Developments in a Methodology of Classifying Sediments in Himalayan Rivers

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Abstract

The sediment loads of Himalayan rivers are amongst the highest in the world, resulting in problems such as the siltation of reservoirs, blockage of river channels, quality of water supplies, transport of chemical pollutants, and the degrading of biological habitats. The major sources of sediment are considered to be glacial debris, landslides, and intensively cultivated hill slopes, but little is known about the characteristics of the sediments from these sources, the movements into the river system, or the transport down the rivers. The aim of the project is to develop a methodology of classifying sediments in the Himalayan rivers, including the full range of sources and methods of transportation, and thus to provide an essential information source for a future project which will aim to quantify the sediment loads of the rivers. Standardised methods of surveying sediments from first-order rivers to the piedmont zone are being developed by field sampling and statistical analysis. In addition, a GIS framework is being developed from two of the study river basins, the Upper Ganges, in north-eastern India, and the Trisuli, in Central Nepal. The establishment of this framework will be fundamental in the quantification of both sediment supply from the major sources and the transportable load within the river channel.

Introduction

The sediment loads of Asian rivers are reported to be the highest in the world, delivering an estimated 80 per cent of the total sediment input to the oceans (Holeman 1968). These large sediment loads are due to the exposure of the geologically young rocks forming the Himalayan mountain chain, which has the world's greatest range of relief and extremes of climate. This results in high erosion rates, estimated to be 1.7mm yr^{-1} for the Central Himalayas (Valdiya and Bartarya 1989) and rapid rates of transport down the rivers. The loads are sometimes said to be the most significant water quality problem in this region of Asia. Problems range from the rapid infilling of reservoirs, reduced quality of potable water, siltation of river channels, transport of chemical pollutants, and the loss of aquatic habitats.

Some data on sediment yields from Himalayan rivers exist, but they are extremely sparse considering the scale of the sediment problem. In addition, few details exist on the type of sediment in the system and the processes of release and transport down the river. For water resources' planning, the size and shape of the particles are important in determining the rate of down-river transport, the impact on the quality of potable water supplies, and the likely distribution of material deposited in reservoirs or in approaches to barrages and bridges. For the transport of chemical pollutants, the main problem is in the erosion of soil from agricultural areas where nutrient wash-out is a problem. As far as aquatic ecosystems are concerned, the sediments create many of the habitats for breeding and feeding, but changes in the sediment characteristics cause impacts such as the loss of habitat from increased mobility or the infilling of interstices by fine particles.

The description and quantification of sediment loads in Himalayan rivers presents a major challenge to the fluvial geomorphologist. Techniques exist for measuring erosion rates on plot scales and for measuring the accumulation of sediment in lakes or reservoirs, but there is no widely accepted method of quantifying the total sediment load being transported within a river system. A new method is currently being developed by the authors to quantify the sediment loads of Himalayan rivers using a classification of the sediments within the channel and relevant spatial data sets for whole river basins. This paper describes the recent developments in the methodology and shows how the new techniques could be applied in the future.

Fluvial Sediments in the Himalayas

The development of a methodology of surveying and quantifying fluvial sediments in the Himalayas relies on a clear understanding of the processes of erosion and transport which are present. The main sediment sources in the Himalayas are widely considered to be landslides (Carson 1985) and glacial debris (Hasnain and Chauhan 1993), but there are few data available on the relative contributions of sediment from either source. In terms of the impact on rivers, the important difference is that the glaciers are usually the source of the river, so the sediments are released directly into the river system, but landslides are often not connected to the river system and it may take centuries for the material to reach the rivers.

Landslides mostly occur during the monsoon months, June to September, and are triggered by high rainfall events of long duration, falling on steep slopes with high antecedent soil water contents (Froehlich and Starkel 1993). The physical properties of the material released are usually directly related to the type of landslide. Surface failures release soils and highly weathered material, while deep failures release soil, weathered material, and, additionally, considerable quantities of fresh, angular bedrock. Material which is discharged directly to the river system (coupled landslides) is transported rapidly down stream by the high energy rivers, assisted by the rapid rates of abrasion of the weathered material and rounding of the bedrock material. Where the released material does not immediately reach the water courses (non-coupled landslides), it is stored within the catchment, possibly to be worked by the river over subsequent decades.

The sediment loads in glaciated valleys are high due to the extensive deposits supplied by the retreating glaciers. The material released into the river system is highly mixed in size, and glacially fed rivers are often identifiable, even some way from the source, by the turbid waters which persist throughout the year. Hasnain and Chauhan (1993) carried out suspended sediment sampling in the Alaknanda and Bhagirathi river basins, in northern India, in June 1992 and found that the sediment loads from the glaciated valleys dominated the river basin. Tributaries with no glacial sources had suspended sediment concentrations of less than 10mg l^{-1}, but the concentration in the main river below a glacier was 2,163mg l^{-1}.

Significant amounts of coarse material, discharged from the glacier during catastrophic events, were reported to have gone into temporary storage within the river channel - to be remobilised by high flows in subsequent years.

The down-river transport of sediment is dependent on the characteristics of the supply catchments (geology, soils, topography, etc), the type of sediment being released, and the hydrology of the river. Few studies have been carried out in Himalayan rivers to classify and quantify these controls, which is essential information if planning of water resources and management of the rivers are to be attempted.

In terms of the development of a methodology for quantifying sediments, it is important to consider the amount of sediment released by each source, the connectivity of the sediment source to the river, whether there is a difference in the type of material released by different sources, and the competence of the river system to transport the sediment.

Measurement of Sediment Population Size and Shape

To quantify the sediment loads of Himalayan rivers, reliable methods of measurement and analysis are required, including an understanding of the sediment population size and shape. Describing sediment particles is not a new technique; a sampling method was proposed by Wolman (1954) which is still widely used, and several fluvial geomorphologists, including Richards (1982) and Church et al (1987), have suggested methods of analysing the data. A standardised technique for applying these methods to river channel deposition features and to the river basin scale is, however, a new venture.

To determine the shape and size of a particle, four measurements are required: long axis, intermediate axis, short axis, and the radius of curvature of the sharpest corner in the plane of the maximum projection. These measurements can then be used to derive standard statistics of mean intermediate axis, sorting, skewedness, kurtosis, sphericity, roundness, and flatness. Some questions which this project is addressing are how many particles must be measured to obtain a representative sample? where in a deposit they are taken from? and which deposits should be sampled?

The question of the number of samples to be taken is being answered by taking very large sample sets (up to 500 particles from a single deposit) and carrying out statistical tests to determine the minimum number which represent the true sample mean. This is done for all seven shape and size variables and, as an example of the results, Figure 1 shows data from a site in the Pindar River in north-western India where the mean intermediate axis size was recalculated by random selections of sub-samples out of the whole population to achieve a stepwise increase in population size from 1 to 500. In this case, a stable mean was established when the sample size reached 43 particles.

Spatial grading of the size and shape of particles can occur in bar-type features because of the action of flood waters and should be considered when selecting the

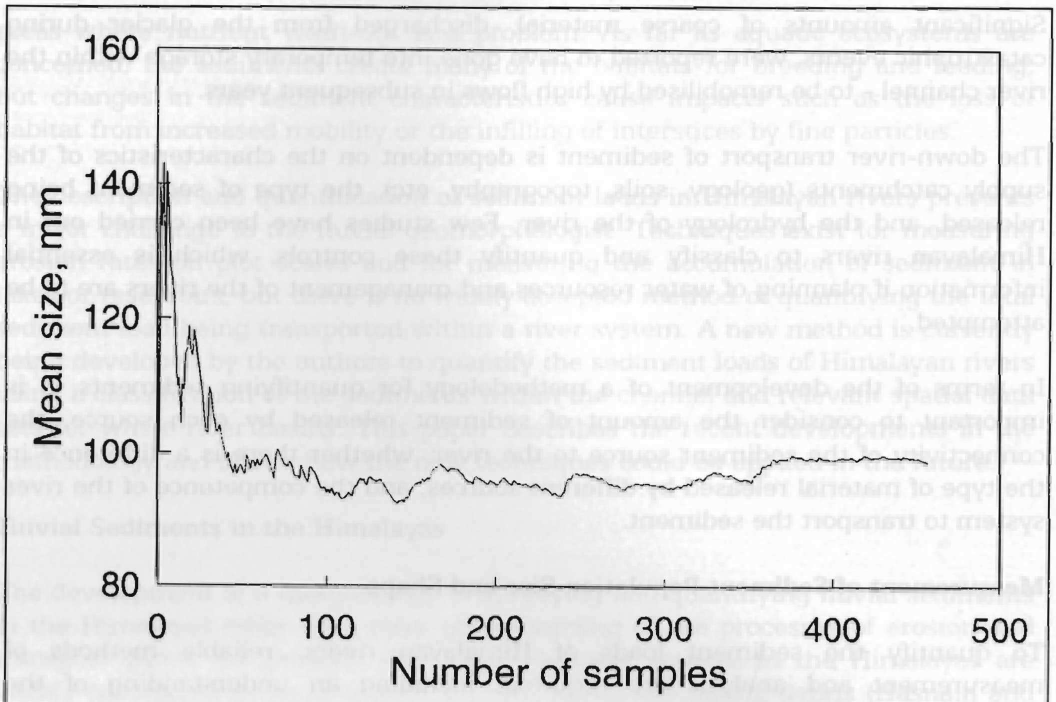

Figure 1: Mean Intermediate Axis Re-calculated Using an Increasing Number of Samples

particles for measurement. Using the same sample set from the Pindar River, the mean size of a series of sub-sets of 43 particles has been calculated from the upstream-to-downstream ends of the bar (Fig. 2). It can be seen that there is a clear gradation, with the particles becoming coarser in a down-river direction, which resulted in the calculated mean values ranging from some 50mm to 140mm compared to the 'true' mean obtained from the full sample size of 98mm. It is, therefore, advisable to select samples systematically from throughout the deposit to eliminate bias. A gridded method of selecting the 43 or more particles for sampling is now being tested, with each particle being selected by a random method within each grid square.

River Basin Strategic Surveys

In designing the strategy for carrying out the sediment surveys on a river basin scale, it has been essential to consider the practical constraints of collecting data in some of these remote areas. A prime example was found when trying to obtain samples from main river channels: many Himalayan rivers are so deeply incised that footpaths only infrequently reach the river. Because of this, a methodology has been developed that only uses tributary rivers, which are easier to reach. This part of the methodology addresses the question of how many tributaries to sample and whether they should be randomly or systematically selected.

The samples collected from the Upper Ganges, Karnali, and Trisuli basins have been analysed to obtain mean values of the seven shape and size statistics and related to land use (Fig. 3). A clear land-use separation can be seen in many of the

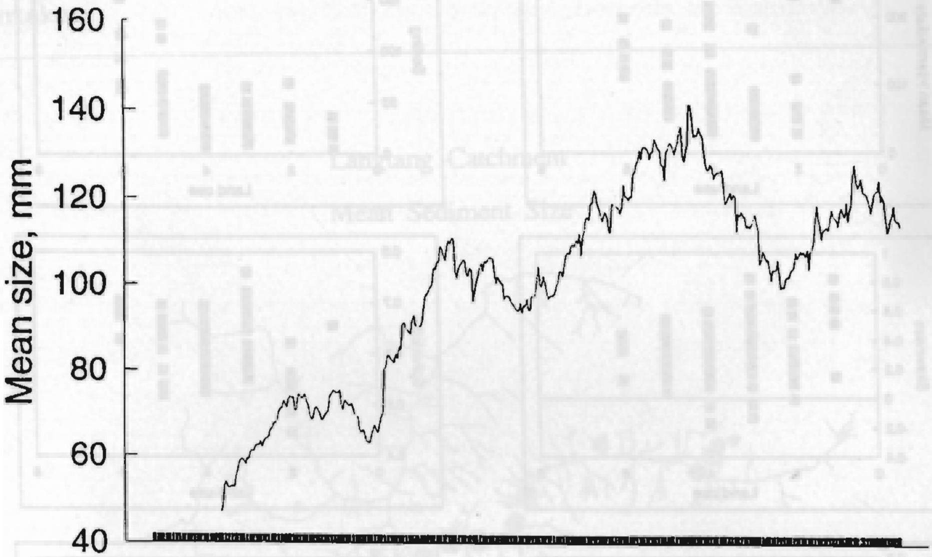

Figure 2: Grading of Mean Intermediate Axis Size over a Sediment Deposition Bar

statistics, although there are clearly other controls on the sediments. Future surveys will also concentrate on solid geology and catchment area as, together with land use, these are three catchment characteristics which are relatively easy to obtain.

This part of the work, therefore, suggests that there should be a systematic choice of tributaries to sample, determined by land use and possibly geology and area, but further work is still needed to determine how many tributaries in each catchment group should be sampled.

Quantification of Catchment Sediment Loads

A GIS framework using Arc/Info is being developed for two of the study catchments, the Upper Ganges in north-western India and the Langtang in Central Nepal. Comprehensive sets of attribute data, including land use, topography, geology, river network, and sediment characteristics, are being digitised to enable analysis of the sediment in a spatially distributed manner on a river basin scale. As examples, the distribution of mean sediment size and roundness in the Langtang catchment are shown in Figures 4 and 5 respectively. The establishment of this framework will be fundamental in the quantification of both sediment supply from the major sources and the transportable load within the river channel.

Previous erosion plot studies in the Nepal Middle Hills (Gardner and Jenkins 1995) have established empirical relationships between rainfall characteristics and runoff and sediment loss. Rainfall characteristics were described by the EI_{15} index, which

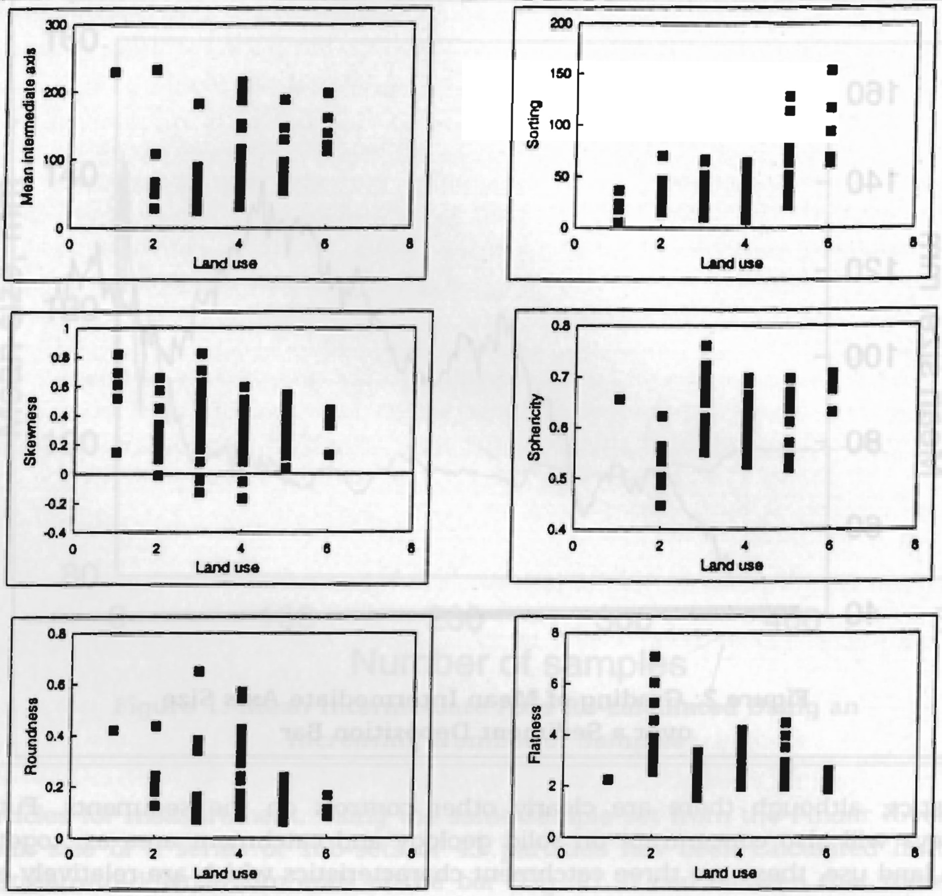

Figure 3: Relationships between Sediment Size and Shape and Land Use

incorporates both the kinetic energy of rainfall and the maximum 15-minute intensity. The relationships were derived through a wide range of storm events and for a number of differing land-use types: *khet* and *bari* terraces, forests of varying density, shrub, grass, and degraded land. These relationships have been applied to the Langtang catchment, which exhibits similar land-use types (Fig. 6), by incorporation into the GIS source code. This enables the quantification of hill slope sediment loss and runoff for a given storm event for each 25,000m^2 land-use grid cell (Fig. 7). *Bari* terraces located on steep slopes and areas of degraded forest are the land-use types most susceptible to sediment loss. Landslides and glaciers in the Langtang Valley, surveyed during December 1995, provide additional point sources of sediment.

Equations incorporating runoff volume and velocity, slope angle, and a land-cover roughness coefficient will be used to model the subsequent movement of runoff and sediment to the nearest river channel. Once the sediment is in the channel, modelling of its downstream movement may be achieved by a number of potentially appropriate transport equations applicable to both bedload and suspended material. These equations will incorporate the sediment characteristics identified by field surveys. Validation of the model performance in predicting the quantity and movement of the suspended load will occur during the monsoon season of 1997 when extensive sampling of rivers during storm events will be undertaken.

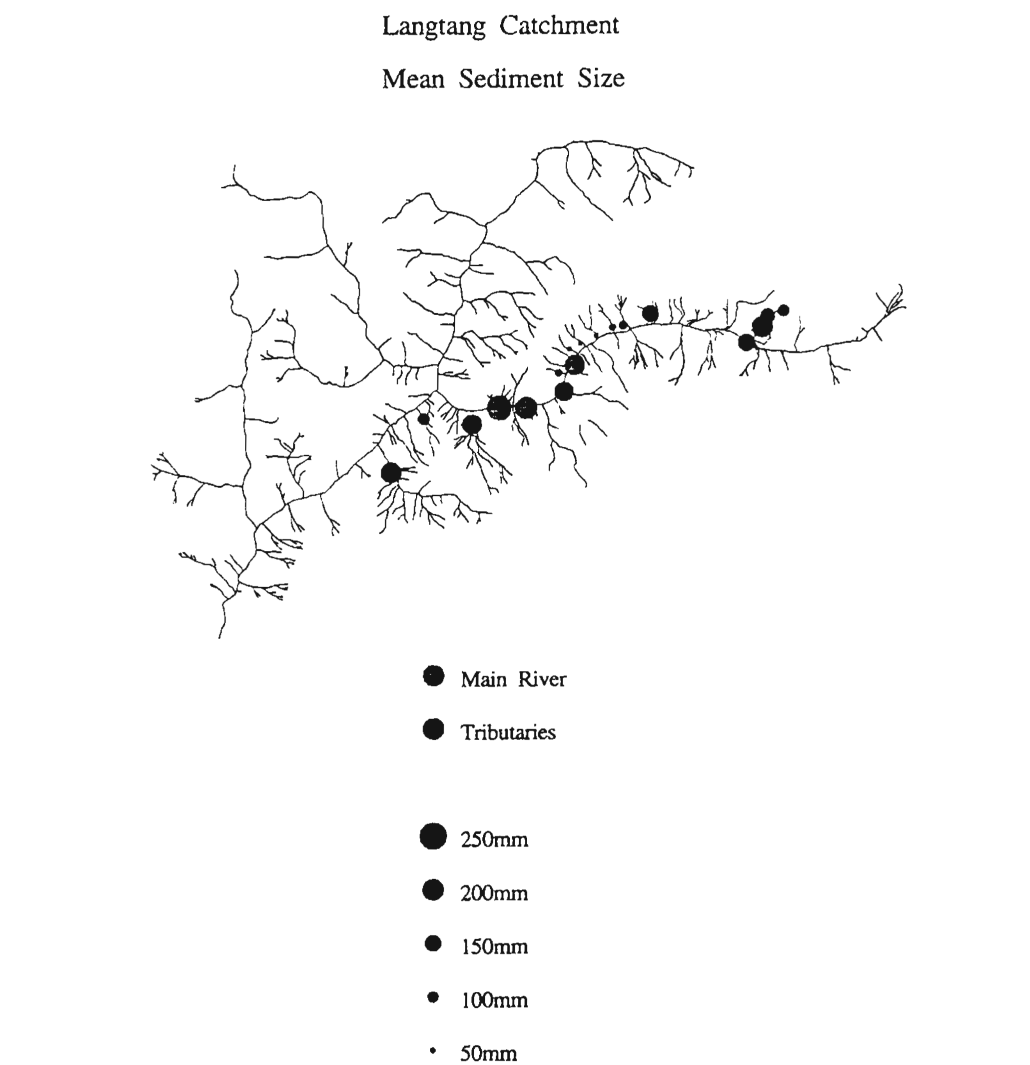

Figure 4: Distribution of Mean Sediment Size in the Langtang Valley, Nepal

Aerial photography potentially enables quantification of the large sediment load deposited to form bars or linear deposits along the river bank. This *in situ* material constitutes a considerable sediment store within the Langtang catchment, particularly in the more gently sloping channel reaches. Much of this store is potentially transportable, particularly during periods of high discharge in the monsoon. A detailed survey of such deposits may provide estimates of the rate of supply of material to the river system. In addition, if a sufficient temporal resolution of survey is adopted, seasonal variations in the supply rate may be identified.

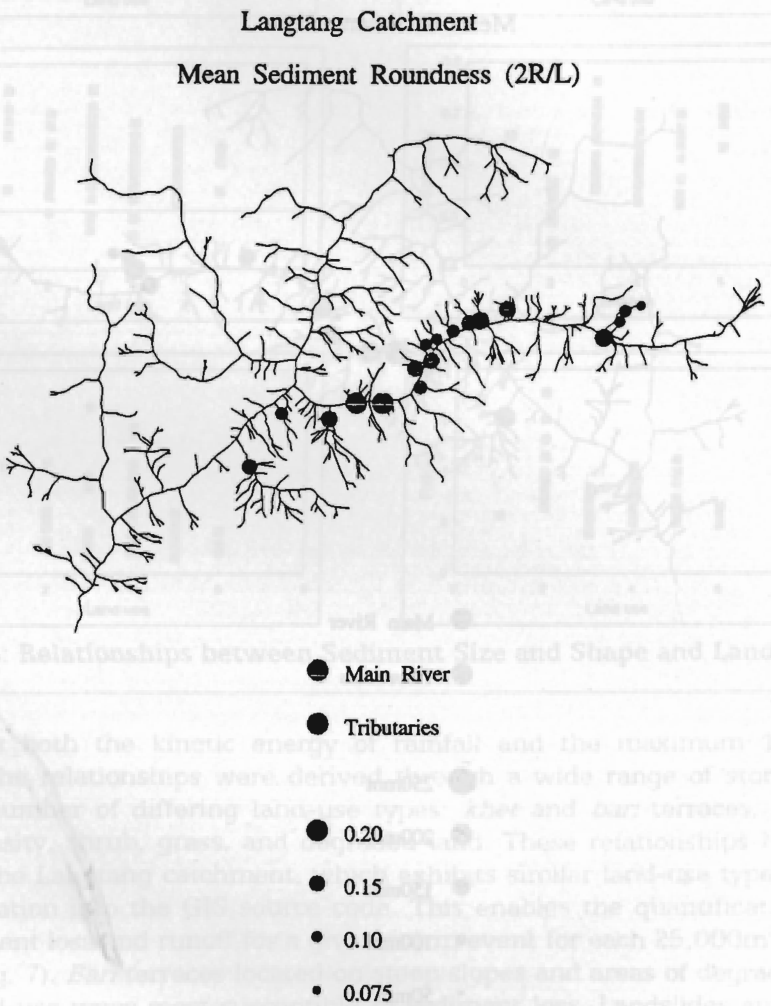

Figure 5: Distribution of Sediment Roundness in the Langtang Valley, Nepal

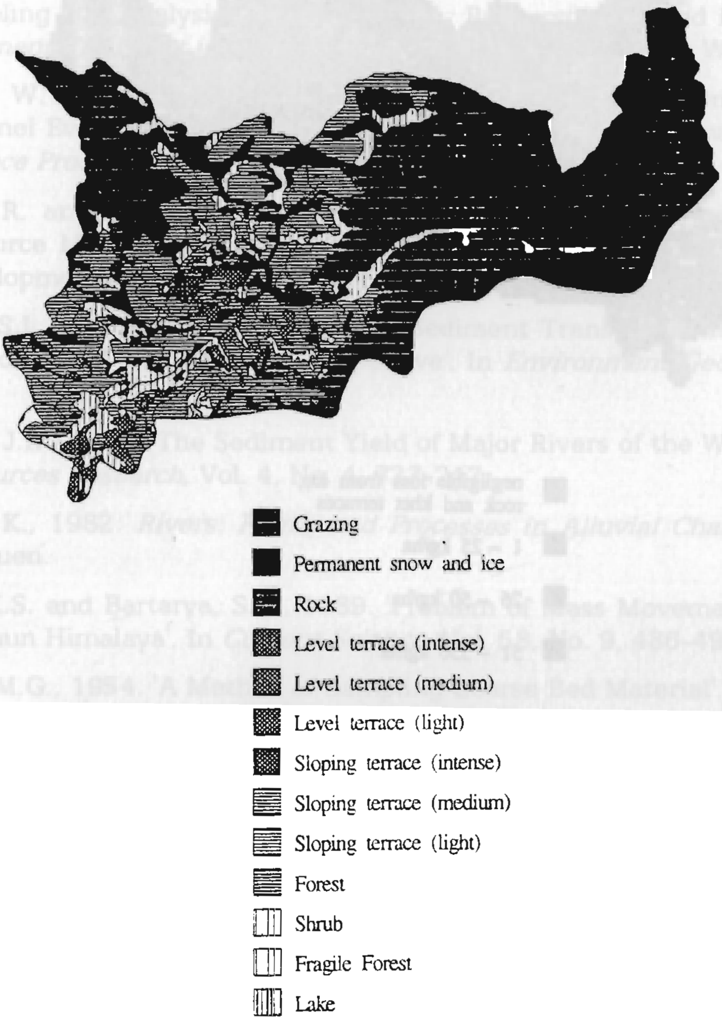

Figure 6: Land Uses in the Langtang Valley, Nepal

Figure 7: Hillslope Sediment Loss in the Langtang Valley, Nepal

Conclusions

A methodology of classifying sediments in Himalayan rivers is being developed by field-based surveys and the development of GIS techniques. Field measurements of sediment particles have shown that four dimensions are needed to give a full analysis of the size and shape. Within sediment deposits, gradation of particles can exist, so a grid system of sampling is required. The minimum number of samples required is being determined. Selection of the number of tributaries to sample within a river basin should be systematic and determined by land use and possibly geology and area. Analysis on a river basin scale should be within a GIS framework into which the sediment characteristics can be incorporated with quantitative estimates of sediment release, connectivity to the river system, and transport down the rivers.

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