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SEDIMENT YIELD ESTIMATION FOR LOWER SATLUJ BASIN

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ABSTRACT

The sediment load (tonnes/year) or yield of sediment (tonnes/km^2/year) in suspension and as bed load of sand and gravel through river channels reflects upland erosion within the drainage basin and change in storage of sediment in alluvial bottomlands. Much of the sediment eroded from upland areas is deposited (stored) on lower hill slopes, in bottomlands, lakes and reservoirs. Estimates of erosion are considered essential for land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. Generally, suspended sediment loads are estimated using an empirical relationship between suspended sediment load and discharge. The relation is usually defined as a power function and is referred to as a suspended sediment rating curve.

In the present study relationship between suspended sediment load and discharge has been developed for three basins namely at Kasol, Suni and lower part of the Satluj basin comprising of the portion covered in between Kasol and Suni. The relationship is represented by the power law. Daily suspended sediment and runoff data collected from Bhakra Beas Management Board (BBMB), for the period from 1991-1996 were used. Sediment yield was also estimated for the basin covered in between Kasol and Suni using empirically developed relationship. For estimation of the sediment using these relationships, various parameters such as geomorphological, landuse, topoghraphical etc. were generated using Geographic Information System (GIS) technique. GIS, a technology designed to store, manipulate, and display spatial and non spatial data, has become an important tool in the spatial analysis of factors such as topography, soil, land use/land cover etc. GIS provides a digital representation of the catchment which can be used in hydrologic modelling. The sediment yield was estimated for 3 years and on the basis of these results a factor and the results were compared with the observed data. There is good match between computed and observed sediment data for this basin.

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1.0 INTRODUCTIION

1.1 General

Sediment yield refers to the amount of sediment transported by a basin over period of time. The sediment load or yield of sediment, in suspension and as bed load of sand and gravel through river channels reflects upland erosion within the drainage basin and change in storage of sediment in alluvial bottomlands. Much of the sediment eroded from upland areas is deposited on lower hill slopes, in bottomlands, in lakes and reservoirs. A major portion of the sediment enters into reservoir located at the down stream limit of the basin and reduce their storage capacity. Generally, sediment is expressed either in terms of sediment load (tonnes/year) or sediment yield (tonnes/km^2/year). Soil erosion is a process of land denudation involving both detachment and transportation of the surface soil materials. The detachment of particles of soil and surfacial sediments and rocks, occurs by hydrological (fluvial) processes of sheet erosion, rill and gully erosion, and through mass wasting and the action of wind. It is a complex dynamic process by which productive surface soils are detached, transported and accumulated at a distant place. It result in exposure of subsurface soil and siltation of reservoirs and natural streams. It leads to general reduction of raised land. Flash floods in ephemeral desert streams may transport very large sediment loads, accounting for unforeseen sedimentation problems in dry land stream reservoirs. Excessive erosion from a basin is considered harmful because of the following reasons:

i) It may lead to severe loss of valuable fertile soil which affects the agricultural productivity,

ii) The loss of the soil cover reduces the water retention capacity of the land and may result in increased runoff,

iii) The downstream surface water resources are polluted by both dissolved and undissolved substances captured by the eroding water,

iv) Structures and agricultural fields lying downstream are damaged or otherwise devalued by the sediments deposited in or on them.

Changes in sediment yield reflect changes in basin conditions, including climate, soils, erosion rates, vegetation, topography and land use. Longterm changes in sediment yield accompany land use conversion, such as from natural to commercially harvested forest, from forest to agriculture, or from agriculture to urban use. Some of the conversions may be reversible, such as the conversion of forest to agricultural use and subsequent recovery of the forest following abandonment of farms (Morris and Fan, 1997).

Estimates of erosion are considered essential for land and water management, including sediment transport and storage in lowlands, reservoirs, estuaries, and irrigation and hydropower systems. In USA, soil has been eroded at about 17 times the rate at which it forms: about 90% of US cropland is currently losing soil above the sustainable rate. Soil erosion rates in Asia, Africa and South America are estimated to be about twice as high as in the USA. Food and Agricultural Organisation (FAO) estimates that 140 million ha of high quality soil, mostly in Africa and Asia, will be degraded by 2010, unless better methods of land management are adopted.

In India a total of 1,75,0000 km^2 out of the total area of 3280000 km^2 is prone to soil erosion. Thus about 53% of the total land area of India is prone to erosion (Narayan and Rambabu, 1983). Most part of the Himalayas, particularly the Shiwaliks which represent the foothills of the Himalayas in the northern and eastern Indian states, are comprised of sandstone, grits and conglomerates with the characteristics of fluvial deposits and with deep soils. These formations are geologically weak, unstable, and hence highly prone to erosion. Excessive erosion has occurred in this region due to extensive deforestation, large scale road construction, mining and cultivation on the hill slopes. Narayana and Rambabu (1983) have estimated that approximately 30, 000 km^2 area has been severely eroded in the northeastern Himalayas due to shifting cultivation. In the high altitude regions of the Himalayas, glaciers also transport a significant amount of sediment in to the rivers.

1.2 TYPE OF SOIL EROSION

The various important agents of soil erosion are running water, groundwater, wind, glacier, gravity etc. Soil erosion has been classified according to the erosive agents (factors causing the occurrence and affecting the course of erosion processes): water, glacier, snow, wind, man, animals, etc.; by the forms which arise due to the effects of exogenous agents on the soil surface and by intensity the extent in which the soil particles are detached and transported. The soil erosion by water is classified as (Bathurst et al., 1991, Oonagh, 1995)

Sheet erosion: Soil erosion resulting from raindrop splash and surface runoff is often called as sheet erosion. This is the uniform removal of soil in thin layers from sloping surface of soil between rills. Although important, sheet erosion is often unnoticed because it occurs gradually. The rain drops cause the soil particles to be detached and the following sedimentation reduces infiltration rate by sealing the soil pores.

Rill erosion: When water takes the path of least resistance to flow over the soil surface, it forms minute channels, known as rills. Rill erosion is the removal of soil by water from small but well advanced channels in which the overland flow concentrates. Both detachability and transportability of soil particles are greater during rill erosion than during sheet erosion because of higher velocities. Rill erosion is most serious in regions, where storms are of high intensity and the top soils are loose and shallow.

Gully erosion: If the channel formed in the land are so deepened and widened by erosion that their size is greater than those of common rills, then the land is no longer readily useable. The effect is then termed as gully erosion. These channels carry water during and immediately after rains. Gullies are usually formed by (i) water fall erosion at the gully head, (ii) channel erosion caused by water flowing through the gully, (iii) alternate freezing and thawing of exposed soil banks, and (iv) slides and mass movement of soil in the gully. Gullies are also referred to as ravines.

Mass erosion : Mass erosion is the simultaneous slippage of large volumes of soil. It often occurs when clay layers below the surface are saturated. It is also associated with road construction in hilly terrain. Mass erosion may also be initiated by de-vegetation of steep slopes, where the network of roots may previously have helped retain the soil in position.

1.3 FACTORS INFLUENECING SOIL EROSION

The main factors influencing soil erosion are climate, soil, vegetation and topography and man. Of these, the vegetation and to some extent the soil and the topography may be controlled. The climatic factors and largely also the topographic and soil factors are beyond the power of man to control.

Climate factors influencing the erosion are precipitation, temperature, wind, humidity and solar radiation. Temperature and wind are the most evident through their effects on evaporation and transpiration. Wind also changes raindrop velocities and angle of impact while low temperatures, frost and snow accumulation can favour subsequent erosion during the soil thawing and snow melting. Humidity and solar radiation have little direct impact on erosion.

Physical properties of the soil affect its infiltration capacity and the extent to which the soil can be detached, dispersed and transported. The properties which most influence erosion include soil structure, texture, organic matter content, moisture content, density (compactness), shear strength as well as chemical and biological characteristics.

The vegetation effects are usually favourable in reducing erosion through interception of rainfall by absorbing energy of the raindrops and thus reducing the runoff, through retardation of erosion by decreased surface water velocity, through physical restraint of soil movement, through improvement of aggregation and porosity of the soil by action of roots and due to increased biological activity nourished by plant residues and through transpiration which decreases soil moisture, resulting in increased storage capacity of the soil.

Topographic features that influence erosion are degree of slope, length of slope and size and shape of the watershed. High water velocities occurring on steep slopes cause serious erosion by scour and sediment transportation.

1.4 STATUS OF SEDIMENT YIELD ESTIMATION

Prediction of sediment from any catchment is a complex phenomena which is affected by various factors. Climate of the catchment, its morphometry, soil properties, landuse/landcover, irrigation and management practices affect the sediment yield from the catchment. There are various model which use different affecting parameters. Various methods/models which have been developed to predict the sediment yield are described in brief here, whereas detail description of various models is given in next chapter.

Sediment delivery ratio (SDR): is derived from empirical equations and relates SDR with basin area and shape. It provides fairly good predictions in specific areas but universal applications needs vast study and long term data collection.

Sediment rating curves : This method use relationship between water discharge and sediment discharge rates based on stream flow sampling. This method is considered to be time consuming and costly as well.

Statistical equations : Sediment yield prediction equations (SYPE) derived from statistical analysis have been frequently used to estimate sediment yield. These equations usually relate sediment yield to one or more basin characteristics climatic factors.

Stochastic method : This method use stochastic runoff models followed by relationship developed between sediment yield and runoff by empirical/deterministic relations.

Deterministic models : There are a number of deterministic models used for estimation of sediment yield from a basin. A discussion of such models is made in this report else where.

2.0 MODELS USED FOR ESTIMATION OF SEDIMENT YIELD

A number of studies have been carried out to investigate the erosion processes and the governing physical factors. Based on these studies, numerous computer-based models have been developed for estimation of rate of soil erosion and sediment yield. Some of these models are described below.

LISEM MODEL :

Limburg Soil Erosion Model (LISEM) is a physically based hydrological and soil erosion model developed by the Department of Physical Geography at Utrecht University and the Soil Physics Division of the Winard Staring Centre in Wageningen, The Netherlands. The LISEM is a powerful model that simulates hydrological and soil erosion processes during single rainfall events on a catchment scale(DeRoo,1996). The various hydrological and soil erosion processes that are simulated using LISEM models are rainfall, infiltration, soil water transport, storage, hydraulic conductivity, splash detachment, sediment bed load, etc. The LISEM is effectively used for planning and conservation purposes. The model incorporates raster based GIS system. The model produces detailed maps of soil erosion and overland flow. The model uses physically based mathematical equation. The use of LISEM model on some studies indicates that results of LISEM 1.0 model are far from the perfect. The main reasons for that includes spatial and temporal variability of the soil parameters and initial pressure head at the basin scale. The second reason is the lack of understanding of the theoretical basis of hydrological and soil erosion processes.

WEPP MODEL

The Water Erosion Prediction Project (WEPP) model represents a new generation technology for estimating soil erosion and sediment delivery from hill slope profiles and small watersheds and is developed by United States Department of Agriculture(USDA) under WATER EROSION PREDICTION PROJECT, called 'WEPP' for the purpose of water conservation, environmental planning and assessment. The WEPP model is a continuous simulation model. The model components include surface and subsurface hydrology, winter process, irrigation, plant growth, and residue decomposition. The WEPP model computes spatial and temporal distributions of soil loss and deposition, and provide explicit estimates of when and where in a watershed or on a hill slope that erosion is occurring so that conservation measures can be selected to most effectively control soil loss and sediment yield. The use of Geographical Information System (GIS) is under investigation.

The physical process in the model include rill and inter rill erosion, sediment transport and deposition, infiltration, soil consolidation, residue and canopy effects on soil detachment and infiltration, surface sealing, rill hydraulics, surface Runoff, plant growth, residue decomposition, percolation, evaporation, transpiration, snow melt, frozen soil effects on infiltration and erodibility, climate, tillage effects on soil properties, effects of soil random roughness, and contour effects including potential overtopping of contour ridges. The model accommodates the spatial and temporal ariability in topography. surface roughness, soil properties, crops, and land use conditions on hill slope.

TOPMODEL

TOPMODEL (a topography based hydrological model) is a set of conceptual tool which is used to simulate the hydrological behaviour of watershed in a distributed or in a semi-distributed way in a relatively simple way, particularly the dynamics of surface and subsurface contributing areas. It is a topography based watershed hydrology model that has been used to study a range of topics, including spatial scale effect on hydrological process, topographic effect on hydrological process, topographic effect on water quality, topographic effect on stream flow, climatic change effect on hydrological process, geomorphological evolution of basin , and the identification of hydrological flow path etc. The simplicity of model comes from using the soil-topographic index as an index of hydrological similarity. It is premised upon following basic assumptions:

1) that the dynamics of the saturated zone can be approximated by successive steady state representations;

2) that the hydraulic gradient of the saturated zone can be approximated by the local surface topographic slope.

3) that the distribution of downslope transmissivity with depth is an exponential function of storage deficit or depth to the water table.

KINEROS MODEL

KINematic EROsion Simulation model (Smith, 1981) is an event oriented, physically based model describing process of interception, infiltration, surface runoff and erosion from small agricultural and urban catchments. It uses the Smith/Parlange infiltration model and the kinematic wave approximation to route overland flow. The catchment is represented by a cascade of planes and channels.

EPIC MODEL:

The Erosion Productivity Impact Calculator (EPIC) model (Williams et al., 1984) was originally developed to assess the effects of the soil erosion productivity of the natural resource base. It is a continuously daily time step model designed to provide simulation output summaries on a daily, monthly, annual and/or multi-year basis. It is frequently used for 50-100 year simulations or longer. The drainage area considered by EPIC is generally a field-sized area, up to 100 ha. The major components and processes simulated by model are hydrology, erosion-sediment,. In more recent years the model has evolved to also address issues of i)water quality with the addition on pesticide fate, better nitrification and volatization submodels, ii) climate change assessment capabilities with addition of CO_2 sensitivity and vapour pressure deficit equations, iii) improved wind erosion sub model, iv) improved estimation curves for peak Runoff rates, v) better manure and organic carbon management and decomposition capabilities.

In EPIC model the runoff volume is determined by using a modification of the soil Conservation Service (SCS) Curve number technique. The EPIC model allows four options for estimating potential evapotranspiration. Hargrieves and Sumani (1985), Priestley and Taylor (1972), Penman(1948), and Penman Monteith (Monteith, 1965) depending upon the amount and type of data available to be used by the user.

The erosion sub model estimates soil losses from six alternative equations designed to predict erosion using various methodologies like MUSLE (Modified Universal Soil Loss Equation), (Williams, 1975),

AGNPS MODEL

Agricultural Non-Point Source (AGNPS)is an event based non point source pollution model for evaluating agricultural watersheds of mild topography. AGNPS can be used for watersheds up to 20,000 ha. in size with element size of 0.4 to 16 ha. Accuracy of result can be increased by reducing the cell size, but this increases the lime and labour required to run the model. The model simulates runoff using SCS curve number method, sediments using modified USLE equation (Wischemeier and Smith, 1978) and nutrients movement adapted from the CREAM model (Frere at el., 1980) from agricultural watersheds. The AGNPS model consists of four components, basically hydrology, erosion, sediments and chemical transport with nitrogen (N) and Phosphorous (P) as major surface water pollutants. Model also consider point source of sediments from Gullies and input of water, sediment, nutrients, and chemical oxygen demand (COD) from animal feedlots, springs and other point source. The distributed parameter approach of this model preserves spatial characteristics and makes it appropriate to use a GIS system for storage of those spatial characteristics.

SWMHMS MODEL

SMALL WATERSHED MONTHLY HYDROLOGIC MODELLING SYSTEM (SWMHMS) is a continuous simulation conceptual modelling program which attempt to account for all watershed precipitation through hydrologic processes such as surface runoff, infiltration, and evapotranspiration from a small non urban watershed. It was written with the purpose of providing a computational less complex computer modelling program capable of accurately predicting monthly runoff while requiring a minimum of watershed data input.

The input needed to run model simulation include daily precipitation, monthly data for evapotranspiration i.e. average temperature, crop consumptive coefficients, and present daylight hours, and six watershed parameters. The output from the models are total daily watershed runoff. Of the six watershed parameters, most sensitive is the curve number, CN. Depending on the watershed, either AWC or IRAC is a distant second. The optimal curve number for the majority of the watershed was found to be closest to an SCS III type value. In terms of monthly runoff prediction, SWMHMS functional best where snowfall accumulation were low. The testing result indicate this modelling programme can be significantly useful for determining water management practices on small agricultural watersheds. SWMHMS is less complex than any other computer model to ca2lculate monthly runoff and it can be used as an educational tool for student learning the principle hydrologic modelling.

In terms of application, the model is useful for establishing hydrologic management practices on small watersheds. Also, conceptually simple nature of SWMHMS allow it to be productively utilised as a tool for teaching hydrologic modelling principles.

SWAT

The Soil and Water Assessment Tool (SWAT), (Arnold et al.,1993) is originally developed by the US Department of Agriculture- Agriculture Research service and modified for use in the Hydrological Unit Model of the United States (HUMUS) support project with the objective is to predict the impact of management on water, sediment and agricultural chemicals on small and large ungauged basins. Like EPIC the SWAT model simulate various processes include hydrology, weather sedimentation, soil temperature, crop growth, nutrients, pesticides, ground water, lateral flow and agricultural management. SWAT functions on daily time step and can simulate in excess of hundred total years. This model is designed to predict stream flow using soil, land use, elevation and weather information. It was constructed to be sensitive to changing land use and environmental practices. SWAT modelling is designed to simulate the nested lay out of the smaller drainage area with in larger basins, and thus support environmental analysis at virtually any level of basin activity thus the environmental effect of proposed policy alternatives can be assessed. The system is built around a GIS framework.

The various physical process included in model are surface water hydrology, percolation, lateral subsurface flow, evapo-transpiration, snowmelt, weather simulation capabilities, and statistics, by selecting a subbasin from a GIS map. This technique greatly facilitates the exploration of alternative watershed management options.

An interface has been developed for SWAT (Srinivas and Arnold, 1993) using the GRASS (Graphical Resources Analysis Support System) (US Army,1988) as the GIS support system. Using submodel developed to support watershed management the interfaces will automatically subdivide a basin (either grids or sub watersheds)and then extract model input data from map layers and associated relational data based for each subbasin, soils, land use, weather, management, and topographic data are collected from the GIS and written to appropriate model input files. In like manner, output interfaces allow the use to display outputs like maps, graphs, hygrographs and other relevant

By using SWAT model, the impact of management of water, sediment and agricultural chemicals on small and large ungauged basin can be examined, also the environmental effect of proposed policy alternative can be assessed effectively and this model capability can be enhanced greatly using GRASS GIS, exploring the alternative watershed management option and planning.

Studies based on Regression analysis

Garde and Kothyari (1987) have reported various sediment yield equations used for Indian catchments which are reproduced here:

1. Khosla (1953) provided the following equation to estimate the annual sediment yield

$$V_s = 3.23 * 10^{-3} A^{0.72} \qquad \text{.........(1)}$$

where V_s = Annual sediment yield (Mm^3),

A = Catchment area in (km^2)

2. Dhurva Narayan et al, (1983) used the following equation for estimating annual sediment yield

$$T_l = 5.5 + 11.1\,Q \qquad \text{.........(2)}$$

$$T_l = 5.3 + 12.7\,Q.W \qquad \text{.........(3)}$$

Where T_l= Annual sedimentation rate (mt/year),

Q = Annual runoff (M ha m.)

$W = T_l/A$,

A = Catchment area (km^2)

3. Garde et al. (1983) used following two equations for sediment yield estimation

$$V_s = 1.182 * 10^{-6} P^{1.29} A^{1.03} D_d^{.40} S^{0.08} F_c^{2.42} \qquad \text{........(4)}$$

Where A is catchment area, (Km^2),

L is stream length (km).

S is catchment slope,

D_d is drainge density,

F_c is vegetation cover factor,

P is annual mean precipitation, mm and

V is sediment load (Mm^3)

Other equation used by Garde et al. (1983) was

$$V_s = 1.067 * 10^{-6} P^{1.38} A^{1.29} D_d^{.40} S^{0.130} F_c^{2.51} \qquad \text{........(5)}$$

The parameters are discribed in equation 4 above.

Varshney (1975) has suggested a number of enveloping curves for the prediction of sediment yield for different catchment areas in India. Correlation studies conducted by Jose et al. (1982) revealed that area alone does not have any significant association with sediment production rate (SPR) and hence it calls for multivariate analysis involving a number of climatic and physiographic parameters.

Rao et al. (1995) has done study on sediment yield estimation for Chenab basin. In this work data of 9 sediment stations with in Chenab basin varying from 17 to 27 years was utilised to develop a statistically significant spatial model to estimate sediment yield using geomorphological, climatic and landuse, landcover parameters. The sediment yield was estimated for total and fine sediment for monsoon, winter, premonsoon and annual seasons. The study revealed the high rates of sedimentation in Chenab basin and its effect on existing Salal dam near Jammu.

Sharma, (1997), carried out study on soil erosion and sediment yield in the Indian arid zone. A compilation of sediment yields for meso scale drainage basins suggests that arid basins export 36 times more material than humid temparate and 21 times more than humid tropical equivalents. Bare soil is highly susceotible to rainsplash and wash erosion, and arid zones produce record suspended sediment concentrations.

3.0 APPLICATION OF GIS IN SEDIMENT YIELD STUDIES

Geographic Information System (GIS), a technology designed to store, manipulate, and display spatial and non spatial data, has become an important tool in the spatial analysis of factors such as topography, soil, land use/land cover etc. GIS provides a digital representation of the catchment which can be used in hydrologic modelling. It is used to estimate the parameters that enter the hydrological models by analysis of terrain, land cover and other features of the basin. The land surface slope, land use and soil characteristics can be extracted using this technique very accurately. Except for few cases, the GIS has usually been employed separately in its own environment, uncoupled to the soil erosion model and requiring the modeller to exchange of data between them manually. This approach has also been applied in present study. Some of the data bases required for empirical relationship have been developed in GIS.

A review of literature given in this section is mainly focused on the studies which used GIS technique was used. The main reason for using GIS for estimating erosion and modelling as well is that runoff and soil erosion processes vary spatially. To account for this variability, the modelled catchment has to be broken down into many cells which are relatively homogeneous. The extent of data required for the large number of cells is enormous and can not be presented and easily entered manually, but can be obtained by using GIS.

Spanner (1982,1983) combined Landsat Multi Spectral Scanner (MSS) data and a digital elevation model (DEM) in a GIS context. A stratification of the landscape according to relief (elevation, steepness) allowed accurate discrimination between orchards and natural vegetation that had not been possible using Landsat data processing alone. The use of DEM helped to quantify three of six coefficients of USLE (slope gradient and length and land cover).

Vieux (1991) integrated a distributed finite element process model of overland flow and the ARC/INFO GIS software. This model represents overland flow as sheet flow which is modelled as such over each finite element. GIS is utilized to provide topographic information for modelling overland flow in a small catchment. The finite element model requires to input the Manning roughness coefficient and the principal slope for each finite element node. Further, the model outputs were displayed using GIS. According to Vieux (1991), the advantage of a GIS is that results can be combined with other map coverages to allow comparison of cause-and-effect relationships or co-occurrences, for example the identification and location of soil series and management that may contribute to surface or subsurface contamination.

Tim et al. (1992) coupled two water quality computer simulation models, viz. Soil loss (SLOSS) model and the Phosphorus yield model (PHOSPH), with a GIS to delineate critical areas of nonpoint source pollution at the catchment level. These models estimated soil erosion, sediment yield, and phosphorus loading from the Nominal Creek catchment located in Westmoreland County, Virginia.

DeRoo (1993) linked the ANSWERS model to raster GIS to achieve a high accuracy and flexibility. The model was modified to incorporate the variable contributing area concept for simulation of saturated overland flow. For this purpose only the information of the Digital Elevation Model was used and the slope gradient and upstream area were evaluated from it. The model was validated by comparing measured and simulated hydrograph runoff and sediment yield at the catchment outlet on two catchments.

Engel et al. (1993a) integrated AGNPS with a raster based GIS tool GRASS (Geographical Resource Analysis Support System). The Input tool of GRASS assisted with preparation and extraction of data from the GIS database for use in the AGNPS model. The 22 inputs required for each AGNPS cell were estimated from six GIS layers: soil series, elevation, land use management practises, fertilizer nutrient inputs and land preparation or type of farm machinery used. The inputs required for the entire catchment were e.g. rainfall amount, rainfall energy and the cell size. Engel (1993b) also integrated ANSWERS and SWAT with GRASS. The intention of the study was to demonstrate the quality of the simulated response for only roughly estimated input parameters using an integrated GIS modelling system. The simulated and observed total runoff and peak runoff rates and delivered nitrate, phosphate and sediment amounts matched reasonably well but additional validations of the model were recommended.

He et al. (1993) integrated GIS and a computer model to evaluate the impacts of agricultural runoff on water quality. Various management scenarios were explored to minimize sedimentation and nutrient loading. The scenarios included variations in crop cover, tillage methods and other agricultural management practices.

Heidtke and Auer (1993) presented also a GIS based method for predicting non-point loadings to lake Owasco in New York. In describing the predominant geographic attributes of the catchment and its hydrologic sub-basins, they identified seven land use categories (cropland, pasture, woodland, water/wetland, residential, commercial and general urban), three soil texture categories and three surface slope categories. As a non- point source calculation method, they first used USLE for estimating the annual soil erosion, which was then multiplied by factors reflecting in-situ soil chemistry and soil enrichment during washoff events to arrive at the total phosphorus unit loads for rural and land use categories.

Another non-point model applying USLE in its erosion part was presented by Preti and Lubello (1993). It is a distributed-parameter model based on square cells of a digital elevation map. It also models the dynamics of herbicides. The hydrological part of the model was schematized as a system of mutually communicating tanks which permits to estimate evapotranspiration, infiltration into the soil, runoff, hypodermic flow, percolation and groundwater flow. In the non-point pollution part, each cell was vertically divided into three layers: the surface or interception layer of a depth of a few centimeters, where runoff and erosion takes place, the root zone layer coinciding with gravitational and capillary volumes of the hydrological model, and the deep or ground waterlayer.

Tim et al. (1994) carried out a study for evaluating agriculture non-point source pollution using an integrated GIS and hydrologic/water quality model. The ARC/INFO GIS provided the tools to generate spatial inputs, while AGNPS model was used to predict several water quality variables including soil erosion and sedimentation within a catchment. The integrated system was used to evaluate the effectiveness of several alternative management strategies in reducing sediment pollution in a catchment. This study demonstrated the utility of integrating a simulation model with GIS for non-point source pollution control and planning.

Savabi et al. (1996) made a study on using GRASS GIS together with WEPP. The GIS package was used to obtain many of the needed input parameters for WEPP. Annual WEPP-simulated and measured storm runoff amounts were compared. The results indicated that DEM and GRASS GIS technique are powerful tools and can be used to parameterize the WEPP model.

4.0 THE STUDY AREA AND DATA AVAILABILITY

4.1 TOPOGRAPHICAL FEATURES OF SATLUJ RIVER BASIN

The Satluj river originates from Rakas-Tal Lake which is fed by Lake Mansrover in Tibet at an altitude of about 4572 m above mean sea level. Between Raskas-Tal and Ship Ki near the Indian border the Satluj river follows a North westerly direction for a length of about 322 km in the Tibetan province of Nari-Khorsam. It is joined by several tributaries in Nari-Khorsam, the bed of which are lower by about 305 m than the general level of the plateau. Their vertical cliffs, like those of Satluj, have been spared from destruction by rain, and flat portions of the plateau now remain standing between deep and narrow gorges.

The total geographical area of Satluj catchment upto Bhakhra dam is about 56,980 km^2 of which about 37,153 km^2 lies in Tibet. The rest about 19,827 km^2 lies in the Indian terrirtory. The major portion of the Satluj basin lies in the greater Himalayan range. The bed slope of Satluj from its source to Bhakhra dam site is quite uniform. The elevation of the bed is 4572 m near Rakas-Tal, 3048 m near Ship-Ki, 914 m at Rampur, 457 m at Bilaspur and 347m at the Bhakhra Dam site. The river bed slope in the reservoir area is about 1.89 to 2.27 m/km. The river leaves the Himalayas near Nangal, where Nagal barrage is located.

The salient characteristics of the whole Satluj catchment are summarised below:

Reach	Catchment area (km^2)	Elevation (m)	Rainfall (mm)	Water sources
Tibetan plateau	37050		Nil	Glacier
Spiti Valley	7084	3300-5300	Scarce	Glacier
Namgia to Rampur	6490	3000-4800	Little	Snowmelt and rainfall
Rampur to Suni	2068	1200-3000	Light to heavy (1000-1500)	Rainfall
Suni to Kasol	700	900-2000	(910-1630)	Rainfall
Kasol to Bhakhra	3108	600-2000	1520	Rainfall

In the reservoir area, the catchment starts from Bhakhra dam, where it is flanked on both sides by the foothills of the Shivalik ranges, diverging from a narrow george to a very wide width of about 24 km and again narrowing down up to Kasol forming the tip of the reservoir. The lower catchment largely drains directly into the reservoir and the the higher slopes drain through tributaries. The important tributaries are the Soel khad, Alseed khad, Ali khad, Gamrola khad, Ghambhar khad, Seer khad, Sukhar khad, Sarhali khad and Lunkar khad.

The catchment receives heavy rainfall during the monsoons from July to mid September, sometimes rainy season extends up to late September and very rarely up to early October. The average rainfall in the catchment is 1140 mm. The Satluj runoff basically consists of two parts, one of which is derived from the melting of the snow and the other resulting from the rainfall in the catchmnet. The monsoon is generally marked by high river flows and occasional floods in Satluj. There is significant contribution from snow and glaciers into stream flows of Satluj. The contribution from snow and Ice varies with season to season being maximum in summer months.

4.2 THE STUDY AREA

For the present study relationship between sediment yield and discharge has been developed for the three basin namely Satluj upto Suni, Satluj upto Kasol and Intermittent basin from Suni to Kasol. sediment yield estimation has been carried out for the area from Suni to Kasol. This area falls in the lower part of the Satluj basin. Kasol is almost at the tip of the reservoir. This area comes in the lower shiwaliks with mountain peaks up to 2134 m height and the rainfall in this region is heavy i.e. 910 mm to 1630 mm. This area being more populated than the higher regions, has poor forests and more cultivation and this its sediment yield is the heaviest. The location of the study area is shown in Fig. 1.

4.2 DATA AVAILABILITY

4.2.1. Topographic data

For studying sediment yield in the lower Satluj basin i.e. from Suni to Kasol, following toposheets at a scale of 1:50,000 were collected.

Toposheets no. are 53 A/15,16 and 53 E/3,4

4.2.2 Field data

For this study field data of rainfall, discharge and sediment yield have been collected from BBMB, Nangal. The rainfall data of the two stations, namely Suni and Kasol, which are falling in the study area were colected. Because the study area comprises the area between Suni to Kasol, covering an area of about 700 km^2, therefore discharge and suspended sediment data have been compiled from daily records maintained at Suni and Kasol. The runoff and sediment derived from the intermittent catchment i.e. from Suni to Kasol were obtained by subtracting the contributions at Suni from Kasol. The above database was prepared for a period of six years from 1991-1996.

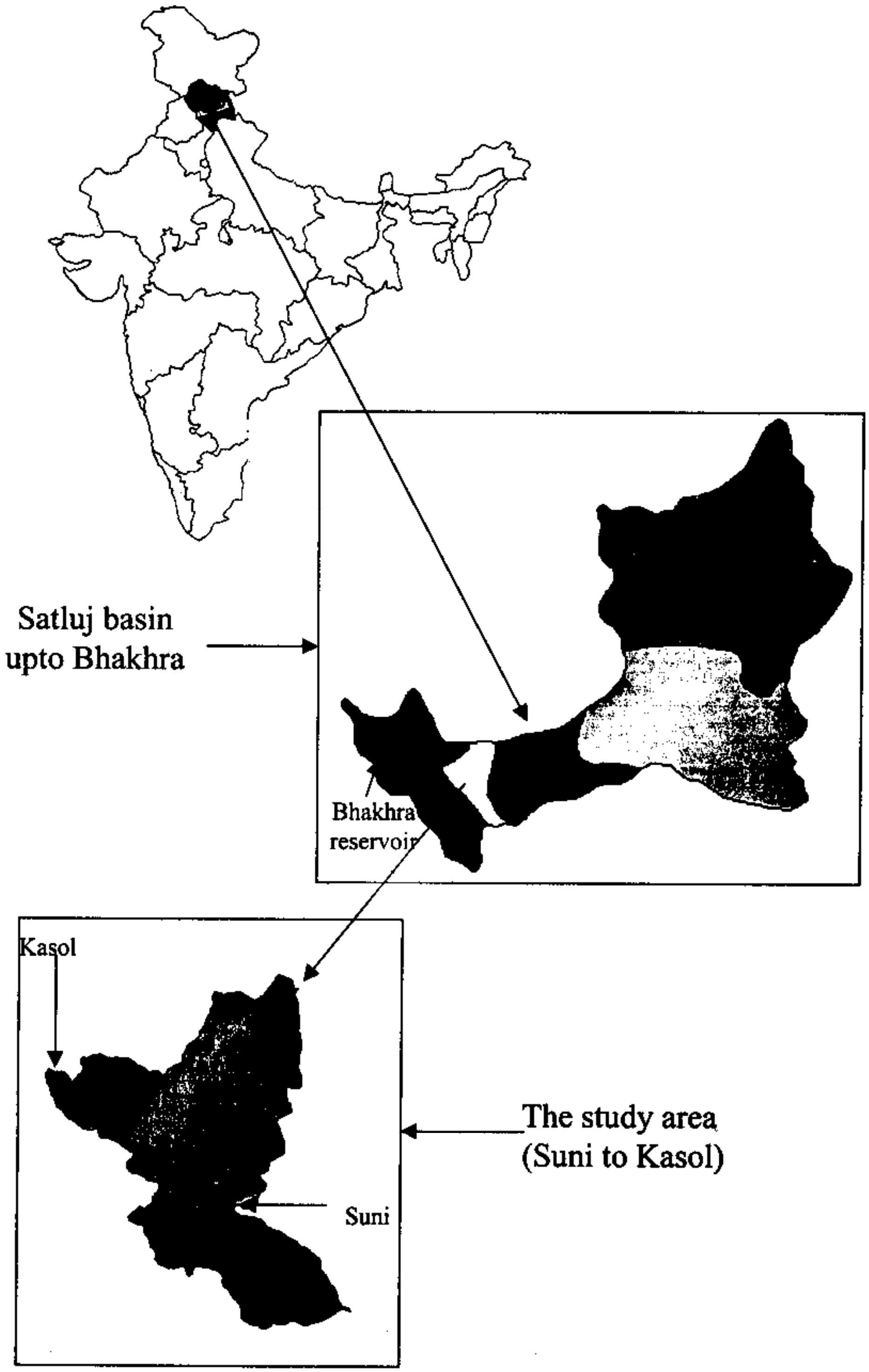

Figure 1 : Location of the study area

5.0 STATEMENT OF THE PROBLEM

In the present study sediment yield estimation in for the lower part of Satluj basin i.e. from Suni to Kasol has been taken. According to sedimentation studies report prepared by BBMB, Nangal, there is heavy erosion in the lower part of the Satluj basin. This was the reason that lower part of Satluj basin was considered in this study. The objective of the study is to establish the relationship between discharge and sediment yield.

It is also proposed to estimate the sediment yield from the standard. For estimation of the sediment using these relationships, various parameters such as geomorphological, landuse, topoghraphical etc. were generated using Geographic Information System (GIS) technique. The sediment yield was estimated for 7 years and the results were compared with the observed data.

6.0 METHODOLOGY

The objective of this study is to estimate sediment yield for lower part of Satluj basin which covers an area from Suni to Kasol. To fulfil these objectives following tasks have been performed:

- Preparation of drainage pattern and contour map of the study area
- Morphometric analysis from the drainage pattern map
- Preparation of Digital Elevation Model (DEM) of the area
- Preparation of land use map from the satellite data
- Derivation of parameters required for sediment yield estimation from the above maps
- Collection of field data (rainfall, discharge, sediment load etc.) from BBMB, Nangal
- Relationship between discharge and sediment yield
- Estimation of sediment yield from the standard equation and comparison of the results with the observed data

The following sections dealt with analysis of the data and methodology of estimation of sediment yield using empirical relationship has been presented. For preparation of database such as topographical factor, land use and morphological factor GIS software, ILWIS has been used.

6.1 ESTIMATION OF SEDIMENT YIELD

Depending upon the methodologies adopted for modelling the sediment yield from a basin, there are numerous models available. These models vary greatly in complexity, from a simple regression relationships, linking spatial variation in annual sediment yield to climatic and physiographic variables, to simulation models. The simulation models provide a physically based representation of the process occurring in small segments of the catchment and route the response of these segments to the catchment outlet. The regression equations which relate the sediment yield to a basin and hydrometerological conditions in that basin, are mostly used for prediction of sediment yield from ungauged catchment. A review of sediment yield equations developed using data from Indian catchments are explained elsewhere in the previous chapters.

The review of literature shows that there are a number of regression equations available which were applied to various Indian catchments. It is also noted that for estimation of sediment yield, mostly three parameters namely land use, topographical/morphological parameters and rainfall/discharge data have been considered.

6.1.1 Estimation of topographical/morphological parameters

For estimation of topographical and morphological parameters Survey of India (SOI) toposheets were used. The discharge data was converted to digital form and a database was created in GIS environment. The GIS software used in this study is ILWIS (Integrated Land and Water Information System). It was developed at the Computer Centre of International Institute of Aerospace Survey and earth sciences (ITC) Enschede, The Netherlands. The process of database creation for the basin in ILWIS involves collection of relevant available data, including these data into digital format, digitization error checking and correction, polygonization of segment files and finally conversion of data acquired in vector structure to raster format. Computation of the parameters required for morphometric analysis using manual methods like area measurement using dot grid method or using planimeter and length measurement using curvimeter are very tedious and time consuming. In the present work ordering, calculation of various inputs which are required for calculating drainage parameters are estimated using GIS technique.

The boundary of drainage catchment, all streams have been mapped at a scale of 1:50,000 from Survey of India toposheets. Also a contour map at the same scale was prepared. Both these maps were then converted to digital form using digitization and stored in ILWIS. Digitization which is the most time consuming part of the analysis, was carried into parts to minimise the digitization errors. Then the digitized map was corrected for any type of error such as proper joining of the streams, proper overlaying of the segments etc. The system then autoedits the coverage and splits the stream of the higher order at the point where they meet. Individual stream (segment) lengths are computed by default and stored in the order table alongwith the order of each stream. The area and perimeter of the basin were computed after converting segment (boundary) map to polygon map. After converting the contour map into digital form, it was rasterised. Then interpolation from isolines was carried out on this map. This interpolated map gives the elevation at each point(pixel) in the basin. This map was reclassified into a interval of 200 m and shown in Figure 2.

For determination of stream order, Strahler's system, which is slightly modified Horton's method, was followed. Application of this order system through ILWIS over the entire drainage network of the study area shows that study basin is a six order basin. In ILWIS length of each stream is stored in a table. Then after adding length of each stream for a order we obtained total length of each order. The drainage network map with orders is shown in figure 3.

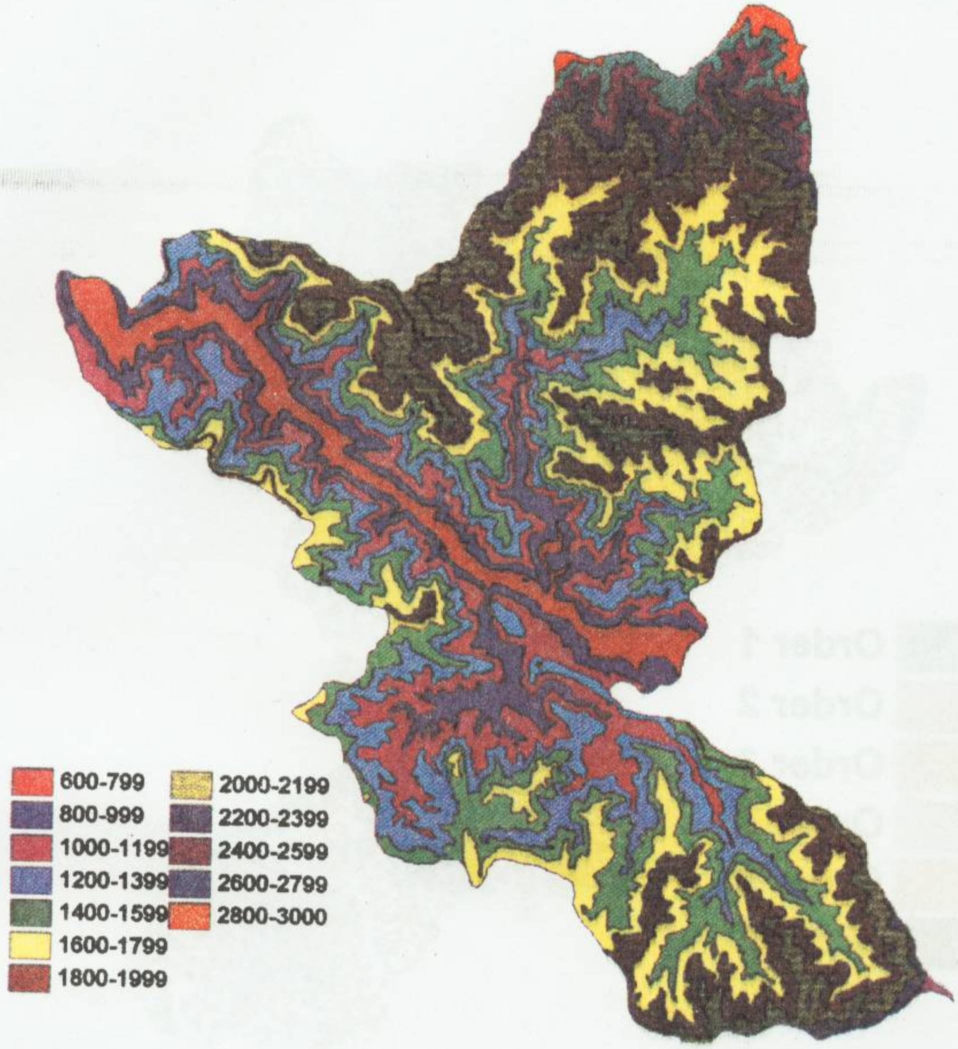

Figure 2: Digital Elevation Model (DEM) of the intermittent catchment

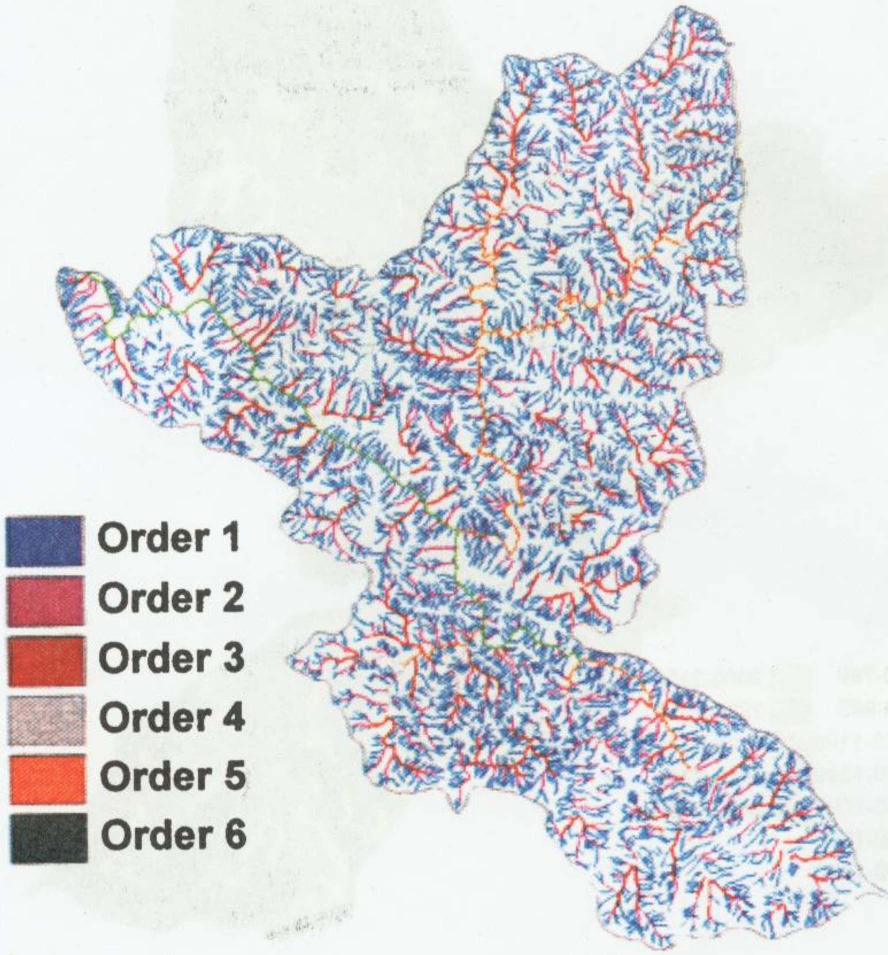

Figure 3: Drainage network map of the intermittent catchment

6.1.2 Use of hydrometeorological data

The rainfall data of the two stations, namely Suni and Kasol, which are falling in the study area were considered. The thiessen polygon for these stations were drawn from the point interpolation and ILWIS was used to determine the weight of each station.

Because the study area comprises the area between Suni to Kasol, covering an area of about 700 km^2, therefore discharge and suspended sediment data have been compiled from daily records maintained at Suni and Kasol. The runoff and sediment derived from the intermittent catchment i.e. from Suni to Kasol were obtained by subtracting the contributions at Suni from Kasol. The above database was prepared for a period of six years from 1991-1996. Because snowfall is not experienced in the lower part of Satluj basin therefore only rainfall data of Suni and Kasol have been analysed for this study.

7.0 ANALYSIS AND RESULTS

As discussed earlier, all the data pertaining to the study area were collected and stored. The following analysis has been made using this data. The estimation of sediment yield using available empirical relationship with the help of GIS is given in next section.

7.1 ANALYSIS OF FIELD DATA

7.1.1 Statistical analysis of sediment yield and discharge data

The sediment yield and discharge data were available for the years (1991-96) at Suni and Kasol. Using this data, sediment yield and discharge for the intermittent catchment between Kasol and Suni were obtained. General statistical analysis for discharge data at Suni, Kasol and intermittent catchement were obtained and presented in the following Tables 2 to 7.

Table 2 : Statistics of discharge (cumec) at Suni using 6 years data (1991-96)

Statistics	1991	1992	1993	1994	1995	1996
Maximum	1636.8	1480.0	1701.7	1898.7	1256.3	1710.2
Minimum	94.9	104.9	102.7	99.2	102.6	102.6
Mean	450.943	383.554	327.222	458.151	382.309	432.277
Stand. Dev.	438.06	353.18	271.57	478.38	344.36	412.90
C_v	0.9714	0.9208	0.8299	1.0441	0.9007	0.9551

Table 3: Statistics of discharge (cumec) at Kasol using 6 years data (1991-96)

Statistics	1991	1992	1993	1994	1995	1996
Maximum	1804.3	1648.7	1873.2	2050.6	1292.2	1861.3
Minimum	99.2	106.3	104.9	100.0	104.9	104.9
Mean	485.183	413.221	344.986	489.201	408.294	465.604
Stand. Dev.	477.61	386.80	291.637	515.699	354.712	438.88
C_v	0.9843	0.9360	0.8453	1.0541	0.8687	0.9426

Table 4: Statistics of discharge (cumec) for Intermittent catchment using 6 years data (1991-96)

Statistics	1991	1992	1993	1994	1995	1996
Maximum	186.1	221.1	223.7	210.3	153.4	184.5
Minimum	0.6	0.4	0.0	0.7	0.3	0.3
Mean	34.239	29.667	17.764	31.050	25.984	33.327
Stand. Dev.	43.26	38.85	25.21	42.40	25.58	35.14
C_v	1.2634	1.3095	1.419162	1.3655	0.9844	1.0544

Table 5 : Statistics of sediment yield (t/km^2) at Suni using 6 years data (1991-96)

Statistics	1991	1992	1993	1994	1995	1996
Maximum	12.597	13.269	13.864	31.474	23.902	24.163
Minimum	0.0039	0.0045	0.0049	0.0049	0.0047	0.0054
Mean	1.575	1.080	0.725	1.962	1.456	1.792
Stand. Dev.	2.597	1.873	1.410	4.006	2.503	3.275
C_v	1.6488	1.7342	1.9448	2.0417	1.7190	1.8275

Table 6: Statistics of sediment yield (t/km^2) at Kasol using 6 years data (1991-96)

Statistics	1991	1992	1993	1994	1995	1996
Maximum	14.23	19.21	23.16	40.32	37.41	27.54
Minimum	0.0057	0.0055	0.0076	0.0072	0.0065	0.0079
Mean	1.886	1.408	0.916	2.396	1.704	2.068
Stand. Dev.	3.07	2.45	1.92	4.97	3.15	3.71
C_v	1.6277	1.7400	2.0960	2.0742	1.8485	1.7940

Table 7 : Statistics of sediment yield (t/km^2) for intermittent catchment using 6 years data (1991-96)

Statistics	1991	1992	1993	1994	1995	1996
Maximum	282.88	420.63	223.7	210.3	948.91	321.83
Minimum	0.0112	0.0112	0.01	0.7	0.0832	0.132
Mean	22.883	23.559	17.764	31.050	18.458	20.671
Stand. Dev.	38.715	45.422	25.214	42.403	58.543	36.911
C_v	1.6918	1.9280	1.4193	1.3656	3.1716	1.7856

The above analysis using 6 years of data shows that the maximum values of sediment yield varies from 14.23 to 40.32, 12.597 to 31.474 t/km^2 being highest during 1994 at both stations for Kasol, Suni and the maximum sediment yield for intermittent catchment ranged from and 210.3 to 948.91 t/km^2. It is to be noted that maximum sediment yield at Suni and Kasol increased significantly after 1994. The mean value of sediment yield varies from 0.916 to 2.396, 0.725 to 1.962 and 17.764 to 23.559 t/km^2 for Kasol, Suni and intermittent catchment respectively. Higher value of sediment yeild from intermittent catchment may be because of high sedimentation rate and lower catchment area. The analysis of discharge at both Suni and Kasol also show that maximum discharge at both the stations were observed in the year 1994.

7.1.2 Distribution of suspended sediment yield

The inter-annual distribution of sediment yield for Suni and Kasol is shown in figures 4 to 9. The suspended sediment concentration begins to increase as the discharge increases from April onward. It remains low during April and May and increases dramatically in the beginning of June and remains high until August. Since discharge in the river is high in the monsoon period, therefore, silt load is also maximum in the river in these months. By the end of September, the concentration reduces significantly and becomes negligible between October and March (winter season). The concentration levels for a particular year, however, cannot be generalised because it varies considerably from year to year and from month to month.

7.1.3 Development of relationship of discharge to suspended sediment yield

As discussed above, the sediment yield is negligible between October and March, therefore relationship was developed between sediment yield, and discharge, for the different years for 6 months, i.e., April to September. The relationship has been determined using six years of (1991-1996) daily data from April to September from the Suni and Kasol stations. The graph showing relationship between discharge and sediment yield are shown in figures 10 to 15 for the different years.

From these figures a relationship between S and Q was developed for the site Kasol, Suni and for intermittent catchment between Suni and Kasol. The relationship is represented in the form of following equation :

$$S = aQ^b \qquad \ldots\ldots\ldots(6)$$

Where S is the sediment yield (t/km^2)

Q is the discharge (cumec), and

a, b are the regression coefficients.

For the years 1991 to 1996, these constants are computed and listed in the Table 8. Also value of coefficient of correlation, r, was also determined and given in the Table 8.

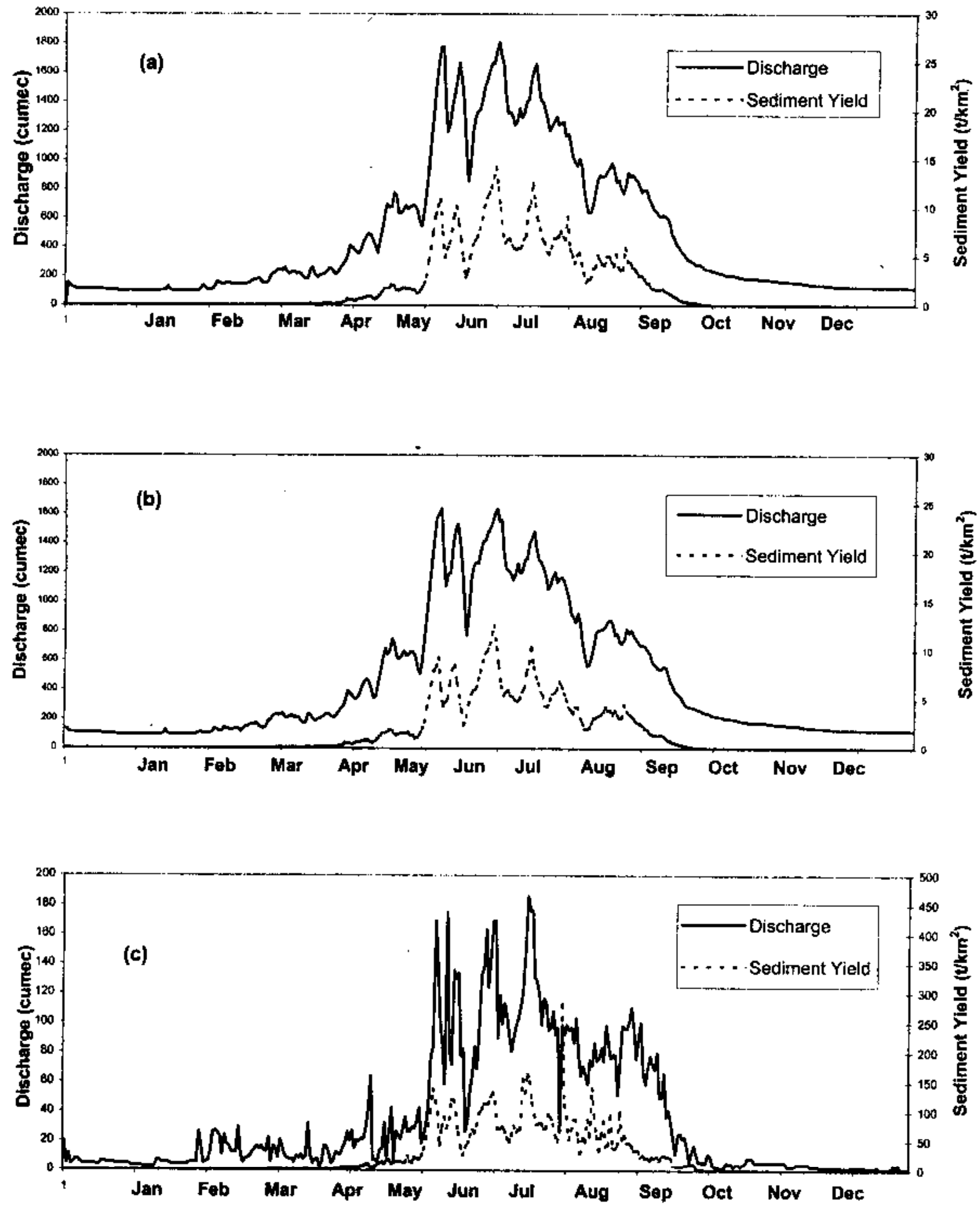

Fig. 4: Daily discharge and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1991)

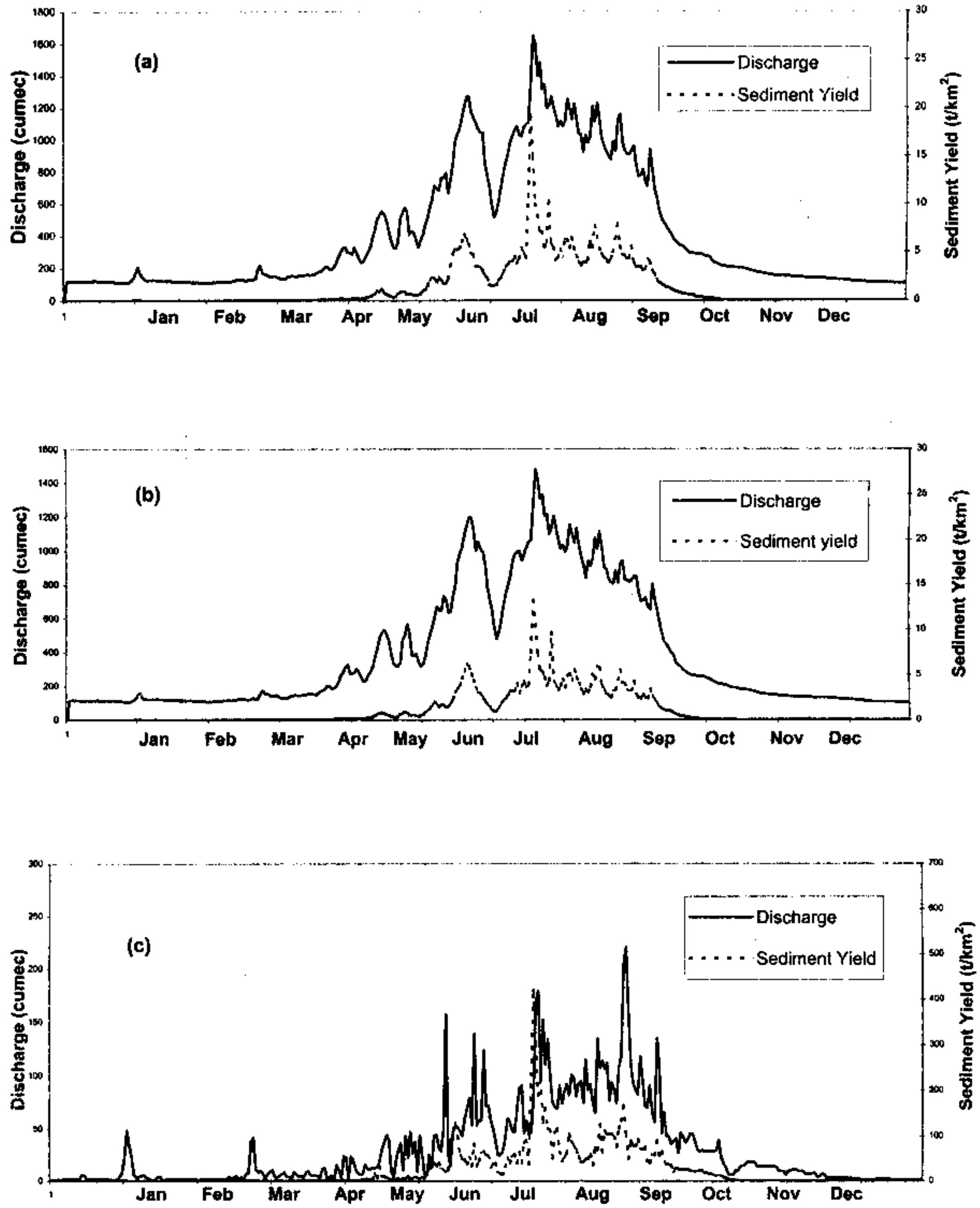

Fig. 5: Daily discharge and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1992)

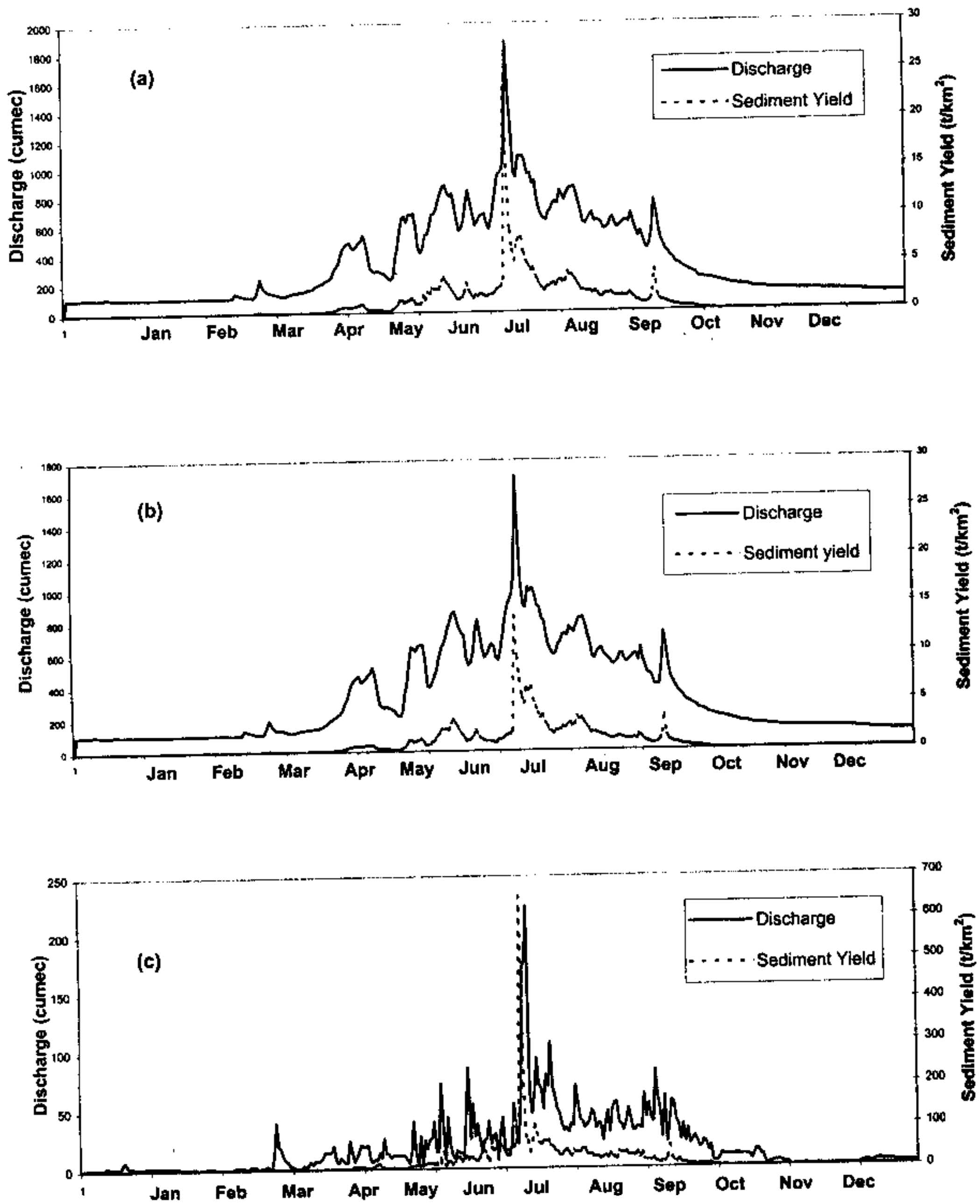

Fig. 6: Daily discharge and suspended sediment yield at (a) Kasol (b) Suni (c) intermittent catchment between Suni and Kasol (1993)

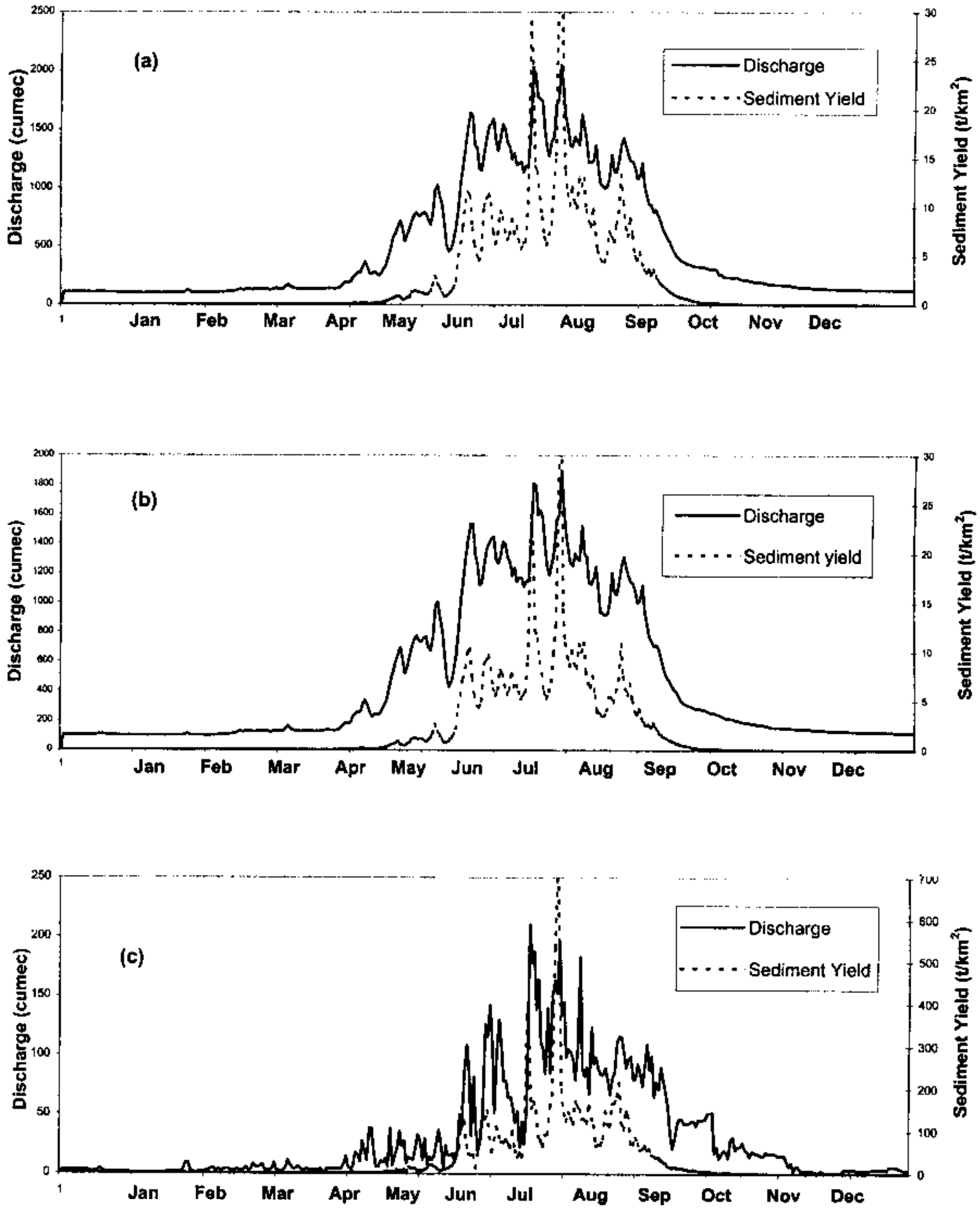

Fig. 7: Daily discharge and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1994)

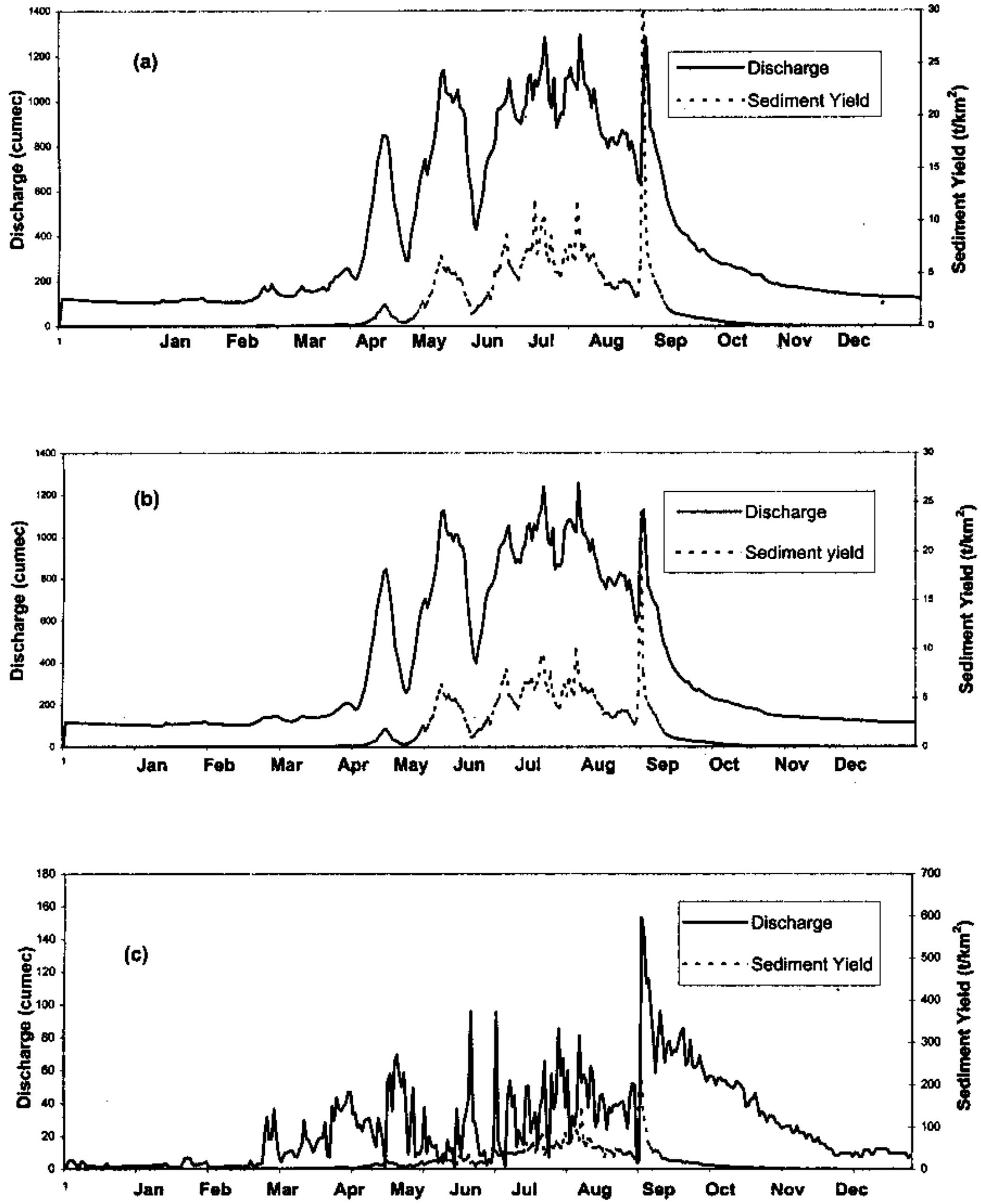

Fig. 8: Daily discharge and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1995)

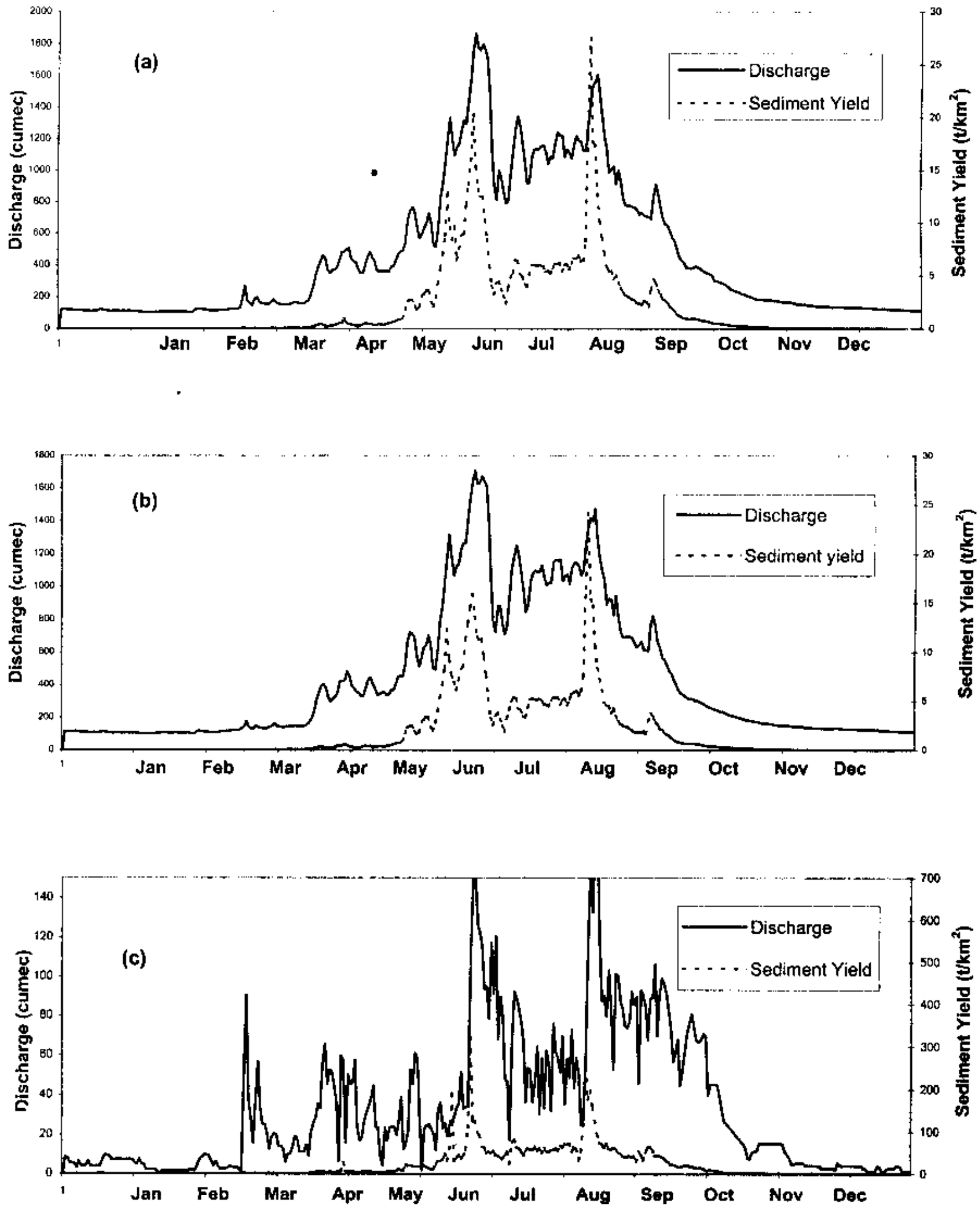

Fig. 9: Daily discharge and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1996)

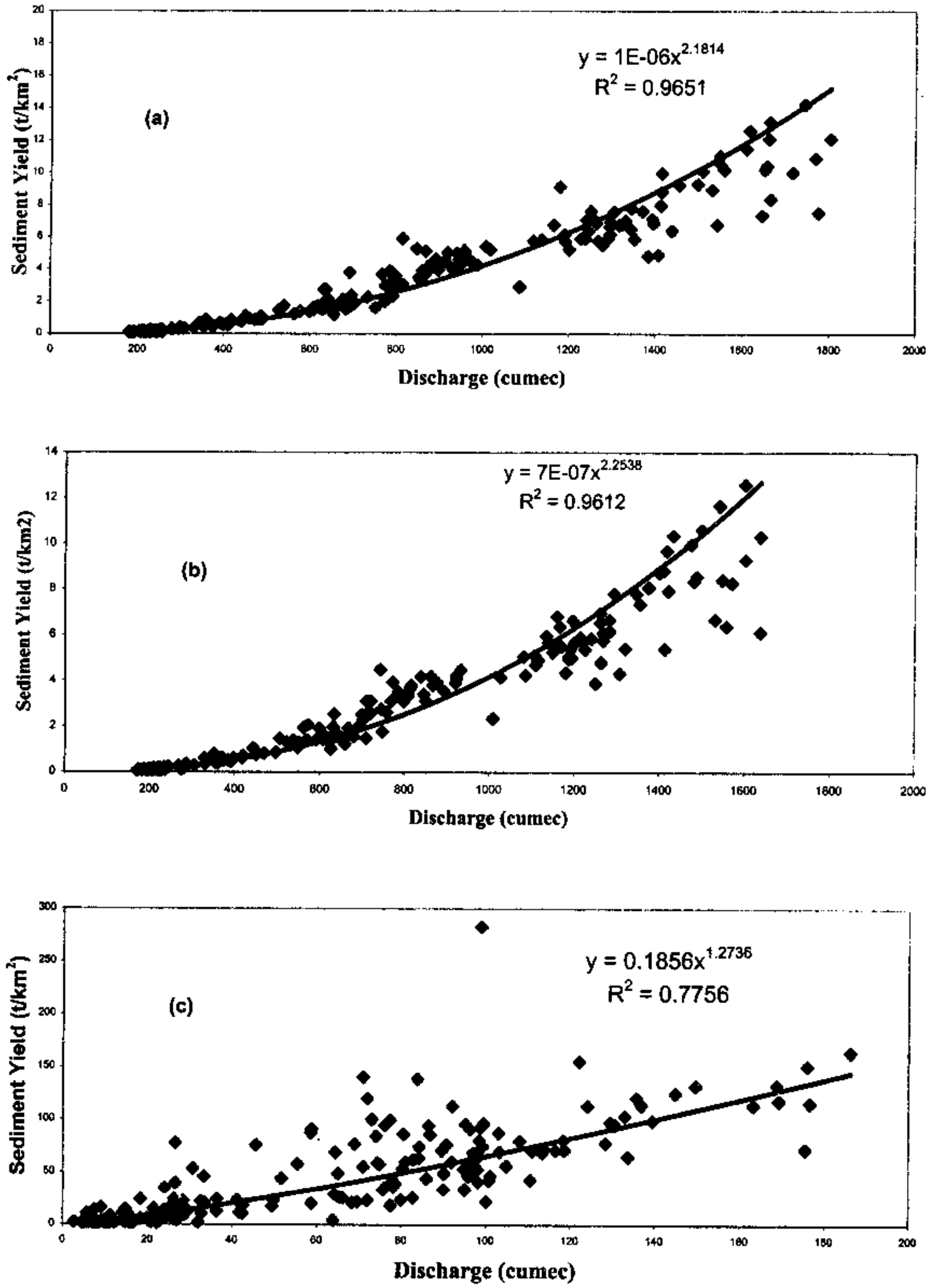

Fig. 10: Relationship of daily discharge and suspended sediment yield from April to Sept. at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol, 1991

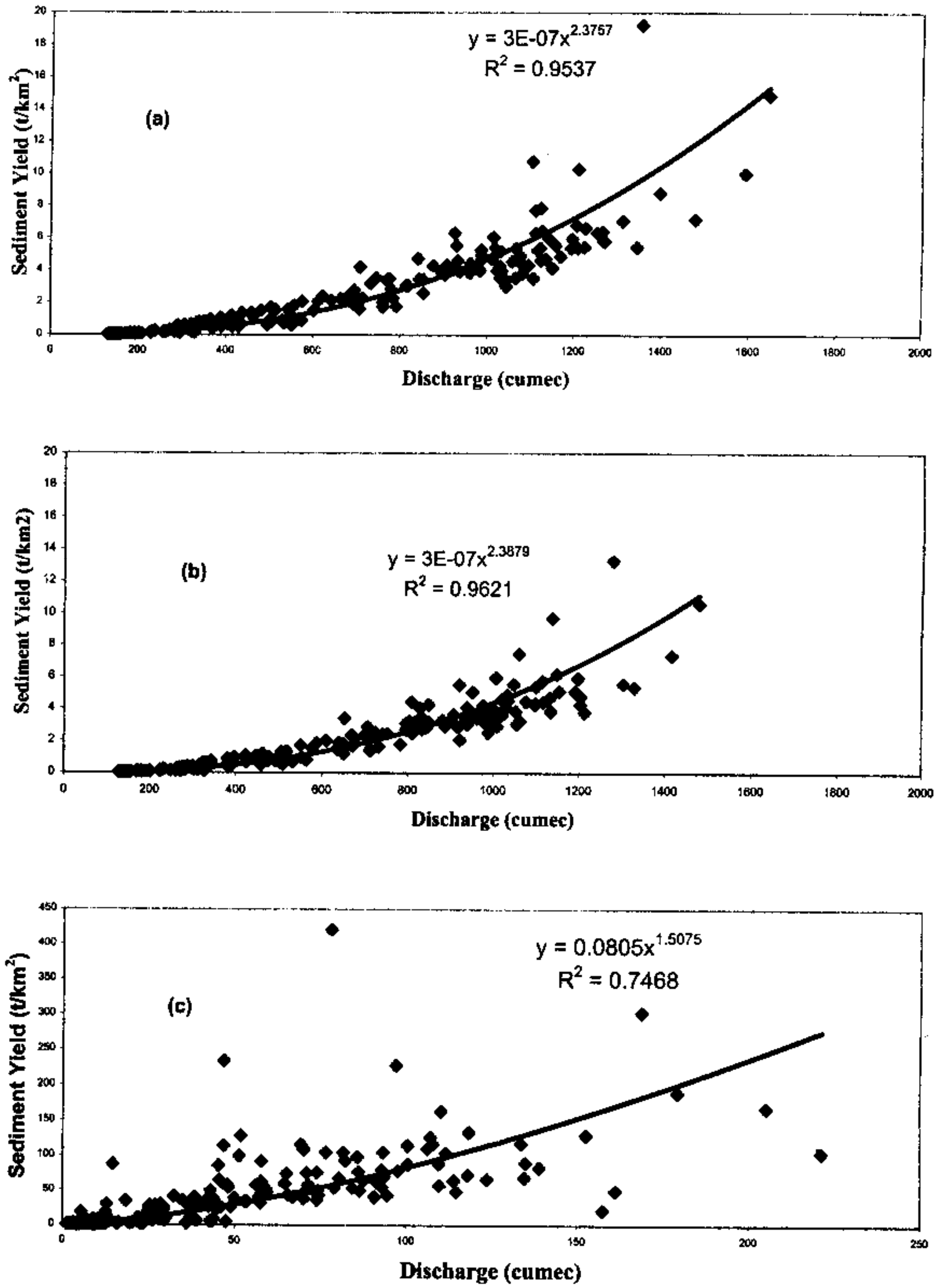

Fig. 11: Relationship of daily discharge and suspended sediment yield from April to Sept. at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol , 1992

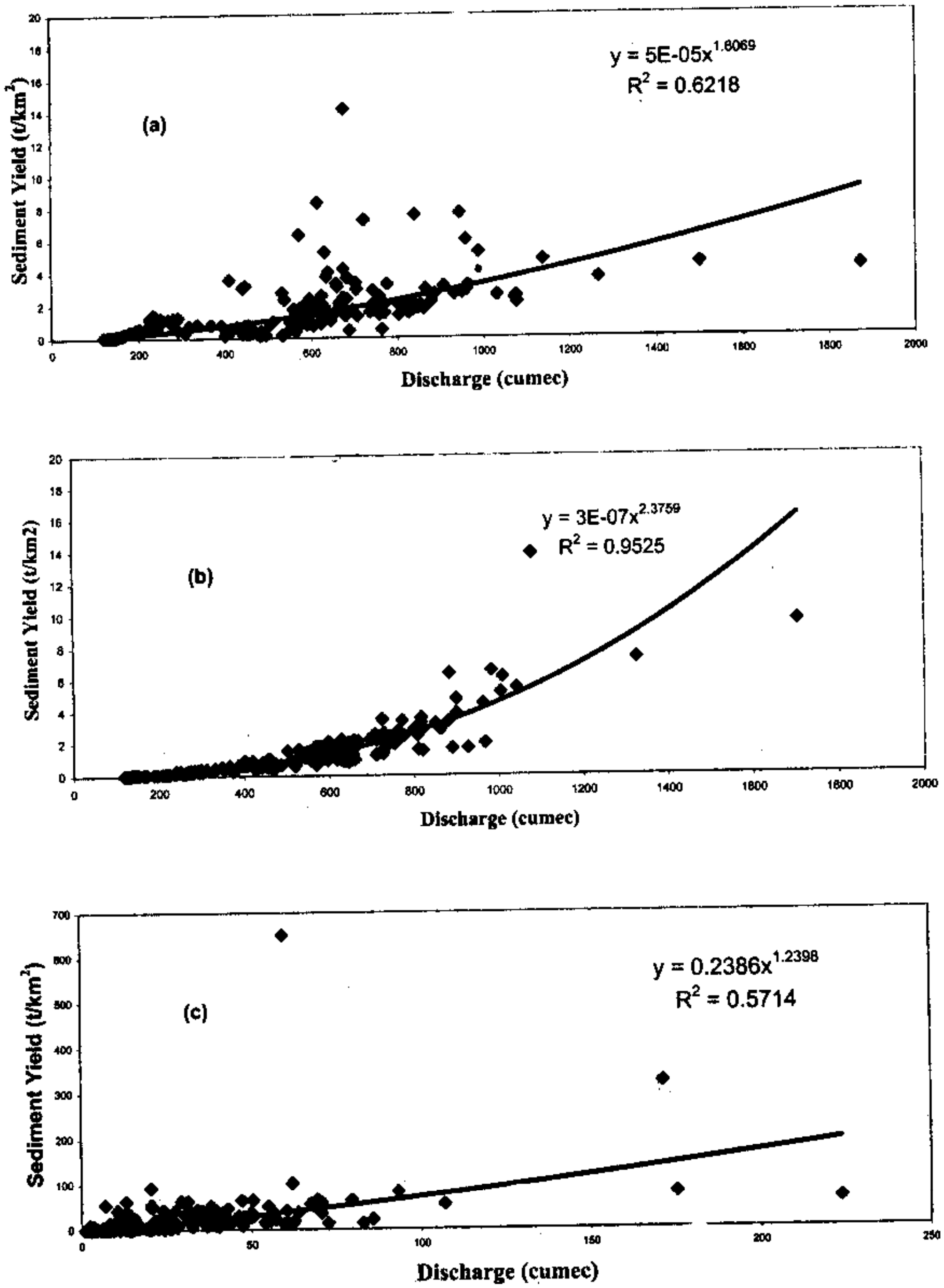

Fig. 12: Relationship of daily discharge and suspended sediment yield from April to Sept. at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol , 1993

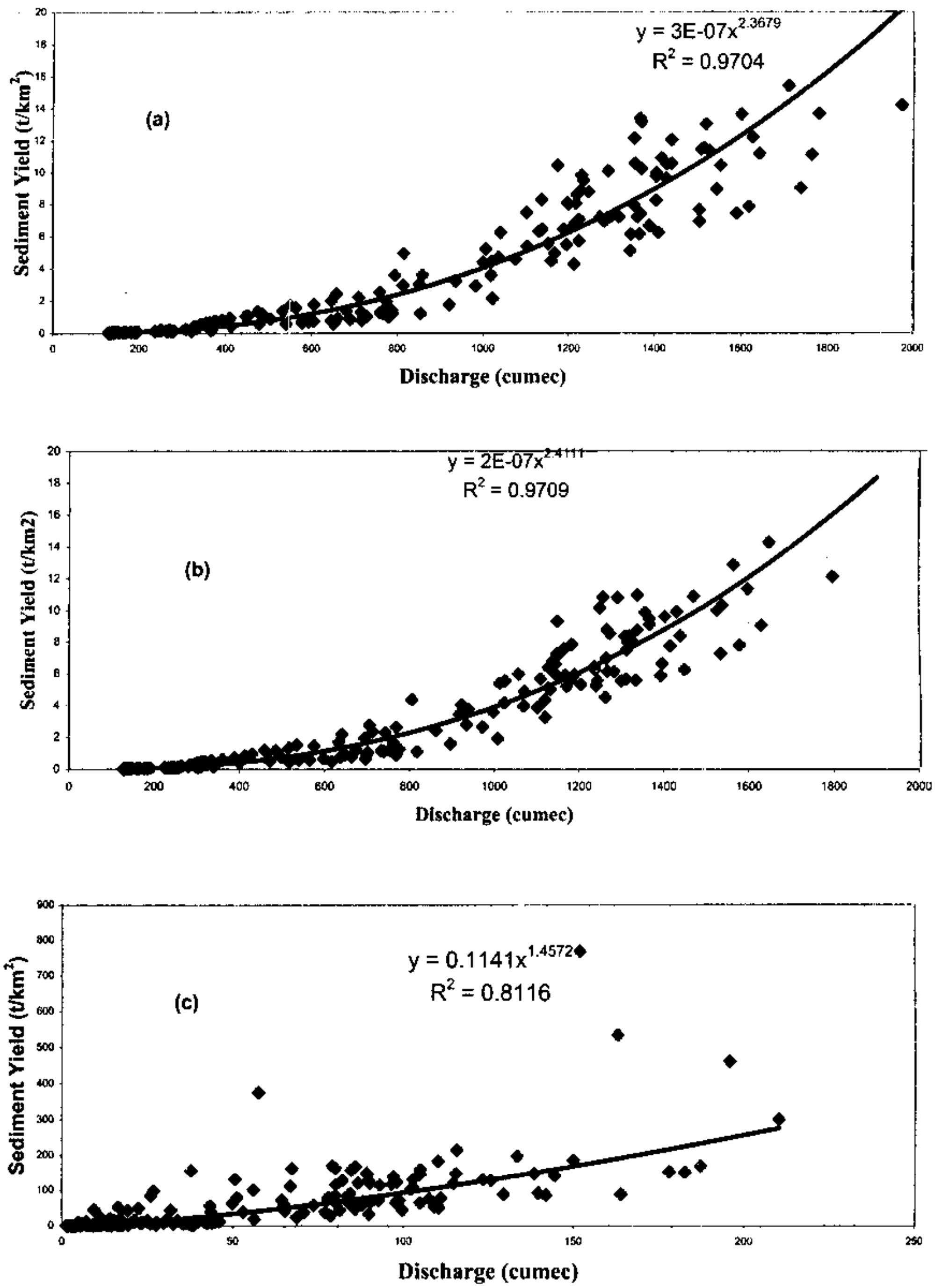

Fig. 13: Relationship of daily discharge and suspended sediment yield from April to Sept. at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol , 1994

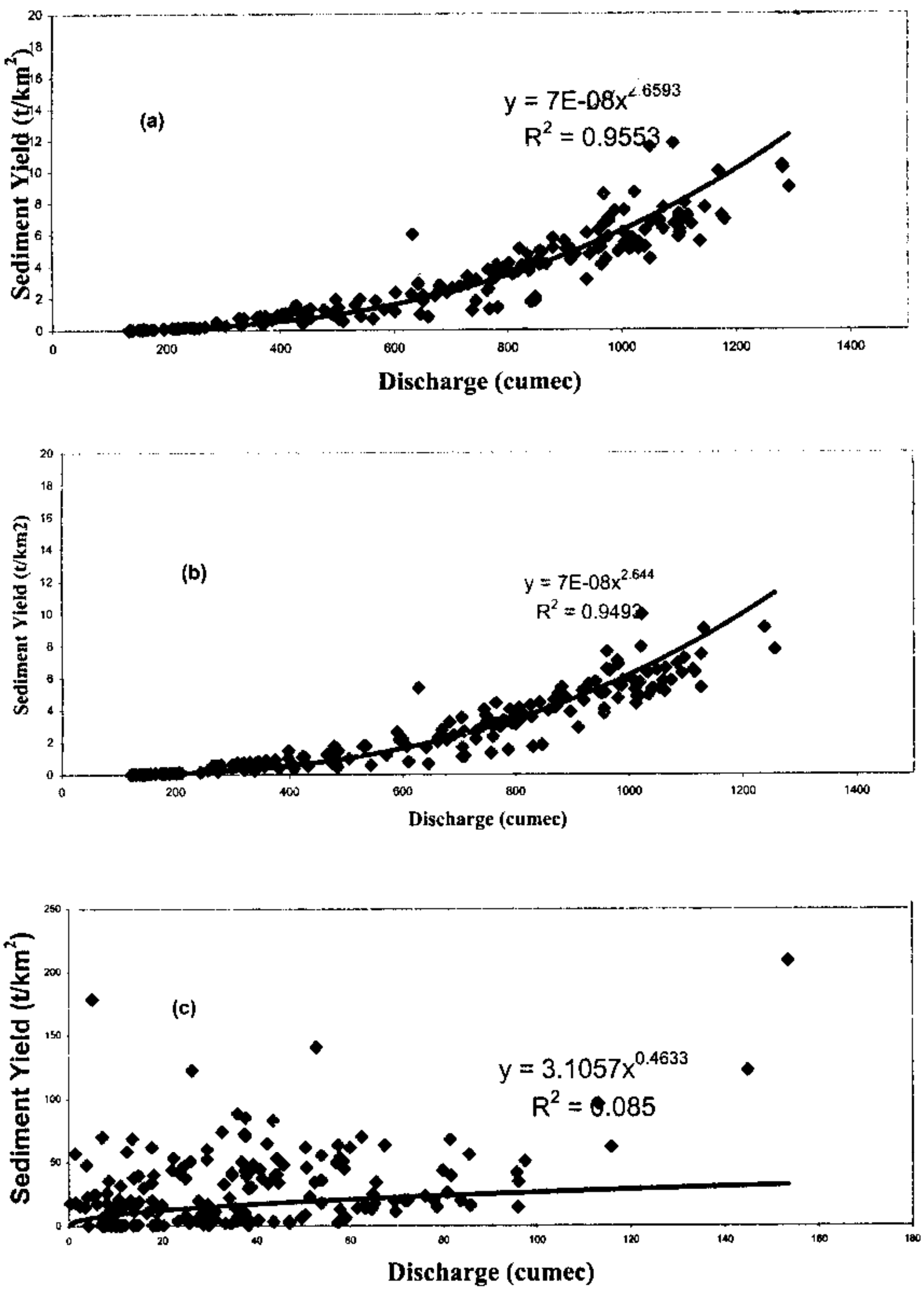

Fig. 14. Relationship of daily discharge and suspended sediment yield from April to Sept. at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol , 1995

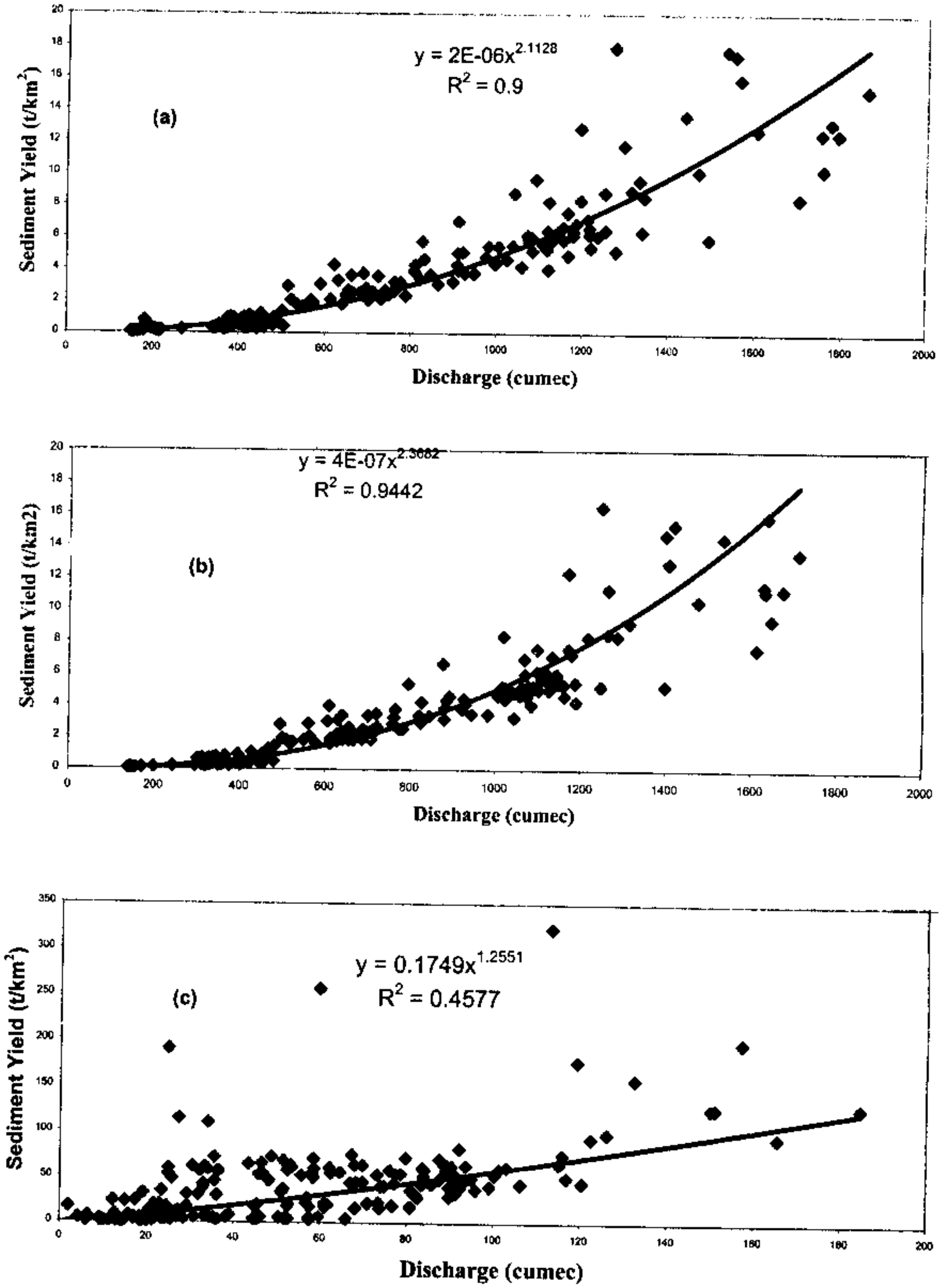

Fig. 15: Relationship of daily discharge and suspended sediment yield from April to Sept. at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol , 1996

Table 8 : The value of regression coefficents a, b and r for different years

Year	Kasol			Suni			Intermittent catchment		
	a	B	r	a	b	r	a	b	r
1991	$1x10^{-6}$	2.1814	0.982	$7x10^{-7}$	2.2538	0.98	0.186	1.274	0.880
1992	$3x10^{-7}$	2.376	0.976	$3x10^{-7}$	2.388	0.981	0.080	1.508	0.864
1993	$5x10^{-5}$	1.607	0.788	$3x10^{-7}$	2.376	0.975	0.238	1.239	0.756
1991-93	$6x10^{-7}$	2.299	0.979	$4x10^{-7}$	2.343	0.978	0.153	1.343	0.80
1994	$3x10^{-7}$	2.368	0.985	$2x10^{-7}$	2.411	0.985	0.114	1.459	0.900
1995	$7x10^{-8}$	2.659	0.977	$7x10^{-8}$	2.644	0.974	3.106	0.463	0.275
1996	$2x10^{-6}$	2.113	0.948	$4x10^{-7}$	2.368	0.971	0.175	1.256	0.676

The sediment yield was highly correlated with discharge ($r>0.94$) for both Suni and Kasol for all the years, except for Kasol for 1993 ($r=0.79$). The correlation coefficient between S and Q was high, for the years, except 1995. The analysis of data shows that poor correlation for 1995 was due to comparatively heavy rainfall for this year for intermittent catchment. The figures from 16 to 21 shows relationship between rainfall and suspended sediment yield for different years.

7.2 ESTIMATION OF SEDIMENT YIELD

7.2.1. Using the developed relationship

In the last section, a relationship between sediment yield and discharge has been developed on the basis of three years data (1991-93). This relationship in the form of power law is as follows:

For the site Kasol

$$S=6E\text{-}07\, Q^{2.299} \qquad (7)$$

For the site Suni

$$S=4E\ 07\, Q^{2.342} \qquad (8)$$

For the intermittent catchment

$$S=0.153\, Q^{1.343} \qquad (9)$$

Now using this relationship, the daily values of sediment yield have been estimated from discharge data for the remaining three years i.e. from 1994 to 1996. These estimated values of sediment yield and observed values of sediment yield for these three years were plotted and shown in figures 22 to 24 for 1994, 1995 and 1996 respectively. From these figures we can see that the estimated values of sediment yield are matching with the observed values with reliable

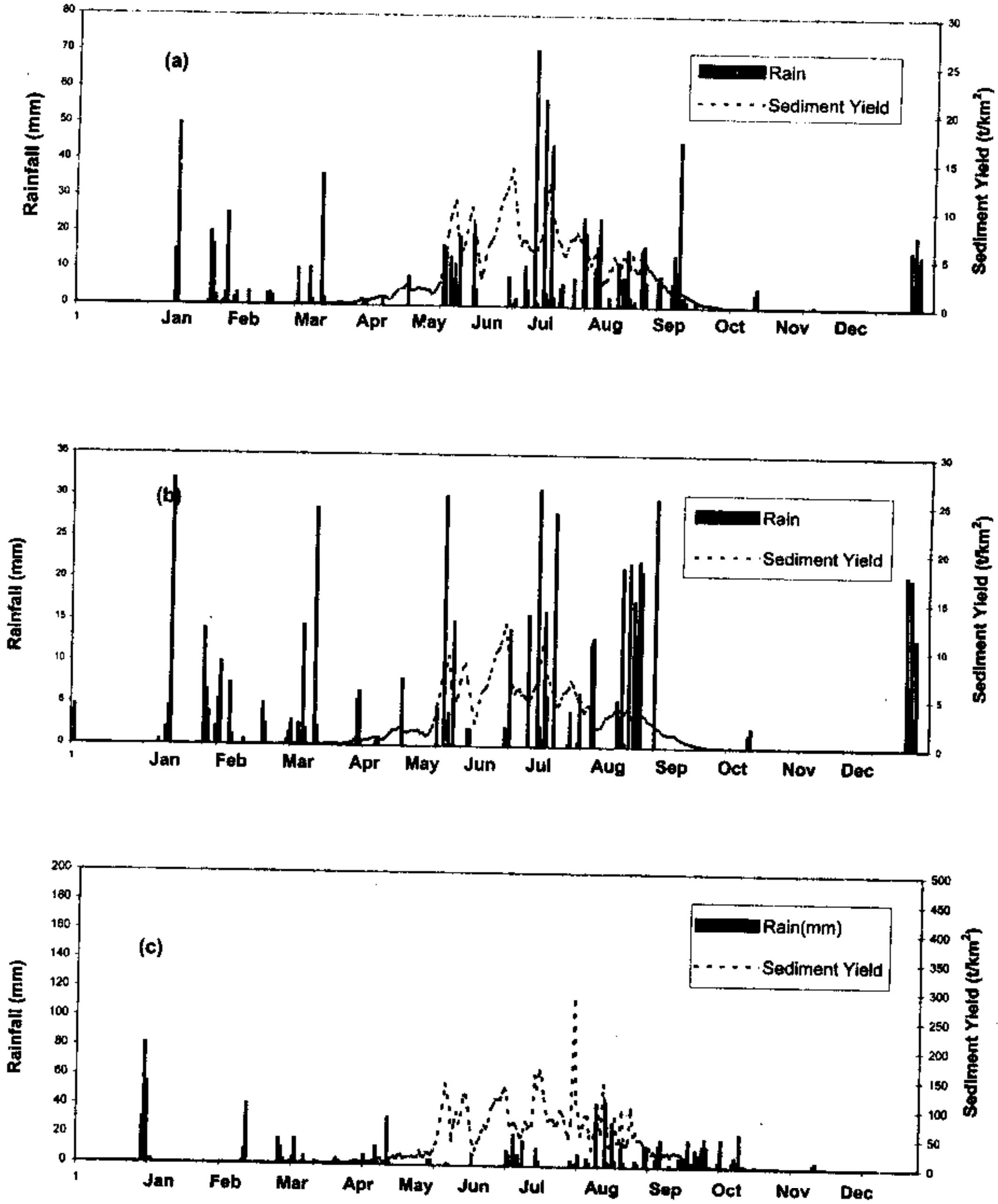

Fig. 16 Daily rainfall and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1991)

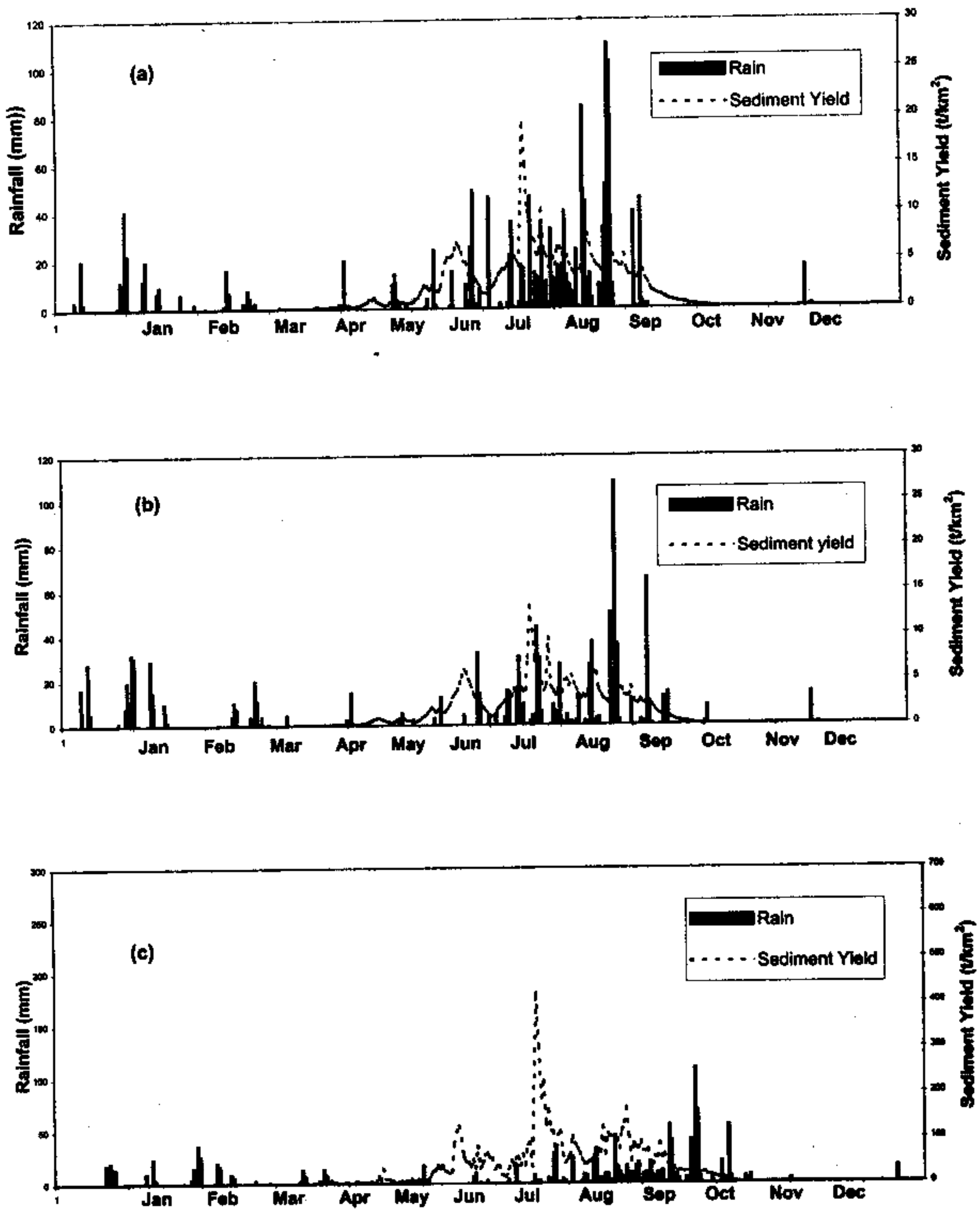

Fig. 17 Daily rainfall and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1992)

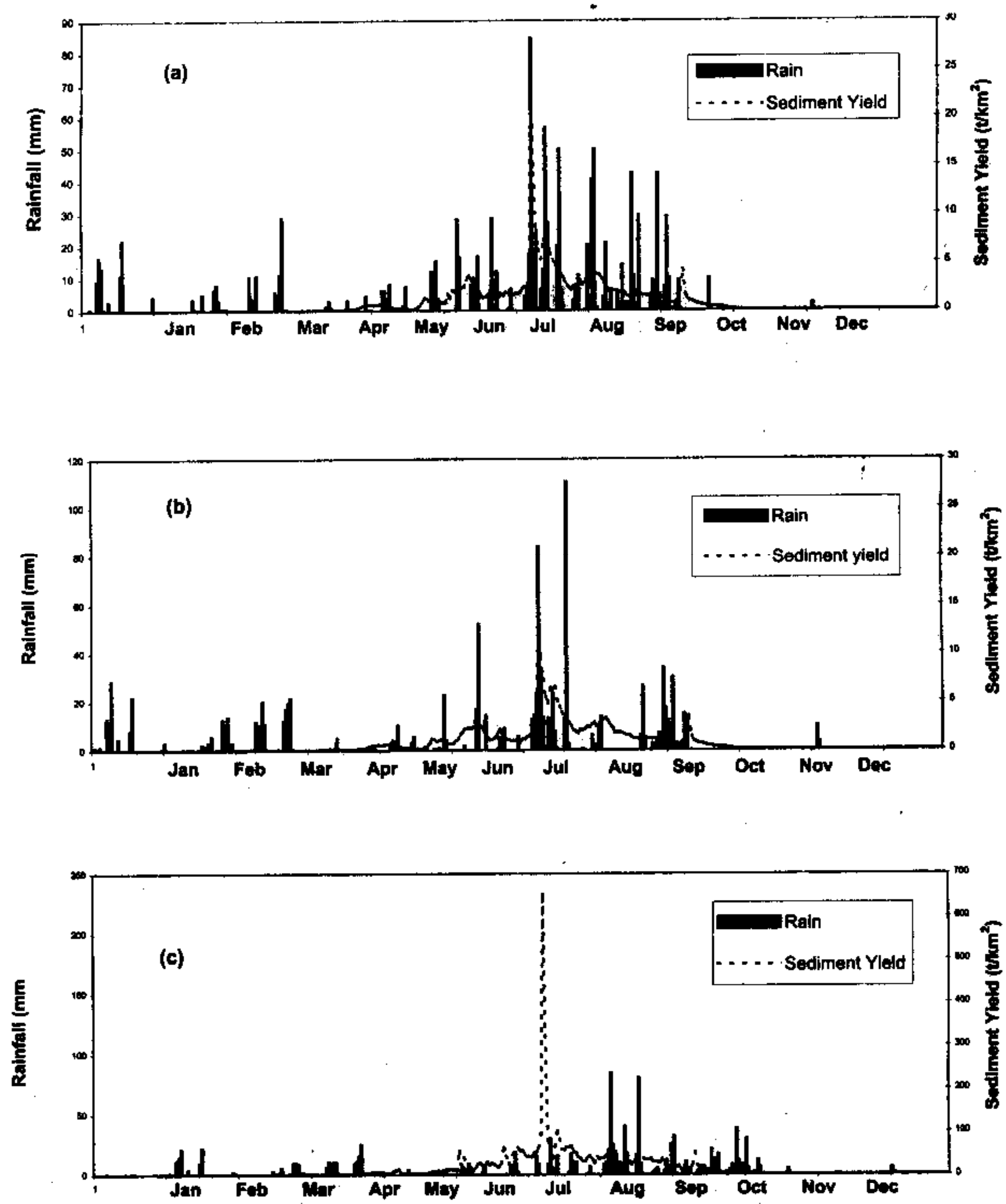

Fig. 18. Daily rainfall and suspended sediment yield at (a) Kasoi (b) Suni (c) Intermittent catchment between Suni and Kasoi (1993)

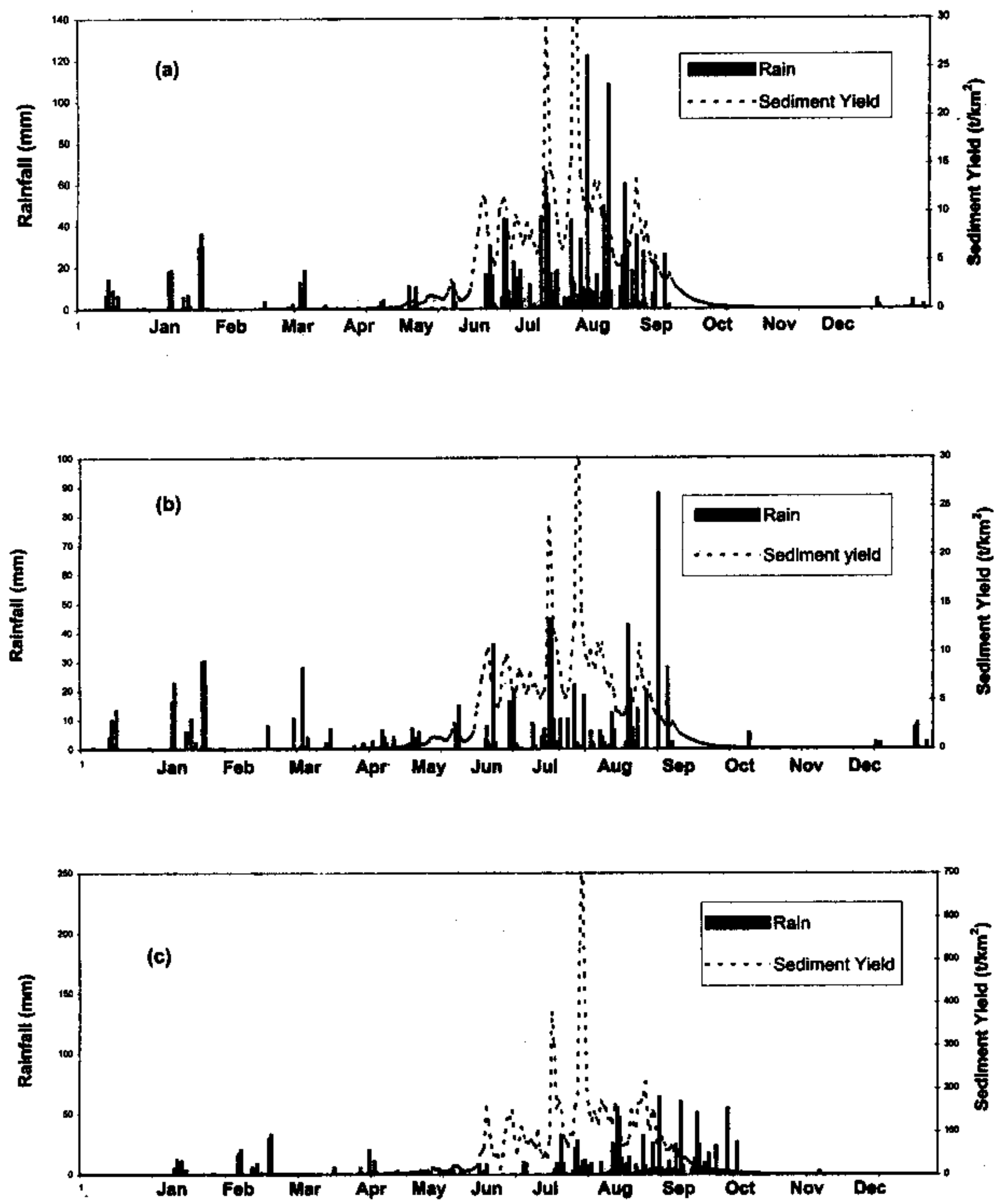

Fig. 19 Daily rainfall and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1994)

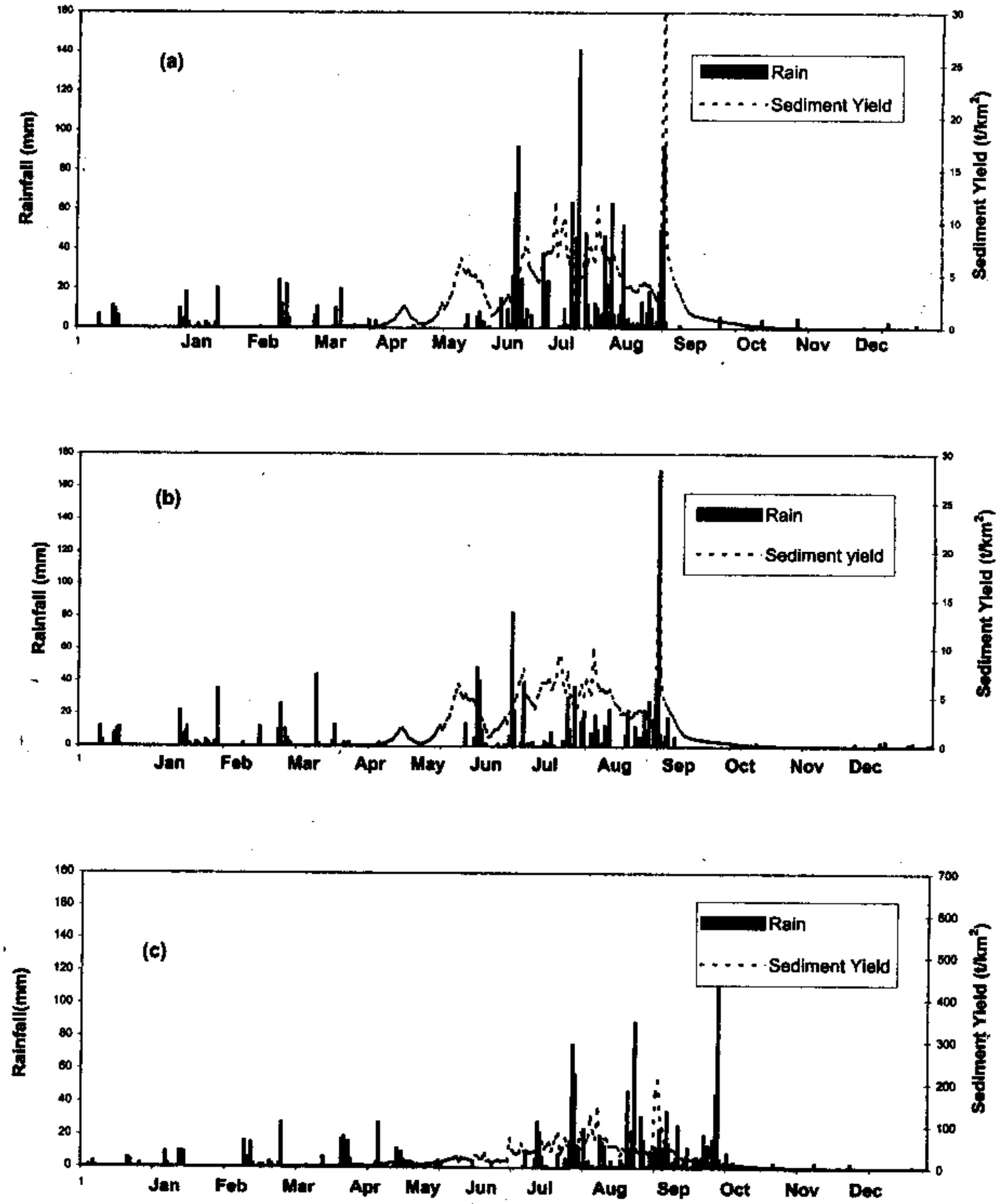

Fig. 20 Daily rainfall and suspended sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment between Suni and Kasol (1995)

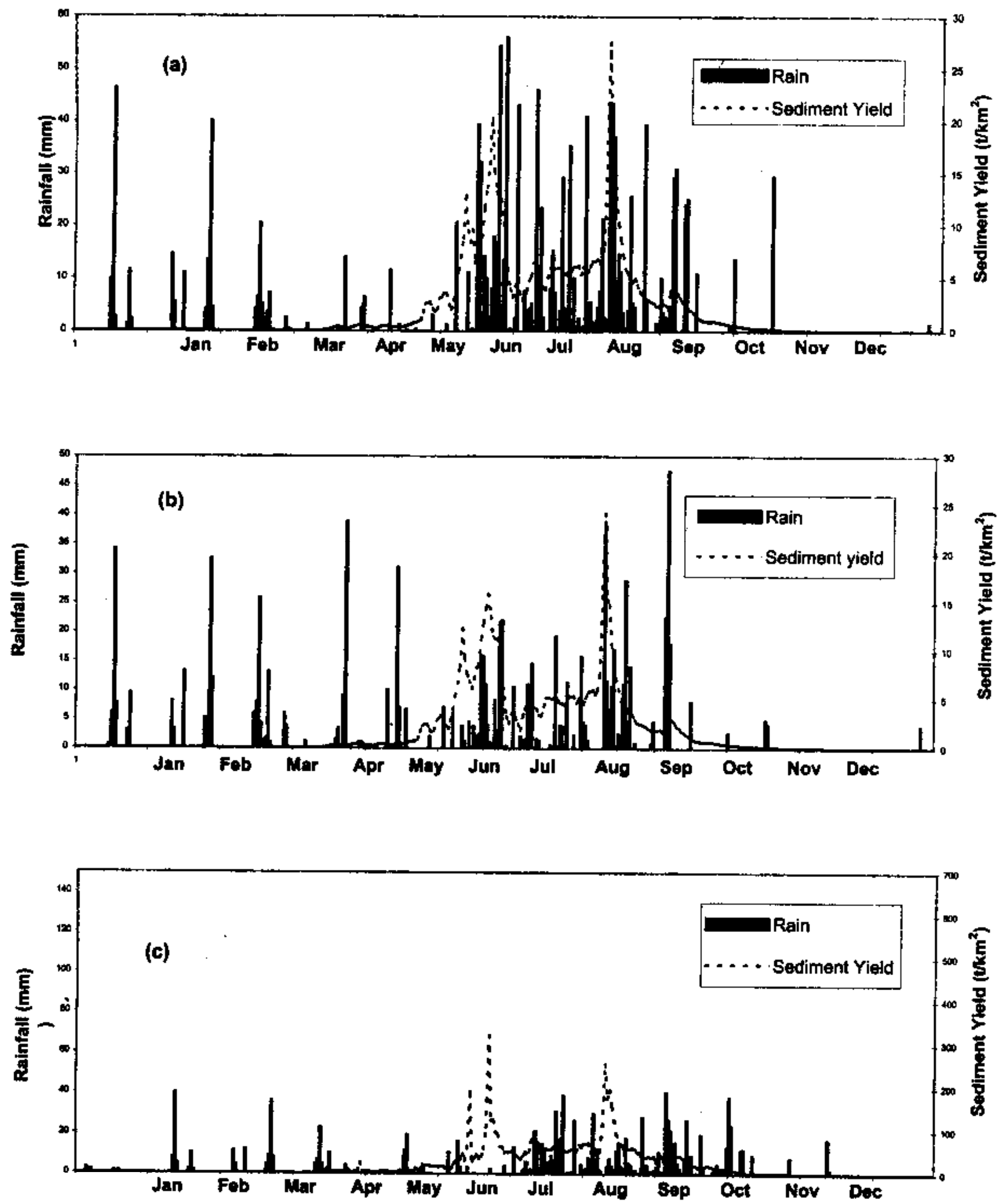

Fig. 21 Daily rainfall and suspended sediment yield at (a) Kasol (b) Suni (c) intermittent catchment between Suni and Kasol (1996)

accuracy. Also relationship between observed and estimated values of sediment yield have been made and plots of these two values for three years are shown in figures 25 to 27 for the three years. From this relationship we can see that these two values are highly correlated with the each other.

7.2.2. Using Empirical relationship

As discussed earlier there are various empirical relationships for estimation of sediment yield. In the present study, the soil erosion was estimated using the relationship given by Garde et al. (1987) and given in the Equation (4).

The parameters like area, drainage density, slope, vegetation factor have been computed using GIS. The methodology adopted has been described earlier. For computation of morphological parameter drainage density (D_d), drainage network map was prepared in ILWIS and Strahler system of ordering was applied and this is shown in Fig. 3 shown earlier. The numbers of different order streams and their lengths are shown in table no. 9 given below.

Table 9: Number of streams and lengths of channels

Order	Number of streams	Length (m)
1	3323	1658
2	1444	442
3	691	198
4	28	103
5	6	56.156
6	1	36.496

Drainage density is the ratio of the total channel length and area, from the above table drainage density for the study area comes out to be 3.58.

For computation of slope, DEM of the study area was prepared and is shown in figure 2. A slope map was prepared using this DEM. The average slope of the study area was calculated to be 0.48.

The land use factor of the study area was computed using the landuse map of the study area (Jain et al., 1998). In this map the forest area and agriculture area is almost similar, therefore the land use factor is taken as 0.5.

Using above determined parameters, the sediment yield for all the years was calculated from the empirical relationships given in the Equations (4) and which is as follows:

$$V_s = 1.182 \times 10^{-6} P^{1.29} A^{1.03} D_d^{.40} S^{0.08} F_c^{2.42}$$

The above equations were developed for Indian catchments. The soil erosion values which were obtained after applying the above relationship and are given in the following Table 10. The estimated values of sediment yield from both the equations underestimated the sediment yield values.

Table 10 : Observed and estimated values of sediment yield (t/km^2) for different years.

	Sediment yield (t/km^2)			
Year	Observed	Estimated using (Eq. 4)	Revised after applying factor	Obs./Est.
1991	4.566	0.666		
1992	4.705	1.197		
1993	2.629	0.854		
1994	5.754	1.081	5.00	1.15
1995	3.063	1.215	5.61	0.55
1996	4.127	1.038	4.79	0.86

As such use of this equation underestimated sediment yield from the study basin. The basic reason for underestimates of sediment yield may be these equations were not developed for mountain basins. To account for this aspect, a ratio between observed and estimated values of sediment yield was determined on the basis of the results of three years. This ratio which comes out to be 4.62, was applied for the remaining three years i.e. for 1994-96. The revised value of sediment yield were estimated and given in the last column in the above table. From these values we can see that for two years, the estimated value of sediment yield is in close agreement.

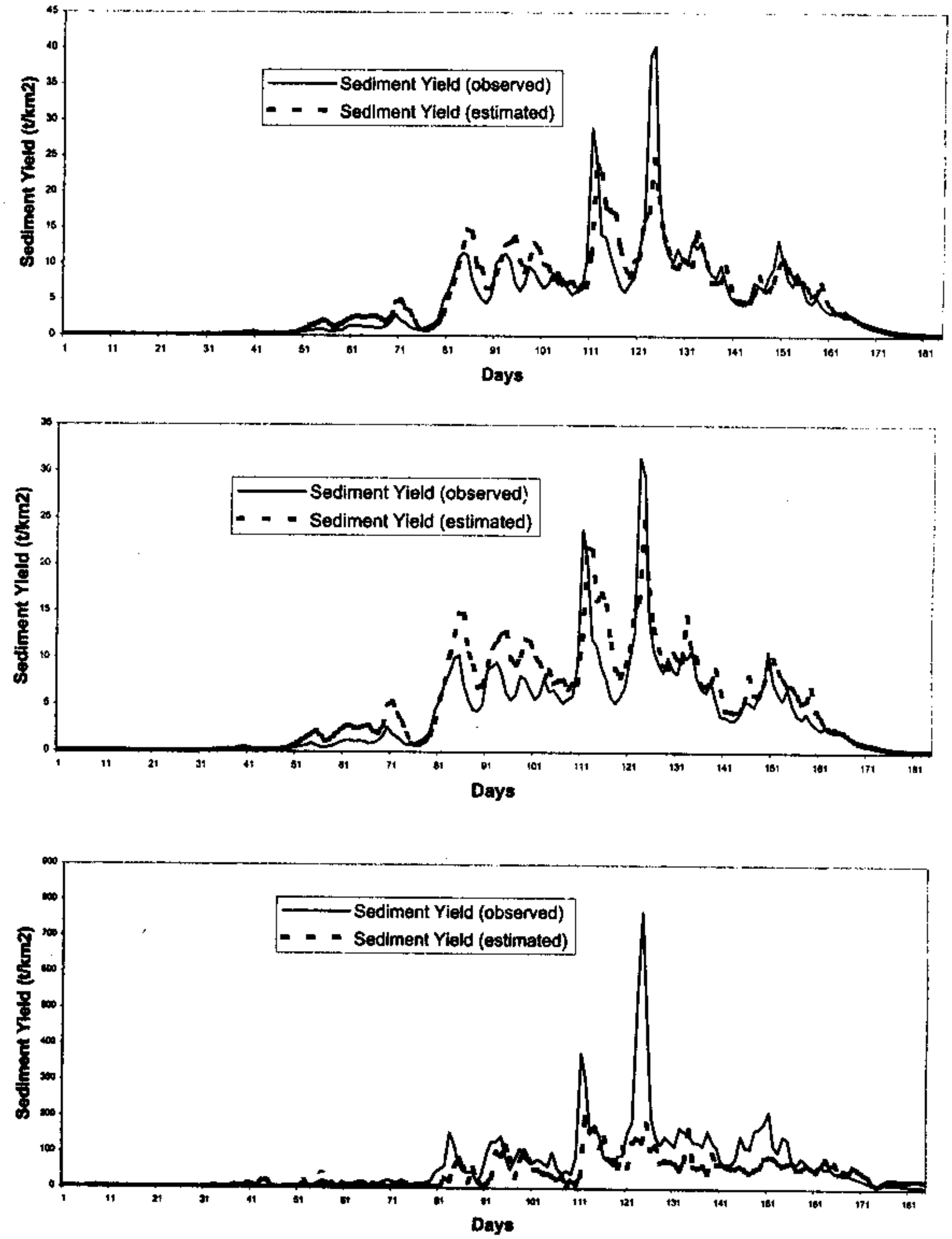

Fig.22: Daily sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment (1994)

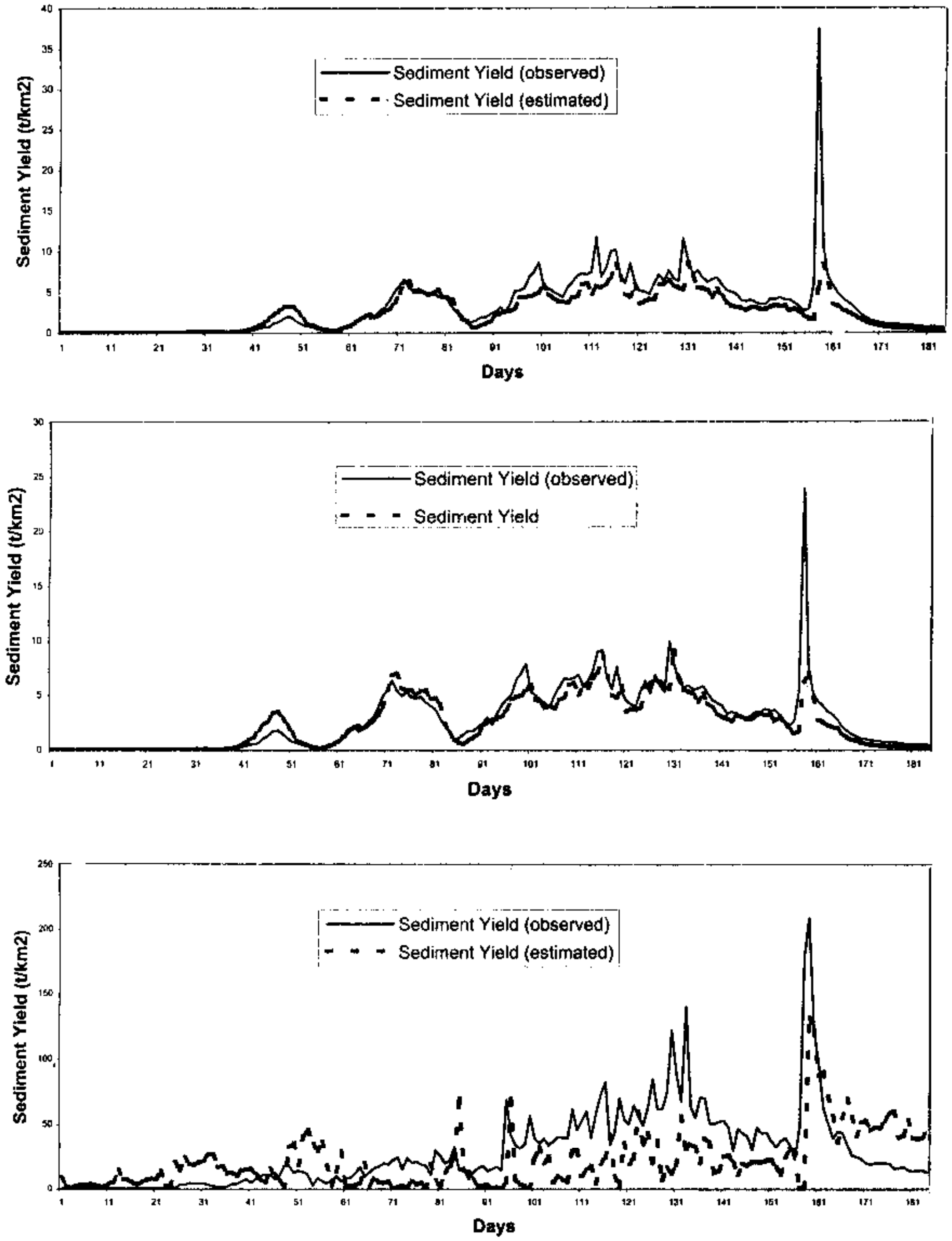

Fig.23 Daily sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment (1995)

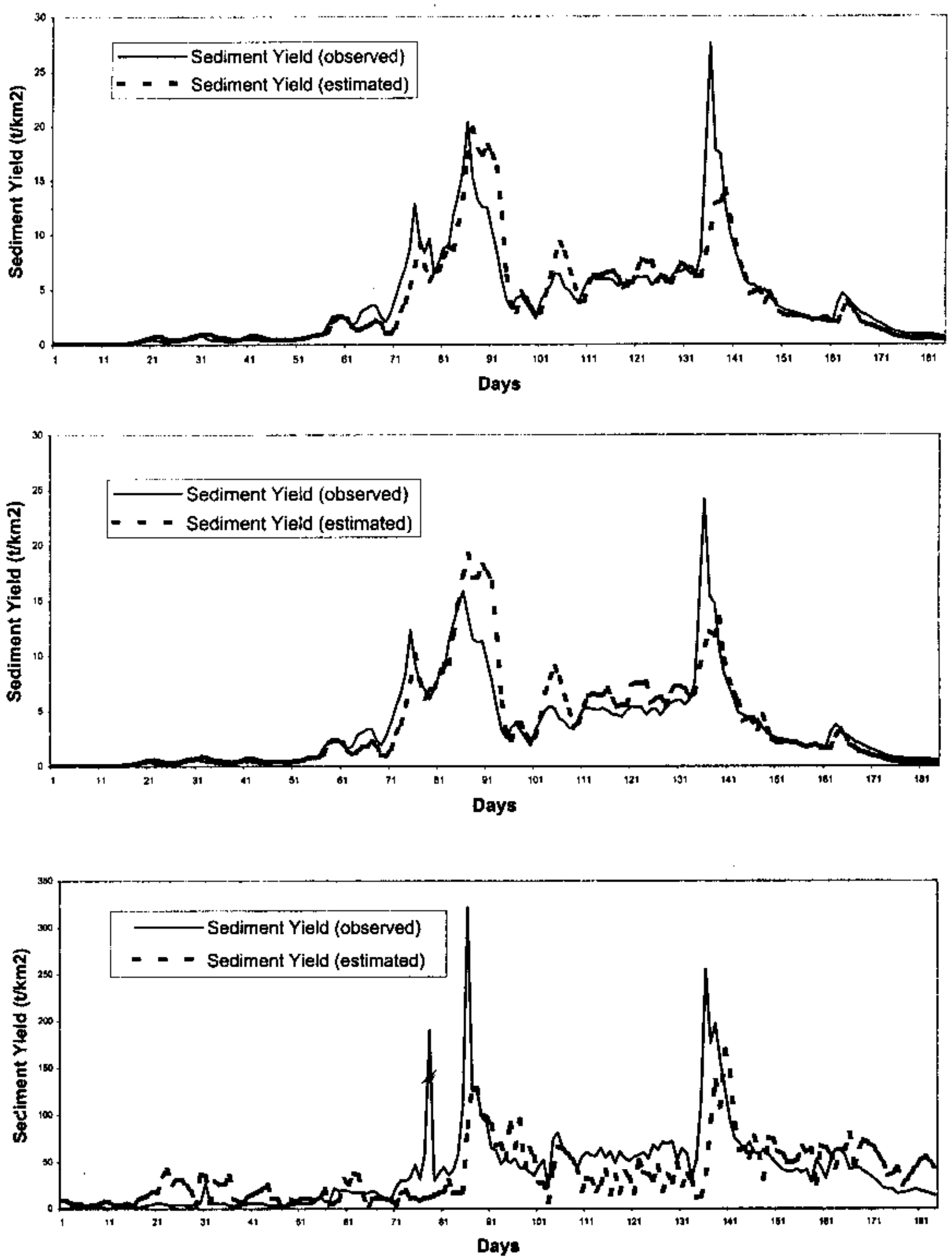

Fig 24 Daily sediment yield at (a) Kasol (b) Suni (c) Intermittent catchment (1996)

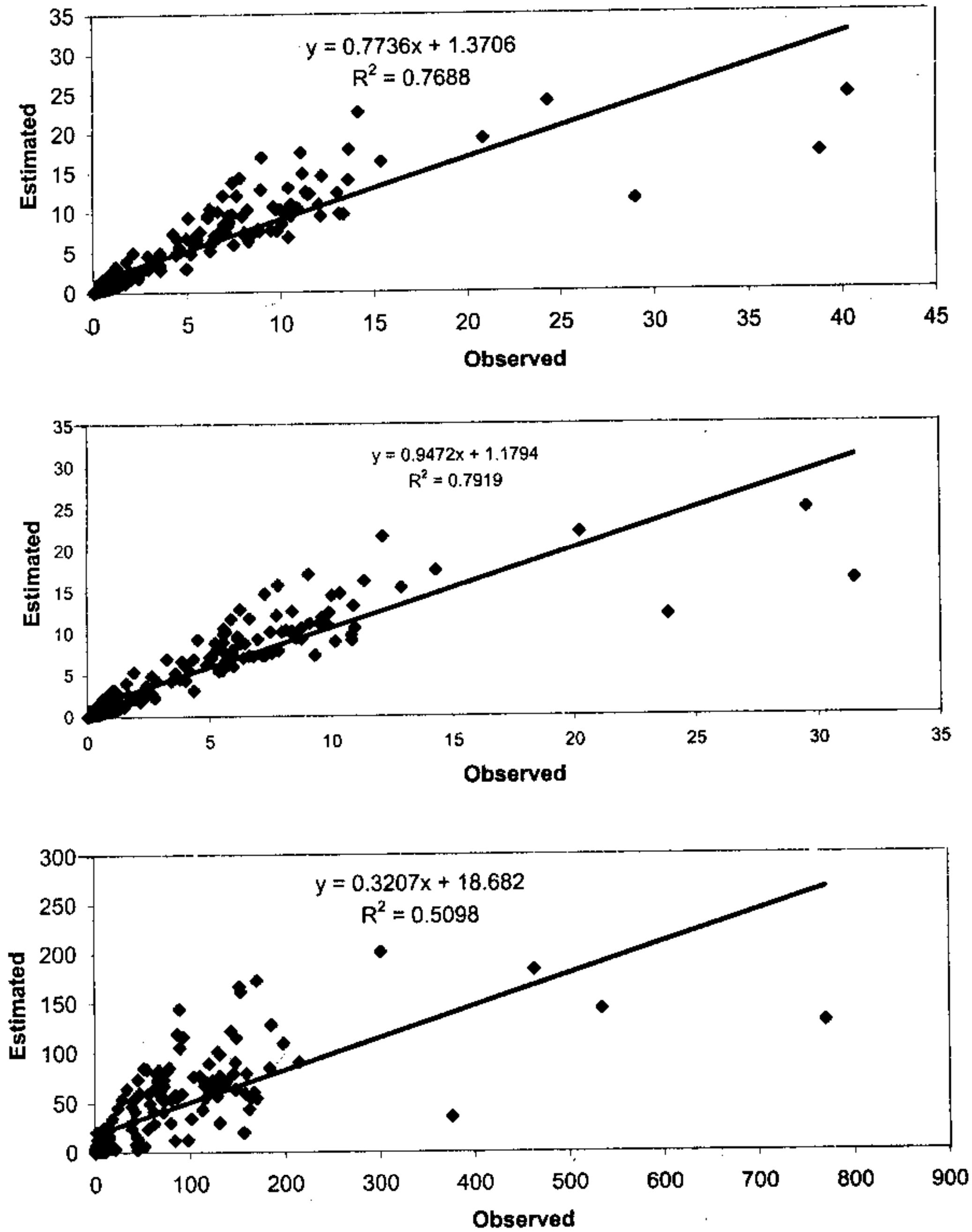

Fig. 25: Relationship of daily sediment yield (observed vs. estimated) from April April to Sept. at (a) Kasol (b) Suni and (c) Intermittent catchment, 1994

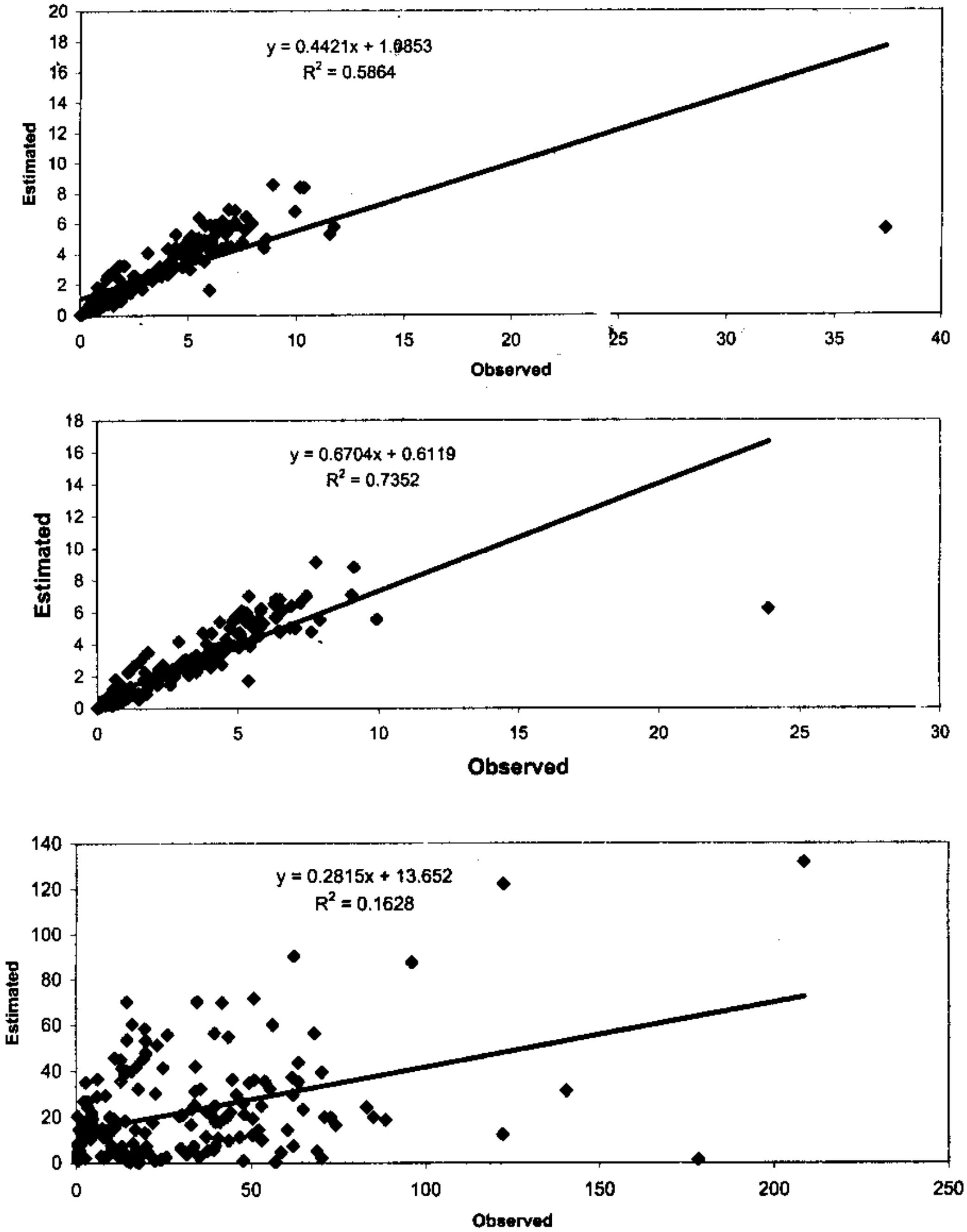

Fig 26: Relationship of daily sediment yield (observed vs. estimated) from April April to Sept.at (a) Kasol (b) Suni and (c) Intermittent catchment, 1995

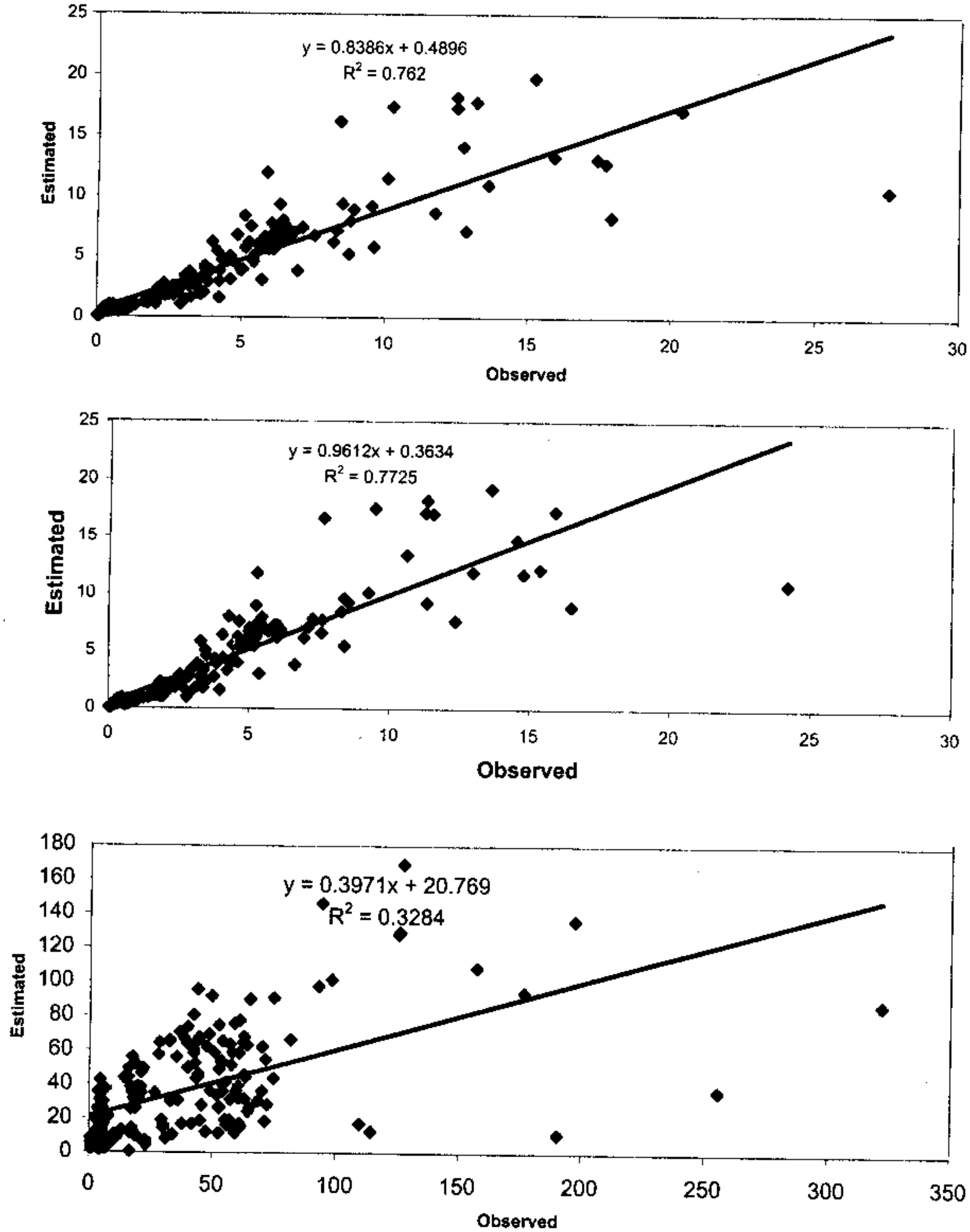

Fig. 27 Relationship of daily sediment yield (observed vs. estimated) from April to Sept.at (a) Kasol (b) Suni and (c) Intermittent catchment, 1996

8.0 CONCLUSIONS

This report deals with estimation of sediment yield for the lower part of Satluj. In this study a relationship between sediment yield and discharge (rating curve) has been established. This relationship was established for the Satluj basin at two sites namely Suni and Kasol and for intermittent basin between these two sites. There was a good correlation between sediment and discharge for all three study areas for all the six years. A general relationship was developed between sediment yield and discharge using three years (1991-93) data on the basis of daily values. This relationship was used to simulate the value of sediment yield for the remaining three years. There is reasonably good aggreement between estimated and observed data for these three years for the basin at two sites i.e. Suni and Kasol and for intermittent catchment. However there was a substantial deviation between observed and estimated values for the year 1995. The reason for this can be attributed to heavy rainfall in this year in comparison to other years. It appears that local events like land slides etc. may have generated high variability in the sediment load. With the help of data for more years, this relationship can be generalised and can be used for generating sediment yield with the help of discharge data. In this way collection of sample in the field and computation of sediment concentration can be minimised.

For estimation of annual sediment yield intermittent basin from Suni to Kasol was selected. The intermittent basin experience only rain and has special importance in reference to high soil erosion rates. Also topographical data for the high altitude region is not available. For the estimation of sediment yield a relationship given by Garde et. al (1987) was used. In this approach physical characteristics of the basin was also considered and these parameters have been derived using GIS approach. The sediment yield by this relationship was significantly underestimated. It is understood that this equation developed using the data of Indian catchments located in plain regions while the study area lies in the outer Himalaya, where heavy rainfall is experienced due to orographic effect on precipitation (Singh and Kumar, 1997). Attempts were made to estimate the sediment yield accurately using a factor in the above equation. For computation of this factor, sediment yield for the three years (1991 to 93) was estimated using the existing relationship. The ratio between observed and estimated values were computed and average value of these ratio was determined. This ratio which may call as orographic ratio and it comes out to be 4.62. The sediment yield for the remaining three years (1994-95) was computed using the relationship and the result was multiplied by this factor. Now the result shows that for two years, the estimated value of sediment yield is in close agreement with the observed value.

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