SEDIMENT LOAD ASSESSMENT OF SMALL EMBANKMENT DAMS IN SOUTHREN REGIONS OF NWFP

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ABSTRACT

Siltation has a large impact in reducing the benefit obtained from sixty two dams constructed in the southern region of NWFP. The United Nations development programme (UNDP) in its poverty reduction project concentrated on the sediment deposited in these dams to safeguards their service lives. A field study was conducted to find sedimentation in nine-sampled reservoirs of the embankment dams during August 2004 to September 2005 at Shakardara District Kohat, Pakistan. The suspended load through integrated approach and the total deposited sediment load cumulated in the reservoirs (By Grid survey) were determined separately. Staff and rain gauges for stage measurement and precipitation in the reservoirs and area were installed. Siltation life of each embankment dam was determined from rate of incoming sediment, trap efficiency and reservoir capacity. The intensity of rainfall observed during the study period (July, 2004 to August, 2005) ranged from 1.2 to 92.1 mm/h. Runoff from the catchments of the embankment dams ranged from 10.49 to 17.02% of the rainfall, with over all average of 13.12%. The result of the study showed that the overall suspended sediment load in runoff ranged from 1478 to 11,812 mg L^{-1} with overall average of 3699 mg L^{-1}. It is also found that the average incoming total sediment load in the selected embankment dams varied from 721 to 1875 tons-$km^{-2}year^{-1}$. The reservoir capacity of the sampled embankment dams ranged from 5,008 to 120,190 m^3 and the siltation lives of the sampled reservoirs ranged from 11 to 99 years with overall average of 38 years. In general, the siltation lives of the sampled embankment dams increased with increase in reservoir capacity. Embankment dams with capacity less than 40,000 m^3 were found to have siltation lives of less than 40 years and their construction should be avoided.

INTRODUCTION

The problems of water scarcity in arid to semi-arid regions with no provision of canal irrigation system, the construction of small dams are only option which can play a vital role in the economic development of these areas. There are strong links between the availability of water and livestock production, and rural income (Wallingford, 2003). To overcome the water shortage problems in drought prone areas of Pakistan, some Non Government Organizations (NGOs) and government agencies constructed many embankment dams to provide water for drinking human and livestock as well as for small-scale irrigation. Due to poor land cover and steep slopes of the catchments the sediment inflow to the reservoirs of the embankment dams in Kohat District are very high and their expected siltation lives are relatively small. Many of the world's reservoirs are suffering significant reductions in storage capacity as a result of sedimentation, experts says unless action is taken, 20% of reservoir capacity will be lost over the coming Very little is known about the rate of sedimentation in the reservoirs of small earthen embankment dam, therefore a study was conducted with the following objectives:

(1) To develop rainfall and runoff relationship for the nine sampled catchments of the embankment dams;
(2) To determine the suspended and total sediment load from the catchments into the reservoir and
(3) To assess the siltation lives of sampled embankment dams.

The yields can be increased from 100 to 400% in arid to semi-arid regions by provision of water for irrigation which helps farmers to reap the economic benefits of growing higher cash crops (FAO, 1996). Sediments through runoff from catchments in arid and semi-arid regions varied from a few hundred to several thousands tons/km^2/year and strongly influenced by wet and drought periods. Elwell (1985) reported that over 50% of 132 small dams surveyed in Masvingo Province in Zimbabwe were silted. The small dams built in villages of India have improved the livelihood and stabilized their agriculture and animal husbandry of the poor farmers living in the vicinity of dams (Cosgrove et al, 2000). Coppock (1994) stated that in the Sidamo regions of Ethopia, women spend around 12% of their working time fetching water to meet households' need. USAID (1982) and Fowler (1977) observed that embankment dams storage volume can be estimated from the dam width, throwback and maximum impounded water depth without a detailed topographic survey. The suggested general equation for capacity (V) is

$$Capacity\ (V) = K_1 * K_2 * D * L \quad [1]$$

Where K_1 is a constant, K_2 is a second constant related to the shape of the valley cross-section, D is the maximum water depth i.e. the difference in

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elevation between the lowest point in the reservoir bed and the dam and spillway crest level, L is the throwback, USAID (1982) used K_1 as 0.4 and K_2 as 1 while Fowler (1977) used K1 value of 0.25 and K_2 as 1.

The simple method of estimating runoff from rainfall is to apply a runoff coefficient to the mean rainfall and can be written as

$$Q = ROC * Pa \qquad [2]$$

Where Q is Mean annual or monthly runoff (mm), Pa is Mean annual or monthly precipitation (mm), ROC is Runoff coefficient. Annual runoff volume can be determined by the equation

$$Vr = Pa * Ac * 1000 \qquad [3]$$

Where Vr is Volume of runoff in m^3, Ac is catchments area (km^2); Pa is annual precipitation in mm. Bangash and Muhammad (2003) proposed a runoff coefficient of 10%, a rainfall intensity of 24.5 mm/hr and a peak flow of 3.53 $m^3/s/km^2$ for Lachi, District Kohat. The predictive equation developed by HR Wallingford (2004) was also used for estimation of sediment yield for the catchments of the sampled embankment dams. The equation can be written as:

$$Sy = 0.0194 * Ac^{-}0.2 * {}_{P}0.7\ {}_{SASE}0.7\ {}_{*Vc}0.5 \qquad [4]$$

Where S_Y is sediment yield in (t/km^2/year), Ac is catchment area (km^2), P is mean annual precipitation (mm), S is stream slope from the catchment boundary to the dam, SASE is sign of active erosion (score from the catchment characterization), STD is soil type and drainage and VC is vegetation condition (score from the catchment characterizations described by Wallingford 2004).

Based on the categories of sediment yield, equation have been developed, which relates catchment's sediment yield to suspended sediment which can be written as

$$Sy=X*MAR/1000 \qquad [5]$$

Where Sy is Catchments sediment yield (t/km^2/year), X is mean annual sediment concentration as described above; MAR is mean annual rainfall (mm).

From the Brune, 1953 data a relationship between sediment trap efficiency and reservoir capacity to inflow ration was developed with coefficient of correlation of R^2 of 0.9024 in the form is given below:

$$St = 0.1116 * \text{In}\,(C / I) \qquad [6]$$

Where St is the sediment trap efficiency in percent, C the reservoir capacity at spillway crest level, I show the inflow volume of water to the reservoir and the relationship predicts the annual sediment trapping efficiency of a dam from the ratio of the dam capacity to the annual inflow volume. Bangash and Muhammad, 2003 also proposed a sedimentation factor of 450 m^3/km^2/year for Lachi area.

MATERIALS AND METHODS

Description of the Project Area

The project area lies in Kohat district and it is located between latitude 33^o 10' N to 33^o 20'N and longitude between 71^o 21'E and 71^o 29$'$ (Fig. 1). The areas consist of four main land form unit i.e. piedmont plain, gravelly, fan/apron, and rough broken land and mountain. The potential evaporation is about 1300 mm per year. The study was conducted during July, 2004 to September, 2005 at nine sampled embankment dams' sites in Soodal and Shakardara. The climate of the project area is arid to semi-arid with mean annual precipitation ranging from about 400 to 450 mm. Generally, the rainfall is erratic and uncertain. About 60% of the rainfall occurs in the Monsoon, followed by winter rain which occurs during the months of March and April.

Fig. 1. Map of Pakistan showing the study area

In summer June and July are the hottest months with a mean temperature of about 40 °C, while December and January are the coldest ones with an average temperature of 10 °C. The main crops in the project area are wheat, oil seed in Rabi; peanut, sorghum and millet in Kharif. The Rabi crops are raised on residual moisture of monsoon season. More than 60% of the land can be classified as marginal unproductive land (non-arable).

Sampled Embankment Dams

Sixty-two embankment dams constructed during the year 1997-2003 by the Lachi Poverty Reduction Project under the United Nations Development Program (LPRP/UNDP) were divided into different categories based on reservoir capacity, catchments area, dam height and location after through assessment. The nine representative embankment-dams were selected based on the above-mentioned criteria. Data related to rainfall, sediment load, land use, ground cover, and topography were used for assessment of sediment load and runoff. Surfer computer model was used for assessment of runoff volume and deposited sediment in the embankment ponds. Besides that one other embankment dam, constructed 28 years ago, was also studied for in-coming sediment load per year for later use to assess the siltation.

Fig.1

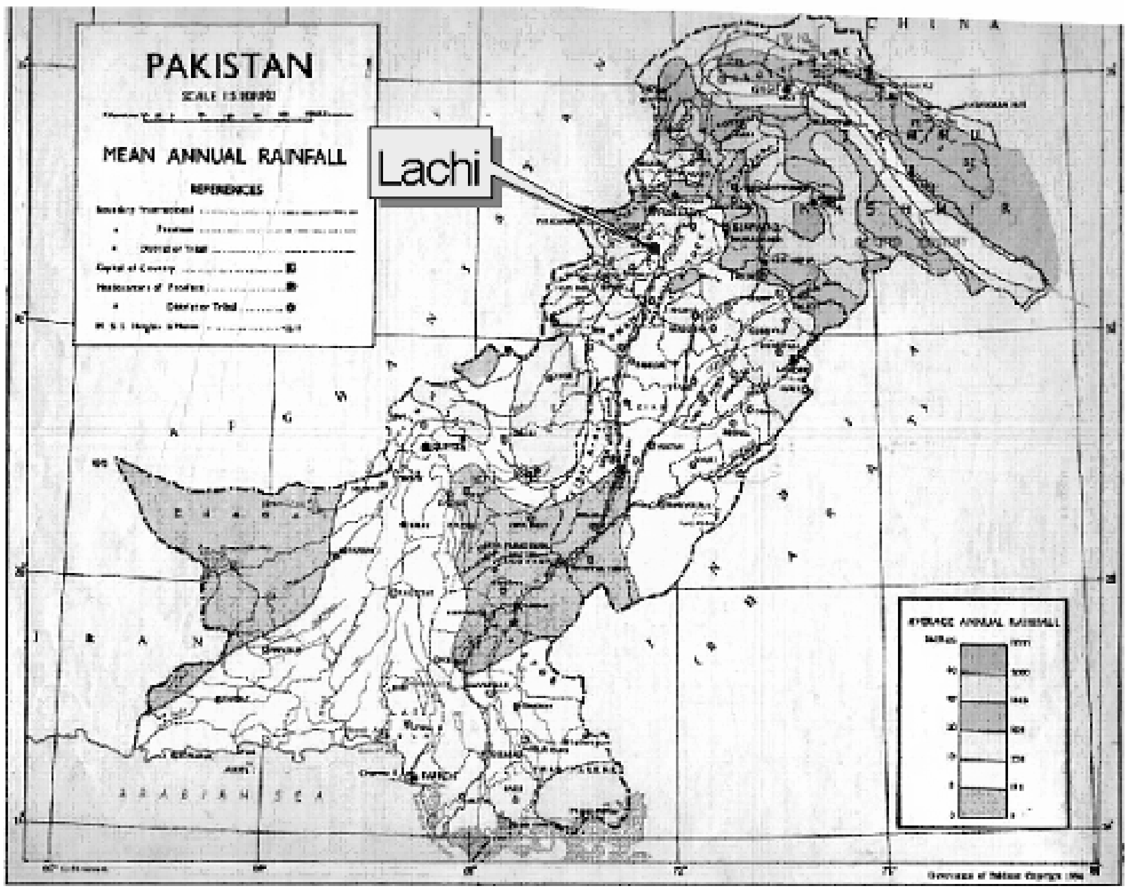

Table I. Physical features of the sampled embankment dams

S. No.	Location	Latitude (N)	Longitude (E)	Altitude (m)	Catch. Area (Km^2)	Reservoir capacity (m^3)	Dam Height (m)	Dam length (m)
1	Takht-1	33,19.92	71,21.40	606.71	0.884	8,069	4.57	23.78
2	Darwazai	33,16.96	71,29.75	450.00	7.580	32,660	7.31	55.98
3	Mohalla Saidan	33,14.73	71,29.80	557.90	1.75	24,680	7.62	83.83
4	Kabal Khel	33,13.32	71,31.85	568.90	1.61	120,190	9.14	57.91
5	Spin Mari	33,13.18	71,31.24	585.10	0.417	5,009	6.70	79.24
6	Shwarpsha	33,11.27	71,37.72	473.48	2.058	36,652	7.61	76.20
7	Sarkidal	33,09.58	71,38.39	532.00	2.358	14,227	9.14	33.53
8	Kalia-1	33,11.47	71,38.75	491.16	0.856	6,111	7.62	16.45
9	Guleenabad	33,09,89	71,38.26	547.26	0.3	19,394	8.53	60.97

Runoff Assessment

The amount of runoff was assessed from the change in volume of the reservoir after heavy rainfall as well as by SCS method. Data related to rainfall duration, duration of runoff, time to peak runoff and total runoff period was also recorded for each individual storm.

Topographic Survey

The reservoir area of the embankment dam was divided in grids of 5 m x 5 m for small dams and 10 m x 10 m for relatively large reservoirs, relative elevation at each grid point was determined from established bench marks and later on GPS was used to find the relative elevation of the established bench marks relative to mean sea level. Each catchment's of the sampled embankment dams was surveyed along the length of the waterways as well as across the longitudinal sections at three locations (Head, middle and tail) for assessment of slope, soil type and surface geology.

Assessment of the Existing Deposited Sediment

The initial pattern and quantity of the deposited sediment was assessed by measuring the length, width and depth of the deposited sediment (area-depth method) in each grid (10 m x 10 m). Auger was used to find the extent of deposited sediment in each grid. By visual observation differentiation between the deposited sediment and bed material was made. Deposited sediment since the construction of embankment dams was assessed. Later, sediment yield per km^2 was determined from the catchment's areas of the embankment dams.

Incoming Sediment Load

For assessment of suspended sediment load, sediment samples were collected at regular intervals during the initial, peak and at the end of the runoff period using depth integrating method. At least five samples were collected during each storm by using depth-integrating method, at start of runoff, during peak flow and recession period.

Assessment of the Deposited Sediment

The pattern and quantity of the deposited sediment in the selected embankment dams were assessed by grid survey before and after the rainy season. Sediment yield (Sy) was calculated using the relationship in the form

$$Sy\ (t/km^2/year) = \frac{\text{Annual sedimentation rate } (m^3/year) \times \text{Sediment density } (t/m^3)}{\text{(Catchment's Area } (km^2) \times \text{Trap Efficiency)}} \quad [7]$$

RESULTS AND DISCUSSION

Rainfall and Runoff

Rainfall and runoff relationship (Fig. 2) was developed for the sampled catchments with area ranged from 0.30 to 7.58 km^2 and rainfall varied from 5 to 50 mm. It is obvious from the figure that the runoff varies significantly with the antecedent soil moisture condition and intensity of rainfall. The runoff coefficient for individual catchment is given in Table II and it ranged from 0.1049 to 0.1702. Figure 3 shows the intensity of the rainfall with duration, it is clear from the figure that intensity of rainfall decreases with increase in rainfall duration. Relatively better correlation was obtained between rainfall intensity and duration of rainfall (Waheedullah and Khan, 2006).

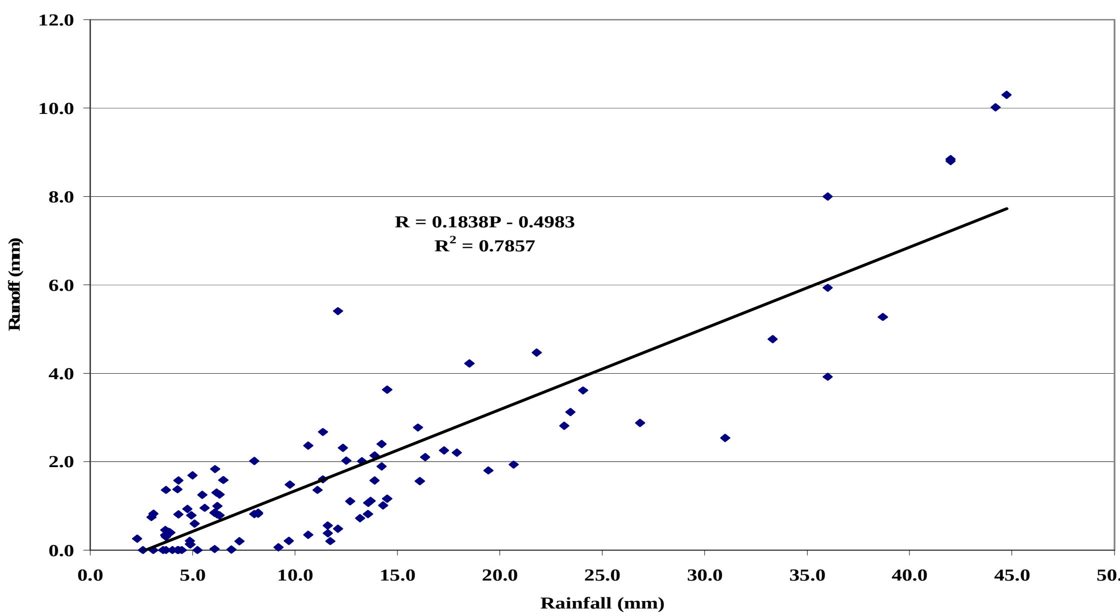

Fig.2. Rainfall and runoff relationship

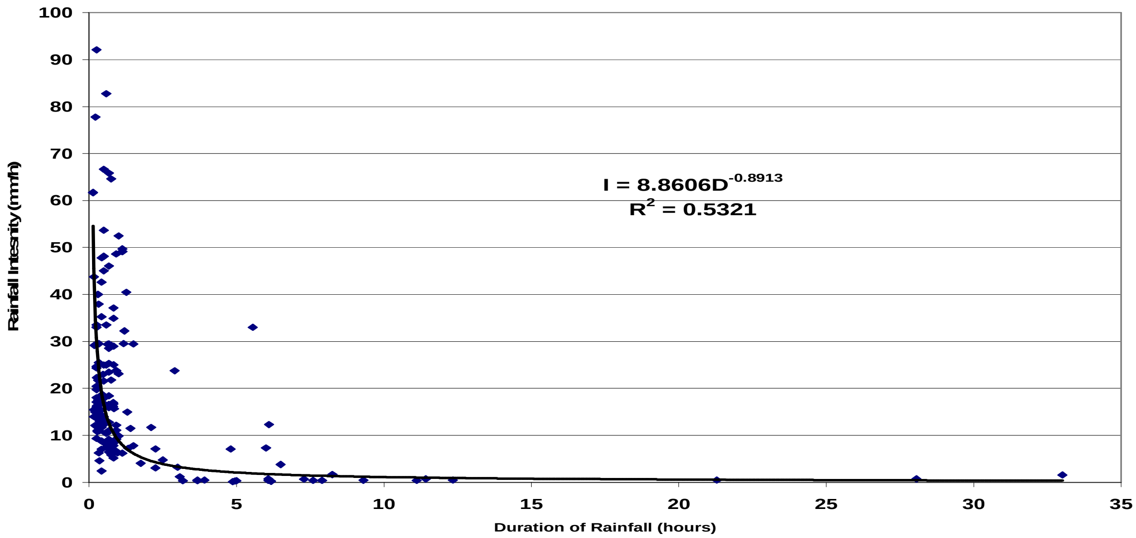

Fig. 3. Rainfall intensity and duration

Reservoir Capacity and Inflow Ratio

The capacity inflow ratio of sampled embankment dams is presented in Table II. It is obvious from the table that 3 out of the 9 sampled embankment dams have capacity-inflow ratio of less or equal 0.1, which is not desirable. It is recommended that it should be greater than 0.3 for long economic life. In highly degraded catchments, where large sediment yield is expected the capacity to inflow ratio of about 0.5 is recommended (Wallingford, 2004). Only two of the dams has capacity inflow ratio greater than 0.5. It is proposed that in future a dam should be constructed only when its capacity to inflow ratio is greater than 0.5 for better siltation life.

The reservoir capacity of the sampled embankment dams obtained from detailed topographic survey of the reservoir area is depicted in Table II. It is obvious from the table that the reservoir capacity ranged from 5,008 to 120,190 m^3 and inflow was determined from the long term (50 years) average rainfall of 547 mm, runoff coefficients and catchment's area of each embankment dam. The reservoir capacity to inflow ratio was used for assessment of sediment trap efficiency of the sampled embankment dams. For the range of practical interest, capacities to inflow volume ratios are between 0.1 and 1.0, for which the trapping efficiency varies between 86 and 100%. Thus virtually all the sediment entering a small dam will be trapped in it. The loss in a dam's storage volume over time is calculated from the product of the annual sediment yield, the number of years being considered, the catchment's area, the dam's sediment trap efficiency and the density of the settled sediments.

Table II Average annual rainfall, runoff and capacity- inflow ratio of the sampled embankment dams

S.No	Location	Catchments Area (km^2)	Reservoir capacity (m^3)	Runoff Coefficient	Annual Runoff (m^3)	Capacity/ annual Inflow	Sediment Trap Efficiency (%)
1	Takht-1	0.884	8,069	0.1167	56430	0.14	91
2	Darwazai	7.580	32,660	0.1049	434943	0.08	88
3	Mohalla Saidan	1.750	24,680	0.1241	118795	0.21	95
4	Kabal Khel	1.610	12,0190	0.1318	116072	1.04	100
5	Spin Mari	0.417	5,008	0.1702	38822	0.13	90
6	Shwarpsha	2.058	36,652	0.1317	148258	0.25	96
7	Sarkidal	2.358	14,247	0.1335	172192	0.08	86
8	Kalia-1	0.856	6,111	0.1318	61713	0.10	88
9	Guleenabad	0.300	19,394	0.1413	23187	0.84	99

Suspended Sediment

The suspended sediment measured in runoff water ranged from 1478 to 11,812 PPM from the catchments is shown in Figure 4 with overall average of 6156 PPM. The lowest sediment loads during runoff from catchment's area of Darwazai and Sarkidal were due to certain reasons, i.e. gentle slope of watershed and comparatively good land cover play significant role in this regard. However in Kabal Khel Dam on the western side of its command area contain three other small embankment dams (including Spin Mari, Wali Asar Khan and one other). Most of the sediments are trapped into these three dams before entering of runoff water into the Kabal Khel Dam. The direct runoff on the western side of Kabal Khel Dam is actually an overflow from Wali Asar Khan Dam. On the eastern side the sediments is efficiently entrapped into the fields provided with high dikes in addition to the check dams provided in the water ways.

The total sediment load into the reservoirs of sampled embankment dams was determined from the suspended sediment load measure in the field during the study period and later converted into tons/km^2/year by using equation 5. The total sediment load determined from each catchment's of the sampled embankment dams is shown in Figure 5. It is obvious from the figure that the sediment load ranged from 175 to 1875 tons/km^2/year. The maximum sedimentation load per year was found at Kalia-1, followed by Kabul Khel and Spin Mary.

The lowest sediments deposition in the embankment dam of Takht-1 is due to range land on its eastern side while western waterways has been provided with few check dams and the land among check dams have been developed into a cultivated land for crops. The eroded mountains of Spin Mari, Mohalla Saidan Guleenabad, and Shwarpsha added significant amount of sediments load into their respective reservoirs. In Shwarpsha and Sarkidal due to management practices of check dams and self help harvesting techniques. The sediment load was relatively less and the highest sediment load recorded at Kalia-1 was due to steep slopes in the upper watershed and filling of check dams.

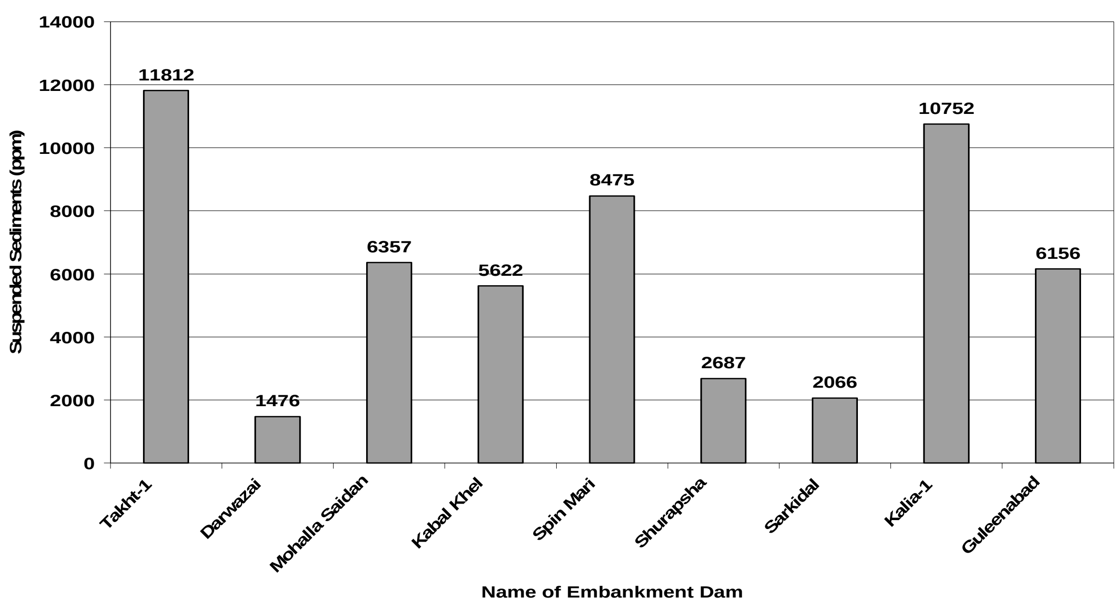

Fig. 4. Suspended sediment in the streams of embankment dams.

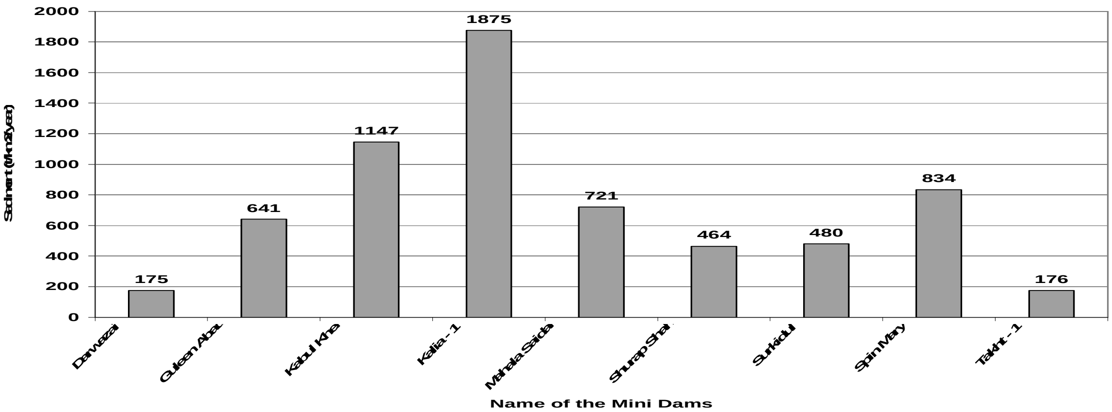

Fig. 5. Total sediment load determined from deposited sediments in the reservoirs of the embankment dams.

Loss of Storage and Siltation Life

The loss of storage and reservoir capacity of the sampled embankment dams are given in Fig. 6. It ranged from 2.5 to 5% except Kalia-1, which has highest loss of storage of 7%. The overall average loss of storage per year was 2.6%. The loss of storage in these embankment dams are relatively high as compared to large dams, it has been estimated that the loss of storage in large dams ranged from 0.5 to 1% per annum (Mahmood, 1987 and White, 2001). The small dams surveyed by Wallingford, 2004 found that from 50% per year to 0.5% per year, they also found median sedimentation rate of 2.6% per year, with a typical dam life of 38 year.

The relationship between the siltation life of the embankment dams and reservoir capacity is depicted in Fig. 7**.** It is obvious from the Figure that the siltation life of the embankment dams increase with increase in reservoir capacity. In general, the siltation life of the embankment dam increases sharply with increase in reservoir capacity up to 40,000 m^3 and after that the rate of increase is relatively slow. Therefore, it can be concluded that the small capacity reservoir silt up within short span of time as compared to larger capacity reservoir. It is therefore, recommended that embankment dams at least up to 40,000 m^3 or greater should be constructed for better economic return and enhanced Sedimentation lifetime.

The siltation life of the sampled embankment dams was estimated from sediment yield, reservoir capacity and sediment trap efficiency. The sediment yield was obtained from the following methods (a) from measured deposited sediment in the reservoirs of the sampled embankment dams during the study period (April, 2004 to August, 2005), (b) secondly from the measured suspended sediments data during the study period and later converted into sediment yield by using equation 5, (c) third from the sediment yield model (equation No.4) developed by HR Wallingford as mentioned in the Report OD- 152 and (d) fourth from the small dam Darwazai Banda 28 years deposited sediment survey conducted during August 2004 by the project staff and obtained a sediment deposition factor of 757.85 m^3/km^2/year (1.59Ac-ft/mile^2/year), which was also for assessment of Sedimentation lifetime of the sampled embankment dams . The Darwazai Banda small dam was constructed in 1976 by the Irrigation Department, Government of N.W.F.P.

The siltation life of the sampled reservoirs ranged from11 to 99 years, with over all average of about 38 years. Better watershed management upstream of the reservoirs of the embankment dams can enhance the life of these reservoirs (Table III). Bangash, 2003 recommended sedimentation factor (450 m^3/km^2/year), the overall siltation life of the sampled embankment dams determined were 54 years, which is 42% higher than the average value (38 years) as given in Table III. In District Kohat it seems to be appropriate to use a sedimentation factor of 766.43 m^3/km^2/year (1.59Ac-ft/mile^2/year) (Khan and Khan, 2005; and Obaidullah and Khan, 2006).

Table III Siltation lives of the sampled embankment dams

S.No	Name of the Embankment Dams	a)Deposited sediment data collected 2004-2005	b) Suspended sediment data collected during 2004-2005	c) HR Wallingford Model with measured parameters	d) A factor based on deposited sediment of 28 years data	Overall average siltation life
		Sedimentation lifetime in of Embankment Dams in Years				
1	Takht-1	20	16	19	13	**17**
2	Darwazai	42	54	48	48	**48**
3	M. Saidan	25	41	34	20	**30**
4	Kabal Khel	78	79	79	99	**84**
5	Spin Mari	19	20	20	18	**19**
6	Shwarpsha	48	45	42	24	**40**
7	Sarkidal	18	16	17	17	**17**
8	Kalia-1	16	13	15	11	**14**
9	Guleenabad	60	82	68	86	**74**
Average siltation life		**36**	**41**	**38**	**37**	**38**

CONCLUSIONS

i. Runoff from the catchments of the embankment dams ranged from 10.49 to 17.02% of the rainfall, with over all average of 13.12%.

ii. The capacity-inflow ratio of the sampled embankment dams ranged from 0.08 to 1.04, it should be at least greater than 0.1, preferably 0.3 or even 0.5 for better effective life. Only 33% of the embankment dams fulfill that criterion.

iii. The sediment trap efficiency of the sampled embankment dams ranged from 0.886 to 1.00.

iv. Suspended sediment from the catchments of the embankment dams ranged from 1416 to 11,812 mg L^{-1} and total sediment load varied from 175 to 1875 $t/km^{-2}/year^{-2}$. The loss of storage reservoir capacity ranged from 2.5 to 7% per year.

v. The siltation life of the sampled reservoirs ranged from 11 - 99 years with overall average of 38 years.

vi. In general, the siltation life of the sampled embankment dams increased with increase in reservoir capacity. Embankment dams with capacity less than 40000 m^3 were found to have Siltation life of less than 40 years.

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