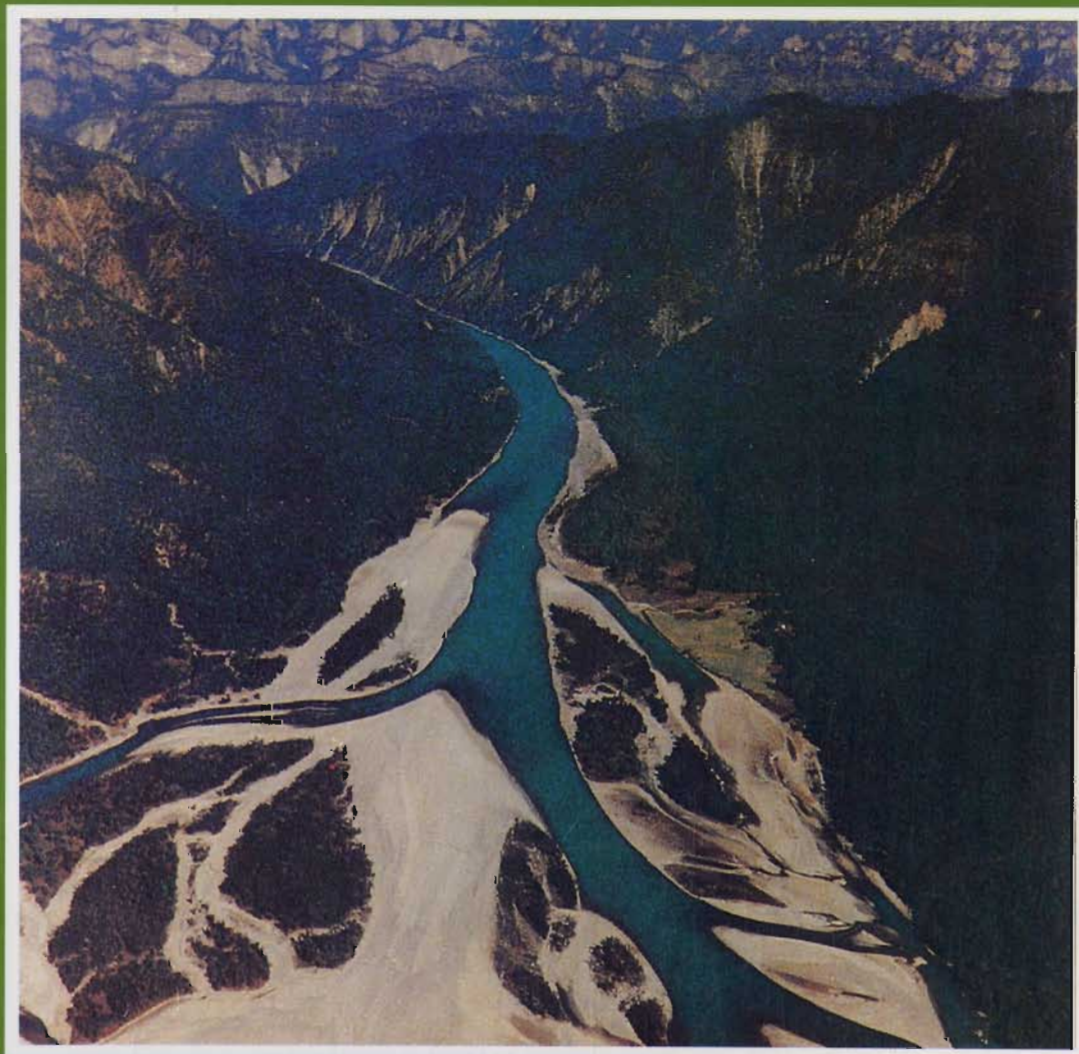


**HIGHLAND-LOWLAND INTERACTIONS IN  
THE GANGES BRAHMAPUTRA RIVER BASIN:  
A REVIEW OF PUBLISHED LITERATURE**



L.A. Bruijnzeel with C.N. Bremmer

**ICIMOD OCCASIONAL PAPER No. 11**

Kathmandu, Nepal  
July 1989

ICIMOD Occasional Papers

- No. 1 EROSION AND SEDIMENTATION PROCESSES IN THE NEPALESE HIMALAYA**  
Brian Carson  
August 1985.
- No. 2 INTEGRATED RURAL DEVELOPMENT PROJECTS IN NEPAL: A REVIEW**  
Bharat B. Pradhan  
December 1985.
- No. 3 SUSTAINING UPLAND RESOURCES: PEOPLE'S PARTICIPATION IN WATERSHED MANAGEMENT**  
Anis Ahmad Dani and J. G. Campbell  
July 1986.
- No. 4 DECENTRALISED ENERGY PLANNING AND MANAGEMENT FOR THE HINDU KUSH-HIMALAYA**  
Deepak Bajracharya  
September 1986.
- No. 5 GLACIAL LAKE OUTBURST FLOODS AND RISK ENGINEERING IN THE HIMALAYA**  
Jack D. Ives  
November 1986.
- No. 6 OPERATIONAL EXPERIENCES IN FOREST MANAGEMENT DEVELOPMENT IN THE HILLS OF NEPAL**  
G.B.Applegate and D.A.Gilmour  
January 1987.
- No. 7 FORESTRY - FARMING LINKAGES IN THE MOUNTAINS**  
T.B.S.Mahat  
March 1987.
- No. 8 ROAD CONSTRUCTION IN THE NEPAL HIMALAYA: THE EXPERIENCE FROM THE LAMOSANGU - JIRI ROAD PROJECT**  
Urs Schaffner  
March 1987.
- No. 9 MOUNTAIN ENVIRONMENTAL MANAGEMENT IN THE ARUN RIVER BASIN OF NEPAL**  
John R. Dunsmore  
December 1988.
- No. 10 HILL AGRICULTURE AND THE WIDER MARKET ECONOMY: TRANSFORMATION PROCESSES AND EXPERIENCE OF THE BAGMATI ZONE IN NEPAL**  
Mahesh Banskota  
May 1989.
- No. 11 HIGHLAND-LOWLAND INTERACTIONS IN THE GANGES-BRAHMAPUTRA RIVER BASIN: A REVIEW OF PUBLISHED LITERATURE**  
L.A. Bruijnzeel and C.N. Bremmer  
July 1989.

**HIGHLAND-LOWLAND INTERACTIONS IN THE GANGES BRAHMAPUTRA RIVER BASIN:  
A REVIEW OF PUBLISHED LITERATURE**

L.A. Bruijnzeel with C.N. Bremmer

ICIMOD OCCASIONAL PAPER No. 11

Published by  
International Centre for Integrated Mountain Development  
Kathmandu, Nepal

Copyright ©1989

International Centre for Integrated Mountain Development

All rights reserved

Cover Photograph: Karnali River of Chisapani, 1978

Published by

International Centre for Integrated Mountain Development, in association with  
Kefford Press Pte Ltd, Singapore

G.P.O Box 3226, Kathmandu, Nepal

ISBN 981-00-1244-6

131

131

International Centre for Integrated Mountain Development

ed by  
Kathmandu

International Centre for Integrated Mountain Development

131

The views and interpretations in this paper are the author's and are not attributable to the International Centre for Integrated Mountain Development (ICIMOD), and so not imply the expressions of any opinion concerning the legal status of any country, territory, city or area of its authorities, or concerning the delimitation of its frontiers or boundaries.

## TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	I
LIST OF ILLUSTRATIONS AND TABLES	II
I. INTRODUCTION	1
II. MOUNTAINS AND PLAINS	4
1. The main river systems	4
2. Geology and geomorphology	6
2.1 Ganges River Basin	6
2.2 Brahmaputra River Basin	18
3. Climate	19
3.1 Spatial and seasonal variations in precipitation	19
3.2 Rainfall extremes	26
3.3 Evaporation	29
4. Vegetation and land use	32
4.1 Natural vegetation	33
4.2 Agriculture	37
4.3 Forest conversion and degradation: a historical perspective	38
III. HYDROLOGY AND SEDIMENTATION	42
1. Annual water yield	42
2. Water budgets	44
3. Seasonal variations in streamflow	45
4. Hillslope hydrological response to rainfall	50
5. Floods: regional patterns	61
6. River sediment loads	67
IV. ROLE OF VEGETATION AND LAND USE	78
1. Hydrology	78
1.1 Annual water yield	78
1.2 Dry-season flow	84
1.3 Peak flows	90
2. Erosion and sedimentation	96
2.1 Surface and gully erosion	96
2.2 Mass movements	104
2.3 River sediment loads	109
V. CONCLUSIONS	
1. The current scientific consensus	116
2. Gaps in our knowledge	118
VI. REFERENCES	120
THE AUTHORS	136

## ACKNOWLEDGEMENTS

The present report is the result of a chain of events: early 1987, I received a request from the "Ganges Working Group", based in Utrecht, the Netherlands, for information on the relationships between land-use practices in the Himalaya and flooding and siltation in the Indo-Gangetic plain. This request was prompted by the concern of these people about the so-called Dutch Inland Water Transport Project, which aimed at improving the navigability of the Ganges between Allahabad and Haldia. The discussion centered around the question to what extent reforestation of the uplands would have any effect on siltation and flooding in the lowlands, and therefore on the feasibility of the said project.

Although I had collected a fair amount of information on the Himalayan environment over the years, I was not aware of any in-depth study of "highland-lowland interactions", based on quantitative information rather than opinions. Christiaan Bremmer, a graduate student in my department, undertook the task of sorting out the literature and writing a very readable account, entitled: "The role of vegetation and land use in flooding, erosion and mass wasting in the Ganges drainage basin, India" as part of his studies in hydrology.

I ventured to send a copy of the review to ICIMOD for comments in the fall of 1987. Then came "the" flood in Bangladesh, and with it the invitation from ICIMOD to convert Bremmer's draft review into an ICIMOD Occasional Paper. Upon arrival in Kathmandu in late December 1988, I felt the need to expand the geographical scope of the study and so the Tsangpo-Brahmaputra basin was included as well. This of course meant that a great deal of new literature had to be included and much of January 1988 was spent in libraries in Kathmandu. Since then, a completely new report has been written, mainly in Amsterdam, based on about three times as many literature references as the original review contained.

It is a great pleasure to record the help received by a large number of individuals, both in Nepal and in the Netherlands. Without their support this report would not have been possible.

First of all I wish to thank Dr. Colin Rosser, Director of ICIMOD, for the opportunity to write this paper and visit Nepal on two occasions, and for his support throughout the course of the undertaking. The weeks spent at ICIMOD were very happy ones indeed, not in the least because of the interaction with its staff, notably Dr. Don Alford, Dr. Jayanta Bandyopadhyay, Professor Suresh Chalise, Dr. Anis Dani and Dr. Kk. Panday, all of whom readily shared their time, knowledge and sense of humour with me on many occasions. Professor Li Tian-chi, head of the Division of Mountain Environmental Management, and his administrative staff were most helpful in getting countless pieces of information xeroxed. It will be hard to forget your smiles. The ingenuity displayed by Mr. R.B. Shrestha (ICIMOD library) in obtaining some of the documents on which this report is based, proved invaluable. I would also like to thank Mr. Surendra Shrestha and Mrs. Priya Trosuwan for their smooth logistic arrangements.

Brian Carson, Vic Galay, Don Gil-mour, Rob Gerritsen, Wolfgang Grabs, P. van Groen, G.J. Klaassen, Peter Laban, Jan Rupke and P.B. Shah all provided literature, slides or other information, which is gratefully acknowledged.

Romée de Vries is thanked for typing the bulk of the report, Saskia Kars and R.Joshi for their skillful draughtswork, Maarten Waterloo for computerized diagrams, and Mrs. Prabha Thacker and Professor Ian Simmers for editorial comments.

Last and certainly not least I wish to express my gratitude to that lady whose support over the past few months has been beyond a simple thank you, and to Alexander M. Smit for helping to keep the right perspective.

Sampurno Bruijnzeel

LIST OF ILLUSTRATIONS

FIGURES		Page
1.	The Ganges-Brahmaputra River Basin: general features.	2
2a.	Approximate longitudinal profile of the river Ganges as determined from small-scale maps.	4
2b.	Longitudinal bank profile of the Brahmaputra River (after Goswami, 1985).	5
3.	Main geo-structural features of the Ganges-Brahmaputra River Basin (after Gansser, 1964).	7
4.	Physiographic zones of the Nepal Himalaya (Galay, 1987; modified from Nelson et al., 1980, and Ramsay, 1986)	7
5.	Generalized geological map of the Ganges-Brahmaputra River Basin (modified from Gansser, 1964; Fuchs, 1980).	8
6a.	Geology, geomorphology and river dynamics of the Siwalik-Piedmont zone (after Weidner, 1981).	17
6b.	Cross section of the Levee-Basin system of the Terai (after Weidner, 1981).	17
6c.	Spatial distribution of relief units distinguished in Figures 6a and b (after Weidner, 1981).	17
7a.	Normal dates of the onset of the southwest monsoon (after Rao, 1981).	20
7b.	Normal dates of the withdrawal of the southwest monsoon (after Rao, 1981).	20
8.	Mean annual (a) and summer monsoon (b) rainfall totals (cm) over the Indian sub-continent (after Rao, 1981).	21
9a.	Isohyetal map of the Assam valley and adjoining highlands (after Goswami, 1985).	23
9b.	Isohyetal map of Bhutan (modified from Sharma, 1985).	23
10.	Principal zones of precipitation in the Nepalese Himalaya (after Hagen, 1969).	24
11.	Mean annual precipitation (mm) in Nepal (after Chyurlia, 1984).	25
12.	Variability index of rainfall polygons in Nepal (after Chyurlia, 1984).	28

	Page	
13.	Approximate maximum observed 24-hr rainfall totals at selected stations in the Ganges-Brahmaputra River Basin (compiled from: Climatological Records of Nepal 1971-1986; Nayava, 1974; Raghavendra, 1982; Rao, 1981; Sharma & Mathur, 1982; Sharma et al., 1982; Starkel, 1972).	30
14.	Mean annual potential evapotranspiration according to Penman (cm) over the Indian sub-continent (after Rao, 1981).	31
15.	Mean reference evapotranspiration (Morton, 1983) over Nepal (after Sapkota, 1984).	32
16.	Vegetation zonation in the Nepalese Himalaya (after Shrestha, 1988).	34
17.	Cross-sectional representation of vegetation zones in the Himalaya (after Hagen, 1969).	34
18.	Agricultural calendar in relation to timing of flooding in Bangladesh (after Currey, 1984).	39
19.	(a) Average precipitation, (b) actual evapotranspiration, (c) surplus, and (d) water deficiency (all in mm/yr) in the Nepalese part of the Sapt Kosi River Basin (after Subramanyam & Upadhyay, 1983).	43
20.	Monthly streamflow (mm) for selected Himalayan rivers (based on data presented by Guan & Chen, 1981; Surface Water Records of Nepal; Sharma, 1977).	46
21.	Hydrograph separation for the Seti river, West Nepal (after Chyurlia, 1984).	48
22.	Water discharge (1) of the Imja Khola at Dingboche, precipitation (2) and air temperature (3) and (4) at Lhajung (eastern Nepal), 1974/75 (after Higuchi et al., 1976).	48
23.	Water discharge ( $m^3/sec$ ) of the Burhi Dihing river, Assam, in 1982 (after Sarma, 1986).	49
24.	Average monthly streamflow totals (mm) for the Brahmaputa at Bahadurabad Ghat and the Ganges at Farakka (based on data presented by Haroun er Rashid (1977) and UNESCO (1971) respectively).	50
25.	(a) Flow paths of the sources of streamflow: $Q_p$ is direct precipitation onto the water surface, $Q_o$ is overland flow, $Q_t$ is throughflow and $Q_g$ is groundwater flow.	52
	(b)-(d) The response of streamflow to precipitation in humid headwater areas: an integrated view (after Ward, 1984)	52



	Page
26. The relative contributions of rainfall to streamflow (after Ward, 1984; based on an original diagram by J.D. Hewlett, 1961).	53
27. Storm-runoff hydrographs from two areas with contrasting topography within the East-Twin basin (0.2 km <sup>2</sup> ), United Kingdom (after Calver et al., 1972).	54
28. Schematic representation of the occurrence of various runoff processes in relation to their major controls (after Dunne, 1978).	54
29. Rainfall-intensity-durations for Dehradun and Kathmandu as compared with infiltration capacities of local forest soils. (Rainfall data after Ram Babu et al., (1978) and Caine & Mool (1982) respectively).	58
30. Runoff response of two small forested headwater catchments in the Indian Siwaliks to 78 mm of rain (after Subba Rao et al., 1985).	59
31. Typical stormflow hydrographs for the pine-forested Bemunda catchment, Tehri Garhwal (after Puri et al., 1982).	59
32. Semi-logarithmic relationship between percentage of direct runoff and antecedent monthly rainfall in Nepal after Chyurlia, 1984).	63
33. Depth-area curves for extreme rainfalls in the Assam valley (after Raghavendra, 1982).	63
34. Schematic illustration of the "backwater effect" (modified from Dutch Inland Water Transport Mission, 1982-83).	65
35. Example of the "backwater effect" on the Ganges near Patna (after Dutch Inland Water Transport Mission, 1982-83).	65
36. Average monthly discharge of the Brahmaputra at Bahadurabad and the Ganges at Sara Bridge (based on data presented by Haroun er Rashid, 1977).	66
37. Sediment yields for Himalayan and Peninsular rivers in India (after Gupta (1975) in Tejwani, 1985).	68
38. Shifting of the Kosi River over its own alluvial fan, 1736-1977 (after Gole & Chitale, 1966; Galay, 1987).	72
39. (a) Annual streamflow and suspended sediment load for the Bhagirathi river, Tehri Garhwal, 1973-1981.	73
(b) Relationship between annual streamflow and amount of sediment carried in suspension by the Bhagirathi river (based on original data of Singha & Gupta, 1982).	73

	Page	
40.	Cumulative percentages of suspended sediment- and water discharges on the Burhi Dihing river against cumulative percentage of time for the year 1974 (after Sarma, 1986).	74
41.	(a) Hypothetical course of rainfall erosive power and state of surface vegetation throughout the year in the Middle Mountains of Nepal (after Carson, 1985).	75
	(b) Instantaneous suspended sediment concentrations for the Narayani river, Narayanghat, June-August, 1979 (after Carson, 1985).	75
42.	Mean monthly flow and sediment discharge for the Brahmaputra river at Pandu, Assam, 1971-1979 (after Goswami, 1985).	77
43.	(a) Five-year moving averages of annual streamflow for the Kosi river at Bharakshetra and rainfall at Chainpur East (mm), 1948-1985.	80
	(b) Annual ratio between streamflow at Bharakshetra and rainfall at Chainpur East, 1948-1985.	80
	(c) Scatter plot of the variables from Figure 43b. (Sources of data: streamflow 1948-1976: Zollinger, 1979; 1977-1986: Uprety, 1988; rainfall: Mr. Madan Basnyat, personal communication).	80
44.	The paired catchment technique: general experimental design (after Hewlett & Fortson, 1983).	81
45.	Evaluation of treatment effect on streamflow by statistical analysis, (a) linear regressions, (b) double mass-curves (after Hsia & Koh, 1983).	81
46.	Decline in dry-season flow rates for the Mid-Mahaweli basin, Sri Lanka (after Madduma Bandara & Kuruppuarachchi, 1988).	85
47.	Monthly rainfall and streamflow for a forested and a cultivated catchment near Gorkha, Nepal (based on original data from Balla, 1988a).	85
48.	Expected rainfall and total flow at 50 and 70% probability levels and monthly reduction in total flow due to afforestation with bluegum ( <u>Eucalyptus globulus</u> ) at Ootacamund (after Sharda et al., 1988).	87
49.	Saturated hydraulic conductivity values for the sample sites of Table 8 at various depths (after Gilmour et al., 1987).	88
50.	Likely trend of changes in field saturated hydraulic conductivity of surface (0-0.1 m) soil following reforestation and protection of heavily grazed and trampled grassland (after Gilmour et al., 1987).	88

	Page	
51.	Hourly infiltration curves for 4 groups of sites in Doon valley: (a) cultivated Himalayan upland, (b) forested Himalayan upland, (c) forested Siwalik slope and (d) cultivated bottom land (after Patnaik & Viridi, 1962).	89
52.	Annual rainfall and streamflow totals (mm) for the Bhaintan watershed, Teri Garhwal (based on data from Anonymous, 1981b/84).	93
53.	Annual peak discharges for different return periods for the river Ganges. (a) at Raiwala (after Sakthivadivel & Raghupathy, 1978). (b) at Farakka (based on UNESCO, 1976; Rodier & Roche, 1984).	95
54.	Frequency of mass movements as a function of slope angle and rock type in the Dhankuta and Leoti Khola areas, East Nepal (after Brunnsden et al., 1981).	106
55.	Preliminary distribution of landslide zones in Nepal (after Paudiyal & Mathur, 1985).	106
56.	Sediment yield vs. basin area for major tropical river basins. Inset (G): Ganges; (K): Krishna, India (after Abbas & Subramanian, 1984)	111

#### PLATES\*

1.	The upper Gandaki river near Kagbeni, southern Mustang, Nepal. Note the various levels of river terraces corresponding with various phases of uplift and river incision.	9
2.	Physical weathering processes are extremely active in the glaciated environment of the High Himalaya (North face of Annapurna, Manang district, Nepal).	10
3.	Upon crossing the High Himalaya, rivers such as the Bhote Kosi in Central Nepal, have carved deep gorges. Note the active erosion and mass-movement processes in the riparian zone.	11
4.	Typical view of the Middle Hill region of Central Nepal near Dhulikhel. Note gully erosion and frequent landslide scars in grazing land.	12
5.	Land use and erosion processes in the Kathmandu valley, Middle Hill region, Central Nepal. Note frequent shallow landslips in scrubland and old major slide in river bend in background.	12

\*Photographs by the senior author unless indicated otherwise

	Page
6. Deep-seated slides on well-forested hillslopes in the Mahabharat range of Central Nepal. Slides of this size are capable of temporarily damming a river, which upon bursting may produce a devastating surge of water and sediment.	14
7. Although the Siwaliks in general still have good forest cover, pressures on this very vulnerable ecosystem are increasing. Note the remarkably wide valley bottoms with braided rivers (Central Nepal).	14
8. A Dun valley in Central Nepal. To the right the well-forested steeply sloping beds of the Upper Siwaliks, to the left the intensively cultivated southern margin of the Mahabharat. Note the huge landslide scars in the foreground.	16
9. Upon entering the piedmont (Bhabar) zone, the Himalayan rivers deposit large amounts of coarse material and continue to flow through unstable channels.	16
10. View of the Jamuna floodplain between Dacca and Bahadurabad, Bangladesh (photograph by G.J. Klaassen).	19
11. Mossy forest at 2600 m a.s.l. in Helambu, Central Nepal (photograph by R. Gerritsen).	36
12. In the dry valleys north of the main range, the drier southerly slopes bear a steppe-like scrub vegetation, whilst the moister northern slopes are covered with a mixture of conifers (Manang district, Nepal).	37
13. Rill and gully erosion on slopes underlain by shales in Dolpo, West Nepal (photograph by P. Laban).	55
14. Tributary valley of the Marsyangdi river near Tal, West-Central Nepal, with steep slopes and narrow valley bottom. Note the enormous boulders in the centre.	57
15. Actively eroding Siwalik landscape south of Hetauda, Central Nepal (photograph by P. Laban).	60
16. The confluence of the rivers Ganges (left) and Jamuna (right) in Bangladesh, June 1986 (photograph by G.J. Klaassen).	66
17. A small glacial lake outburst flood disrupting a bridge on the Dudh Kosi river, Central Nepal, July 1984 (photograph by J. Desloges).	67
18. Prolonged overgrazing after forest removal produced this seriously eroding landscape on vulnerable red soils in the Kabhu Palanchok district, Central Nepal.	103

		Page
19.	Excellent terracing of a hillslope in the Middle Mountain zone of the Kumaon Himalaya enables sustainable rice cultivation (photograph by J. Rupke).	103
20.	Undercutting of steep slopes in river bends constitutes a major sediment producing mechanism in the Himalaya. Note the fully forested condition of the slope.	107
21.	Repeated phases of uplift and river incision have produced this fine series of river terraces in the Middle Mountain zone of the Kumaon Himalaya (photo by J. Rupke)	111

#### LIST OF TABLES

1.	Precipitation totals at selected stations in the Himalaya between December and March (after Dhar et al., 1987).	27
2.	Relative proportions of land-use types in the physiographic zones of Nepal (after Carson et al., 1986).	39
3.	(a) Annual number of days with certain 5-minute rainfall intensities as recorded at Kathmandu, June - September, 1971-1979 (after Gilmour et al., 1987).	57
	(b) Frequency distribution of rainfall intensity in different vegetation zones in the Kumaon Himalaya, June - September, 1981-1982 (after Pandey et al., 1984).	57
4.	Mean annual streamflow and suspended sediment loads (1948-1959) for the three major tributaries of the Kosi river, eastern Nepal (after Das, 1968).	70
5.	Suspended sediment loads for selected rivers of intermediate size in the Ganges-Brahmaputra river basin.	70
6.	Rates of sedimentation for major reservoirs in and around the Ganges River Basin.	71
7.	Land-cover transformations and changes in water yield: results from selected studies.	83
8.	Description of locations of infiltration tests carried out by Gilmour et al., (1987).	88
9.	Annual number (and percentage) of rain-days during the monsoon in the Middle Hills of Nepal, where 5-minute rainfall intensity exceeds $\log K_s$ at for the impeding layers at the sites of Table 8 (after Gilmour et al., 1987).	88
10.	Effects of (changes in) land cover on stormflow volumes and peakflows: results from selected small-catchment studies.	91

11.	Surface erosion (t/ha/yr) in tropical forest and tree crop systems (after Wiersum, 1984)	96
12.	Effects of land cover on surface and/or gully erosion in the Ganges-Brahmaputra River Basin.	98