Chapter IV

CONCLUSION
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The fluvial system, consisting of upland erosion zone, transportation zone and downstream sedimentation zone, is an open system that is susceptible to modification by climate change and human activities. Changes in erosion pattern and transportation processes in the first two zones, influence the sedimentation rate within the third zone. If a relationship between the response of a fluvial system to changes in climate and human activities can be established based on recent past data, then the future scenarios can be predicted in response to global climate changes and urban expansion. The present study has been formulated to understand the temporal and spatial variation in suspended sediment input by the tropical rivers of Kerala State, India, to the coastal eco-system and to identify the factors influencing these variations, in line with the above thoughts.

The water and sediment yield data of 15 years (from 1986-87 to 2000-01) for 16 west flowing rivers of Kerala, have been collected and analyzed to study the discharge and sediment carrying characteristics of individual rivers on monthly, seasonal and annual basis. Based on the spatial and temporal distribution of rainfall, topography, geology, and basin characteristics, the variation in the sediment yielding capacities of each river has been analyzed. Further, Pamba river has been selected for detailed studies and for testing the applicability of rating curve methodology. Contributions from its major tributaries have been estimated. Three micro-watersheds have been selected within the Pamba river basin to compare the suitability of three sediment yield models.

Large variations in the discharge and sediment quantities were noticed during a particular year between the river basins investigated and for an individual river basin during the years for which the data was available. In general, the sediment yield pattern follows the seasonal distribution of rainfall, discharge and physiography of the land. This confirms with similar studies made for other Indian rivers.
The analyses of data reveal that the variations of water and sediment yield manifest the following:

- northern and southern Ghat regions are more prone to erosion than the central region
- distribution of rainfall and topographical features are the major factors influencing the sediment yield
- monsoon supplies major share of sediment load; SW monsoon is the driving factor for northern region, whereas both SW and NE monsoons control the sediment flow pattern for southern regions
- sediment yield during non-monsoon season is very low for northern rivers, whereas its contribution is considerable for southern rivers
- within central Kerala, erosion processes have become more stabilized than northern and southern regions, which results in lower sediment yields

To pin point, major findings from the analyses of sediment data for the 16 rivers are:

- Periyar river yields maximum average yearly discharge of 6,895 MCM while Vamanapuram contributes the minimum of 701 MCM
- Chaliyar contributes the maximum average yearly sediment load of $0.40 \times 10^6$ ton and Meenachil transports the minimum of $0.04 \times 10^6$ ton
- Northern rivers are having comparatively large values of sediment yield (235 ton/km$^2$), followed by southern rivers (90 - 130 ton/km$^2$) and central Kerala rivers, which yield unstable erosion rates (40 - 130 ton/km$^2$)
- Except Valapatanam, Chaliyar, Bharathapuzha, Chalakudy and Pamba (5 rivers), all other rivers show a decreasing trend in sediment load transport from 1986-87 to 2000-01, even though the discharge show increasing trends
- Monsoon months (July to November) are responsible for transporting about 95% of the sediment
- Few days in monsoon accounts for bulk of the sediment load
- Northern rivers exhibits a uni-mode distribution of % monthly sediment load, whereas the distribution is bi-modal for the southern rivers
Rating curve analyses show that northern and southern rivers produce flat rating curves, which is indicative of river reaches with intensively weathered material that can be transported easily.

Since the gauging sites are within the downstream reach of the rivers, the suspended sediment load is dominated by finer particles (< 0.075 mm).

Pamba river basin was considered for detailed studies for understanding seasonal distribution of sediment dynamics in tropics. Data collected on a daily basis were used to study the seasonal variation in sediment transport and hysteresis effects. Rating curves were developed and tested with the observed data. Contributions from different tributaries were monitored to identify the major source of sediment flow.

The following conclusions are drawn with respect to Pamba river basin:

- Discharge in the river was minimum at 3,116 MCM during 1986-87 and maximum at 5,397 MCM during 1992-93.
- River transported a minimum sediment load of 65,770 ton in 1990-91 and a maximum sediment load of 5,01,562 ton in 1992-93.
- SW and NE monsoon accounted for 95% of the sediment load.
- Maximum discharge occurred during the month of July, whereas it was during the month of October, that the sediment load attained the maximum value.
- Maximum sediment concentration recorded was 896 mg/l on 10th October 1992, which accounted for 35% of annual load.
- It is found that clockwise hysteresis appears common for this river basin; however, anti-clockwise loops are also noted during the months of July and August.
- Pamba Ar (tributary) accounted for about 50% of the sediment load to the main river system.
- Sediment rating curves computed on daily data failed to predict sediment load values accurately.
- Rating curves developed based on seasonal and monthly data gives a better result as per the statistical goodness of fit analyses; however, still rating curves were inadequate to simulate large sediment load values.
In order to model the sediment dynamics, three micro-watersheds were selected with varying characteristics, vis-à-vis, topography, drainage density and land use. Average one-hour Unit Sediment Graphs (USG) was computed for each of these watersheds. It is seen that the sediment graphs, simulated using the average USGs were comparable with the observed sediment graphs in its shape and peak.

Next, more advanced tools were utilized for the estimation of average erosion rates in the above watersheds - an empirical model, Modified Universal Soil Loss Equation (MUSLE) in GIS environment, another - conceptual model based on USG, and thirdly, a physically distributed model, Water Erosion Prediction Project (WEPP), and the results were compared with the observed data. It was found that the USG based model predicted the sediment yield rates better than the other two models.

Conceptually, it was observed from this study, that the quantity of sediment transported downstream shows a decreasing trend over the years corresponding to increase in discharge. For sound and sustainable management of coastal zones, it is important to understand the balance between erosion and retention and to quantify the exact amount of the sediments reaching this eco-system. This, of course, necessitates a good length of time series data and more focused research on the behaviour of each river system, both present and past. In this realm of river inputs to ocean system, each of the 41 rivers of Kerala may have dominant yet diversified roles to influence the coastal ecosystem as reflected from this study on the major fraction of transport, namely the suspended sediments.

Additionally, based on the analyses of seasonal variation of discharge and sediment load/yield, a marked feature of variation is noticed from north to south. When this aspect was studied in detail with respect to the distribution of sediment, discharge and rainfall, it was found that the State of Kerala could be divided into four zones as shown in figure 14:
North zone, with very large sediment yield, majority of which are being transported during SW monsoon

North-central zone, where the sediment yield characteristics are comparatively lesser than all the other three zones, with small contributions during NE and non-monsoon seasons

South-central zone, is noted for major sediment yield in SW monsoon; during NE monsoon and non-monsoon seasons, yield is appreciable compared to north-central zone

South zone, with large sediment yield, where sediment contribution from both the monsoon seasons are almost equal

The table on next page provides the characteristics of the four specifically defined sediment yielding zones.

It is observed from the table below, that river discharge in NCZ is appreciably lower compared to SCZ though the amount of rainfall is nearly equal. This feature relates mainly to the inter basin transfer of water from Periyar river in NCZ to the Muvattupuzha river in SCZ, which directly results in lowering of the runoff coefficient for the NCZ and conversely, a higher value for SCZ.

The NCZ produces the maximum quantum of sediment load followed by NZ. This is due to the fact that two major rivers in terms of catchment area and discharge (Bharathapuzha and Periyar) are located within this zone. However, in the case of NZ, higher erodibility as represented by sediment yield (235 ton/km²) results in heavy suspended sediment transport. The role of high rainfall intensity in this zone may also be a contributing factor. Added to the above, the physiography of this region does not account for retention in the absence of a defined midland. Denudation rate of 0.168 mm/year in NZ denotes a process linked to the flattening of the Ghats of this zone at a faster pace which is comparable with high sediment yielding Himalayan rivers.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>North Zone (NZ)</th>
<th>North-Central Zone (NCZ)</th>
<th>South-Central Zone (SCZ)</th>
<th>South Zone (SZ)</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall (P mm)</td>
<td>3800</td>
<td>3100</td>
<td>3200</td>
<td>2600</td>
<td>Gradation from north to south direction</td>
</tr>
<tr>
<td>% P (SW)</td>
<td>80</td>
<td>78</td>
<td>62</td>
<td>54</td>
<td>Seasonal variation in north - south direction</td>
</tr>
<tr>
<td>% P (NE)</td>
<td>10</td>
<td>15</td>
<td>19</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>Discharge (Q mm)</td>
<td>2588</td>
<td>1235</td>
<td>2997</td>
<td>1400</td>
<td>The contrast between NCZ and SCZ is due to inter basin transfer</td>
</tr>
<tr>
<td>Runoff Coefficient (P/Q)</td>
<td>0.68</td>
<td>0.41</td>
<td>0.94</td>
<td>0.55</td>
<td></td>
</tr>
<tr>
<td>% Q (SW)</td>
<td>83</td>
<td>74</td>
<td>68</td>
<td>55</td>
<td>Similar to the % P variations</td>
</tr>
<tr>
<td>% Q (NE)</td>
<td>14</td>
<td>20</td>
<td>22</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>Sediment Load (S ton)</td>
<td>8,93,692</td>
<td>9,26,391</td>
<td>4,65,571</td>
<td>2,50,196</td>
<td>Values related to size of the catchment for NCZ and high erodibility for NZ</td>
</tr>
<tr>
<td>% S (SW)</td>
<td>90</td>
<td>82</td>
<td>68</td>
<td>45</td>
<td>Similar to the % P and % Q variations</td>
</tr>
<tr>
<td>% S (NE)</td>
<td>9</td>
<td>17</td>
<td>28</td>
<td>49</td>
<td>Maximum erodibility in NZ</td>
</tr>
<tr>
<td>Sediment Yield (ton/km²)</td>
<td>235</td>
<td>75</td>
<td>90</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>Average S/Q</td>
<td>7.8</td>
<td>4.9</td>
<td>2.9</td>
<td>6.5</td>
<td>SCZ is geologically more stabilized</td>
</tr>
<tr>
<td>Slope</td>
<td>0.013</td>
<td>0.011</td>
<td>0.012</td>
<td>0.014</td>
<td>Refers to river longitudinal slope</td>
</tr>
<tr>
<td>Fine particles (%)</td>
<td>65 - 75</td>
<td>80 - 95</td>
<td>75 - 85</td>
<td>85 - 90</td>
<td>NZ texture reflects on comparatively coarser particles</td>
</tr>
<tr>
<td>Rating 'a'</td>
<td>0.35</td>
<td>0.16</td>
<td>0.08</td>
<td>0.25</td>
<td>Large 'a' denotes erodibility; large 'b' refers to erosive power of river</td>
</tr>
<tr>
<td>Parameters</td>
<td>1.31</td>
<td>1.34</td>
<td>1.39</td>
<td>1.38</td>
<td></td>
</tr>
<tr>
<td>Denudation Rate (mm/year)</td>
<td>0.168</td>
<td>0.054</td>
<td>0.065</td>
<td>0.079</td>
<td>High value in NZ reflects active terrain processes</td>
</tr>
</tbody>
</table>
Another feature relates to the higher input of sediment load during NE monsoon for the southern rivers, which conflict with the contribution of rainfall and subsequent runoff. The above fact is related to the occurrence of peak sediment load during the month of October (falling within NE monsoon) contrary to the peak discharge recorded during the month of July (falling within SW monsoon). This may be due to the availability of sediment material from distant source(s) or from flood plains or possibilities associated with soil creep.

The central (both NCZ and SCZ) zones feature broad land cross sections, more stable topography and geology, regulated rivers having a long course with flood plains and larger extent of forest cover in the catchment areas. Therefore the yields are less or moderate for these zones compared to the two extreme segments of the State.

Most of the rivers from north and south zones are showing a reducing trend in sediment transport for corresponding increase in discharge over the study period. These rivers are non-regulated compared to the major rivers in the central zones. This trend has to be treated as a matter of concern (for the coastal zone) and strict measures have to be considered to regulate sand mining, which may be a major reason for the above trend. The decreasing yields may reflect a gradual slowing process in fluvial dynamics or does this qualify as part of geo-morphological ageing process? Often, the fluvial system may try to balance this condition by fulfilling its carrying capacity by bank or bed erosion, which could be again detrimental to the ongoing surface process.

It is observed that year-to-year variation in discharge is marginal whereas the corresponding change in sediment load is substantial. Smaller rivers draining north zone and south zone transport at a high rate due to reasons explained in the above sections: this has also been reflected while analyzing the rating curve parameters. Slight changes in any of the influencing parameters will bring about drastic changes in the sediment transport regime of these regions. This signifies the importance of studies in sediment dynamics for the tropical rivers.
Unit sediment graphs, representing a particular watershed, can be computed at certain intervals of time (as illustrated herein) or at instances when changes in sediment transport regime are expected. These changes, due to the alterations in the natural equilibrium of the watershed, can be identified by the modification in peak and spread of the subsequent USGs developed. This approach will then serve as a tool for studies in catchment area management.

It is imperative that taking cognizance of the knowledge of new trends which have been studied and reported herein, more and more rivers be brought under monitoring programs and gauged for both river water and particulate load estimates as these have proved beyond doubt in enhancing our understanding of the vital links pertaining to the land – water surface processes, which impact the eco-system.

The state of Kerala is not only blessed with rains and plenty of runoff but also adequate, purposeful quantum of sediments, which in other quantifiable terms measures to sizable quantities of nutrient load; these, when transported downstream, favour sustainable coastal ecosystems which are complex but highly diversified for this part of the globe. Any active surface process will lead to upset the balance and needs continuous monitoring and corrections, in case of deviations; such an approach is warranted under these circumstances when disparities are abound within the short stretch of this State.