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GRAIN SIZE DISTRIBUTION AND NUMERICAL SIMULATION OF SEDIMENT SYSTEMS IN CAUVERY DELTA BASIN, TAMILNADU, INDIA

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Abstract: A stream is a dynamic system. Streams flow over loose erodible sediments and they carry, scour and deposit these sediments in the deltaic plain. As a result, meander, braid and branch out. Contributing to these stream characteristics are hydraulic and environmental factors. The time period could range from million of years to centuries to decades. Streams alter the landscape of the earth's surface, i.e. changes in morphology which has a direct impact on earth's landscape. The present model aims at the simulation of stream morphodynamics as a function of water discharge and sediment supply. The model is implemented as a system subdivided into three main modules: channel morphology, water flow and sediment transport. A negative feedback between the sediment transport and channel morphology causes the system to be inherently stable and a dynamic equilibrium could be reached. The objective of this work is to study the fluvial systems respond to environmental change and develop the response of numerical simulation on grain size distribution in the Cauvery deltaic basin.
Keywords: Stream, Sediment, Grain size, Numerical Modeling, Cauvery Delta Basin.

1. Introduction

During the last decades, substantial progress has been made on understanding of the evolution of large stream systems during the Quaternary, especially as a function of the major climatic changes. [Huisink 1997, 1998; Kasse et al. 1995; Tornqvist 1998; Vandenberghe 1995; Vandenberghe et al. 1993 and Tebbens 1999]. Despite these research efforts, little is known about this evolution from a process based- viewpoint at Cauvery delta. This is due to a number of reasons: i) the inherent complexity of the fluvial system. ii) the failure to date fluvial sediments accurately enough to link them with palaeoenvironmental change on the scale of hundreds of years, and iii) the emphasis on reconstruction of the palaeoenvironment based on geomorphology (terrace mapping), sedimentology (facies reconstruction), and palaeoecology (vegetation reconstruction), where geomorphologic processes could be inferred from the traces left in the landscape.

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A stream is a dynamic system. Streams flow over loose erodible sediments and they carry, scour and deposit these sediments in the deltaic plain. As a result, meander, braid and branch out. Contributing to these stream characteristics are hydraulic and environmental factors. The time period could range from million of years to centuries to decades. Streams alter the landscape of the earth's surface, i.e changes in morphology which has a direct impact on earth's landscape. Sediment transport deals with both flow of water and sediment particles. Therefore, properties and theories of both water flow and sediment transport should be studied. In a water body sediments are transported as suspended and bed load, depending upon the sediment particle size, as shown in **figure.1.**

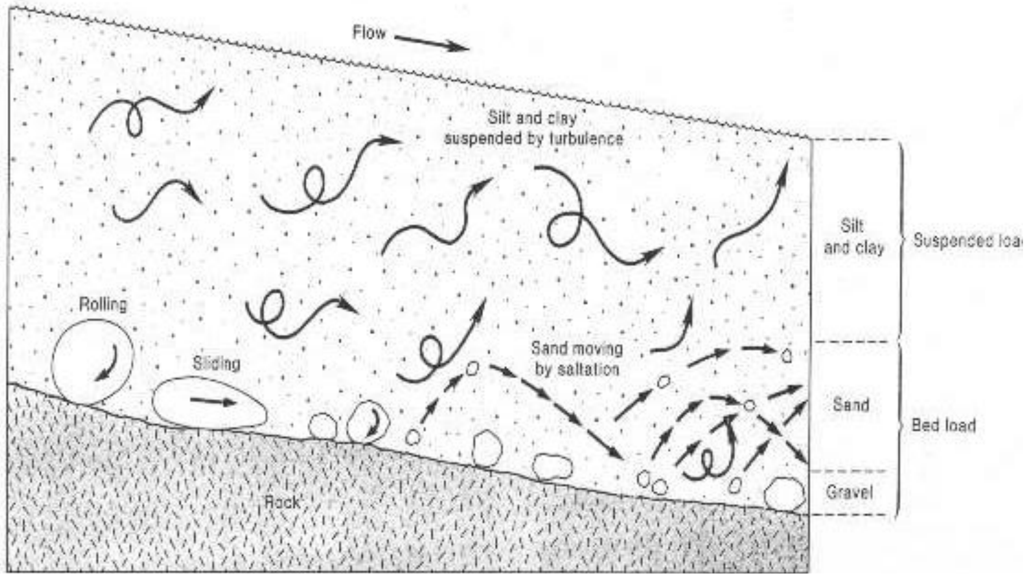

Figure 1. Sediment transport in the flow of water in Stream bed

Sediment transport involves complex interaction between numerous interrelated variables. Theoretical approaches in the study of sediment transport are based on simplified and idealized assumptions. Empirical methods emphasize only certain parameters which are considered to be more relevant by the researchers. Therefore, the applicability of an equation to estimate the transport rates under field conditions relies not only the theoretical formulations, but also on the data used in its development and calibration. For the purpose of developing estimates from a transport formula, the large variability, combined with the steep nonlinear relations governing transport, make predictions based on spatial and temporal data. The second constraint sparse information is directly related to the first. If there were little variability in the transport, only a few observations would provide a representative sample. Sparse information strongly affects our ability to estimate transport from a formula. Models those are sensitive to local details of flow and bed material (e.g. mixed-size transport models using many size fractions). It requires abundant local information for accurate predictions. This information is seldom available for an existing channel, and can be specified for a design reach only at the time of construction. Transport and sediment supply in the subsequent transport events will alter the composition and topography of the stream bed. Transport estimates are typically developed either from formula or from empirical relations from field observations. Some of the primary concerns with each approach are discussed in order to develop the basis for a third, hybrid approach that offers a favorable combination of accuracy and cost. The objective of this work is to study the fluvial systems respond to environmental change and develop the numerical simulation on grain size and heavy mineral distribution in the Cauvery deltaic basin.

1.1 Back ground

The present model aims at the simulation of stream morphodynamics as a function of water discharge and sediment supply. The model is implemented as a system subdivided into three main modules: channel morphology, water flow and sediment transport. A negative feedback between the sediment transport and channel morphology causes the system to be inherently stable and a dynamic equilibrium could be reached. The interplay between the system's relaxation time and the frequency of external events will determine if this equilibrium will be reached eventually. For example, if climate changes faster than the time span needed for adaptation by the stream system, equilibrium will not be reached. If changes occur less frequently, equilibrium will be reached, although for a limited duration [*Bull*, 1991]. The status of the fluvial system's components as either 'dependent' or 'independent' of other components in the stream morphology [*Lane and Richards*, 1997; *Schumm and Lichty*, 1965]. For instance on short time scales, channel slope is independent on sediment transport, but on (much) larger time scales it is dependent, because channel slope slowly adjusts to the prevailing sediment transport regime by means of incision/aggradations and/or sinuosity adjustment in the stream flow direction.

2.0. Study area

Cauvery lies in the eastern part of Tamil Nadu between 10.00°-11.30°, North latitude and between 78.15° – 79.45° longitude. It is bounded by the Bay of Bengal on the East and the Palk straight on the South, Trichy district on the west, Perambalur, Ariyalur districts on the north west, Cuddalore district on the North and Puddukkottai district on the South West. The Cauvery rises at Thalacauvery on the Bramagiri Hills of Western Ghats in the state of

Karnataka and runs through Tamil Nadu, before joining the Bay of Bengal. The total catchment area of the Cauvery is about 81155 km^2, of which 34273km^2 lies in the State of Karnataka, 2866 km^2 in the State of Kerala and 44016 km^2 in the State of Tamil Nadu. The upper part of the Cauvery basin receives rainfall during the Southwest Monsoon (June to September) season and the lower part, lying in Tamil Nadu, during the Northeast Monsoon (October to December) season. The flow of freshwater in the Cauvery reaches a peak during the Southwest monsoon season when the rainfall is high.

It also spelled Cauvery in English, is one of the major Rivers of India, which is considered sacred by Hindus. The River originates at Tala Cauvery in the Western Ghats in the state of Karnataka, flows generally south and east through Karnataka and Tamil Nadu and across the southern Deccan plateau through the southeastern lowlands, emptying into the Bay of Bengal through two principal mouths **(fig.2a).** After the river leaves the Kodagu hills and flows onto the Deccan plateau, it forms two islands, Srirangapatna and Shivanasamudra. It also drops into the Hogenakal Falls just before it arrives in the towns of Hogenakal in the state of Karnataka and Srirangam in Tamil Nadu shown in the **figure. 2b.**

After entering Tamil Nadu, the Cauvery flows into Stanley Reservoir, and exits the reservoir at Mettur Dam. The Cauvery forms the boundary between the Erode District and the Salem district. The Bhavani River joins the Cauvery at the town of Bhavani, where the Sangameshwara Temple, an important pilgrimage spot in southern India, was built at the confluence of the two rivers. The Amaravati River joins the Cauvery at a place called Tirumukkudalur near Karur.

Sweeping past the historic rock of Tiruchirapalli, it breaks into two channels (at the island of Srirangam), which enclose between them the delta of Thanjavur (Tanjore), considered both the "rice bowl" and garden spot of southern India. The northern channel is called the Kollidam (Coleroon). The other channel keeps the name of Cauvery and empties into the Bay of Bengal at Poompuhar, a few hundred miles south of Chennai or Madras. On the seaward face of its delta are the seaports of Nagapattinam and Karaikal. The chief 19th century work is the anicut across the Kollidam which is 2250 ft. long, and was constructed by Sir Arthur Cotton between 1836 and 1838. Along this study area the Appanallur, Pappapatty, Sittilarai and Anjalam are selected for grain size distribution and numerical simulation studies.

2.1 Geology of the Study area

The Cauvery drainage system in the upper reaches flows through the Archean granitoid gneisses (amphibolite-facies) and intrusives, Closepet granite, Precambrian granulites (ranging in composition from granite to gabbro) and supracrustal belts. The supracrustal belts belonging to the Sargur group occur in southern Dharwar craton, in which marble bands of a few hundred metres long and few metres wide have been reported. The Dharwar group of supracrustal rocks consists of predominantly theolitic metavolcanics,felsic volcanics, clastic and chemical sediments. The Bhavani, a major tributary of the Cauvery passes through granulites of the Nilgiri range, which include garnetiferous enderbites and basic granulites (gabbroic-to-anorthositic in composition). Two pyroxene granulites and pyroxinites occur as extended bodies, lenses and pods with increasing abundance towards north in the Nilgiri range. Rocks in the middle reaches of the Cauvery River are predominantly granulitic gneisses. Cretaceous sediments are exposed north of Tiruchirapalli, where the Cauvery starts forming a delta (**Figure 2a**). These sediments consist of conglomeratic sandstone, fossiliferous limestone and shale. The delta and mouth of the river consist of recent alluvium deposits.

3.0 Materials and Methods

This function of water discharge and sediment supply is implemented as a system subdivided into three main modules: Channel morphology, water flow and sediment transport. The cyclic interdependence of these modules as depicted in **figure.3**, reflect the mutual dependency of form and process within the fluvial system. A negative feedback between the sediment transport and channel morphology causes the system to be inherently stable and a dynamic equilibrium could be reached. The interplay between the system’s relaxation time and the frequency of external events will determine if this equilibrium will be reached eventually. For example, if climate changes faster than the time span needed for adaptation by the stream system, equilibrium will not be reached. If changes occur less frequently, equilibrium will be reached, although for a limited duration [Bull, 1991]. The status of the fluvial system’s components as either ‘dependent’ or ’independent’ of other components is a matter of scale [Lane and Richards, 1997; Schumm and Lichty, 1965]. For instance, on short time scales, channel slope is independent on sediment transport, but on (much) larger time scales it is dependent, because channel slope slowly adjusts to the prevailing sediment transport regime by means of incision /aggradations and/or sinuosity adjustment. Within the context of this study, we regard all the system’s components as dependent on each other. In the next sections, the model’s main modules will be presented with respect to their Physics and Numerical modeling.

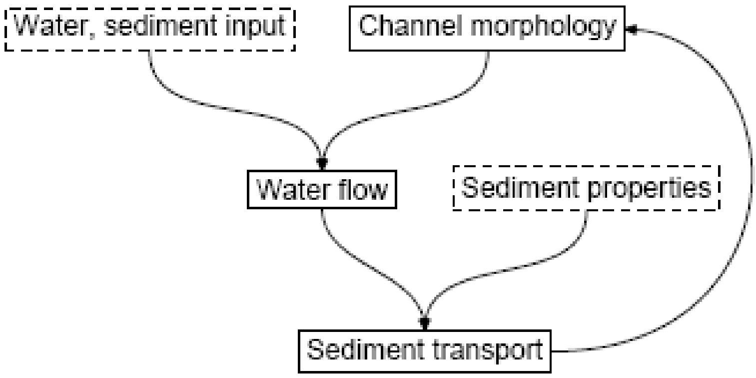

Figure 3. Indicating numerical modeling together with their interaction.

4.0 Grain-Size Distribution

4.1 Transport and morphological modeling for mixtures of various grain-sizes

Grain size analysis is the epicenter of any sedimentological research. Distributions of sediments provide voluminous information about the fundamental property and the depositional environment of the sediments. Since the early nineteenth century, pioneering research have been attempted to make use of grain size characteristics of sands. Various researchers attempted to discriminate the environments like stream, beach and dune using textural parameters (Table.1 to 4). Yet another group of researchers have tried to differentiate beach sand from dune sand and beach sand from stream sand using textural characteristics. **Figure.4** shows the grain-size distribution and the cumulative weight percentage of the sands together with the data for the 50-50% mixture. The figure.4 confirms the small overlap in grain size of the two initial fractions and shows the somewhat shouldered distribution of the mixture.

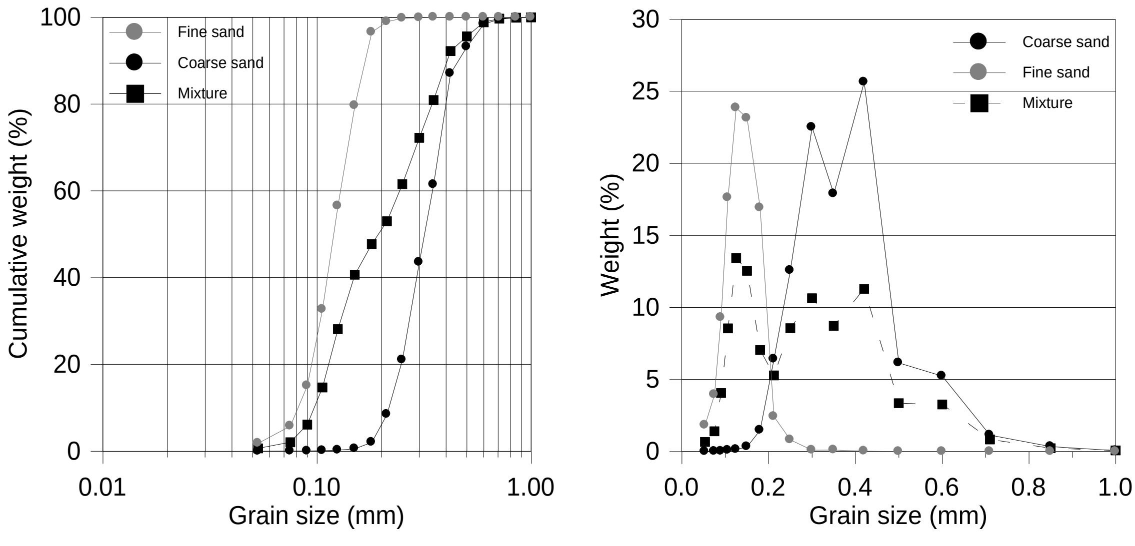

Figure 4. Grain-size distribution and cumulative weight percentage for fine and coarse quartz sand and their 50-50% mixture used in the size-gradation experiments.

The next important aspect in situations with graded sediment is the description of the sediment exchange between stream and bottom. The stream is schematised by one ”mixing layer” in the bottom and one “transport layer” in the stream (two-layer model). The two layers interact through the sediment continuity equation and the bed material composition is computed. The consideration of the suspended sediment vertical requires in principle a third layer so that the sediments are free to deviate from local equilibrium and their vertical distribution depends on the upstream conditions (three-layer model). Moreover, the mixing or exchange layer in the bottom can be divided in two parts: a pavement and a sub pavement (four-layer model). The above work on graded sediment transport is mainly applied to sediment transport and morphological development in the present streams. Applications to a coastal environment are still limited. The present experiments provide the opportunity to test the validity of the size-fraction method and to investigate the influence of the type of uniform transport formula in applying the size-fraction method **figure 4a**.

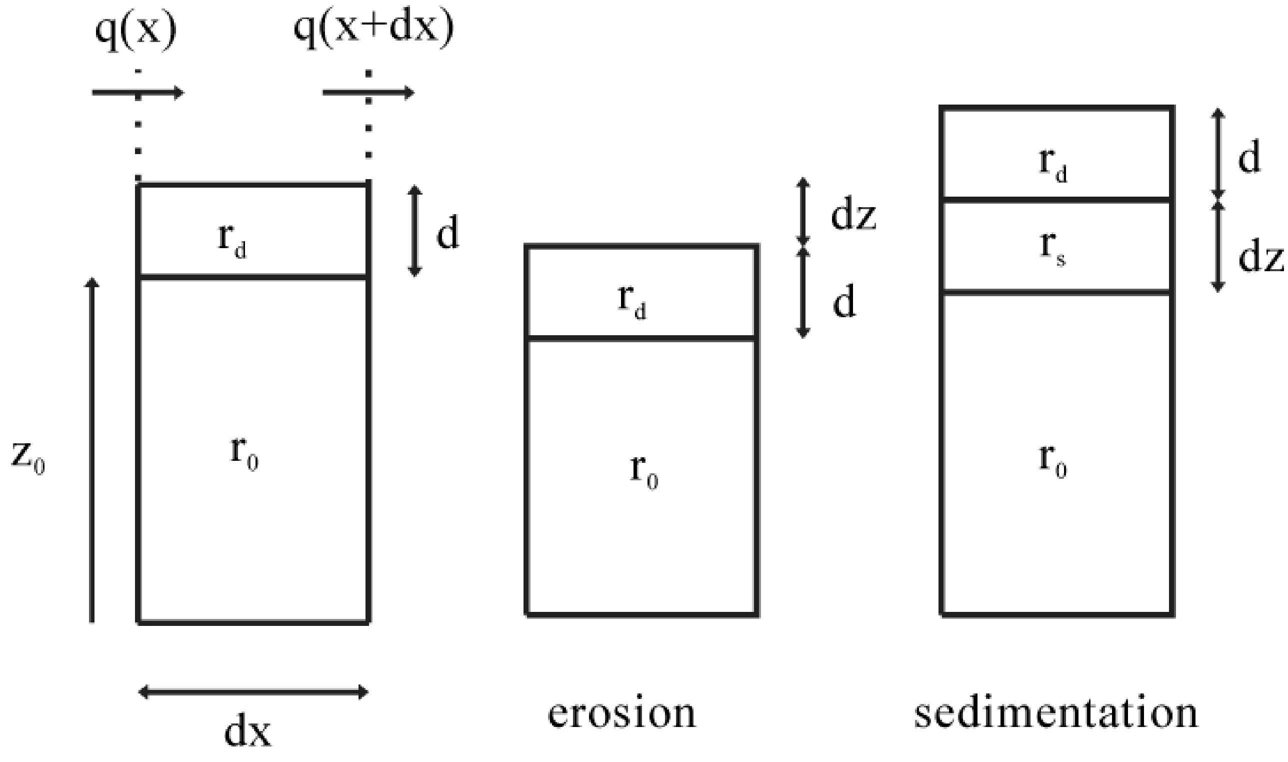

Fig. 4a. A section in the tunnel with sediment flow q(x). The sediment bed consists of a passive layer with density ρ_0, and an active layer with constant thickness d and density ρ_1. If the gradient of q(x) is positive erosion occurs and the thickness of the passive layer decreases by dz. If the gradient of q(x) is negative sedimentation occurs and the thickness of the passive layer increases by dz, but with density ρ_2.

4.2 Sediment Transport

Sediment is transported in water bodies as suspended load and bed load. Bed load is defined as the sediment load which moves along the bed. Suspended load is defined as the sediment load which moves in suspension and occupies the entire flow depth above the bed load layer. According to the sediment particle contribution to bed evolution, the total sediment transport can be divided in to bed material load or wash load. Wash load is the part of sediment load which washes through the channel. It consists of very fine silt and clay and they do not play a significant role in evolution of bed and because of that the percentage of these size particles in bed is relatively less. The grain size distributions along the study area are tabulated in **tables 1 to 4** and **figures.4b to 4e**.

Bed load is also part of the sediment load that is mainly responsible for bed evolution. Bed material mainly consists of these sediment particles. **Figure.5** shows a schematic diagram of total sediment load in the river bed. In this figure it is assumed that both wash load and bed material consist of suspended load and bed load. Different mode of sediment transport load as bed material load is most important in bed evolution; the bed material load transport 12 is simulated in the model. The bed load and suspended load of bed material load are simulated separately to take account of their individual properties. In the model, when mode of transport for a particular sediment size fraction is defined as a choice, it means that the user has to define the mode of transport to explain the nature of heavy mineral placer accumulation in the concentration as well as the gradation and slope changes. In this thesis sediment transport is preliminarily evaluated. It requires increment investigations in the field and flume.

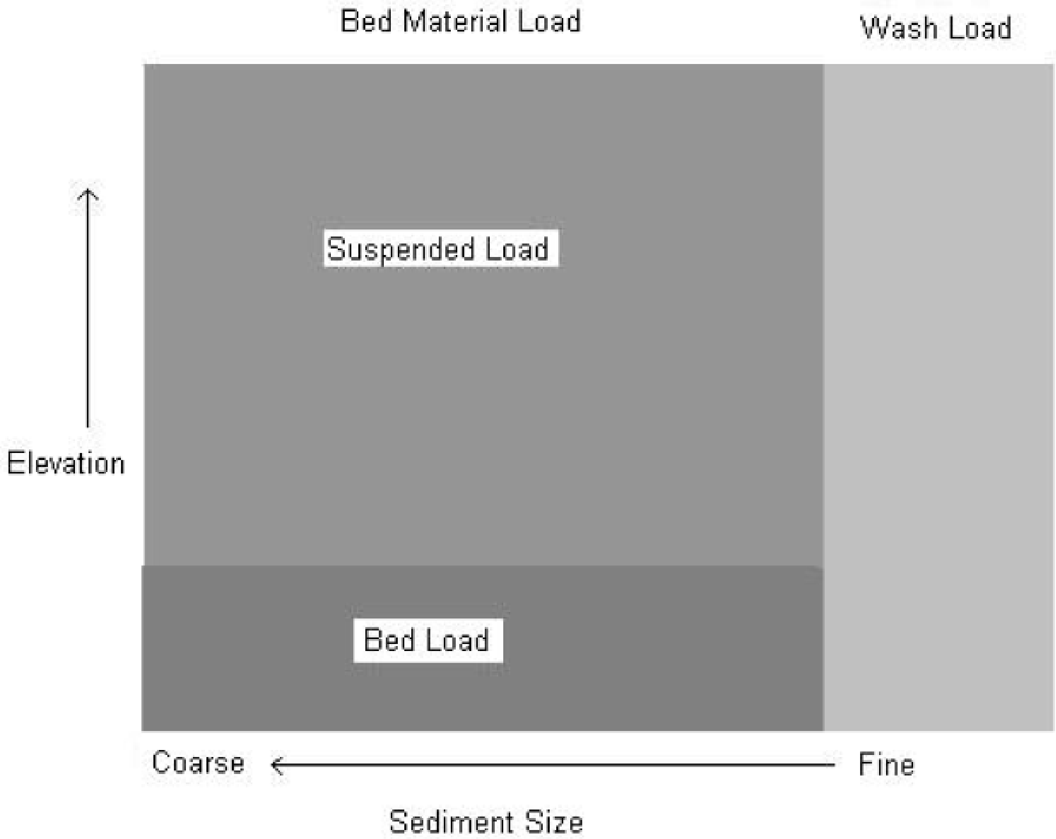

Figure 5: Sediment size distribution in the stream bed

5.0 Conclusions

A numerical model presented here is very simplified. It is based on a process-based paradigm. The model is very effective for Quaternary time scales of 0.1–100 kyr. The results of the first experiment with this model show that phases of incision and aggradations could be explained by changes in sediment supply or discharge, which are not necessarily coupled. It also shows that, there is a correlation between incision/aggradations and channel pattern. We could conclude directly that channel pattern is mainly controlled by incision/aggradations. Instead, it is also proposed that both incision/aggradations and channel pattern are a function of the ratio between sediment supply and bankfull discharge.

The results of the second experiment show that the time lag between changes in stream discharge and sediment supply determine the stream response to these changes. However field evidence is required to test this model. These results will have major implications for the reconstruction of climate events based on documented stream response in the geological record. They show that incision/aggradations is not necessarily climate induced to changes in water and sediment supply as such, but more precisely to the phase-lags between them. Therefore, one cannot use observed phases of incision and aggradations to infer changes in sediment supply, without considering the discharges as well, because the effect of discharge changes is unknown. However, the link between reconstructed incision/aggradations events and palaeo-hydrology can still be made by taking palaeo channel width into account. Since channel width is determined by (bank full) discharge directly, it can be used as a proxy for the latter. In a hypothetical situation where no net aggradations or incision occurred over (a series of) known climate transitions, while changes in channel width and discharge, did occur. The conclusion must be that sediment supply is changed with discharge.

The result of the third experiment show that a gradual downstream, temporarily varying increase in discharge can result in a complex response of channel pattern, which varies for different sub-reaches of the stream. The implication of this result is that stream pattern is not only dynamic in time but also in space, due to downstream variations in the controlling factors [Tebbens, 1999]. It is part of the canonical fluvial geomorphologic knowledge that streams tend to braid in their upper reaches, and meander in their lower reaches (and even change to anatomizing in their deltas). There-fore, the modelling results do not extend current knowledge *per se*, but they do provide a quantitative explanation for field-derived knowledge, and are a tool to asses the relative importance of the different driving forces behind stream response to environmental change. This experiment is very useful to quantify the fluvial sand quarrying and its impact on bed movement. It is further shown that this model is also capable of simulating climate transitions, both for conceptual and actual streams. Although validation against reconstructed climate data and fluvial evolution remains necessary, the preliminary model applications reported here already show agreement with these reconstructions in both a qualitative and quantitative way.

The model presented here can easily be criticized on the underlying assumptions and choices, as it has assumptions that are false and that are known to be false [Beven, 1997]. However, this should not hamper application of the model to real-world problems, provided the model is not used as a prediction tool, but as a conceptual/theoretical connection between input data and stream response. More often, one might see that the model does not predict very well the actual quantitative morph-response for a given time series of input.

6.0 Recommendation

The following studies have to be attempted to validate the model for sediment concentration particularly heavy mineral accumulation in a particular fluvial forms.

i. The grain size, sediment transport, fluvial hydraulic, etc are to be correlated with reference to fluvial morphology and discharge of sediment water.

ii. The simulated model has to be verified with reference to different heavy minerals concentration in the river bed.

iii. Density of drainage morphology and its grain size, heavy mineral content, shape of the land forms, etc have to be taken to quantify the climate change and weathering of drainage rocks.

iv. Detailed study on heavy mineral concentration in braided, meander, point bar, etc are to be studied systematically.

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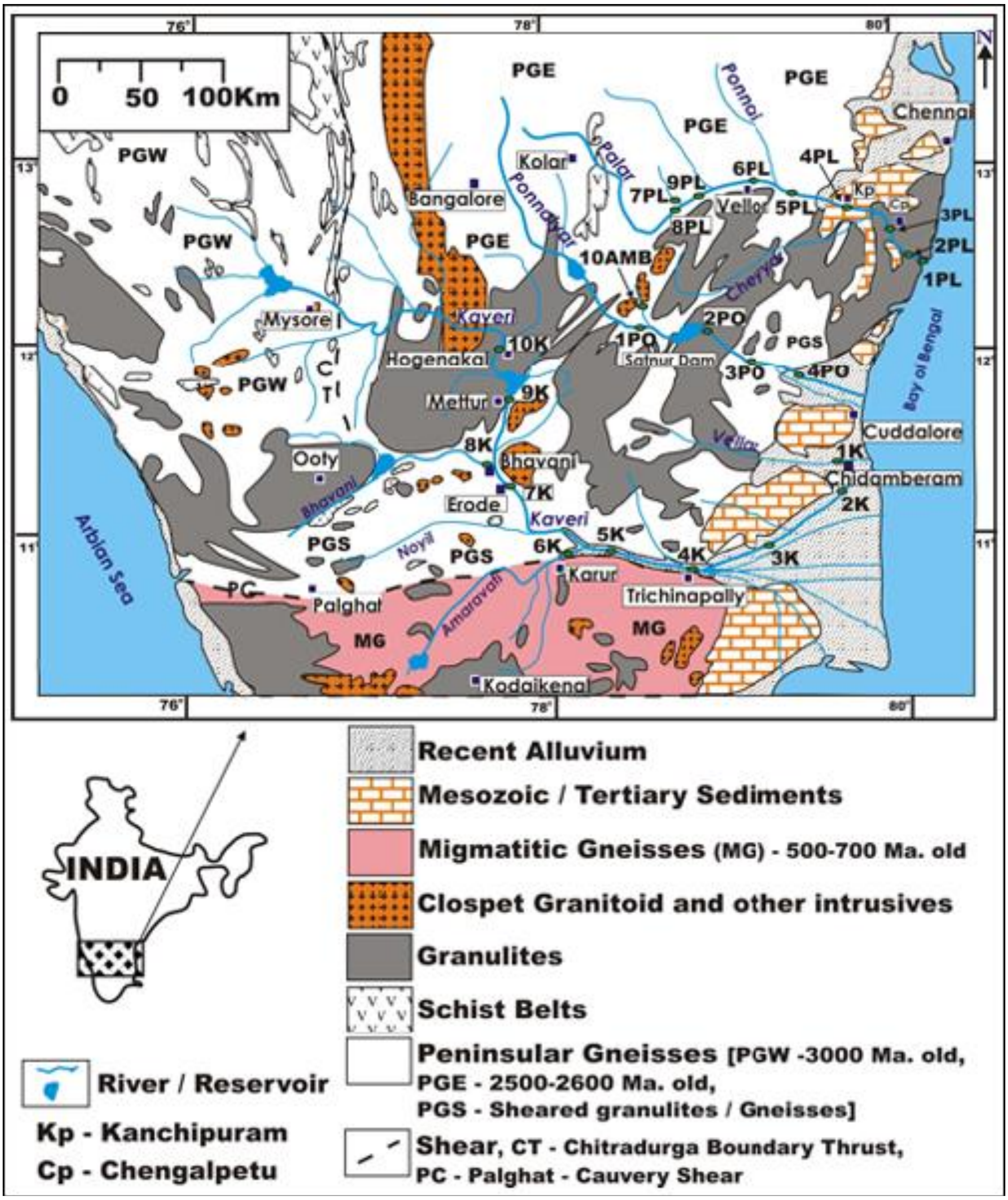

Figure 2a: Study area and geology map of Cauvery River

Figure 2b Cauvery after Hogenakal Falls

AREA	Appanallur														
MESH	10	12	14	16	18	20	25	30	35	40	45	50	60	70	80	PAN
WT 200 gm	12	8.6	3.1	9.3	7.1	20.5	14.4	6.1	32.2	16.5	19.9	15.6	17.2	0.2	8.6	8.2
WT %	6	4.3	1.55	4.65	3.55	10.25	7.2	3.05	16.1	8.25	9.95	7.8	8.6	0.1	4.3	4.1
CUM %	6	10.3	11.85	16.5	20.05	30.3	37.5	40.55	56.65	64.9	74.85	82.65	91.25	91.35	95.65	99.75

Table 1: Grain size distribution in Appanallur

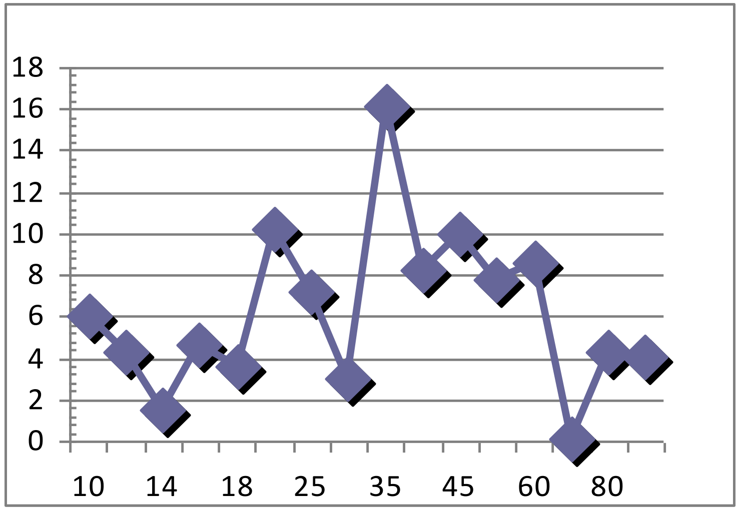

Figure.4b. Grain size distribution curve in Appanallur

AREA	PAPPAPATTY														
MESH	10	12	14	16	18	20	25	30	35	40	45	50	60	70	80	PAN
WT 200 gm		18.5	13.8	5.2	12.9	8.3	23.6	17.9	6	36.1	13.6	15.7	10.4	9.6	0.3	4.3
WT %	9.25	6.9	2.6	6.45	4.15	11.8	8.95	3	18.05	6.8	7.85	5.2	4.8	0.15	2.15	1.65
CUM %	9.25	16.15	18.75	25.2	29.35	41.15	50.1	53.1	71.15	77.95	85.8	91	95.8	95.95	98.1	99.75

Table.2 Grain size distribution in Pappapatty

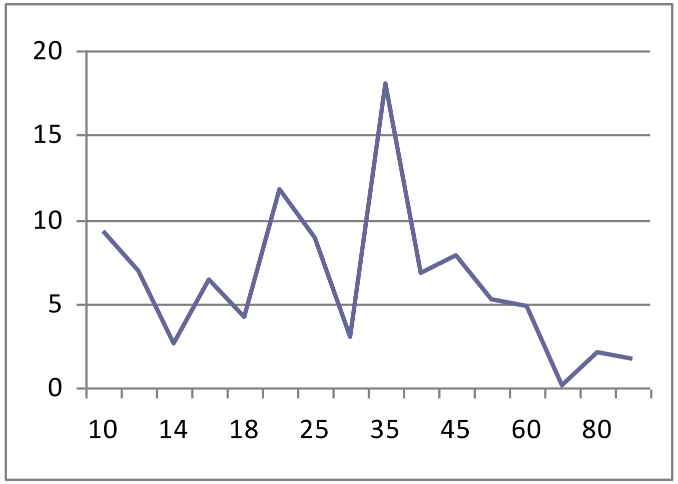

Figure.4c. Grain size distribution curve in Pappapatty

AREA	SITTILARAI															
MESH	10	12	14	16	18	20	25	30	35	40	45	50	60	70	80	PAN
WT 200 gm	24.9	12.8	4.1	9.7	6.5	15	10.8	4.5	27	13	19.9	16.8	18.2	0.2	9.3	7.2
WT %	12.45	6.4	2.05	4.85	3.25	7.5	5.4	2.25	13.5	6.5	9.95	8.4	9.1	0.1	4.65	3.6
CUM %	12.45	18.85	20.9	25.75	29	36.5	41.9	44.15	57.65	64.15	74.1	82.5	91.6	91.7	96.35	99.95

Table. 3 Grain size distributions in Sittilarai

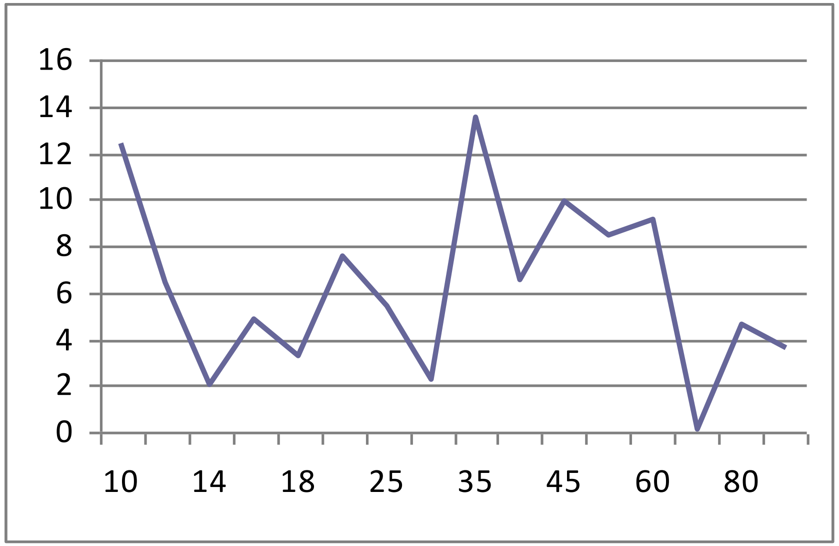

Figure.4d. Grain size distribution curve in Sittilarai

MESH	WT 200 gm	WT %	CUM %
10	3.4	1.7	1.7
12	4.7	2.35	4.05
14	2	1	5.05
16	6.1	3.05	8.1
18	4.9	2.45	10.55
20	14.5	7.25	17.8
25	13.1	6.55	24.35
30	6	3	27.35
35	38.2	19.1	46.45
40	22.4	11.2	57.65
45	25.6	12.8	70.45
50	24.4	12.2	82.65
60	19.9	9.95	92.6
70	0.4	0.2	92.8
80	8	4	96.8
PAN	5.8	2.9	99.6

Table 4: Grain size distributions in Anjalam

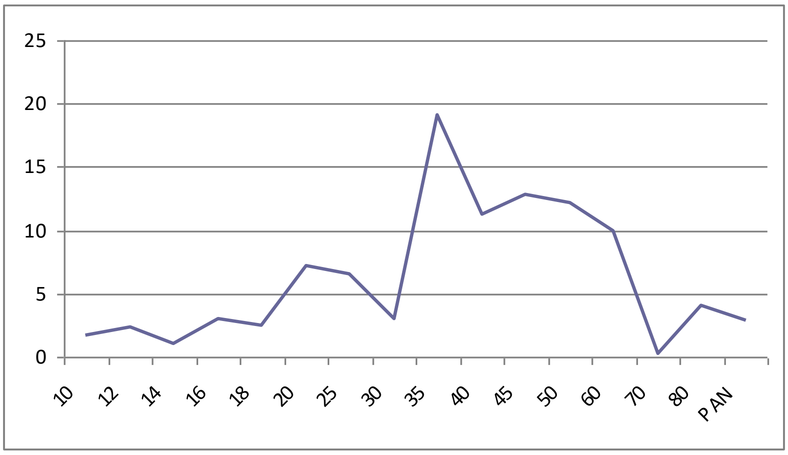

Figure 4e. Grain size distribution curve in Anjalam