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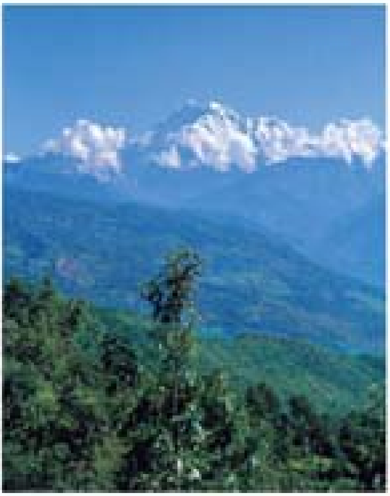
Water Balances, Floods and Sediment Transport in the Hindu Kush-Himalayas

Data analyses, modelling and comparison of selected meso-scale catchments

Juerg Merz



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ICIMOD

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Water Balances, Floods and Sediment Transport in the Hindu Kush-Himalayas

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The following software packages were used by the author for this study.

• MSWord 2000	word processing
• MSExcel 2000	tabulation of data, graphics and basic statistics
• SPSS 10.0	advanced statistics
• ArcView 3.2	mapping and GIS applications
• CorelDraw 9	graphics
• MSAccess 2000	data management
• HYMOS 4.03	data management and advanced hydrological analyses

Foreword

According to the first proposal, the research for this thesis should have been carried out entirely in the Yarsha Khola catchment area, comprising a field-based and in-depth process understanding of streamflow generation in a middle mountain catchment of the Hindu Kush-Himalayas. However, the political situation in Nepal did not allow extended field work, particularly after the incident at the Yarsha Khola field office on February 2, 1999. A second proposal was drafted one year into the work, detailing preparations for the first extended field season, due to begin in March 1999 with the onset of the pre-monsoon rains. This proposal aimed to review the existing database of the Jhikhu Khola catchment and attempted to synthesise information already collected. While field-based work in the Yarsha Khola catchment may have engendered a more proactive approach, with more chances to generate 'new knowledge', the reactive approach that was subsequently adopted for work in the Jhikku Khola catchment is probably more helpful in terms of understanding how far we have reached in the project over the years. The new knowledge in this study is the detailed interpretation of information and data from different surveys, measurement campaigns, and long-term data monitoring.

Juerg Merz
April 13, 2003

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Over my five years in the PARDYP project at ICIMOD, I have met many interesting and challenging people who have all contributed to this thesis by stimulating my thinking. Thanks are due to all of them. I have learned a tremendous amount, not only through carrying out this study, but also from the day-to-day activities of a regional research-for -development project.

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The project activities would have been only half the fun without the regional coordinators. Firstly, I really enjoyed working with Richard Allen, in whom I had a great supporter of most of my ideas, and with whom I enjoyed great days in the different PARDYP catchments. With his successor, Roger White, I remember many discussions on institutional capacities, sediment, and collaboration in development. I would also like to thank him for his comments on the first draft of this thesis.

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Executive Summary

This study is embedded in the People and Resource Dynamics of Mountain Catchments in the Hindu Kush-Himalayas Project (PARDYP). PARDYP is a regional research-for- development project, working in natural resources and watershed management. The project includes five catchments of 20 to 110 km^2 across the Hindu Kush-Himalayan region, with sites in China, India, Pakistan, and two sites in Nepal.

The study examines the current situation of water resources in selected meso-scale catchments in both the biophysical and socioeconomic contexts. It focuses primarily on the Jhikhu Khola catchment (Kavrepalanchok district) in the middle mountains of Nepal, and compares the results with the Yarsha Khola catchment (Dolakha district), as well as with the PARDYP catchments in China, India, and Pakistan. It aims to contribute to increased understanding of water resources and water-related processes, such as soil erosion and land degradation, as well as contributing towards knowledge about integrated catchment development with minimised water-induced land degradation and minimised water resource degradation. The main components of the study are as follow:

- runoff generation and floods,
- sediment mobilisation and transport,
- water availability for domestic and agricultural purposes
- impact of future change on water resources and related processes, and
- synthesis and development of a framework for comparison of catchments in the region.

Research was based on the results of various surveys and mapping campaigns carried out in the catchments, and on detailed hydro-meteorological data collected according to the nested approach. This approach allowed the investigation of processes from the micro- to the meso-scale, that is, from plot to catchment level. It also determined the scale dependency of these processes.

To begin with, the inherent conditions of the catchments regarding flood generation, land degradation, and water scarcity from the perspectives of catchment characteristics, human settings, and processes were assessed. According to these criteria, the PARDYP Nepal catchments are in a fragile and vulnerable region. Water scarcity is caused mainly by the seasonality of water resources and their management. Precipitation is highly seasonal, with 75 to 80 % of the rainfall occurring during the monsoon season, and 10 to 15 % falling during the pre-monsoon season. The rest of the year is virtually dry. Evapotranspiration rates peak during the pre-monsoon season, making March to April the driest time of the year, as runoff also reaches its lowest point during this time. Water supply for domestic use is at a minimum during this time and many households face hardship fetching water. In terms of water quality concerns, the peak risk season is the early monsoon, with the highest microbiological and chemical contamination. Local water use for agriculture is, in general, well adapted to seasonality. Even so, farmers perceive there to be a water shortage since they are not able to grow any additional crops during this time. Farmers at the tail end of irrigation systems receive inadequate water supply even during the wet season. The time of highest risk for farmers is the time between the first pre-monsoon rains and the onset of the monsoon, as this is the time when maize is planted and the rice nurseries are prepared. Agriculture is also vulnerable in the winter season, when wheat and potatoes are grown. Rainfed crops can be damaged in dry conditions, and little rainfall might mean that one less crop can be planted on irrigated land. In addition, the growing number of farmers producing cash crops puts an additional stress on water resources. These issues suggest that in future the focus should be on improved management of irrigation systems, catchment-based management of water resources, appropriate technologies to reduce water demand and increase water availability during the dry season, and improved water quality management.

Floods are generated mainly in the monsoon season. In general, it is during this time that the most intense rainfall events with the highest intensities and volumes occur. It was shown that runoff generation on degraded areas as well as on grasslands contributes most to flood volumes, while rainfed agricultural land only contributes marginally to flood behaviour. It is important to keep this in mind for the discussion on the impact of Himalayan farmers on downstream flooding. Cultivated land in general has a beneficial impact on flood generation, while degraded land and grassland increases the volume as well as the peaks. A cluster approach defined rainfall intensity and volume as the main determinants for flood generation. On degraded land and grassland, infiltration excess overland flow is expected to produce surface runoff; while, on agricultural land, it is largely saturation excess overland flow that is responsible for producing surface runoff. At the catchment level, processes similar to those on degraded land contribute to flood generation. In terms of the largest flood events, no particular pattern was observed, except that these events generally occur when rainfall throughout the catchment exceeds 25 mm, with a maximum of 30-minute rainfall intensities of >10 mm/h; or events in pocket areas of the catchment with more than 10 mm rainfall and more than 20 mm/h, 30-minute intensity. In addition, it was observed that land use had no impact on the largest events. In terms of flood protection and management, downstream planning and prohibition of river channel encroachment will yield better results than small-scale land-use changes in the upland catchments.

Soil loss was shown to be greatest on degraded land, followed by agricultural land, and grassland. A difference was observed between the seasons on the agricultural land in the Jhikhu Khola catchment, while in the Yarsha Khola catchment no difference was observed. Likewise, on grassland as well as on degraded land, no difference was observed between the seasons. From a total soil loss perspective, the current soil loss rates from the agricultural land are not of major concern as they balance the natural soil development. Surface erosion on degraded patches as well as gulling on these areas produce much higher loads and are of particular concern for downstream areas. The surface soil loss, in addition to the sediment produced in the streambed and the roads, adds up to sediment loads of medium to high magnitude.

Farmers themselves do not see surface erosion from their fields as a major issue. Soil conservation activities will only be successful if farmers see an additional benefit to soil conservation, such as increased fertility, increased income, or increased fodder availability. To reduce the sediment yield from the catchments, focus should be given to the streambanks, the road network, and the degraded areas.

The study also investigated the possible impacts of future changes on established and inherent conditions under different scenarios. To date, these include increasing population, global climate change, and marginalisation or extensification of the areas. It was shown that potential climate change might lead to lower water availability in the presently critical seasons, while increased rainfall may increase the magnitude and number of flood peaks. Population growth will lead to increased water demands for domestic purposes, while an intensification in the already highly intense farming systems is less likely, and food will have to be produced elsewhere, or more focus will have to be given to staple food production in the future. The land-use scenarios could not deliver conclusive answers, as the vegetation parameters were inadequate and need to be improved with the availability of the respective data. From a methodological perspective, the distributed model PREVAH (precipitation-runoff-evapotranspiration-hydrotope model) showed the best performance with potential improvement possibilities. The Tank model was the most user-friendly model tested. These models will have to receive further attention in terms of incorporation of rainfall intensity and calculation of evapotranspiration.

For the comparison of catchments in the region, an index approach for the assessment of the three susceptibilities is proposed. The Water Poverty Index (WPI), the Flood Generation Index (FGI), and the Water Induced Degradation Index (WDI) have shown good first results during the comparison of the PARDYP Nepal catchments and could be used to compare these catchments with those in Pakistan and India. The Jhikhu Khola catchment had a lower WPI than the Yarsha Khola catchment, mainly due to fewer water resources, less access, greater use, and more adverse effects on the environment, while in the Yarsha Khola catchment the capacity score was lower.

This study concludes that the most important considerations when developing water management decision-support systems are: location with reference to potential water sources, water use, and temporal distribution of water demand and availability.

Acronyms and Abbreviations

ADB	Asian Development Bank
ADR	altitude dependent regression
AET	actual evapotranspiration
API	antecedent precipitation index
BFI	base flow index
BSc	Bachelor of Science
CEAPRED	Centre for Environmental and Agricultural Policy Research, Extension and Development
CEC	cation exchange capacity
CEH	Centre for Ecology and Hydrology
CIAT	Centro Internacional de Agricultura Tropical (International Centre for Tropical Agriculture)
CR	criticality ratio
CV	coefficient of variation (= standard deviation/mean)
CWC	Central Water Commission
DDC	district development committee
DEM	digital elevation model
DHI	Danish Hydraulics Institute
DHM	Department of Hydrology and Meteorology
DSS	decision support system
DWSS	Department of Water Supply and Sewerage
EAWAG	Swiss Federal Institute of Environmental Science and Technology
ETH	Swiss Federal Technical High School
FAO	Food and Agricultural Organization of the United Nations
FGI	Flood Generation Index
FMIS	farmer managed irrigation systems
GBM	Ganges-Brahmaputra-Meghna basin
GBPIHED	G.B. Pant Institute for Himalayan Environment and Development
GCA	gross command area
GCM	global climate models
GEV	Gumbel extreme value distribution
GIS	geographic information systems
GLOF	glacial lake outburst flood
GRDC	Global Runoff Data Centre
HH	household
HKH	Hindu Kush-Himalayas
HMG	His Majesty's Government
HRU	hydrological response unit
HYREUETH	hydrological response unit – ETH
IAHS	International Association of Hydrological Sciences
ICIMOD	International Centre for Integrated Mountain Development
IDE	International Development Enterprises
IDF	intensity-duration-frequency
IDRC	International Development Research Centre
IDS	Institute of Development Studies
IDW	inverse distance weighting
IGCEDP	Indo-German Changar Eco Development Project
IIASA	International Institute for Applied Systems Analysis

IIDS	Institute for Integrated Development Studies
ILACO	International Land Development Consultants
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
JK	Jhikhu Khola catchment
KIB	Kunming Institute of Botany
KU	Kathmandu University
LRMP	Land Resource Mapping Project
masl	metres above (mean) sea level
MENRIS	Mountain Environment and Natural Resources Information System (ICIMOD)
MOPE	Ministry of Population and Environment
MRE	Mountain Risk Engineering Unit
MRM	Mountain Resources Management Project
MSc	Master of Science
NARC	Nepal Agricultural Research Council
NIH	National Institute of Hydrology
NPC	Nepal Planning Commission
NRs	Nepalese Rupee (1 US$ ~ 76 NRs; June 26, 2003)
NST	Nepal Standard Time (GMT + 5 3/4h)
OECD	Organisation for Economic Cooperation and Development
PAR	participatory action research
PARDYP	People and Resources Dynamics in Mountain Catchments of the Hindu Kush-Himalayas
PFI	Pakistan Forest Institute
PMP	probable maximum precipitation
PRA	participatory rural appraisal
PREVAH	precipitation-runoff-evapotranspiration-hydrotope model
RCM	regional climate models
RWSSSP	Rural Water Supply and Sanitation Support Programme
SDC	Swiss Agency for Development and Cooperation
SDR	sediment delivery ratio
SODIS	solar disinfection
SRI	system for rice intensification
TDR	time dependant reflectory
T&D	test and demonstration
TLU	tropical livestock unit
UBC	University of British Columbia
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFPA	United Nations Population Fund
UoB	University of Bern
VDC	village development committee
WECS	Water and Energy Commission Secretariat (Nepal)
WDI	Water Induced Degradation Index
WPI	Water Poverty Index
WMO	World Meteorological Organisation
WSSCC	Water Supply and Sanitation Collaborative Council
WWC	World Water Council
WWF	World Wildlife Fund for Nature
YK	Yarsha Khola catchment

Glossary

In this report the term catchment is used as a synonym for watershed, meaning the area drained by one particular river or stream. To indicate that the discussion is focusing on part of a catchment, the term ‘sub-catchment’ is used. Watershed is used as the term for catchment boundary or divide.

bari	rainfed agricultural land (Nepali)
bazaar	market (Nepali)
criticality ratio	ratio of average annual water withdrawal to water availability (Alcamo et al. 2000)
dry spell	a period of 15 days with no more than 1 mm of rain each day (Mosley and Pearson 1997)
hydrograph	graph of discharge as a function of time at a given station
hydrological response unit	catchment area unit with similar hydrological response
hyetograph	graph of rainfall as a function of time at a given station
Hymos	software for environmental data management distributed by Delft Hydraulics, the Netherlands
khet	irrigated agricultural land
khola	river, stream (Nepali)
kosi	river (Nepali)
kuwa	spring box (Nepali)
Landflucht	outmigration of people from rural to urban areas; urbanisation from the perspective of the rural areas
model calibration	process of appropriate parameter selection (Sorooshian and Gupta 1995)
model validation	process of parameter verification on a new dataset previously not used in the calibration procedure (Sorooshian and Gupta 1995)
rainy day	day with equal or more than 1 mm of rain per day
sanitation	use of sanitary means of excreta disposal using flush toilets or pit latrines (NPC 2000)

Symbols and Units

Units

In general SI units are used throughout this study.

Symbols

a	runoff coefficient
A	area
a, b, c	coefficients
AET	actual evapotranspiration
a_i	area of the hill slope per unit contour length that drains through point i
AI_{10}	erosivity based on 10-minute intensity
AI_{1030m}	erosivity based on 10- and 3-minute intensity
CD_i	cost-distance value of cell i
E	east
ET_0	reference evapotranspiration
H0	null hypotheses
HA	alternative hypotheses
I_{10max}	maximum 10-minute rainfall intensity during the event
I_{30max}	maximum 30-minute rainfall intensity during the event
I_{60max}	maximum 60-minute rainfall intensity during the event
I_{ave}	average rainfall intensity during the event
I_m	m-minute rainfall intensity
K_c	crop coefficient
n	number of observations
P	precipitation
p	probability
P_{25}	rainfall amount after 25 % of the event
P_{50}	rainfall amount after 50 % of the event
P_{75}	rainfall amount after 75 % of the event
Q_{max}	event peak flow
Q_{obs}	observed discharge
Q_{sim}	simulated discharge
Q_{start}	flow at the beginning of the event
Q_{tot}	total runoff, i.e. runoff between zero and hydrograph
R_i	relative contributing area
Sig.	significance level
ß	slope
T	return period
t	time/duration
t_P	rainfall event duration
t_Q	event duration
t_{rec}	time between peak and start of baseflow
t_{rise}	time between start of hydrograph rise and peak
U	test statistic for U-test Wilcoxon, Man and Whitney
w_i	weight
WT	water table
z	elevation
z	test value

Contents

All chapters are concluded with a brief synopsis targetted at development actors and policy-makers. The concluding remarks, including the outlook, should be relevant to all PARDYP clients.

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