Sediment yield investigations for controlling sedimentation in the catchment of the Sriramsagar reservoir, India

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Abstract The high sediment yield of the catchment of the Sriramsagar reservoir in India is threatening the storage capacity of the reservoir. In this study estimates of sediment yield for three sub-watersheds obtained using a commonly-used prediction equation are compared with direct measurements. The sediment yield measurements were obtained by installing automatic water level recorders on the streams and by measuring the flow velocity using a current meter. Stream water samples were analysed in the laboratory to obtain the values of suspended sediment concentration required to calculate the sediment load. The sediment yields from the watersheds are also estimated using the Garde *et al.* equation, which employs parameters including a vegetative cover factor, slope, drainage density, annual runoff, annual precipitation and the area of the watershed. The measured sediment yields were in broad agreement with the estimated values, with the measured sediment yield for the three watersheds averaging 991.5 m^3 km^{-2} $year^{-1}$ and the estimated sediment yield averaging 813.3 m^3 km^{-2} $year^{-1}$ over the study period 2006–2008. In view of the need to reduce sediment deposition in the Sriramsagar reservoir, potential soil conservation measures are considered.

Key words reservoir siltation; Sriramsagar reservoir; sediment yield; measurement; prediction; conservation measures

INTRODUCTION

It is commonly assumed that catchments underlain by hard rocks do not generate high sediment yields (Uppal, 1966). However it has been reported that loss of reservoir storage capacity due to sedimentation is a serious problem in the reservoirs constructed on the Deccan plateau of southern India, where most of the terrain is underlain by hard rocks (Shangle, 1991).

The Sriramsagar reservoir is a major irrigation supply reservoir built on the Godavari River in the Nizamabad district of Andra Pradesh, southern India (Fig.1). The catchment of the reservoir extends over parts of three states, namely Maharashtra, Andhra Pradesh and Karnataka. The Sriramsagar reservoir is recognised as being amongst the reservoirs most seriously affected by sediment in India (APERL, 1984). The total loss of storage capacity of the Sriramsagar reservoir to date is 36.8% (Shangle, 1991). Earlier reconnaissance studies in this area carried out by the Andhra Pradesh State Remote Sensing Applications Centre (APSRAC) indicated that the sediment yield from the reservoir catchment is very high (APSRAC, 1993). The Centre for Water Resources of JNT University, Hyderabad, has also conducted modelling investigations in the Suddavagu watershed (Sekhar & Rao, 2002). These studies estimated sediment yields to be about 1186 m^3 km^{-2} $year^{-1}$. However, the equivalent design value for the Sriramsagar project is only 571.5 m^3 km^{-2} $year^{-1}$. In those studies the estimated sediment yields have not been verified by direct measurements of the sediment load of the rivers. In the present paper, the estimated sediment yield is verified using the observed sediment yield from the three selected watersheds in the catchment. These selected watersheds are the Poulang, Haldi and Jukal watersheds (Fig. 1).

METHODOLOGY

The sediment yields of the three study watersheds have been estimated using a prediction procedure based on various watershed parameters such the as area of the watershed, runoff, temperature and a vegetative cover factor derived from satellite data and toposheets. These parameters are introduced into the formula proposed by Garde *et al.* (1983), for estimating watershed sediment yield. Direct measurements of sediment yield from the same watersheds have

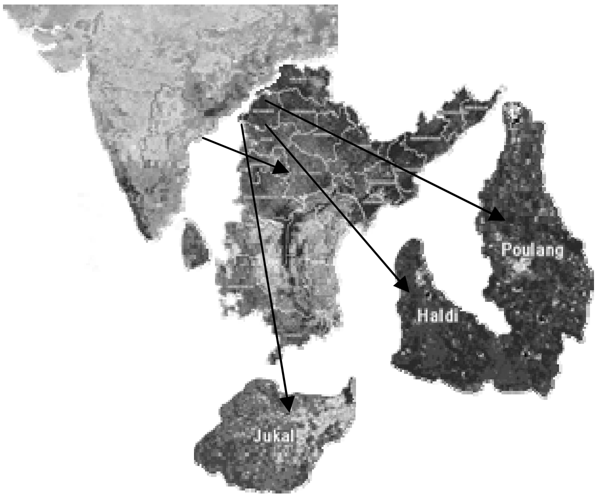

Fig. 1 The study area and the location of the Poulang, Haldi and Jukal watersheds.

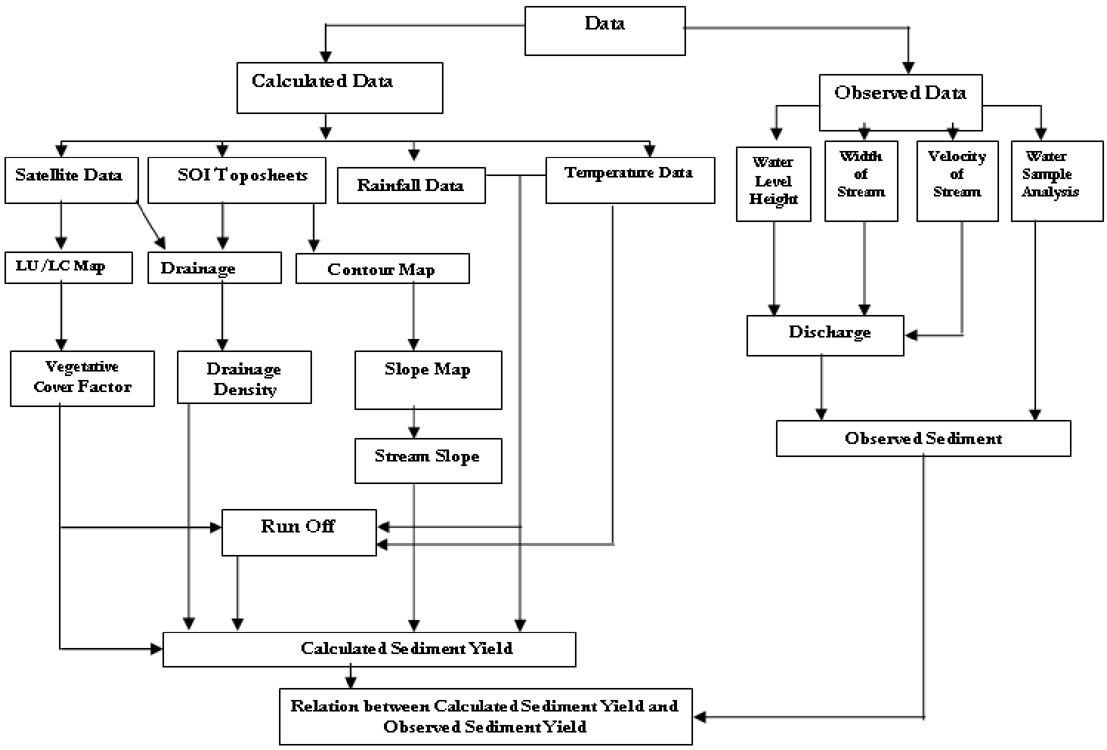

Fig. 2 A flow chart showing the methodology employed in the study.

been obtained using the discharge records for the watershed outlets coupled with values of suspended sediment concentration obtained by analysing water samples collected from the flow gauging site. The estimated or calculated values of sediment yield are compared with the observed values and an attempt is made to establish a relationship between the two. A schematic diagram of the methodology is presented in Fig. 2.

With respect to the above methodology, the data collected to derive the watershed parameters includes rainfall data from the Bureau of Economics and Statistics, Hyderabad; air temperature data from the Indian Meteorological Department, Hyderabad and satellite remote sensing data (IRS P6 LISS III) from the National Remote Sensing Centre (NRSC), Hyderabad, for the years

2006, 2007 and 2008. The satellite data relate to the month of November in respective years and cloud free data were selected.

Preparation of thematic maps

The drainage network maps were prepared from the Survey of India toposheets using GIS software. These maps were used to derive the drainage densities of the watersheds. Contour maps were prepared for each of the three study watersheds using the Survey of India toposheets and these maps were used to produce slope maps. SRTM satellite data were also used in the production of the drainage network and contour maps to improve their resolution. Remote Sensing satellite data from the NRSC has also been used to prepare Land Use/Land Cover maps for the watersheds using ERDAS 8.1 software. These maps have provided data on the areas under each classification of land use/land cover.

Calculation of the vegetative cover factor

To calculate the vegetative cover factor the equation used is:

$$F_c = \frac{(0.2F_1 + 0.2F_2 + 0.6F_3 + 0.8F_4 + F_5)}{(F_1 + F_2 + F_3 + F_4 + F_5)} \quad (1)$$

where F_c = vegetative cover factor; F_1 = area under reserved and protected forest in km^2; F_2 = unclassified forest area in km^2; F_3 = cultivated area in km^2; F_4= grass and pasture land in km^2; F_5 = waste land in km^2.

The above values are obtained from the land use and land cover maps prepared from satellite imagery. The values of F_c obtained for the three study watersheds are listed in Table 1. For Indian catchments the vegetative cover factors normally varies between 0.28 and 1.0.

Table 1 Values of the vegetative cover factor (Fc) obtained for the study watersheds.

Year	Jukal F_c	Haldi F_c	Poulang F_c
2006	0.668	0.568	0.601
2007	0.677	0.586	0.579
2008	0.645	0.614	0.613

Sediment yield estimation

Sediment yields were estimated for the study watersheds using the Garde *et al.* (1983) equation:

$$V_{SAB} = 1.182 \times 10^{-6} \times A^{1.03} \times P^{1.29} \times S^{0.08} \times Dd^{0.4} \times F_C^{2.51} \quad (2)$$

where V_{SAB} = absolute volume of eroded material in Mm^3 year^{-1}; A = catchment area, km^2; P = annual rainfall, cm; Q = annual runoff, Mm^3; S = stream slope; Dd = drainage density, km km^{-2}; Fc = vegetative cover factor.

The annual runoff can be estimated using the following equation developed by Garde & Kothyari, (1985).

$$R_m = \frac{\left(F_c^{0.49}(P_m - 0.5T_m)^{0.59}(P_m - 0.5T_m)\right)}{26.5} \quad (3)$$

where R_m = mean annual runoff, cm; P_m = mean annual rainfall, cm; T_m = mean annual temperature in degrees Celsius; F_c = vegetative cover factor.

The rainfall data were obtained from the Bureau of Economics and Statistics and the temperature data were obtained from the Indian Meteorological Department. The estimated runoff values are shown in Table 3.

The estimated sediment yields for the study watersheds for the years 2007 and 2008 are also listed in Table 3. For the year 2006 the calculated sediment yield for the Poulang watershed is 961 m^3 km^{-2} year^{-1}, for Haldi it is 670 m^3 km^{-2} year^{-1}and for Jukal it is 869 m^3 km^{-2} year^{-1}.

Calculation of stream discharge from the observed data

The flow velocity is measured with a current meter at three places along the river cross-section and at the three depths, at regular intervals during flood periods. At the same time an automatic water level recorder records the water level in the stream using a pressure sensor. The water column height is multiplied by the width of the strip to establish the cross-sectional area of the strip. The total cross-section area is obtained by adding the cross-sectional areas of the constituent strips. The discharge values are obtained by multiplying the cross-sectional area by the average velocity of a particular strip and total discharge in the stream is obtained by adding the discharges of the individual strips. A rating curve can be constructed by plotting water stage *versus* discharge. In the present study the observations were made at a bridge and the channel cross-section is almost rectangular in shape. Most of the time water depths do not exceed more than 1 or 2 m and on some occasions velocity was measured at only a single depth. An example of the calculation of discharge values from velocity measurements undertaken at regular intervals is provided in Table 2.

Table 2 Calculation of discharge from observed values of velocity in the Haldi watershed.

Date	Time	Stream flow Water depth (m)	Stream width (m)	Cross sectional Area = Depth × Width (m^2)	Average Velocity (m/s)	Discharge = Area × Velocity (m^3/s)
06/06/07	3:33:31	0.05	90	4.5	0.98	4.41
06/06/07	3:43:31	0.05	90	4.5	0.98	4.41
06/06/07	3:53:31	0.03	90	2.7	0.98	2.64
06/06/07	4:03:31	0.03	90	2.7	0.98	2.64
06/06/07	4:13:31	0.02	90	1.8	0.98	1.76
06/06/07	4:23:31	0.00	90	0.0	0.98	0.00
06/06/07	4:33:31	0.00	90	0.0	0.98	0.00
06/06/07	4:43:31	0.00	90	0.0	0.98	0.00

Table 3 A comparison of the estimated and measured values of runoff and sediment yield.

Watershed	Results for 2007				Results for 2008			
	Garde’s equation		Measured in the field		Garde’s equation		Measured in the field	
	Runoff (Mm^3)	Sediment yield (m^3 km^{-2} $year^{-1}$)	Runoff (Mm^3)	Sediment yield (m^3 km^{-2} $year^{-1}$)	Runoff (Mm^3)	Sediment yield (m^3 km^{-2} $year^{-1}$)	Runoff (Mm^3)	Sediment yield ($m^3 km^{-2}$ $year^{-1}$)
Poulang	176.3	835	55	1750	219.7	1172	238	1135
Haldi	80.3	447	200	1204	88.3	837	127	1108
Jukal	101.2	912	54	1066	82.7	677	112	1311

Estimation of sediment yield using the water samples

Water samples were collected from the streams at the depths where the velocity was measured. The samples were analysed to determine their suspended sediment concentrations following the procedure detailed below:

- 4 g of alum ($Al_2(SO_4)_3 16H_2O$) is added to100 ml of water.
- 5 ml of the above solution is added to 1 L of the sample.
- Then sample is well stirred and allowed to settle overnight to separate the sediment.
- Next day, the sample is filtered to recover the sediment using pre-weighed filter paper.
- After filtration, the filter paper and the sediment on the filter are allowed to dry.
- After drying, the filter paper plus sediment are weighed.
- Finally, sediment weight = final weight (filter paper +sediment) – filter paper weight.

The values of measured runoff and sediment yield for the three study watersheds for the years 2007 and 2008 are shown in Table 3, where they are compared with the estimates obtained using the Garde *et al.* equation. It was not possible to compare the data for 2006, because the water level sensors were damaged by debris transported by major floods.

RESULTS AND DISCUSSION OF THE SEDIMENT YIELD DATA

Estimated and measured values of runoff and sediment yield are only available for the years 2007 and 2008 and are presented in Table 3. Table 3 indicates that that the values of sediment yield estimated using the Garde *et al.* equation approximately match the measured sediment yields from the study watersheds. However, there are significant differences between the two values (calculated and observed sediment), which can differ by as much as 50%. An attempt has been made to derive a relationship between observed and estimated sediment yield. Similarly a relationship between observed runoff and calculated runoff has also been derived. The data have been fitted by regression equations (Tables 4 and 5), using power fitting, polynomial fitting, linear fitting and logarithmic fitting. It should be noted that the data from all three watersheds have been used in deriving the relationships, in view of their similar morphometry and their location close to each other.

Table 4 Estimated *versus* observed runoff regression equations**.**

Type of regression	Equation	Coefficient of determination (R^2)
Linear	$y = 1.1237x$	0.0133
Log	$y = 160052\text{Ln}(x) - 2\text{E}{+}06$	0.0183
Power	$y = 22.401\, x^{-0}.7426$	0.0229
Polynomial	$y = 1\text{E-}18\, x^5 – 1\text{E-}12\, x^4 + 5\text{E-}07\, x^3 – 0.0784\, x^2 + 4542.1\, x$	0.1228

Table 5 Estimated *versus* observed sediment regression equations.

Type of Regression	Equation	Coefficient of determination (R^2)
Linear	$y = 1.435\, x$	0.020
Log	$y = –200.49\text{Ln}(x) + 2555.4$	0.1374
Power	$y = 3553.4\, x^{-0}.1619$	0.1180
Polynomial	$y = –2\text{E}–10\, x^5 + 5\text{E}–07\, x^4 – 0.0006\, x^3 + 0.2937\, x^2 – 48.214\, x$	0.7074

where *y* is the observed sediment yield and *x* is the estimated sediment yield.

From the above tables it can be observed that only the polynomial function produced relatively high R^2 values for both for the runoff and sediment. However, the value for the runoff is still low. For the sediment yield the polynomial equation of the form $y = –2\text{E}–10x^5 + 5\text{E-}07x^4 – 0.0006x^3 + 0.2937x^2 – 48.214x$ predicts the observed sediment of the watershed with an R^2 value of 0.70. The resulting equation can be utilized to provide a best estimate of the sediment yield of other ungauged watersheds, based on the value provided by the Garde *et al.* equation. The observed mean sediment yield for the study watersheds during the study period 2007–2008 is ~991 $m^3\, km^{-2}\, year^{-1}$ while the calculated sediment yield is ~813 $m^3\, km^{-2}\, year^{-1}$, indicating that the Garde *et al.* equation is underestimating the value by 20%. Since the actual design value used for the Sriramsagar reservoir to calculate sediment storage was only 571.5 $m^3\, km^{-2}\, year^{-1}$ there is a need to introduce soil conservation measures into the Sriramsagar catchment to extend the life of the reservoir.

IDENTIFICATION OF SOIL CONSERVATION STRUCTURES IN THE WATERSHEDS

Since the measured sediment yield is nearly double the actual design value for the Sriramsagar reservoir, maps of potential soil conservation measures in the study watersheds have been prepared. Two types of watershed treatment measures have been considered, namely, (i) engineering measures, and (ii) agricultural measures. In the present study planning of engineering measures has been limited to the identification of suitable sites for the construction of check dams in the watersheds, since they have proved to be effective at the large scale. The methodology followed is as follows:

(i) The drainage map is overlaid on the slope map.
(ii) The drainage pattern and the slope of the watershed area are carefully studied.
(iii) Check dams are located where the terrain is fairly level below steeper slopes, where the drainage thalweg is nearly straight, and the soil mantle is fairly thick. The resulting maps are shown in Figs 3, 4 and 5 for the three study watersheds.

The agricultural measures have been identified based on the studies of the Land use / Land cover maps (Figs 3, 4 and 5). It is recognised that areas of scrub have the greatest potential for afforestation compared to other land-use units mapped in the watersheds. Therefore land under scrub is shown as land suitable for afforestation, because scrub areas are usually characterized by sparse bushes and with large areas of bare soil exposed to erosion.

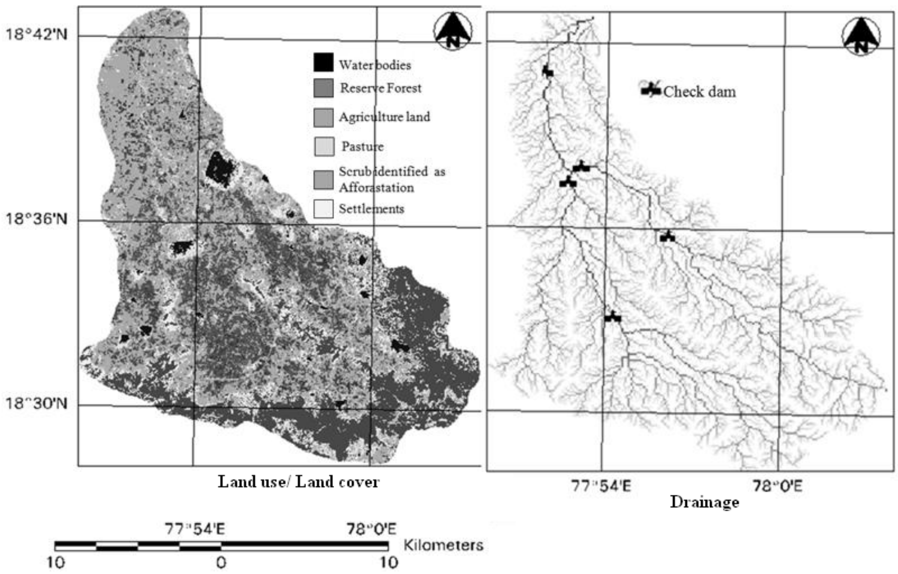

Fig. 3 Land use / land cover and drainage network map of the Haldi Watershed.

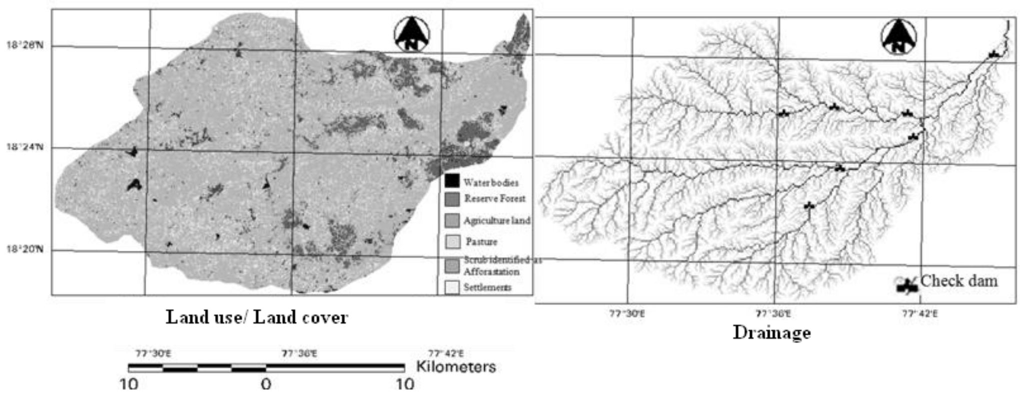

Fig. 4 Land use / land cover and drainage network map of the Jukal Watershed.

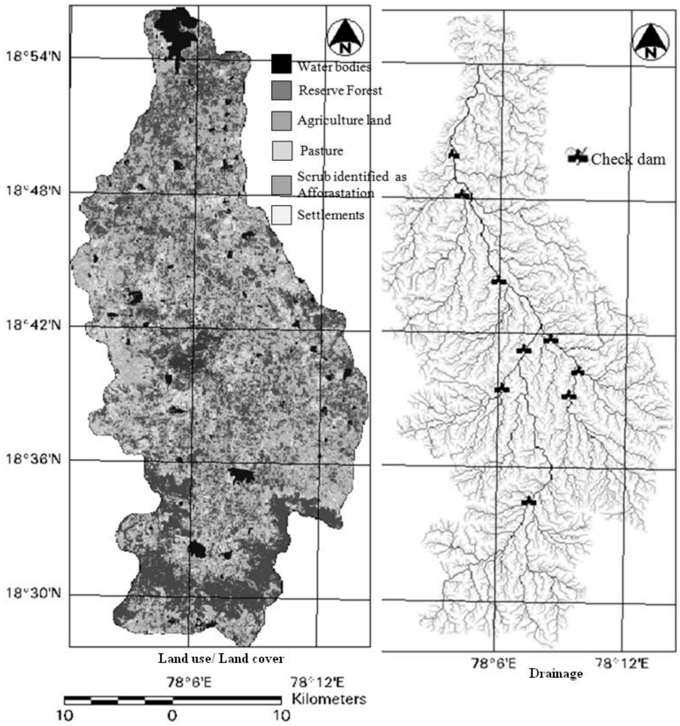

Fig. 5 Land use / land cover and drainage network map of the Poulang Watershed.

CONCLUSIONS

The estimated average sediment yield from the three study watersheds in the catchment of the Sriramsagar reservoir is of the order of 813 $m^3\ km^{-2}\ year^{-1}$ while the observed sediment yield is of the order of 991 $m^3\ km^{-2}\ year^{-1}$. The polynomial equation $y = –2E–10x^5 + 5E\text{-}07x^4 – 0.0006x^3 + 0.2937x^2 – 48.214x$ can be used to predict the observed sediment (y) of the watersheds for a given estimated sediment yield (x). Since the observed sediment yield in the catchment is almost double the design value of 571.5 $m^3\ km^{-2}\ year^{-1}$, soil conservation measures, including construction of check dams and afforestation, particularly of the scrub lands, have been identified for the watersheds.

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