

Development of Sediment Rating Curves Based on Cumulative Monthly Averaged Data

Y.C. Jabbar^{a,*}, S.M. Yadav^b

¹Research Scholar, Department of Civil Engineering, S. V. National Institute of Technology, Surat - 395007, Gujarat, India

²Professor, Department of Civil Engineering, S. V. National Institute of Technology, Surat - 395007, Gujarat, India

ABSTRACT

The measurement of hydrometric data, such as discharge and suspended sediment concentration, is conducted at various gauging stations in India. The relationship between these two variables is established using the sediment rating curve (SRC), which allows for estimating suspended sediment load based on the data. However, it is crucial to ensure the accuracy of the estimated sediment load in order to maintain the reliability of the SRC. The main focus of this research paper is to investigate the impact of data grouping on the development of sediment rating curves (SRCs) for estimating suspended sediment load from discharge data. To conduct this analysis, ten years of data from the Sarangkhedha gauging station on the Tapi River in India are utilized. Various methods of data grouping, such as daily, monthly, and cumulative averages, are compared. The findings of the study demonstrate that relying on data from a single year can result in significant errors and uncertainties in SRCs. Conversely, utilizing cumulative data improves the accuracy and reliability of SRCs. Moreover, it is suggested that a minimum of seven years of cumulative data is necessary to establish a robust SRC model.

Keywords: Sediment rating curve, suspended sediment load, hydrometric observations, cumulative monthly average.

1. INTRODUCTION

Suspended sediment load entrapped in the flow is to be known for better water management. For example, the ability to measure the sediment load correctly and precisely is important in evaluating the rate of filling up of reservoir's useful storage. Suspended sediment rating curves are used to estimate the mean suspended sediment concentration (Heng and Suetsugi 2014; Hu et al. 2011; Khaledian et al. 2017; Mimikou 1982; Ndomba et al. 2008). The rating curve is established using suspended-sediment concentration (c) and discharge/streamflow (Q). This relation is typically expressed as a power function ($c = a Q^b$).

The rating curve parameters are obtained by linear or nonlinear regression. In order to have a linear relationship from a power form of relationship, transformation of data by logarithm is to be done (Asselman 2000; Crawford 1991; Crowder et al. 2007; Sadeghi et al. 2008). The resolution of data used to fit the curve is also important (Tfwala and Wang 2016; Turowski et al. 2010). Daily mean of suspended sediment concentration and discharge data may generate a different rating curve as compared to monthly mean data. Period of data used to generate a

suspended sediment rating curve is also of importance. For a range of discharge values if the concentration is noted, for the complete rise and fall of the hydrograph. Then an efficient sediment rating curve can be developed. Thus sediment rating curves are dependent on three basic criteria 1. Fitting procedure (linear fitting or nonlinear fitting and fitting technique used) 2. Resolution of data used to fit suspended sediment rating curve 3. Period of data used. A good suspended sediment rating curve is generated if it incorporates seasonal variability and hysteresis of suspended sediment concentration with the flow hydrograph. In India suspended sediment concentration is measured as instantaneous point measurement by central water commission, hysteresis effect is thus not absorbed in the data. A sediment rating curve with daily data points thus may lead to under or over prediction. In the present study, an approach of generating a sediment rating curve from cumulative monthly average data is shown and comparison of the developed rating curve is done with the rating curve generated from cumulative daily, daily and monthly average data. It is hypothesized that if the catchment characteristics and climatic conditions do not show a change of data trend than a cumulative monthly average suspended sediment rating curve developed from consecutive years of data can be a better predictor. Period of data required, for which the cumulative monthly average data may give good predictions of concentration is identified with the exercise carried in the research.

The objective of this research paper is to investigate the impact of data grouping on the development of sediment rating curves (SRCs) for estimating suspended sediment load from discharge data. The study aims to compare various methods of data grouping, such as daily, monthly, and cumulative averages, and analyze their effects on the accuracy and reliability of SRCs. Additionally, the objective is to determine the minimum number of years of cumulative data required to establish a robust SRC model.

2. STUDY AREA

The study has been undertaken at Sarangkhedha gauging station of Tapi Basin having a drainage area of 58,400 (Sq. km.). Sarangkhedha is a gauge, discharge and sediment gauging station. The station is located (Figure 1) at Latitude 21° 25' 55" (N), Longitude 74° 31' 37" (E).

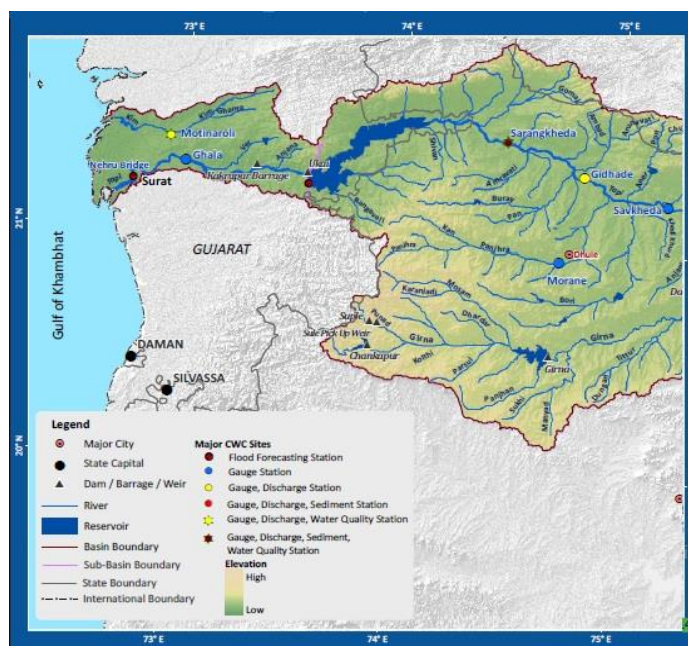


Figure 1. Location of Sarangkhedha gauging station in lower Tapi Basin

Sediment measurement started at Sarangkhedha gauging station from July 1984. Study period selected for the study is of 1984 to 1994 (eleven years). Statistical summary of discharge and sediment observed at Sarangkhedha gauging station is presented in Table 1.

Table 1: Daily - discharge and suspended sediment concentration's descriptive statistics (Period: 1984 to 1994)

Statistical Parameter	Discharge (cumecs)	Total Suspended Sediment (g/L)
Mean	306.68	0.45
Standard Error	16.46	0.03
Median	10.55	0.02
Standard Deviation	977.61	1.30
Sample Variance	955713.38	1.68
Kurtosis	74.48	42.29
Skewness	7.32	5.56
Maximum	15626	17
Count	3528	2425

The monthly average of discharge and suspended sediment concentration is computed and are presented (Figure 2) to note their variations. It is observed that direct trend line of the data does not correlate as that of four points moving average line.

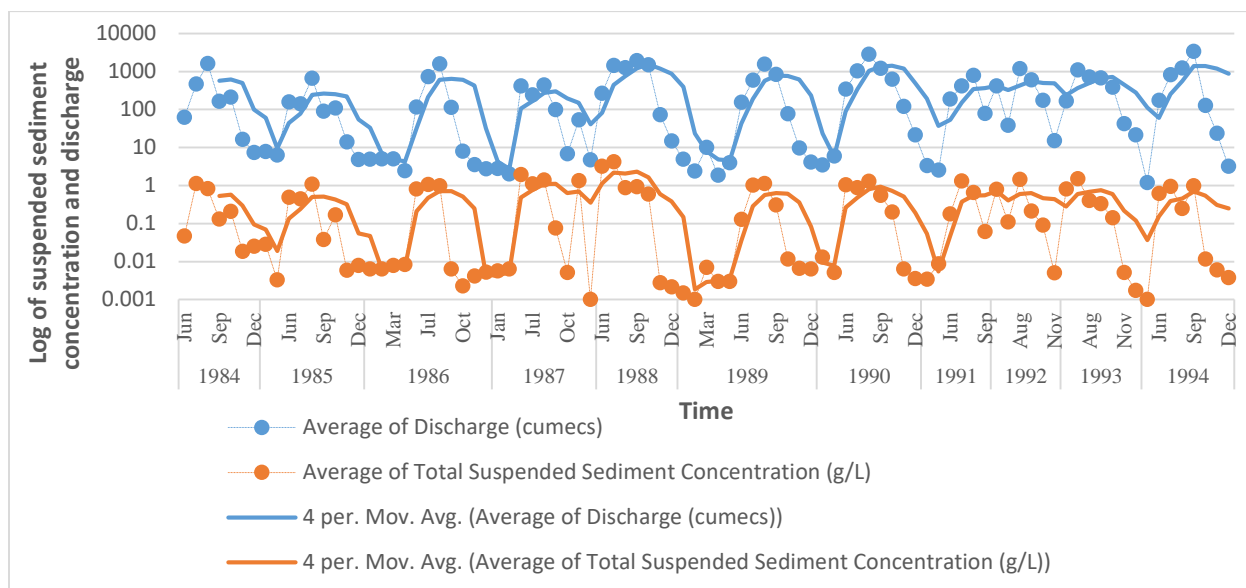


Figure 2. Moving average curve of discharge and suspended sediment concentration

3. METHODOLOGY

Development of Sediment Rating Curve (SRC) is reliant on the resolution and pre-processing of suspended sediment concentration and discharge data. Four sorts of sediment rating curves are developed in the present study using daily data, monthly average data, cumulative daily data and cumulative monthly average data. Curve fitting of SRC is done using nonlinear regression fitting. Power-form model has been fitted to the SRC. Curve fitting procedure also influences the SRC model generation. The present study has been intended to understand how the different data groups effect SRC and so a common nonlinear power fit model has been fitted by nonlinear regression fitting.

3.1 Daily Data Based SRC

The daily data of suspended sediment concentration and discharge are grouped year wise and from each group of each year, an individual SRC model has been developed. The developed models are as given in Table 2 and the sediment rating curve for this model are presented in Figure 3.

Table 2: Coefficient of nonlinear regression for daily data SRC (Period of analysis 1984 to 1994)

Year	Data points	a	b	Remarks	Coefficient of Determination, R ²
1984	202	0.0028	0.7463	Concave	0.7535
1985	273	0.0007	1.0173	Convex	0.6903
1986	334	0.002	0.7015	Concave	0.5919
1987	244	0.0008	1.1728	Convex	0.8184
1988	199	7.00E-05	1.2899	Convex	0.5801
1989	223	0.0009	0.8533	Concave	0.726
1990	225	0.0007	0.8912	Concave	0.58
1991	198	0.0012	0.8745	Concave	0.7171
1992	163	0.0005	1.0084	Convex	0.5908
1993	189	3.00E-05	1.3733	Convex	0.7754
1994	175	0.0002	1.07	Convex	0.7165

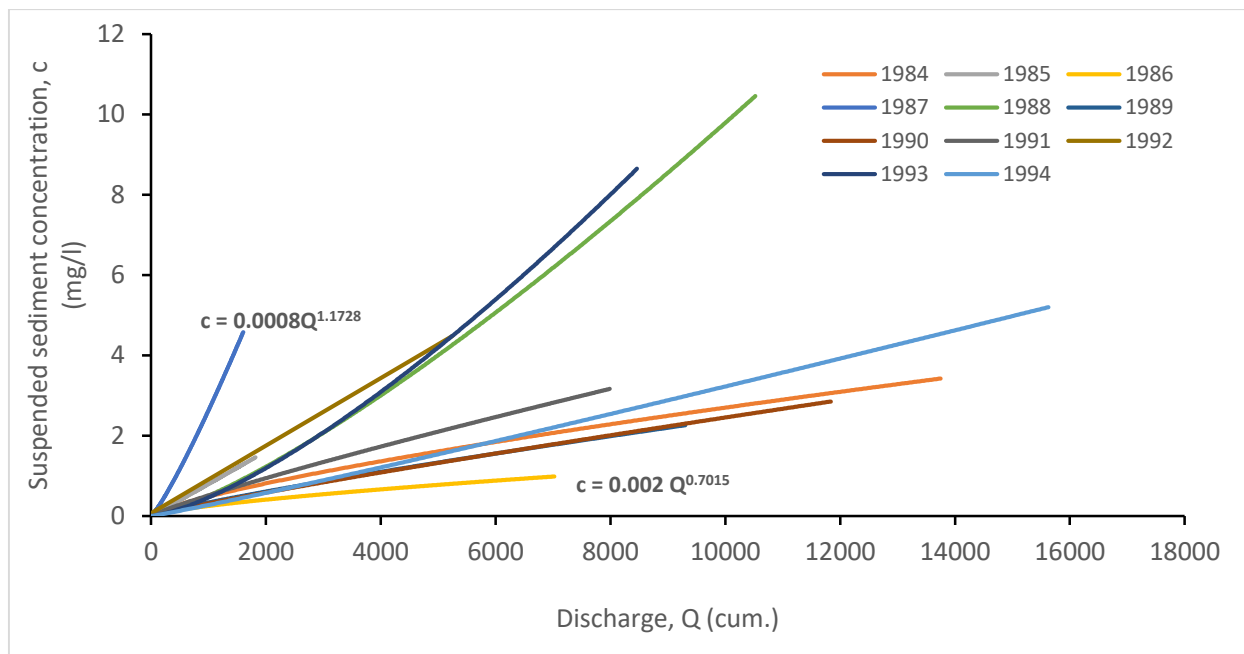


Figure 3. Daily data based SRC

3.2 Monthly Average Data SRC Model

Daily data of suspended sediment concentration and discharge is grouped year wise and sub grouped month wise. An average value of discharge and suspended sediment concentration is computed for every month of individual years. Thus from the monthly averages, eleven models are developed for eleven years of study period. In each model, twelve data points should have been used for curve generation. The developed SRC models are given in Table 3 and the generated SRC are shown in Figure 4.

Table 3: Coefficient of nonlinear regression of monthly average data SRC (Period of analysis 1984 to 1994)

Year	Data points	a	b	Remarks	Coefficient of Determination, R ²
1984	202	0.0028	0.8105	Concave	0.8778
1985	273	0.0009	1.1203	Convex	0.8437
1986	334	0.0015	0.8806	Concave	0.7359
1987	244	0.0009	1.2495	Convex	0.827
1988	199	4.00E-05	1.4479	Convex	0.7219
1989	223	0.0007	0.9727	Concave	0.9164
1990	225	0.001	0.8885	Concave	0.7334
1991	198	0.0019	0.9255	Concave	0.9239
1992	163	0.0006	1.0556	Convex	0.7943
1993	189	0.00002	1.5501	Convex	0.8158
1994	175	0.0008	0.8961	Concave	0.8317

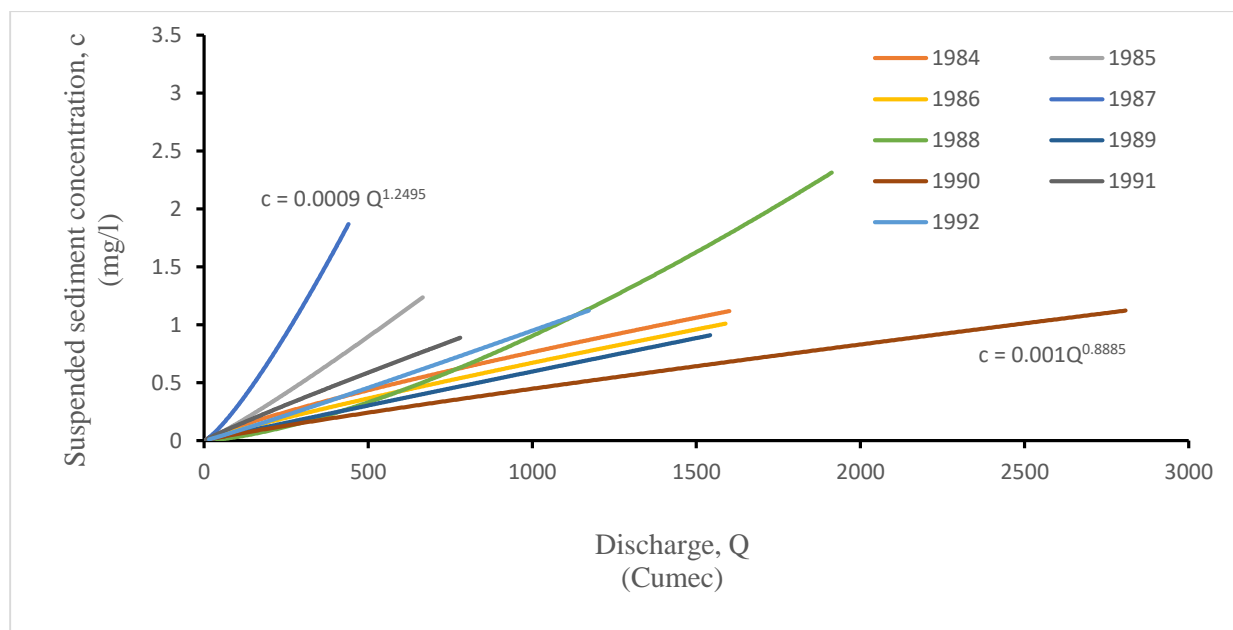


Figure 4. Monthly averaged data based SRC

3.3 Cumulative Daily Data Based SRC

SRC developed by successive cumulating daily data, incremental with each year are said as cumulative daily SRC. For each successive year's SRC the addition of that year data is done to the existing data of previous years. Which can be understood by seeing the number of data points used in SRC generation for each successive year shown in Table 4 along with the coefficients of the SRC models. The SRC developed from cumulative daily data is presented in Figure 5.

Table 4: Coefficient of nonlinear regression of cumulative daily average data SRC (Period of analysis 1984 to 1994)

Year	Data points	a	b	Coefficient of Determination, R ²
1984	202	0.0028	0.7463	0.7535
1985	475	0.0012	0.9143	0.7078
1986	809	0.0016	0.8145	0.6649
1987	1053	0.0014	0.887	0.6864
1988	1252	0.0012	0.8819	0.6498
1989	1475	0.0012	0.8722	0.6575
1990	1700	0.0012	0.8594	0.6444
1991	1898	0.0012	0.8594	0.6511
1992	2061	0.0012	0.8628	0.6476
1993	2250	0.0011	0.8687	0.6401
1994	2425	0.0010	0.8663	0.638

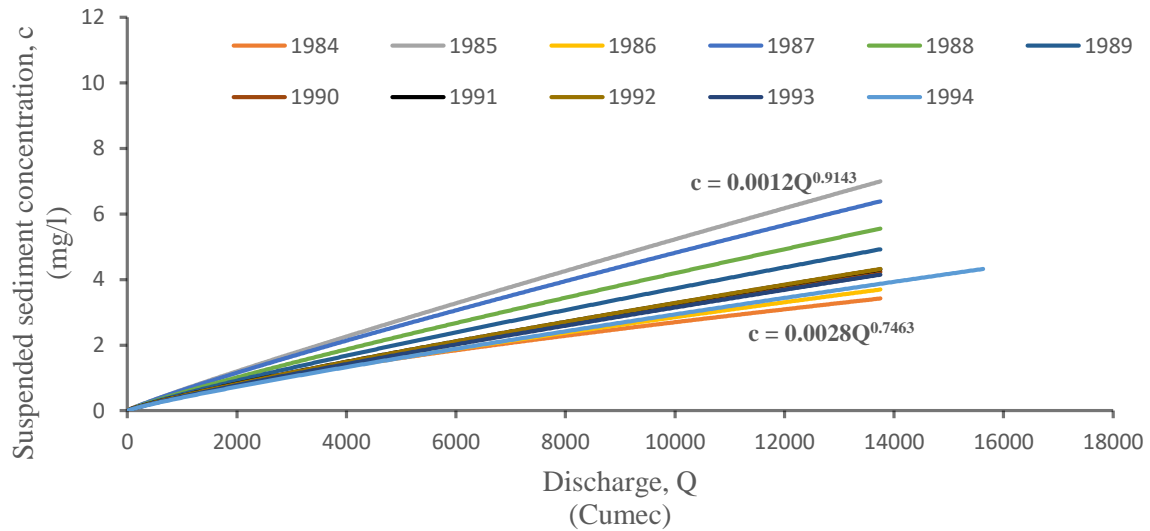


Figure 5. Cumulative daily data based SRC

3.4 Cumulative Monthly Average Data Based SRC

The data of suspended sediment concentration and discharge are grouped month wise for every year and for each group month wise sub-groups are made. Average of each sub-group of the month is computed. Accumulation of data is done in yearly steps i.e. eleven models are generated and in each model, an increment of 12 data points is done. For the first year model, the data point's used can be twelve. While, for the second year in consecution, accumulation of first and second year's monthly average is used (24 data points). The increment of data points shown in Table 5 along with model's coefficient gives a better understanding of the cumulation of monthly average data. The developed SRC are shown in Figure 6.

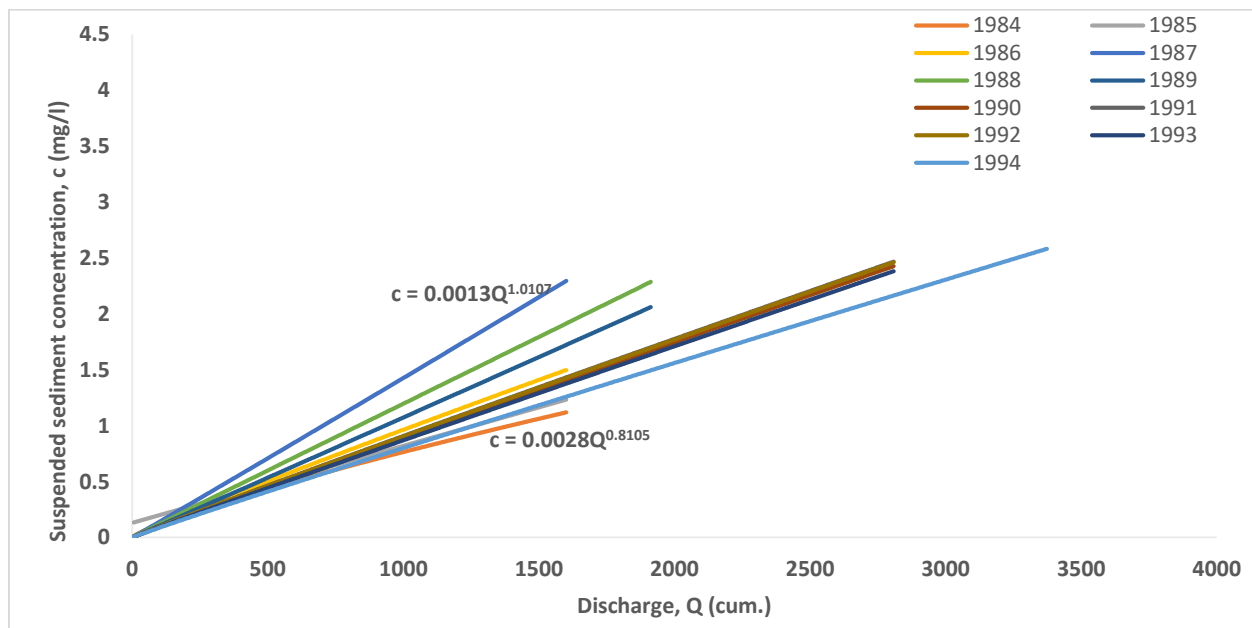


Figure 6. Cumulative monthly averaged data based SRC

Table 5: Coefficient of nonlinear regression of cumulative monthly average data SRC (Period of analysis 1984 to 1994)

Year	Data points	a	b	Coefficient of Determination, R ²
1984	202	0.0028	0.8105	0.8778
1985	475	0.0014	0.9683	0.8401
1986	809	0.0015	0.9379	0.8
1987	1053	0.0013	1.0107	0.7831
1988	1252	0.0012	0.9985	0.749
1989	1475	0.001	1.0061	0.7825
1990	1700	0.0011	0.9723	0.7687
1991	1898	0.0011	0.9686	0.7772
1992	2061	0.0011	0.9701	0.7801
1993	2250	0.001	0.9763	0.7694
1994	2425	0.001	0.9637	0.771

4. Statistical Error functions

The developed SRC models are verified for its goodness of fit not only by the coefficient of determination but are tested for its predictive capacity to predict suspended sediment load. Suspended sediment concentration predicted by each individual SRC model is used in Equation 1 to find suspended sediment load. If suspended sediment concentration is used in Equation 1 to compute load it is said as predicted load, where's by using observed suspended sediment load, observed load is computed.

$$l_{t=1day} = c_t * Q_t * \frac{(24 * 60 * 60)}{1000} \quad (1)$$

Where, l_t = Suspended sediment load passing the gauging station in tonne/day

c_t = Average daily suspended sediment concentration observed/predicted in gm/litter or kg/cu.m.

Q_t = Average daily discharge observed in cumec

Computed observed and predicted suspended sediment load is accumulated for the period of study and Percentage Error (PE), Discrepancy Ratio (DR) and Nash–Sutcliffe Model Efficiency Factor (NSMEF) (Willmott 1981) is found for each SRC model. Figure 7, 8 and 9 show the PE, DR, and NSMEF of daily data based SRC models and monthly average data based SRC models. The abscissa of Figure 7, 8 and 9 represents a model number. One stands for the model developed from 1984 data, two for the model developed from 1985 up till eleven, where eleven is for the model developed from 1994 data.

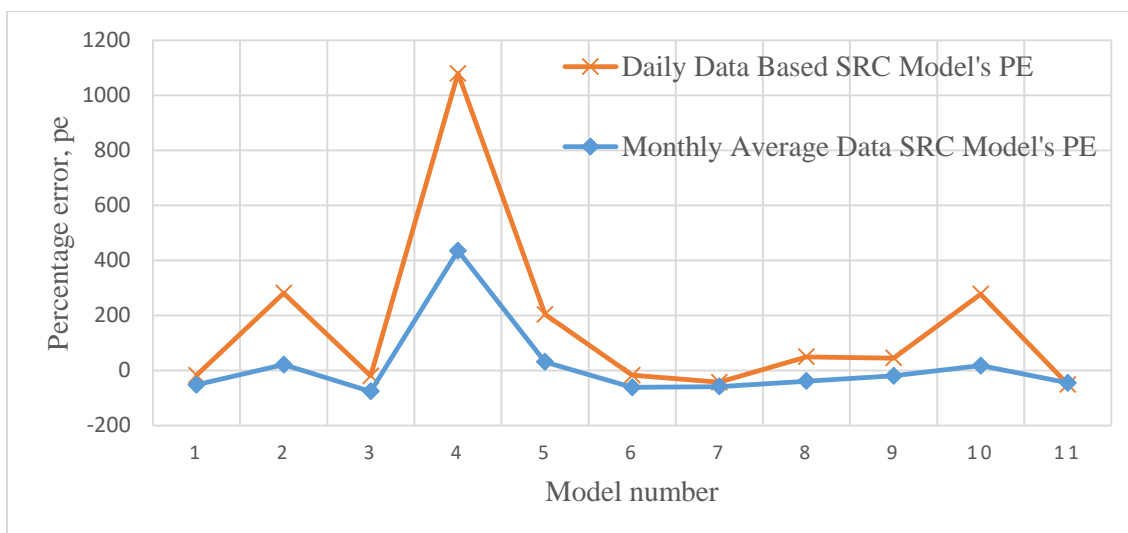


Figure 7. Percentage error of daily and monthly data based SRC models

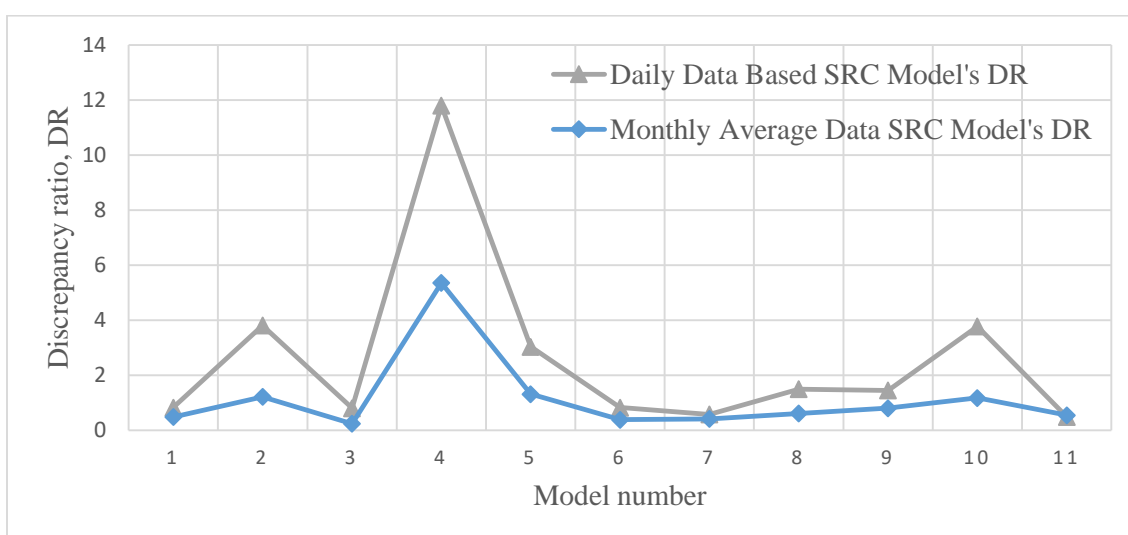


Figure 8. Discrepancy ratio of daily and monthly data based SRC models

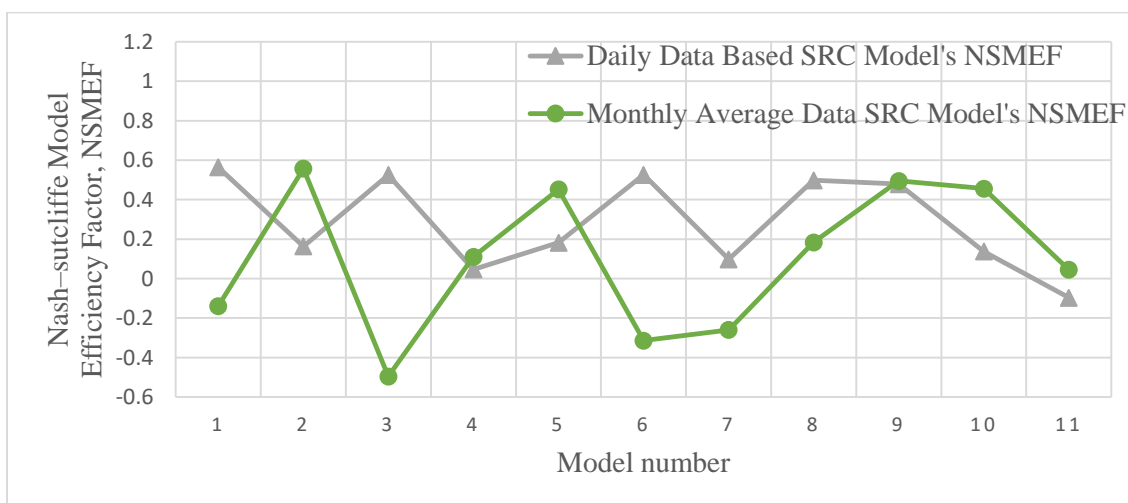


Figure 9. NMEF of daily and monthly data based SRC models

Whereas Figure 10, 11 and 12 show the PE, DR, and NSMEF of cumulative daily data based SRC models and cumulative monthly average data based SRC models. The abscissa of Figure 10, 11 and 12 represent model number. One stand for the model developed from 1984 data only, two for the model developed from 1984 and 1985 up till eleven. Where eleven as the model developed from data of 1984 to 1994.

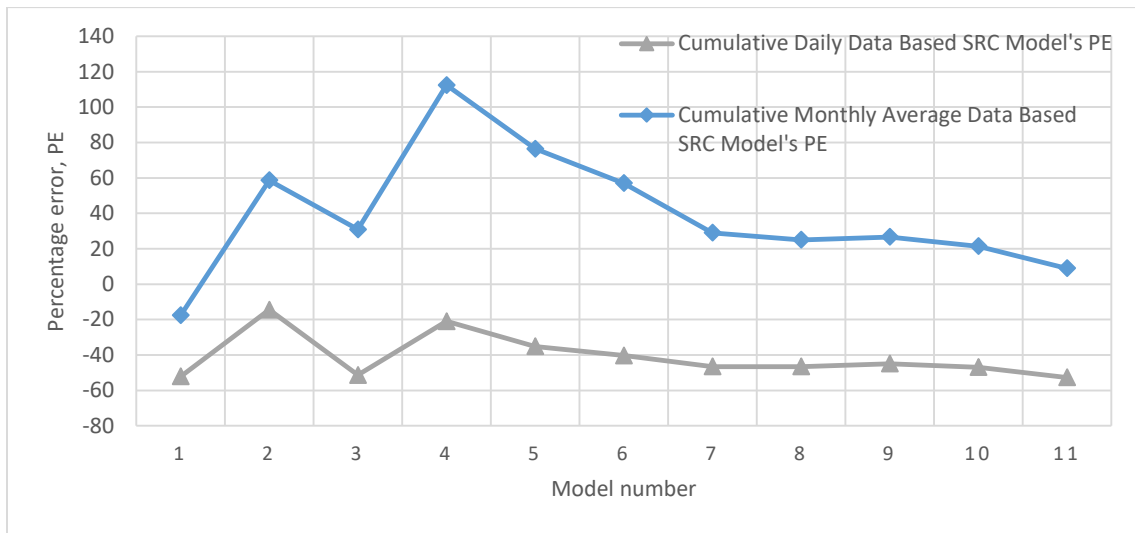


Figure 10. Percentage error of cumulative daily and cumulative monthly data based SRC models

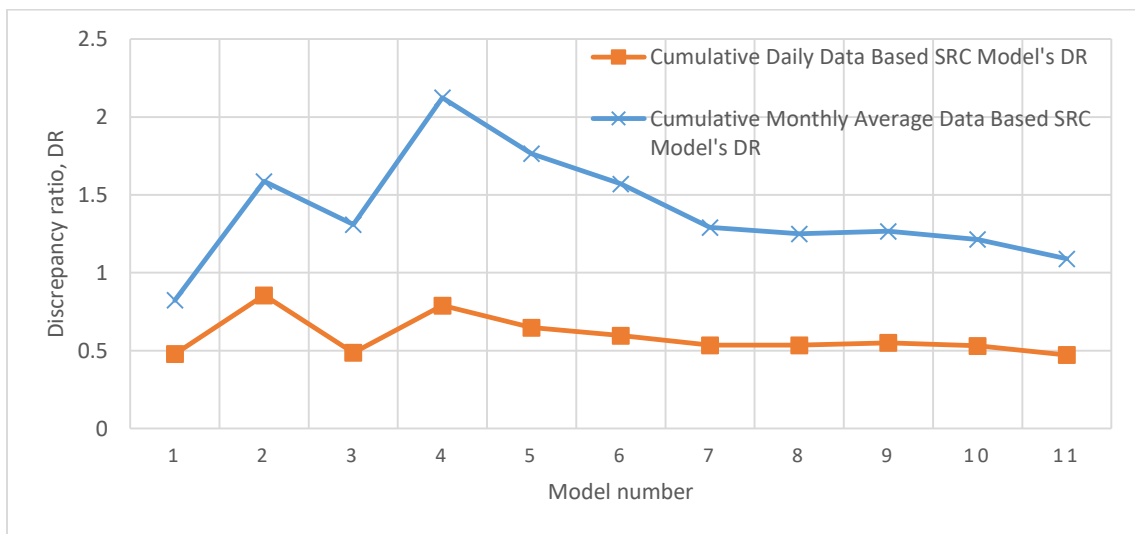


Figure 11. Discrepancy ratio of cumulative daily and cumulative monthly data based SRC models

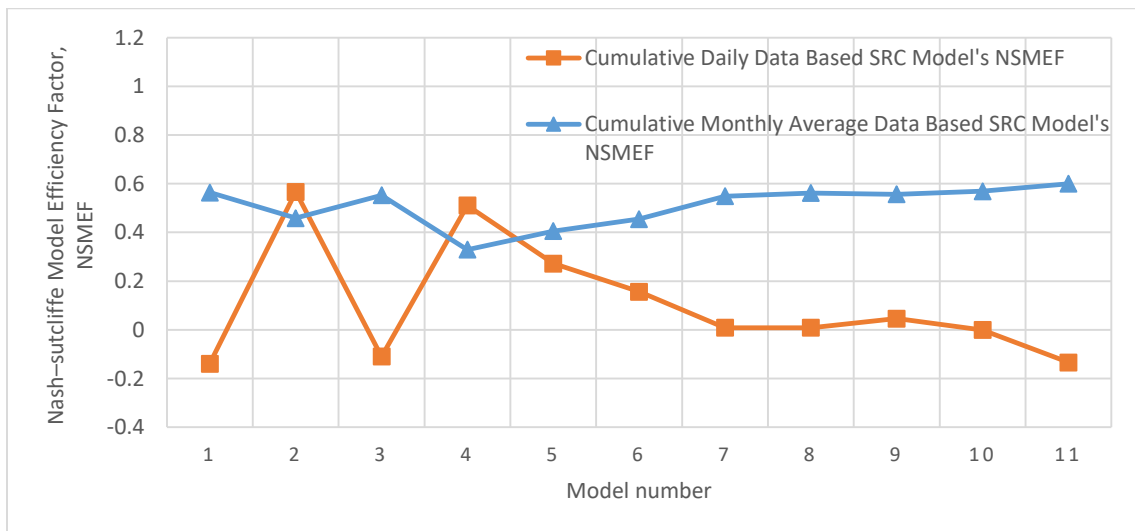


Figure 12. NSMEF of cumulative daily and cumulative monthly data based SRC models

Discussion

We find that using daily or monthly average data from a single year can lead to large errors in estimating suspended sediment load. The percentage error can vary from -76.55% to 1079.75%. SRCs based on daily and monthly average data can have different shapes (concave or convex) for different years of data, which can result in underestimation or overestimation of suspended sediment load. To avoid this, we propose to use cumulative data to plot SRCs that capture all the variations in the data. We compare SRCs based on cumulative daily and cumulative monthly average data and find that they have similar statistical error functions. Therefore, we can use either type of data depending on the availability. However, we still need to determine how many years of cumulative data are required to produce a reliable SRC. In this study, we suggest that seven years of cumulative data can yield a good SRC, but less than that can produce uncertain estimates even with accumulation.

Conclusion

This research examines how the grouping of data affects the relationship between suspended sediment load and discharge. We find that the choice of data grouping influences the performance of SRC models. We suggest that using cumulative monthly average data can improve the accuracy of suspended sediment load estimates. We also estimate that at least seven years of data are needed to produce a reliable SRC model. Therefore, we recommend that soft computing models based on data should use no less than seven years of data for better predictions of suspended sediment load.

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