Research on Environmental Change in Southern Tibet

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Abstract

Indications of an environmental change in southern Tibet are derived from a time series analysis of temperature and precipitation of 17 meteorological stations and from long-term measurements of river discharge and suspended load discharge of 16 hydrological stations. A general increase of the temperature level in southern Tibet within the last four decades is calculated by regression analysis of the mean total annual temperatures. In total, 16 out of 17 stations show warming trends between 0.0001 and 0.07°C/year. Due to the very strong variability of precipitation within the observation period, an analysis of long-term trends of total annual precipitation is difficult. For meteorological stations in southern Tibet with an observation period of more than 25 years, positive as well as negative trend rates were computed, although it is possible to assume that there is a trend towards an increasing amount of rainfall in the south and southwest and a decreasing one in the central and northern part of the area studied. The analysis of the long-term monthly data shows clearly that the precipitation is concentrated during the summer months (May to October), when southern Tibet is under the influence of humid low-level south-westerlies moving moist air currents up the Himalayan valleys to the north, contributing in general more than 90 per cent to the total annual precipitation. Heavy downpours during the period of the summer monsoon can contribute considerable amounts (up to 15%) to the total annual precipitation, thereby accelerating severe areal and gully erosion in southern Tibet. All gauging stations in southern Tibet show a low basic discharge during the dry season, due mainly to glacial and snowmelt, but the major part of discharge and suspended load discharge is concentrated during the summer monsoon season. Although the suspension load in the drainage systems represents only (an unknown) part of the total erosion, the amount of suspended load can be taken as a factor figuring into the amount of erosion of the different recharge areas. In the east of the Gangdise-Nianqingtanggula Range, the discharge at Lhasa hydrological station reaches its maximum at 35 l/s per km² in August. Due to the diminishing influence of the summer monsoon, the maximum discharge in the west, in the area of Lhaze and Rigeze, only attains values between 9 and 10 l/s per km² in the same period. The amount of suspension load in the rivers measured at the hydrological stations as eroded material per km² within the given drainage basin (which can only be seen as a first attempt in estimating the total erosion) shows a clear relation to the different lithologies and weathering processes. Accordingly, erosion is up to 250 per cent higher in the Flysch zone south of the Yarlungzangbo River than in the plutonitic areas in the north.

Introduction

Within the scope of an ongoing, interdisciplinary cooperative project between the Institute of Geology of the University of Vienna, the Institute of Remote Sensing Application of the Chinese Academy of Sciences (CAS), and other institutions, detailed geoscientific studies are currently being carried out in southern Tibet. Through the interpretation of a set of multitempor and multisensoral remote-sensing data in combination with field evidence relating to geology and geomorphology, as well as through the interpretation of climatological and hydrological data and the integration of other collateral geoscientific information, the setting up of a geographic information system (GIS) will be facilitated (Buchroithner et al. 1993, Häusler et al. 1993, Häusler and Leber 1994, Leber et al. 1994, Leber et al. 1995a, Leber et al. 1995b).

The investigations focus mainly on the southern part of the Tibetan Autonomous Region (TAR). The area north of the Himalayan chain and south of the Gangdise-Nianqingtanggula Range, at a longitude between 85° and 93°, represents the region's key farming area, where approximately 40 per cent of the population is concentrated (Hofer and Leber 1995). The area is drained predominantly in a west-to-east direction by the Yarlungzangbo River (the upper reaches of the Brahmaputra) and its tributaries such as the Lhasa He and the Nyang Qu. Only the southernmost part, near the border to Nepal, Sikkim, and Bhutan, is drained to the south (e.g., by the Pum Qu River, flowing into the upper reaches of the Arun River), thereby leading to the formation of deep gorges dissecting the Himalayan Range (Fig. 1).

To study the relationship between temperature, precipitation, discharge, and erosion (suspended load) within a pseudo-homogenous drainage area, we used meteorologic time series (mean monthly temperature and total monthly precipitation and heavy downpours) of 17 stations and hydrologic time series (total monthly precipitation, mean monthly water discharge, and mean monthly suspended load discharge) of 16 stations (Fig. 1 and Table 1). The data used were extracted from Chinese books published in 1985 by the Meteorological Bureau of the Xizang (Tibet) Autonomous Region (Mbtar 1985) and one publication by the Hydrological Bureau (Hbtar 1984), or else they were submitted in handwritten lists by the bureaus mentioned above during field investigations in the summers of 1992 and 1993.

In terms of the physio-geographic sub-division of Tibet presented by CAS (1982) and Zhao 1986 and 1994, where seven main sub-regions were delineated, the area investigated, as covered by the meteorological and hydrological data, belongs entirely to the "Broad Valleys and Basins of the South Tibetan Zone of Montane Shrubby Steppe and Alpine Steppe." Only the region around the meteorological station of Nyalam (12) in the extreme south, near the Nepalese border, belongs to the physio-geographic unit of the "Southern slopes of the Himalayan Zone of Rainforests and Montane Evergeen Broad-leaved Forests." The stations of Pali (13) and Cuona (19) are located in a transitional area between these physio-geographic units.

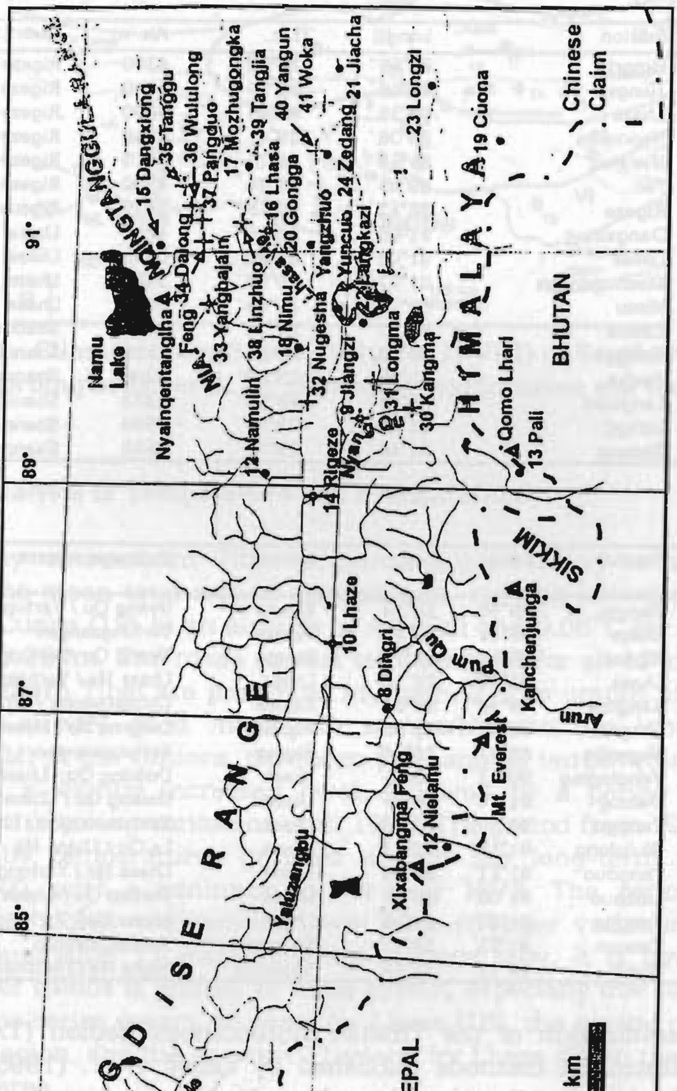

Figure 1: Sketch Map of the Study Area in Southern Tibet with 17 Meteorological and 16 Hydrological Stations (compare Table 1)

Table 1: Location of a) Meteorological Stations and b) Hydrological Stations in Southern Tibet

a

No.	Station	Long.	Lat.	Alt. m	District
8	Dingri	87°05′	28°38′	4300	Rigeze
9	Jiangzi	89°36′	28°55′	4040	Rigeze
10	Lhaze	87°36′	29°05′	4000	Rigeze
11	Nanmulin	89°06′	29°41′	4050	Rigeze
12	Nielamu	85°58′	28°11′	3810	Rigeze
13	Pali	89°05′	27°44′	4300	Rigeze
14	Rigeze	88°53′	29°15′	3836	Rigeze
15	Dangxiong	91°06′	30°29′	4200	Lhasa
16	Lhasa	91°08′	29°40′	3649	Lhasa
17	Mozhugongka	91°47′	29°53′	3824	Lhasa
18	Nimu	90°10′	29°26′	3809	Lhasa
19	Cuona	91°57′	27°59′	4280	Shannan
20	Gongga	90°59′	29°18′	3555	Shannan
21	Jiacha	92°35′	29°09′	3260	Shannan
22	Langkazi	90°25′	28°58′	4432	Shannan
23	Longzi	92°28′	28°25′	3860	Shannan
24	Zedang	91°46′	29°15′	3552	Shannan

b

No.	Station	Long.	Lat.	District	Drainage system
9	Jiangzi	89°36'	28°54'	Rigeze	Nyang Qu / Yarlungzangbo
10	Lhaze	87°41'	29°10'	Rigeze	Yarlungzangbo
14	Rigeze	88°54'	29°11'	Rigeze	Nyang Qu /Yarlungzangbo
16	Lhasa	91°09'	29°38'	Lhasa	Lhasa He / Yarlungzangbo
30	Kangma	89°40'	28°34'	Rigeze	Chongbayong / Nyang Qu
31	Longma	89°56'	28°51'	Rigeze	Longma He / Nyang Qu
32	Nugesha	89°43'	29°20'	Rigeze	Yarlungzangbo
33	Yangbajing	90°33'	30°05'	Lhasa	Duilong Qu / Lhasa He
34	Dalong	91°14'	30°05'	Lhasa	Dalong Qu / Lhasa He
35	Tanggu	91°30'	30°18'	Lhasa	Rezhenzangbu / Lhasa He
36	Wululong	91°15'	30°13'	Lhasa	La Qu / Lhasa He
37	Pangduo	91°21'	30°06'	Lhasa	Lhasa He / Yarlungzangbo
38	Linzhuo	91°06'	29°55'	Lhasa	Yunian Qu / Lhasa He
39	Tangjia	91°47'	29°53'	Lhasa	Lhasa He / Yarlungzangbo
40	Yancun	91°53'	29°17'	Shannan	Yarlungzangbo
41	Woka	92°12'	29°18'	Shannan	Woka He /Yarlungzangbo

A climatic classification of the Tibetan Autonomous Region (TAR) using the multivariate statistical methods published by Leber et al. (1995b) led to the delineation of coherent climatic sub-regions. Under this classification, the area between the Gangdise-Nianqingtanggula Range in the north and the Himalayas in the south is comprised of different climatic zones, which are characterised as follows (Fig. 2). The northern part of the area studied shows a sub-frigid and semi-moist climate (cluster VII; with a mean total annual precipitation (MAP) between 450 and 690mm and mean annual temperatures (MAT) between - 0.6 and 3.3°C. The central part is characterised by a temperate semi-moist to semi-arid climate (cluster III; MAP 300 to 490mm; MAT 5.8 to 9.1°C), and farther to the south and west by a semi-temperate and semi-arid climate (cluster V; MAP 200 to 400mm; MAT 2.6 to 5.3°C). The southern part shows a semi-temperate and semi-moist climate (cluster VI; MAP 330 to 600mm; MAT 7.5 to 7.8°C), and the southernmost area near the border to Nepal a semi-temperate and moist climate (cluster IV; MAP 600 to 900mm, MAT 3.5°C).

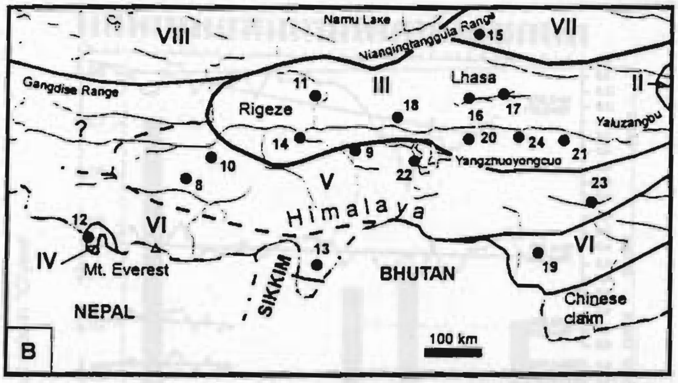

Figure 2: Climatic Classification (Cluster II-VIII) of Southern Tibet According to Leber et al. 1995b (For explanation see text.)

Time Series Analysis of Temperature and Precipitation

The topography of southern Tibet is pronounced, leading to a very strong variability in the mean total annual temperature, ranging between - 0.39°C for the station of Cuona (19) at an altitude of 4,280m and 9.06°C for Jiacha (21) at an altitude of 3,260m. The mean annual temperatures for all 17 meteorological stations in southern Tibet are presented in Figure 3. The graphs of the different stations show a very good match. In comparison to the long-term mean temperatures (M) at the stations, the mean total annual temperatures from 1952 to 1961 show a slightly increased level, followed by a period of decreased temperatures with strong variations until 1972. The period from 1973 to 1983 is characterised by temperatures grouped around the long-term mean annual temperature (M), with a minimum in the year 1978. The period after 1983 shows a slightly higher temperature level with stronger variations. Given the data bases, comprising 17 meteorological stations only, it is obvious that an interpretation of trends is limited to some extent, especially due to the fact that the longest time series covers 40 years for Lhasa (16), the capital of the Tibetan Autonomous Region, and the shortest 11 years, for Lhaze (9), in the western part of the studied area.

Nevertheless a general increase of the temperature level in southern Tibet within the last four decades can be inferred from a regression analyis of the mean total annual temperatures. Figure 3 shows the best fitting lines and the calculated trend rates (TR) at the different stations. Figure 4 shows the trend rates as a bar chart.

In total, 16 out of 17 stations show warming trends between 0.0001°C/year (Rigeze [14]) and 0.07°C/year (Dingri [8]). Only at the station of Nanmulin (12), with data available for only 11 years (1980-91), is there a decreasing trend of - 0.012°C/year.

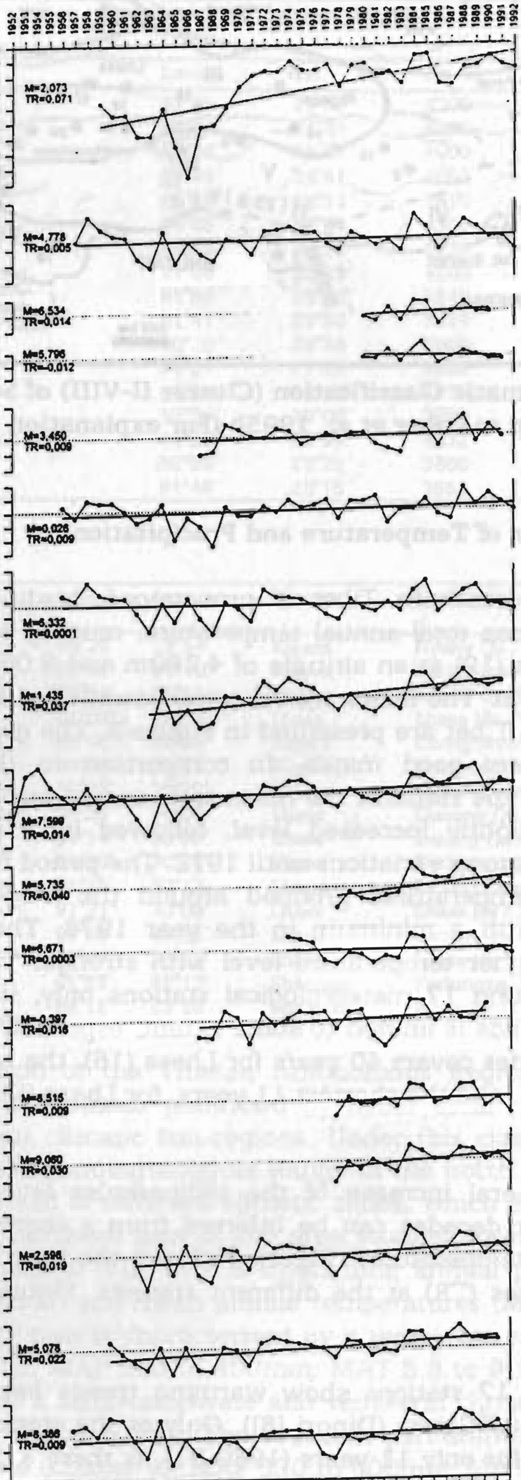

Figure 3: Long-term Mean Annual Temperatures Measured at Meteorological Stations in Southern Tibet from 1952 to 1992 (Dotted line: long-term mean annual temperature (M). Solid line: best fitting line and respective trend rates (TR).)

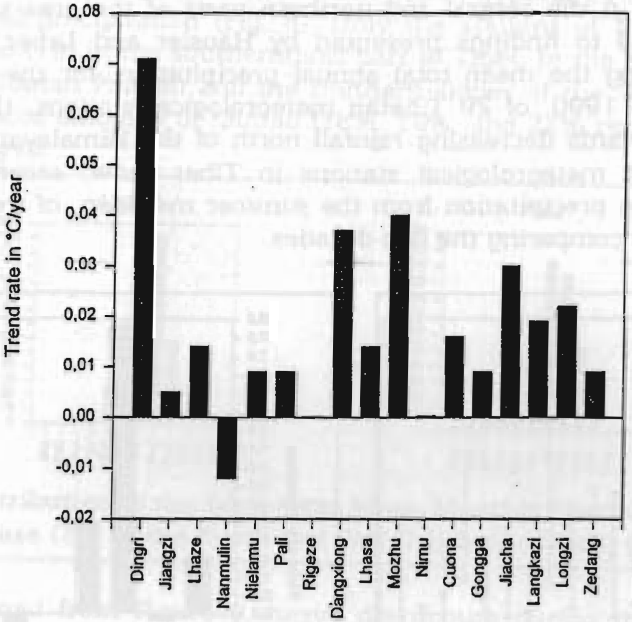

Figure 4: Temperature Trend Rates Calculated by Regression Analysis of the Mean Annual Temperatures of 17 Meteorological Stations in Southern Tibet

These results correspond to regression analysis on a monthly basis of long-term data from 29 meteorological stations in the Tibetan Autonomous Region presented by Leber et al. (1995a). In more than 15 per cent of all station-months with significant trends at a five per cent level, a significant increase of the mean monthly temperatures was found. While there are only a few significant changes in the mean highest monthly temperatures, in more than 20 per cent of the station-months a significant increase of the mean lowest monthly temperatures was detected (Leber et al. 1995a).

The precipitation in southern Tibet shows, on the one hand, very strong deviations (Fig. 5) between the different stations, demonstrating very clearly the influence of the topography hampering or aiding the advance of the Indian monsoon. On the other hand, the total annual precipitation can show a very strong deviation from the long-term mean. This can be seen in Figure 5 which reflects the influence of a weakened or strengthened Indian monsoon on the weather situation. The long-term mean total annual precipitation in southern Tibet ranges from 263mm for Dingri (8), at an altitude of 4,300m to 674mm for Nielamu (12), at an altitude of 3,810m.

Due to the pronounced deviation of the total annual precipitation for one station in different years from the long-term mean, an analysis of a long-term trend of the total annual precipitation is very difficult. When only meteorological stations in southern Tibet, with an observation period of over 25 years (compare Fig. 6), are taken into account, positive as well as negative trend rates are evident. From the location of the stations it is possible to assume that there is a trend towards an increasing amount of rainfall in the south and south-west and towards a decreasing trend in the central and northern parts of the area studied. These results correspond to findings presented by Häusler and Leber (1994). They showed, comparing the mean total annual precipitation, for the years 1971 - 1980 and 1981 - 1990, of 29 Tibetan meteorological stations, that there is a general trend towards decreasing rainfall north of the Himalayan Range. Only the southernmost meteorological stations in Tibet show, according to their studies, increasing precipitation from the summer monsoon, of from 3 per cent up to 25 per cent, comparing the two decades.

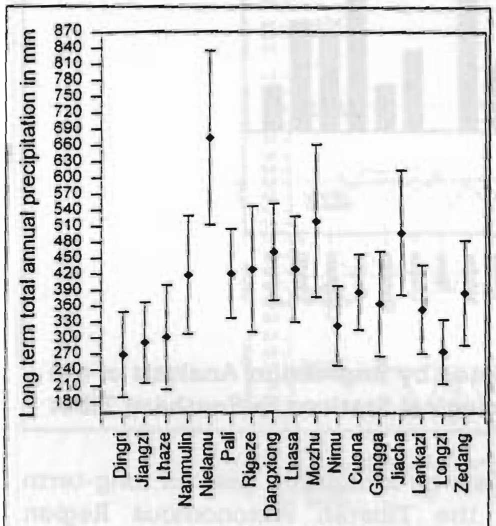

Figure 5: Long-term Total Annual Precipitation of 17 Meteorological stations in Southern Tibet (Indicated are the long-term mean and the standard deviation.)

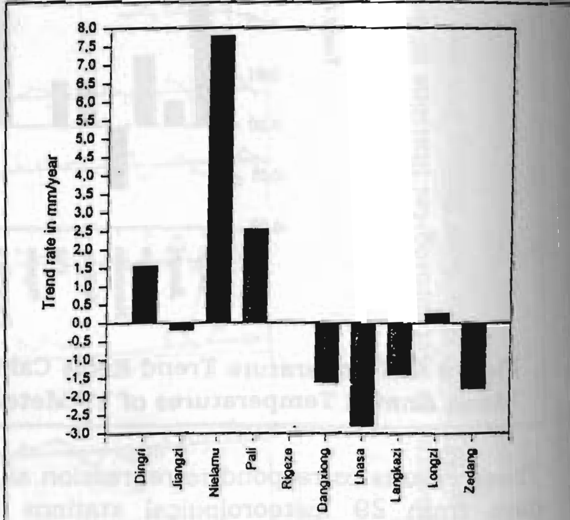

Figure 6: Precipitation Trend Rate Calculated by Regression Analysis of the Total Annual Precipitation of 9 Meteorological Stations in Southern Tibet with an observation period of more than 25 years

Distribution of Precipitation and Heavy Downpours Accelerating Soil Erosion

Precipitation in southern Tibet is concentrated very clearly during the summer months (May to October), the time when the territory is under the influence of the Asian monsoon. The monsoon season in southern Asia starts generally during May due to the fact that the southern branch of the high-level westerly jet stream currents begins to break down and to shift northwards over the Tibetan plateau (Barry and Chorley 1992). With the arrival of the humid low-level south-westerlies, moist air currents move up the Himalayan valleys to the north. The long-term mean monthly precipitation represented as a bar chart in Figure 6 shows clearly the concentration of rainfall from May to October, although there can be a time difference of up to two months (March/April) for the onset of the rainy season at the meteorological stations of Lhasa (16) in the north and Pali (13) in the south because of their latitudinal location and the surrounding topography (Fig.7). An analysis showed that precipitation during the summer monsoon (May to October) contributes in general 95 to 99 per cent to the total annual precipitation (Fig. 8). Only the stations of Nielamu (12), Pali (13), and Cuona (19) in the southernmost part of Tibet, in the transititional area between the Tibetan Plateau and the southern slopes of the Himalayan Range, show considerable amounts of rainfall (38%, 14%, and 22% respectively) during the rest of the year.

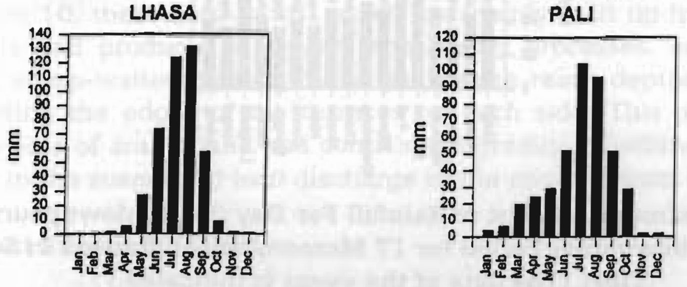

Figure 7: Distribution of the Long-term Mean Monthly Precipitation for the Stations of Lhasa (16) in the North and Pali (13) in the South (see Figure 1)

As can be learned from Figure 9, heavy downpours during the period of the summer monsoon can contribute a considerable amount to the total annual precipitation even in the semi-arid western part of the studied area, thereby accelerating severe linear and areal erosion in southern Tibet. In general the maximum rainfall recorded in one day ranges around 40mm for the major part of southern Tibet; only the southernmost stations of Nielamu (12) and Pali (13) show higher values. Although the total annual rainfall at the station of Dingri (8), for example, only attains amounts between 104 and 474mm, with a long-

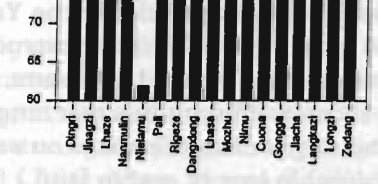

Figure 8: Contribution of Monsoonal Summer Precipitation (May to October) in Per Cent to Long-term Mean Total Annual Precipitation at 17 Meteorological Stations (Only at the southernmost meteorological stations of Nielamu (12), Pali (13) and Cuona (19) does the precipitation during winter monsoon reach more than 10%.)

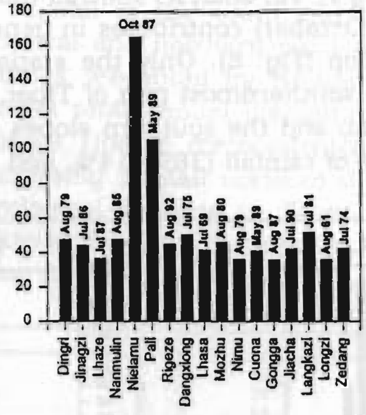

Figure 9: Maximum Amount of Rainfall Per Day (heavy downpours in mm) within the Observation Period for 17 Meteorological Stations in Southern Tibet (The date of the event is indicated.)

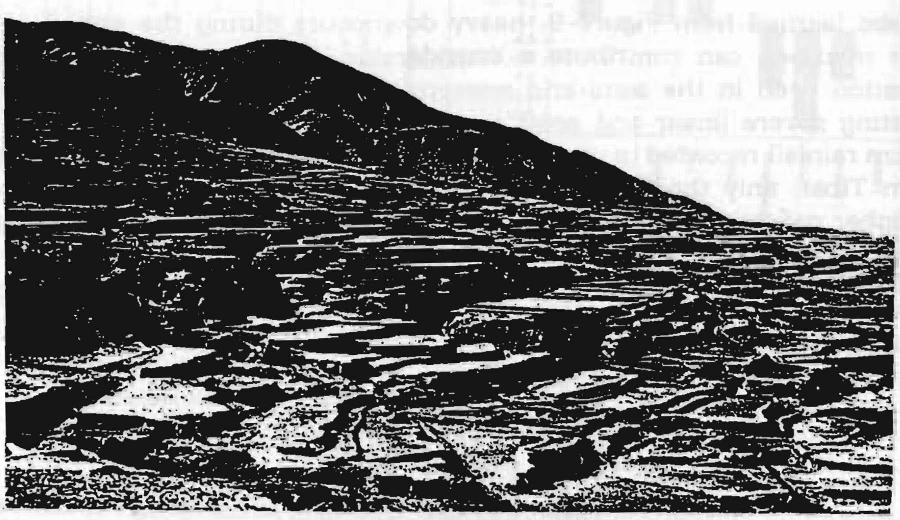

Figure 10: Piedmont Slopes Covered by Redeposited Loess-like Silts and Products of *in situ* weathering near Dagzhuka in the Yarlungzangbo Valley (These landforms are used extensively for the construction of agricultural terraces and as pastures. Due to heavy downpours, the terraces are dissected by steep-sided, short-walled gullies reaching depths of up to 30 metres, thereby eroding the edges of the terraces on each side leading to a considerable loss of arable land.)

term mean of 263mm, the maximum rainfall recorded in one day in August 1979 was 47.8mm (= 15% of the total annual precipitation in 1979)! Similar trends can be observed at the other stations.

Despite other natural parameters determining erosional processes, such as lithology and the weathering of basement rocks, exposition and dip of slope, soil cover, and vegetation cover, the influence of heavy downpours must not be underestimated. Very good examples of erosional features induced by heavy downpours can be observed in the valleys of the Yarlungzangbo, the Nyang Qu, and Lhasa He. Besides the broad flood plains formed by the braided river systems, it is the alluvial fans covering the piedmont slopes of the mountain ranges that tend to be used extensively for farming and as pastures. As can be seen in Figure 10, these land forms, which are mainly built up from redeposited loesslike silts and products of *in situ* weathering processes, are dissected by steep-sided, sharp-walled gullies. These gullies can reach depths of up to 30m, thereby eroding the edges of the terraces on each side. This process leads to considerable loss of arable land and contributes greatly to sediment transport in general and to the suspended load discharge in the river systems in particular.

Discharge and Suspended Load

From the hydrological data set of 16 stations in southern Tibet used for our studies (compare Table 1), long-term mean monthly discharge and long-term mean monthly suspended load discharge data of two gauging stations along the Yarlungzangbo River, the main river system draining southern Tibet in an eastward direction, and of two important stations along tributaries, have been extracted and represented in Figure 11. The station of Lhaze (87°41´E/29°10´N) is located on the Yarlungzangbo in the western part of the studied region, covering a drainage area of 49,370sq.km. (HBTAR 1984) between the watersheds of the Himalayan Range in the south and the Gangdise Range in the north, including the headwater region of the Yarlungzangbo in the area of the famous holy Kailas Mountain. The gauging station of Nugesha (89°43´E/29°20´N) is located approximately 200km farther to the east, covering a drainage area of 106,121sq.km. (HBTAR 1984). There the power of the stream is already strengthened by absorption of the discharge of major river systems like the Nyang Qu. The gauging station at Rigeze (88°54´E/29°11´N) covers an area of 11,121sq.km. (HBTAR 1984) north of the Himalayan Range and west of the beautiful Yangzhuoyongcuo Lake, drained by the Nyang Qu River. The gauging station at Lhasa (91°09´E/28°38´N) records the hydrological parameters of the Lhasa He, which drains an area of 26,255sq.km. (HBTAR 1984) south of the Nianqingtanggula Range.

As can be seen from Figure 11, the discharge is, like the precipitation, clearly concentrated in the summer months, with a slight time shift compared to the onset of the rainy season at the stations. All the gauging stations show a certain value of basic discharge during the dry season (Nugesha 151 - 280m^3/sec; Lhaze 47 - 82m^3/sec, Lhasa 48 - 126m^3/sec, Rigeze 7 - 21m^3/sec), mainly due to glacial and snowmelt. Starting in June, the mean monthly discharge rates increase rapidly to reach their culmination in August (Nugesha 1,864m^3/sec; Rigeze 100m^3/sec; Lhasa 888m^3/sec; Lhaze 524m^3/sec). More striking is the distribution of the long-term mean monthly suspended load discharge. It is obvious that there is nearly no erosion and sediment transportation and redeposition during the dry season and that the basic discharge contributes nearly nothing to the

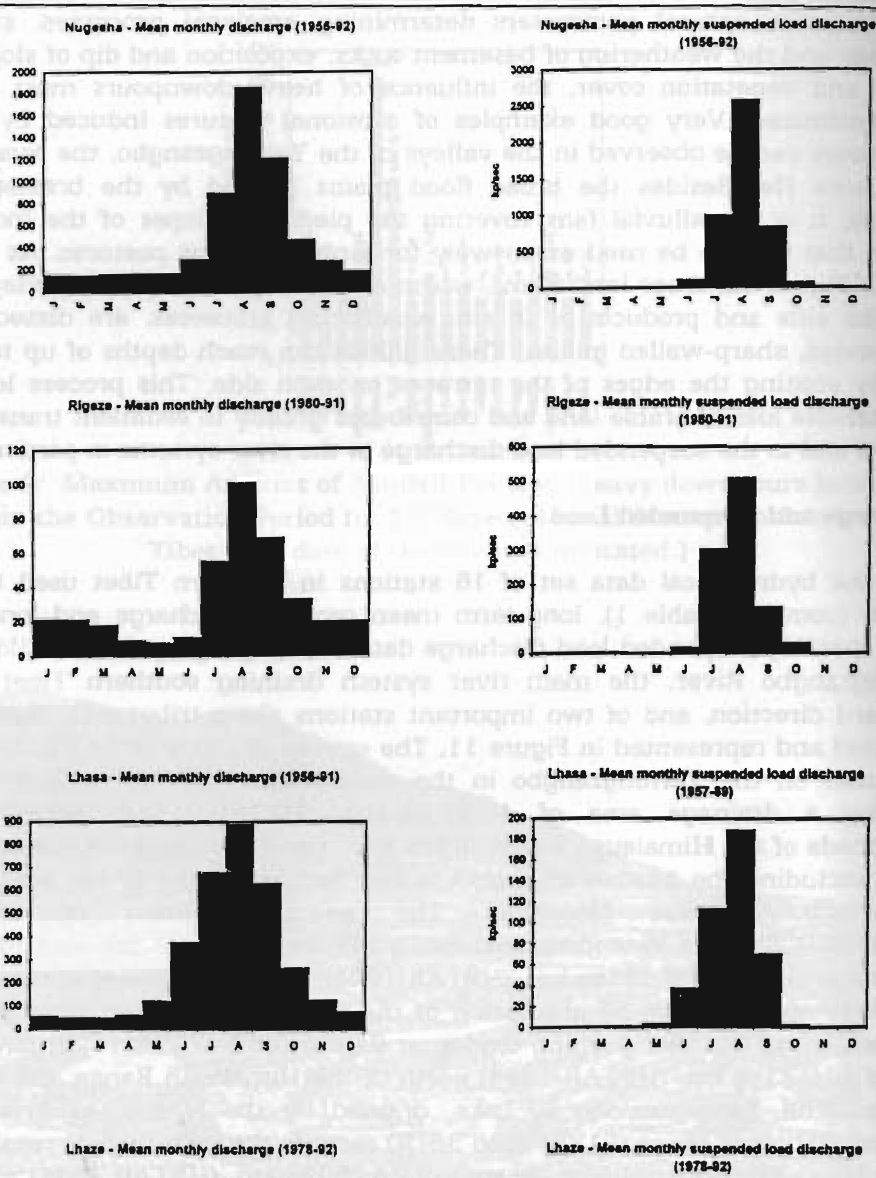

Figure 11: Long-term Mean Monthly Discharge Rates and Long-term Mean Monthly Suspended Load Rates at the Different Gauging Stations in Southern Tibet (In general the maximum of discharge correlates with the maximum of suspended load in August.)

suspended load discharge, whereas the precipitation, especially in the form of heavy downpours during the monsoon season, leads to severe soil erosion and removal of sediments (particularly mudflows and gully erosion), thereby contributing to the huge quantities of suspended load discharge measured at the gauging stations during (May) June to October, with a peak in July and August (Nugesha 2,578kp/sec; Rigeze 510kp/sec; Lhasa 189kp/sec; and Lhaze 243kp/sec).

An analysis showed that the amount of suspended load discharge at the different stations in southern Tibet can directly be related to the lithology of the bedrock and the weathering processes in the drainage area. Table 2 provides information about the standardised amount of suspended material (grammes per litre per second; g/l/sec) in August in relation to the size of the drainage basin (per km^2.; H). The suspension load at Rigeze (5g/l/s calculated per sq.km. of recharge area) in August is up to 25 times higher than at Lhasa (0.2g/l/s per km^2.), which can be explained by the different weathering of the bedrock. The higher amount of silt and sand of the Nyang Qu River is due to the weathering of sandy and shaly Flysch formations (Xigaze Group, Triassic Flysch) and the erosion of sand dunes and redeposited loess-like silts south and south-east of Rigeze. The smaller amount of suspension load of the Lhasa He generally reflects the scarce weathering of plutonitic rocks nowadays, whereas the erosion of sand dunes is common around Lhasa, as elsewhere.

The small amount of suspension load in August at the station of Lhaze (0.5 g/l/s per km^2.) can be explained by the semi-arid-to-arid climatic conditions in the watershed.

Table 2: Approximate Water and Sediment Discharge

Hydrologic station	A Drainage basin sq.km.	B Discharge m^3/s August	C Suspension load (kp/s) August	D Discharge $l/s/km^2$ August	E Silt/sand transporatedg/s/km^2 August	F Suspended load $g/l/s/km^2$ August
Lhaze	50	524	243	10.48	4.86	0.46
Rigeze	11	100	510	9.09	46.36	5.10
Nugesha	106	1864	2578	17.58	24.32	1.38
Lhasa	26	888	189	34.15	7.69	0.23

The long-term mean annual precipitation amounts to 263mm at the meteorological station of Dingri (8) and diminishes farther to the west.

The relatively small value of suspension load in August at Nugesha, only 1.3g/l/s per km^2, can be explained from two factors. First, from the vast extension of the drainage area to the dry west (including the drainage area of Lhaze), and second, from the fact that the broad area of the Pum Qu (Upper Arun watershed), which is more than twice the size of the recharge area of Rigeze hydrologic station, discharges to Nepal. Because of the similar geological framework in the Pum Qu drainage basin and Rigeze recharge area, a high amount of suspension load can be expected to be discharged to the south.

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