-2008).

Year	Total	Total events	Rainfall during monsoon (mm)	Number of events	% of Total rainfall (mm)
2006	1208	77	789	33	65
2007	1360	75	877	37	64
2008	1409	90	727	34	52

Table 3. Recorded rainfall events and runoff generated during monsoon for the study period (2006-2008).

Year	2006	2007	2008
July			
Events	2	8	6
Rainfall (mm)	65	222	239
Runoff (mm)	29	47	115
August			
Events	5	8	5
Rainfall (mm)	217	335	274
Runoff (mm)	86	144	127
Rainfall-Runoff coefficient (%)	41	34	47

Table 4. Distribution of Rainfall, Runoff, Sediment Load and Peak unit discharge during recorded events in monsoon season (2006-2008).

Parameters	Years		
	2006	2007	2008
Events recorded in monsoon	7	16	11
Rainfall in recorded events for runoff generation (mm)	282	557	512
Total Runoff in Monsoon as per recorded events (mm)	115	191	241
% of total rainfall as per runoff record	41	34	47
Rainfall generating maximum runoff (mm)	22 (28.7.2006)	76 (24.8.2007)	132 (8.7.2008)
Maximum runoff recorded in single event basis (mm)	20	55	80
Total soil loss of recorded rainfall-runoff events (ton/ha)	0.944	2.417	2.571
Maximum soil loss during recoded events (ton/ha)	0.331	0.734	0.960
Average soil loss recorded events (ton/ha)	0.135	0.151	0.234
Maximum peak unit discharge (lit/sec/ha)	136.69	177.38	189.63
Minimum peak unit discharge (lit/sec/ha)	1.37	1.90	4.29
Average peak unit discharge (lit/sec/ha)	66.59	56.41	76.90

Table 5. Values of 'a', 'b' and R^2 for Relationship between Runoff and Sediment loss during monsoon season.

Year	a	b	R^2
2006	6.377	1.0786	0.9238
2007	7.1649	1.1271	0.8539
2008	7.1655	1.0835	0.9528

Sediment load analysis

The sediment load was measured during the monsoon seasons of the study period (2006-2008). The total soil loss was measured to be 0.944, 2.417 and 2.571 tons/ha, and an averagely 0.135, 0.151 and 0.234 tons/ha with 7, 16 and 11 rainfall - runoff events. The maximum sediment load of 0.331, 0.734 and 0.960 tons/ha against the generated runoff of 20, 55 and 80 mm out of 22, 76 and 132 mm rainfall was recorded on 28. 7. 2006, 24. 8. 2007 and 8. 7. 2008, respectively (Table 4).
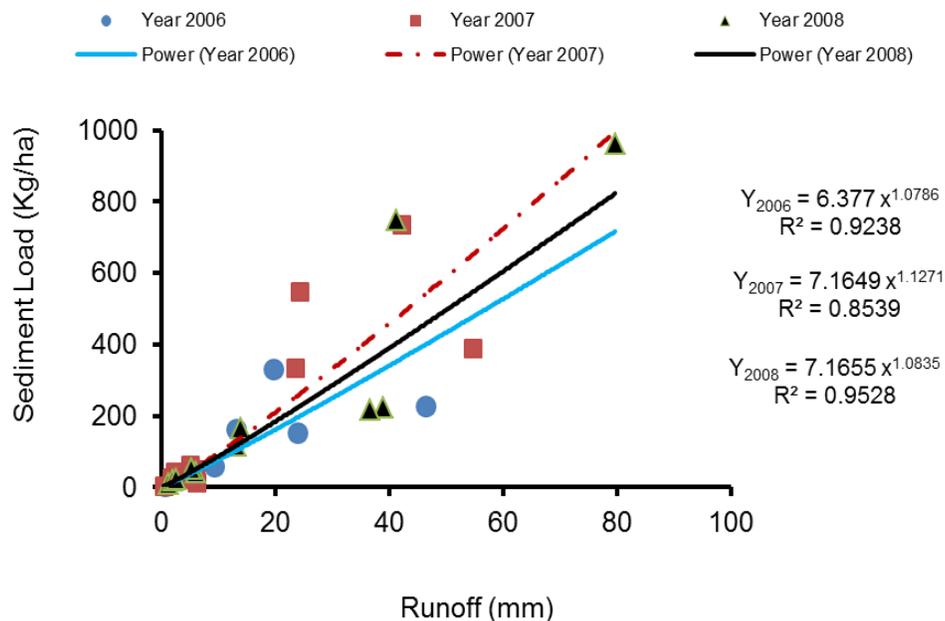

Figure 5. Relationship between Runoff and sediment loss during (2006-2008).

Peak unit discharge

The peak unit discharge 189.63 lps/ha was observed in 2008 during the sample data of monsoon season with an average values ranging from 56 to 77 lps/ha

during 2006-2008 year. It indicates that the peak runoff data are needed for design of structure for erosion control and watershed management (Table 4).

Relationship between runoff and sediment loss

The relationship between runoff and sediment loss was established using power function. The values of 'a', 'b' and R^2 for recorded runoff events during the study period are presented in (Table 5). The runoff and sediment loss data of the recorded rainfall events revealed that sediment loss increased with the increase in runoff discharge for all years during monsoon season. The best fitted curves with highest value of 'R2' for each year were drawn (Figure 5). However, the Runoff and sediment loss have a strong relationship, and the maximum value of 'R2' was found 0.9528 during 2008 year.

CONCLUSION

The total runoff was measured 115, 191 and 241 mm during monsoon as per recorded events out of 282, 557 and 512 mm rainfall in 2006, 2007, and 2008 years respectively. It was observed that only 23, 41, 36 % runoff contributing the total sediment load as 0.944, 2.417 and 2.517 tons/hac for 2006, 2007 and 2008 year respectively. The maximum sediment load 0.331 (35 % of total), 0.734 (30 % of total) and 0.960 (37 % of total) was observed on 8.7.2006,14.8.2007 and 4.8.2008 respectively during the recorded rainfall events, and further 65, 70 and 63 % sediment load was observed in remaining runoff events during monsoon season of 2006, 2007 and 2008 year respectively. It is therefore, the maximum sediment load as total (2.517 tons/ha) against the runoff of 241 mm out of 512 mm rainfall with 190 lit/sec/ha maximum peak unit discharge was observed during the monsoon season of 2008 year It was observed that maximum peak unit discharge was 136.69, 177.38 and 189.63 lit/sec/ha in month of July, August and July with an average peak unit discharge were 66.59, 56.41 and 76.90 lit/sec/ha for 2006, 2007 2008 years respectively. However, the peak unit discharge data were needed to design the hydraulic structures to control the erosion/sediment for sub-watershed management.

ACKNOWLEDGMENT

REFERENCES

Ahmad, S., M. Khan and M. Z. Ikram. 1990. Soil and water conservation and integrated land use in Pothwar, Pakistan. In: Soil physics: applications under stress environments. Pakistan Agriculture Research Council, Islamabad. pp. 301-312.

Alam, S. M. 2000. Pakistan and Rainfed Agriculture. Pak and Gulf Economist, 24-30, 2000. http://www.pakistaneconomist.com/issue2000 (Industry and Economy, 2000).

Ashraf, M., F. Hassan and M. A. Khan. 2000. Sustainable environment management: impact of agriculture. J. Sci., Tech. Develop., 19 (4): 51-57.

Belaud, G., A. K. Khan and G. Nabi. 1998. Sediment behaviour of Sangro distributery, Mirpurkhas sub-division, Sindh. International Irrigation Management Institute (IIMI) Report No. R-50. p. 69.

Bhutta, I. A. 1999. Achievements and issues in 20th century in Small Dams (rainwater harvesting). In: Chandio B.A. (Ed), Proceedings of the national workshop on: water resources achievements and issues in 20th century and challenges for the next millennium. Pakistan Council of Research in Water Resources, Islamabad-Pakistan, pp.64-69.

Brown, R. G. 1988. Effect of Precipitation and Landuse on Storm Runoff. Water Resources Bulletin, AWRA, 24 (2): 421-426.

Gifford, G. F. and R. H. Hawkins. 1978. Hydrologic Impact of Effect of Grazing on Infiltration: A critical Review. Water resources Research, 14: 305-313.

GoP, 2009. Federal Bureau of Statistics, Statistics Division (2008-09). Ministry of Finance and Economic Affairs, Government of Pakistan.

Nasir, A., U. Kazunori, M. Shafiq and M. Khan. 2002. Monitoring soil erosion in a mountainous watershed under high rainfall zone in Pakistan, J. Rural Environ. Eng., 43: 23-30.

Pakistan. 2011. Study to enhance storage capacity of Terbella, Pakistan Report, News Channel. http://www.pakissan.com/english/news (Lahore, May 17, 2011).

Shafiq, M., A. Nasir and B. Ahmad. 1998. Hydrological characteristics and soil erosion from shrub forest watershed under high rainfall zone of Pothwar. Agro-Environ International Symposium, Faisalabad, Pakistan, 25-30 May, pp. 219-222.

Shafiq, M., S. Ahmad, A. Nasir, M. Z. Ikram, M. Aslam and M. Khan. 1997. Surface runoff from degraded scrub forest watershed under high rainfall zone. J. Eng. Appli. Sci., 16: 7-12.

Zia-ul-Hassan and M. Arshad. 2007. Land Degradation in Pakistan: A Serious Threat to Environments and Economic Sustainability. http://www.eco-web.com/edi/index.htm.