Regional sediment yield pattern for the west flowing rivers of Kerala state, India

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Received: December 4, 2007 **Accepted:** December 19, 2007

Abstract: This study aims to understand the spatial and seasonal distribution of suspended sediment load carried by major west flowing rivers of Kerala State, India, which lies in the humid climatic zone. While comparing sediment yield pattern among individual rivers with the aid of daily discharge and sediment load data, it was noticed that the State could be broadly delineated into four distinct sediment yielding zones. This aspect was dealt in detail and the influencing factors were analyzed. The sediment yield characteristics for each of these zones were explained mainly with respect to the two major rainfall seasons of the State, namely Southwest (SW) monsoon and Northeast (NE) monsoon and their spatial and temporal coverage over the state.

Key words: suspended sediment, yield, erosion, discharge, monsoon, Kerala

Introduction

In recent times, due to various developmental activities within the river basins, the rate of soil erosion, its transport, and deposition downstream have considerably altered. Such changes in sediment movement will have its impact on the river system, reservoirs, estuaries and coastal regions.

While studying the environmental problems of a region, land, water, and biomass have to be considered together. An integrated approach has to be followed while suggesting solutions to such problems. Kerala, which is the southernmost state of India, faces numerous environmental issues (Basak, 1998) such as uncontrolled developmental activities on the upstream reaches, land use changes, flash floods, droughts, sedimentation, excessive sand mining, deterioration of water quality, etc. Hence it is important to study the water and sediment yields together and its relation to the drainage basin environment.

The Kerala State, situated in the humid tropics lies between 8° 18' and 12° 48' N and 74° 52' and 77° 22' E. Based on the topography, the state can be divided into three well-defined natural landforms: the

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lowlands with altitude less than 7.5 m; midlands with altitude between 7.5 and 75 m; and the highlands with altitudes greater than 75 m. The state is a narrow strip of land with width varying from 30 km in the north and south to about 130 km in the central region. The Western Ghat forms a continuous mountain wall on the eastern border of the state while Arabian Sea is the margin to west.

Geologically the major formations of the state are, crystalline rocks of Archaen age; sedimentary rocks of Tertiary age; laterites capping the crystalline and sedimentary rocks; and recent to sub-recent sediments forming the low-lying areas and river valleys. Lateritic and coastal loams cover the major soil types of the State. There are mainly five broad categories of land use distributed unevenly, arable land, forestland, plantation, grassland and wasteland (NAIR, 1987).

The average annual rainfall for the State is about 3000 mm. It ranges in the lowland, from 900 mm in the south to 3500 mm in the north; in the midland, from 1400 mm to 4000mm; and in the highland, from 2500 mm to 6000 mm (CWRDM, 1995). About 65 % of this rainfall is received during the southwest (SW) monsoon and 25 % during northeast (NE) monsoon. However, for the southern parts, NE monsoon is active compared to the northern Kerala.

Forty-four (44) rivers, with lengths more than 15 km, originate from the Western Ghat, out of which 41 flows towards west and the other three rivers towards east. Periyar, Bharathapuzha, Pamba, and Chaliyar are the major rivers of the state. The net annual discharge from all these rivers is estimated to be 77,900 MCM (CWRDM, 1995). The drainage basin area and the discharge carried by these rivers are small compared to other major rivers in India.

MATERIALS AND METHODS

Numerous studies were undertaken in the past to analyze the sediment yield from large and medium rivers of the world (HOLEMAN, 1968; WILSON, 1972; GRIFFITHS, 1982; KEOWN et al., 1986; LAJCZAK and JANSSON, 1993; YANG et al., 2002). In India also, such studies were carried out for most of the major rivers (ABBAS and SUBRAMANIAN, 1984; GOSWAMI, 1985; BIKSHAM and SUBRAMANIAN, 1988; RAMESH & SUBRAMANIAN, 1988; VAITHYANATHAN et al., 1992; CHAKRAPANI and SUBRAMANIAN, 1993; RAO et al., 1997). These studies have contributed much to the understanding of the sediment yield processes and the regional factors influencing these processes.

In the present study, an attempt was made to understand the spatial and temporal variation of sediment transport characteristics of the rivers of Kerala and the factors affecting this variability. The Central Water Commission (CWC), Govt. of India, is maintaining 16 sediment gauges in Kerala for daily river gauge measurements and sediment sampling. In order to utilize this long-term data, these 16 river basins were selected for the present study.

Location of these rivers with the sediment gauge sites is shown in Figure 1. The daily

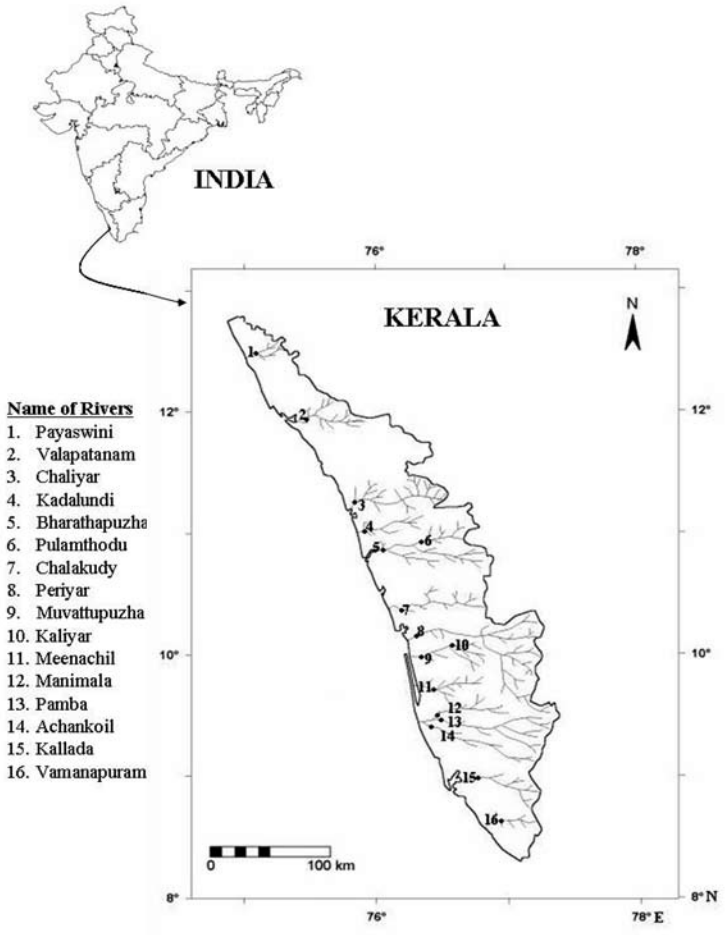

Figure 1. Location of rivers and the sediment gauge sites

suspended sediment concentration (mg/l) and corresponding discharge (cumec) data were collected for fifteen years, from 1986-87 to 2000-01. Average monthly rainfall (mm) for each river basin was calculated from the daily data of rain gauge stations located within these basins. Length of the main streams, average slope and drainage area were extracted from Survey of India toposheets. General and hydrological characteristic of the river basins are given in Table 1.

The daily data on suspended sediment concentration [C in mg/l] were converted into sediment load [S in ton]. Daily discharge values were added to get the monthly and yearly discharge in cumec-days. The monthly discharge and sediment load values were used to estimate the percentage monthly and seasonal contributions. While analyzing the sediment and discharge data for the rivers of Kerala, it is noticed that there is a marked change in the pattern (seasonal as well as annual) of carrying capacities of

these rivers from north to south. Hence this aspect was studied in detail. Such studies to delineate quantitatively, broad regions with similar erosional patterns were carried out earlier by GRIFFITHS (1982) for North Island basins, New Zealand and LAJCZAK and JANSSON (1993) for Baltic Drainage basins.

The analysis of seasonal and annual contribution of discharge and suspended sediment load will not yield much inference on the comparative characteristics of individual rivers originating and flowing through different topographical conditions. Sediment load from a river basin depends mainly on the size of the catchment and on the discharge, which carries the sediment. Hence, the erosion rate or sediment yield, which is the ratio of sediment load to catchment area [S/A]; and the ratio of sediment load to discharge [S/Q], which is a measure of average sediment concentration, were considered for analyzing the spatial yield characteristics of the rivers.

RESULTS AND DISCUSSION

Seasonal discharge and sediment contribution for individual rivers is given in Table 2. It can be seen that most of the rivers drain 95-98 % of its sediment load during the monsoon season. However, its distribution during the southwest (SW) and northeast (NE) monsoons gives an entirely different pattern for the rivers flowing through the northern and southern regions of the State. This aspect was analyzed in detail using different criterion.

Table 1. Characteristics of the river basins studied

Name of the River	Annual rainfall (mm)	River Basin area [A] (km^2)	Length (km)	Slope (m/m)	Annual discharge (MCM)	Average annual sediment load (ton)	Max. observed sediment conc. (mg/l)
Payaswini	4000	957	105	0.012	2384	239934	1090
Valapatanam	3600	1070	101	0.013	3543	252144	613
Chaliyar	3800	1876	169	0.012	4175	401614	1024
Kadalundi	3400	750	86	0.013	1303	85171	345
Bharathpuzha	2300	5755	209	0.009	4326	369186	1163
Pulanthode	2600	940	78	0.013	1756	101771	791
Chalakudy	3600	1342	120	0.010	1798	50234	167
Periyar	3200	4234	244	0.007	6895	320029	739
Muvattupuzha	3100	1208	92	0.011	5068	157001	595
Kaliyar	3000	405	71	0.014	1194	44667	557
Meenachil	3000	615	61	0.017	1756	36566	1091
Manimala	3300	731	90	0.012	1795	70486	559
Pamba	3600	1654	176	0.009	4016	156851	896
Achankovil	2600	810	138	0.005	1247	77130	904
Kallada	2800	1210	92	0.016	1636	104447	802
Vamanapuram	2200	540	88	0.020	701	68619	2944

Table 2. Seasonal variation of % Q and % S for the rivers

Name of the River	% Discharge [Q]				% Sediment Load [S]			
	Monsoon			Non-monsoon	Monsoon			Non-monsoon
	SW	NE	Total		SW	NE	Total	
Payaswini	83.5	13.5	97.0	3.0	90.0	9.5	99.5	0.5
Valapatanam	86.2	11.3	97.5	2.5	94.0	5.3	99.3	0.7
Chaliyar	79.6	15.8	95.4	4.6	87.0	11.9	98.9	1.1
Kadalundi	77.3	20.0	97.3	2.7	79.0	19.6	98.6	1.4
Bharthapuza	74.5	19.7	94.2	5.8	79.9	18.1	98.0	2.0
Pulamthode	72.6	21.8	94.4	5.6	73.8	24.3	98.1	1.9
Chalakudy	75.7	16.8	92.5	7.5	84.2	14.1	98.3	1.7
Periyar	67.9	18.2	86.1	13.9	89.8	8.3	98.1	1.9
Muvattupuzha	56.9	19.2	76.1	23.9	65.9	25.4	91.3	8.7
Kaliyar	77.1	18.9	96.0	4.0	75.7	22.6	98.3	1.7
Meenachil	69.7	22.8	92.5	7.5	71.8	23.7	95.5	4.5
Manimala	69.4	23.6	93.0	7.0	68.1	27.4	95.5	4.5
Pamba	65.5	23.3	88.8	11.2	54.9	40.3	95.2	4.8
Achankovil	62.3	29.7	92.0	8.0	53.9	41.7	95.6	4.4
Kallada	50.7	32.4	83.1	16.9	39.8	53.8	93.6	6.4
Vamnapuram	50.3	35.2	85.5	14.5	41.4	51.4	92.8	7.2

***** Seasons as per the Indian Meteorological Department (IMD) norms

M - Monsoon (June to Nov.)
NM - Non-Monsoon (Dec. to May)
SW - Southwest Monsoon (June to Sept.)
NE - Northeast Monsoon (Oct. and Nov.)
W - Winter (Dec. to Feb.)
S - Summer (March to May)

Seasonal and spatial variation of sediment load and discharge

Based on the 15 years of data, River Periyar carries maximum yearly discharge (9968 MCM) while Vamanapuram yields the minimum discharge of 288 MCM. Chaliyar supplies the maximum sediment load (0.8 x 10^6 ton) and Meenachil supplies the minimum (0.02 x 10^6 ton).

The seasonal variation of discharge and sediment load can be represented graphically (Figure 2). A definite grouping of data into four zones: north zone (NZ), north-central zone (NCZ), south-central zone (SCZ) and south zone (SZ), can be observed from the graph for SW and NE monsoon seasons. The rivers from the 4 zones are also shown in separate groups in Table 2.

Southwest (SW) monsoon is the major source of discharge for northern rivers. The percentage discharge during SW monsoon decreases steadily from north to south as shown in Table 2, about 84 % in the north to 50 % in the south. On the other hand, the northeast (NE) monsoon yields about 14 % discharge for the rivers from NZ, whereas the percentage increases to 32 % for the SZ rivers. The Muvattupuzha river shows 23 % yield during non-monsoon season, since it includes the diverted water from the tail-race of Idukki hydroelectric project in River Periyar.

Major amount of the annual sediment load is transported during monsoon season. SW monsoon sediment load ranges from 74-94 % for northern rivers (NZ + NCZ) whereas

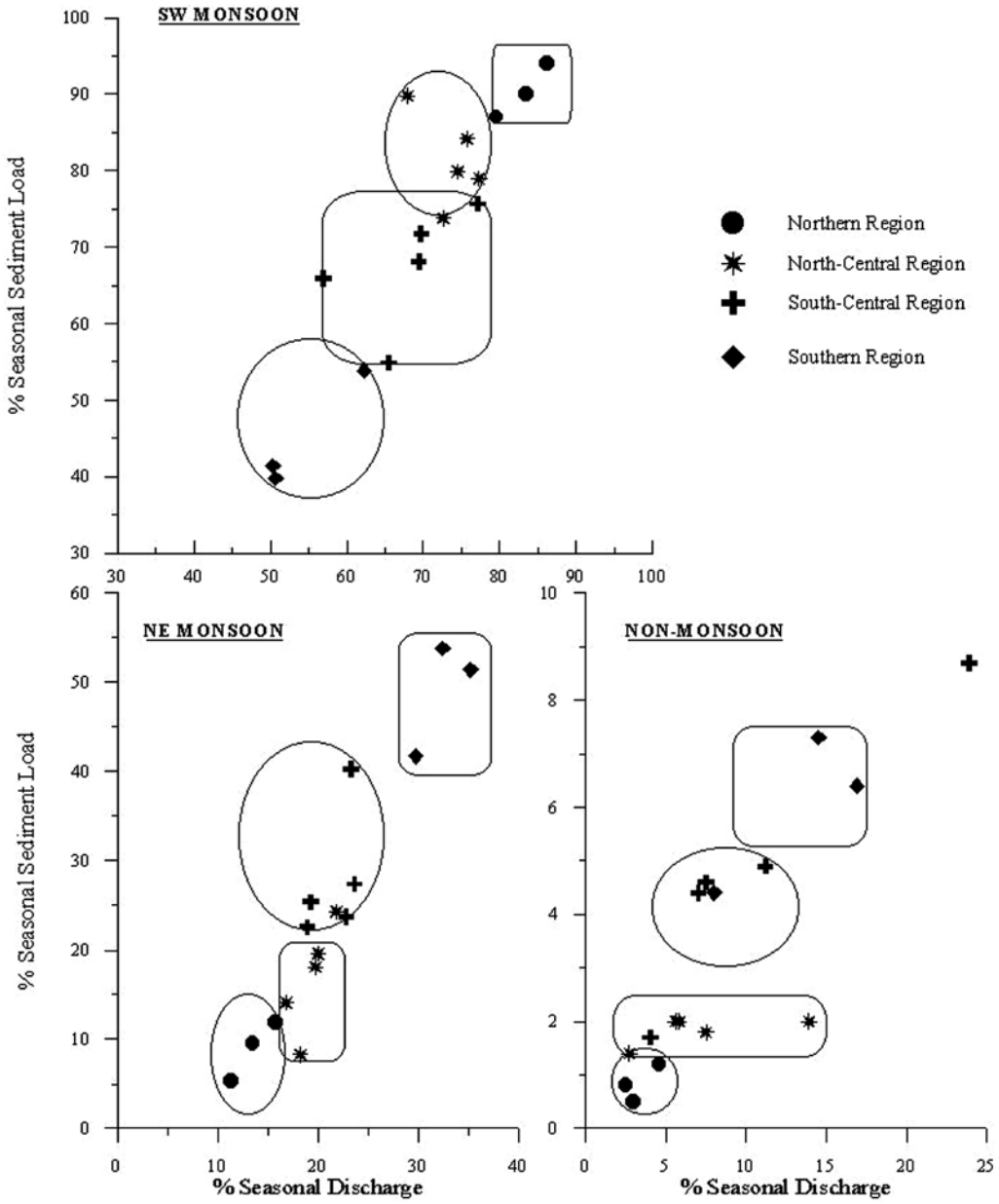

Figure 2. Seasonal % (Q Vs S) relationship showing the demarcation of zones

this is about 42-76 % for southern rivers (SZ + SCZ). During NE monsoon season, northern rivers (NZ + NCZ) yield 5-24 % of the total sediment load whereas it is 23-54 % for the southern rivers (SZ + SCZ). Sediment load for non-monsoon season is nominal for northern rivers while southern rivers register about 2-9 % of the annual sediment load.

The sediment yielding characteristics of these individual zones can be further illustrated as in Figure 3, where monthly variation of rainfall [P], discharge [Q] and sediment load [S] contributions of representative rivers from each of the above four zones is demonstrated. It can be seen that the discharge and sediment flow pattern closely follow the monthly rainfall distribution. Northern rivers (NZ + NCZ) showed an asymmetrical uni-mode distribution whereas south-central and SZ Rivers developed a bi-mode distribution. The dominance of NE monsoon rainfall on sediment transport over the southern zone (SZ + SCZ) can be clearly seen.

The spatial and seasonal variation of sediment yield [S/A] and average sediment concentration [S/Q] for the rivers are given in Table 3. The division of the State into different zones, as discussed in Figure 2 and Table 2, can be seen in this case also.

Average Sediment Concentration [S/Q]

This ratio is large for the northern rivers, shows a declining trend towards central rivers and again increases towards south. This denotes high erodibility of the northern and southern zones and indicates the availability of material for transport rather than the stream conditions. Slope of the terrain also is a factor, which is more for the northern and southern Kerala where the land becomes narrow. The specific sediment yielding zones, as explained based on the % [Q-S] relationship is valid here also.

When season-wise yield is considered, the trend is similar for monsoon season. The ratio during SW monsoon is more for northern rivers while it is higher during NE monsoon for southern rivers. During the non-monsoon season, the ratio is almost constant except for the southern most rivers, where the summer rains are of appreciable quantity.

Sediment Yield [(S/A]

From Table 3, it can be seen that the sediment yield is maximum for the northern rivers. The rivers in the central and southern zones show highly unstable values, with a reducing trend towards central parts of the State and increasing towards southern zone. This factor also denotes the high erosion rates for the northern rivers, lesser for southern rivers and least for the central rivers.

The presence of four sediment-yielding zones is noticeable in this case also. However, the demarcation between south-central and north-central zones is not so well defined. The unstable values for the central zones (NCZ + SCZ) may be due to the fact that comparatively larger rivers drain this zones. Inter basin water transfer exists between Periyar and Muvattupuzha, which results in large yields even during non-monsoon season. Also, some extreme discharge and sediment load events were noticed for these rivers from the data set, which affects the [S/A] ratio. The effect of these outliers may not appear in [S/Q] ratio, since both discharge and sediment load varies simultaneously.

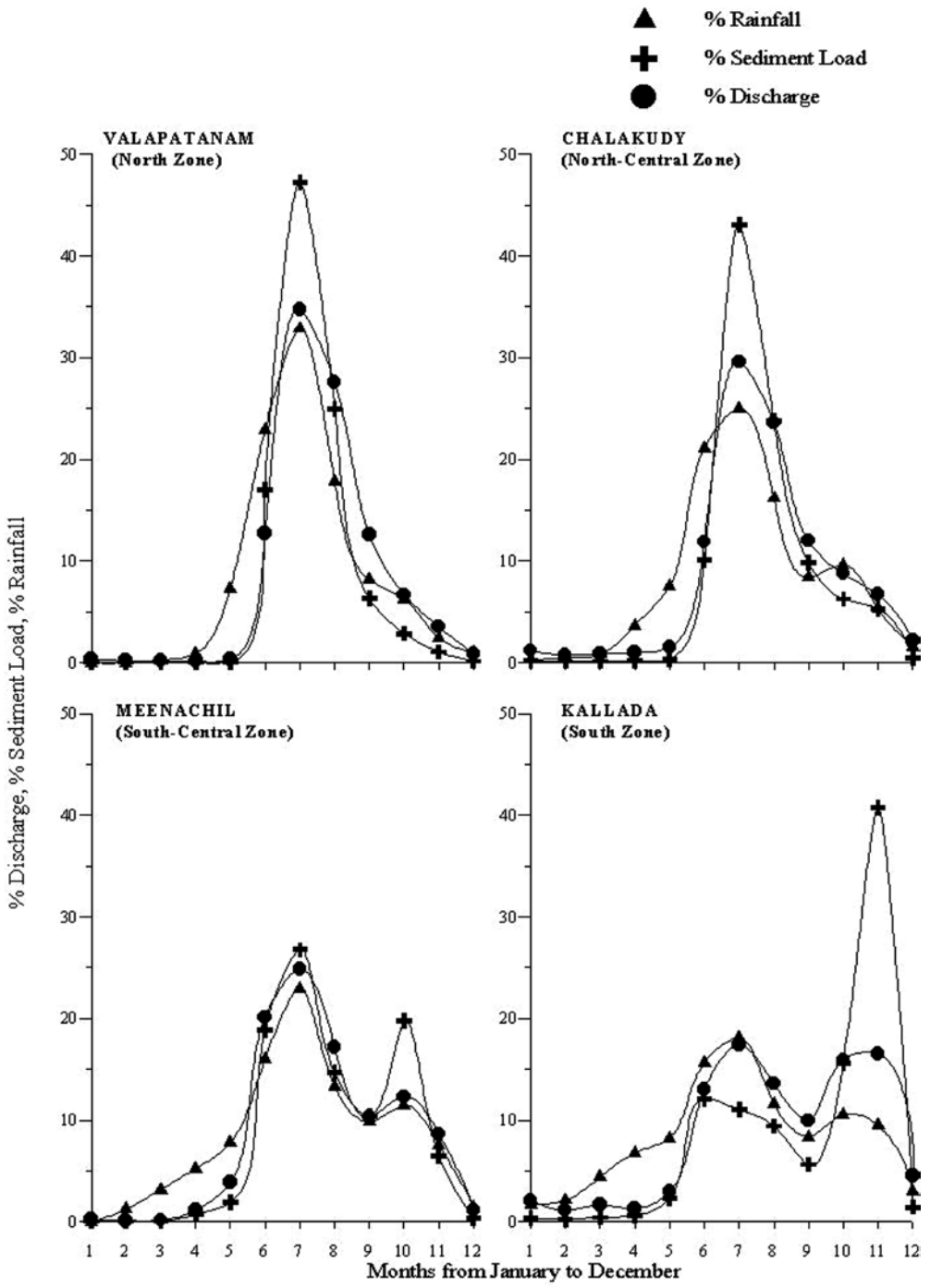

Figure 3. Monthly distribution of (%) rainfall, discharge and sediment load for rivers from different zones

Table 3. Variation of the [S/Q] and [S/A] ratios for the rivers

Name of the River	Sediment Load/ Discharge (S/Q)					Sediment Load/ Catchment Area (S/A)				
	Year	M	NM	SW	NE	Year	M	NM	SW	NE
Payaswini	8.7	8.9	1.3	9.4	6.2	250.7	249.6	1.2	225.7	23.9
Valapatanam	6.2	6.3	1.9	6.7	2.9	235.7	233.8	1.8	221.4	12.4
Chaliyar	8.3	8.6	2.1	9.1	6.3	214.1	211.6	2.5	186.2	25.4
Kadalundi	5.7	5.7	3.0	5.8	5.5	113.6	112.0	1.6	89.7	22.3
Bharatapuzha	7.4	7.7	2.5	7.9	6.8	64.2	62.9	1.3	51.3	11.6
Pulanthode	5.0	5.2	1.7	5.1	5.6	108.3	106.2	2.1	79.9	26.3
Chalakudy	2.4	2.6	0.6	2.7	2.0	37.4	36.8	0.7	31.5	5.3
Periyar	4.0	4.6	0.6	5.3	1.8	75.6	74.1	1.5	67.9	6.2
Muvattupuzha	2.7	3.2	1.0	3.1	3.6	130.0	118.6	11.4	85.7	33.0
Kaliyar	3.2	3.3	1.4	3.2	3.9	110.3	108.4	1.9	83.5	25.0
Meenachil	1.8	1.9	1.1	1.9	1.9	59.5	56.8	2.7	42.7	14.1
Manimala	3.4	3.5	2.2	3.3	4.0	96.4	92.1	4.3	65.7	26.5
Pamba	3.4	3.6	1.5	2.8	5.8	91.6	87.1	4.5	50.3	36.9
Achankovil	5.4	5.6	3.0	4.6	7.5	95.2	91.0	4.2	51.3	39.7
Kallada	5.5	6.2	2.1	4.3	9.2	86.3	80.8	5.6	34.4	46.4
Vamnapuram	8.5	9.2	4.2	7.0	12.4	127.1	117.9	9.2	52.6	65.3

Regional Division

Based on the analyses of annual and seasonal water and sediment yield, the Kerala State can be roughly divided into four zones with similar sediment transport characteristics. These four zones namely; North Zone (NZ), North-Central Zone (NCZ), South-Central Zone (SCZ), and South Zone (SZ); can be delineated as shown in Figure 4. The difference in transport characteristics among the zones is mainly attributed to the spatial variation of rainfall and discharge, slope along the course of rivers, and physiography of the river basins. The seasonal distribution of discharge and sediment load and the variation in sediment yield, for these four zones, are given in Table 4. The average sediment yield for the northern rivers goes up to 240 ton/km^2, whereas for the rest of the state this ranges between 80 and 100. However, the difference in distribution of sediment load and to some extent the discharge, from north to south, during the two monsoon seasons is obvious as can be noticed from the Table 4.

Conclusions

Water and sediment yield data of 15 years (from 1986-87 to 2000-01) for 16 west flowing rivers of Kerala, India, were collected and analyzed to compare the discharge and suspended sediment carrying characteristics of these rivers. In general, the sediment yield pattern follows the seasonal distribution of rainfall and the topography of the river basin.

From the spatial and seasonal analyses of the data, it is found that a broad division of the state into four zones is possible. These are, high sediment yielding North Zone; North-Central Zone with low yield; South-Central Zone with low to medium yield, a sizeable share of which occurs during

northeast monsoon season; and South Zone with medium yield, where the yield is almost equal for both the monsoon seasons.

The reasons for the above sediment yielding zones for the State is basically due to the spatial distribution of rainfall during the two monsoons over various parts of the State. NE monsoon plays a major roll in the sediment yield characteristics of SZ rivers, whereas SW monsoon is responsible for supplying major share of sediment load for northern rivers (NZ + NCZ). The other factors affecting the variation in suspended sediment transport are slope of the river basin, geology, soil type and land use activities.

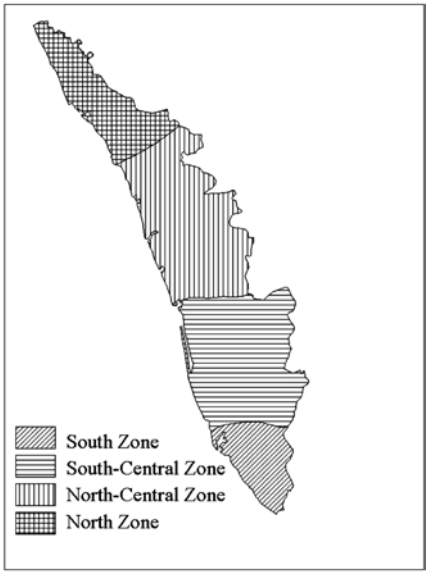

Figure 4. Sediment yielding zones of Kerala

Acknowledgements

The authors acknowledge the Central Water Commission (CWC), for providing sediment data and the facilities offered at Cochin University of Science and Technology (CUSAT), Kerala, for the study. The first author is thankful to National Institute of Hydrology for sanctioning study leave to undertake the doctoral program.

Table 4. Seasonal distribution of discharge, sediment load and sediment yield for the four zones of the state

% Discharge				% Sediment Load				Sediment Yield (ton/km2)			
NZ	NCZ	SCZ	SZ	NZ	NCZ	SCZ	SZ	NZ	NCZ	SCZ	SZ
ANNUAL											
								233.5	79.8	89.4	102.9
MONSOON											
96.6	92.9	92.6	86.9	99.2	98.2	96.1	94.0	231.7	78.4	86.1	96.6
SW MONSOON											
83.1	73.6	70.4	54.4	90.3	81.3	67.6	45.0	211.1	64.1	60.6	46.1
NE MONSOON											
13.5	19.3	22.2	32.4	8.9	16.9	28.5	49.0	20.6	23.3	25.6	50.5
NON-MONSOON											
3.4	7.1	7.4	13.3	0.8	1.8	3.9	6.0	1.8	1.4	3.4	6.3

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