Vulnerability of water discharge of large Chinese rivers to environmental changes: an overview

X. X. Lu

Abstract In an era of rapid environmental change, China is facing increasing problems in the management of its large rivers and water resources. The disastrous 1998 Yangtze floods and the emerging water shortages in north China raised further concerns about the potential impact of environmental change on extreme hydrological events such as floods and droughts. Over the past few decades, increasing water consumption by the domestic, industrial and agricultural sectors, as well as a number of human activities such as deforestation, agricultural land expansion, wetland reclamation, construction of reservoirs and roads, water diversion, and sand/stone excavation significantly affect hydro-geomorphic processes such as water discharge and sediment flux throughout China. This paper aims to provide an overview of recent research on the water discharge changes occurring in major Chinese rivers and their vulnerability to environmental change. Most of the rivers, notably in north China, have experienced significant changes in water discharge over the last few decades, indicating that they are vulnerable to climatic variations and human activities. In contrast to north China, the rivers in south China have experienced less change, but some of the detected changes displayed similar trends to those in north China, though at a slower pace. These profound changes, in addition to the on-going projects such as the Three Gorges Dam Project and the South-North Water Transfer Project, will completely alter China’s waterscape.

Introduction

The assessment of the vulnerability of water resources to climate change and human activities has been done extensively at both regional/country and global scales (Vörösmarty et al. 2000; Shiklomanov 1996). For example, Vörösmarty et al. (2000) examined the vulnerability of global water resources to climate change and population growth. They demonstrated that a large proportion of the world’s population is currently experiencing water stress, with rising water demands greatly outweighing greenhouse warming within the next 25 years. Such an assessment is therefore necessary in China, a country which is characterized by water scarcity, uneven distribution of water resources, population size and rapid economic development. Increasing water consumption by the domestic, industrial and agricultural sectors, and a number of human activities such as deforestation, agricultural land expansion, wetland reclamation, construction of reservoirs and roads, water diversion, and sand/stone excavation significantly affect hydro-geomorphic processes and hence have altered water discharge and sediment flux over the past decades throughout China.

Various reports on the water resources and management issues in China have emerged recently (e.g. McCormack 2001; Xia and Chen 2001; Zhang and Zhang 2001; Varis and Vakkilainen 2001). For example, Zhang and Zhang (2001) have examined five current important water issues, and suggested measures to counter the challenges of sustainable development, whereas Varis and Vakkilainen (2001) have outlined eight challenges to water resources management in the first quarter of the 21st century. River water discharge, the sum of surface and subsurface (shallow aquifer) (Vörösmarty et al. 2000), constitutes the sustainable water supply to which local people can have access (United Nations 1997). Therefore, the assessment of river water discharge in its response to environmental change is an important component of water resources assessment.

The aim of this paper is to provide an overview of recent research on the water discharge change over the past decades across major Chinese river systems. First, the water discharge changes of major Chinese rivers are summarized, drawing on available data and literature. Second, the susceptibility of river water discharge to...
climate changes and human activities, mainly water consumption by the domestic, industrial and agricultural sectors, construction of reservoirs/dams, and land surface disturbance such as land use alteration and subsequent soil erosion and sedimentation, is examined.

**River systems in China**

Major Chinese rivers from north to south include the Heilongjiang, Songhuajiang, Liaohai, Haihe, Luanhe, Huanghe, Huahe, Changjiang, Minjiang, Zhujiang, Lancangjiang (Mekong), Nujiang and Yaluzangbujiang (Fig. 1). According to UN ESCAP (1997), China can be divided into nine regions based on its major river systems (Table 1). Huaihe is a traditional divide of climate between north and south China. The regional climates can be divided into six groups from south to north on the basis of precipitation and temperature regimes: humid tropical, humid subtropical, temperate, semi-arid, arid and Qinghai-Tibet Plateau region (Fig. 1). Runoff ratios (runoff divided by precipitation) vary from one climate zone to another, but generally decrease from south to north (Fig. 2). On average, about half of the annual precipitation becomes the annual runoff. Monthly water discharge varies considerably under monsoon climate, which is higher in summer (from July to September) and lower in winter (Fig. 3). Variations of the monthly water discharge between the dry and wet years are higher in north China (e.g. Luanhe and Huanghe) and lower in south China (e.g. Changjiang and Xijiang).

Table 2 summarizes the time series changes in the annual water discharge of major Chinese rivers, based on data from both this study and available literature (i.e. Wang and Cheng 2000; Yang et al. 1998; Liu and Qimeidouji 1999; Liu and Zheng 2002). While annual mean water discharge for each year was averaged from 12 calendar months, annual minimum and maximum water discharges were actual monthly measurements in
Table 1

<table>
<thead>
<tr>
<th>System Regions</th>
<th>Main Rivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeastern</td>
<td>Heilong Jiang (Amur), Songhua, Wusuli, Liao He, Yalu, Tumen</td>
</tr>
<tr>
<td>Haihe-Luanhe Basin</td>
<td>Haihe, Luanhe</td>
</tr>
<tr>
<td>Huanghe Basin</td>
<td>Huanghe (Yellow River)</td>
</tr>
<tr>
<td>Changjiang Basin</td>
<td>Changjiang (Yangtze River)</td>
</tr>
<tr>
<td>Southern</td>
<td>Xijiang (Pearl River) and others</td>
</tr>
<tr>
<td>Northeastern</td>
<td>Minjiang and others</td>
</tr>
<tr>
<td>Southern</td>
<td>Yarlung Zangbo, Lancang Jiang, Nu Jiang, Yuan Jiang</td>
</tr>
<tr>
<td>Southwestern</td>
<td>Tarim, Ill, Ertix (Irysh) and others</td>
</tr>
<tr>
<td>Interior Basin</td>
<td></td>
</tr>
</tbody>
</table>

Table 2 indicates that north China, i.e. the Northeastern region, Interior Basin (Northwestern), Haihe-Luanhe Basin, Huanghe Basin and Huaihe Basin, has more rivers which have experienced change in water discharge than south China, i.e. the Changjiang Basin, Southern and Southwestern region.

In north China, the majority of rivers has experienced decreases in both the annual mean and the annual maximum water discharge. Yongdinghe and Luanhe show significant decreases in all the three variables since the 1950s (see Fig. 4 for Yongdinghe at Guanting). Both rivers flow through the areas of Beijing, Tianjing and Tangshan where water shortage has been a chronic problem. Huanghe at Huayuankou has also experienced decreases in the annual mean and the annual maximum discharge since the 1950s (Fig. 4), though the annual mean discharge at this station was not as significant as Lijin station (further down Huanghe in Fig. 1), as documented by previous studies (Yang et al. 1998; Brown and Halweil 1998). In fact, Huayuankou and Sanmenxia stations have actually experienced increasing trends in the annual minimum discharges from the 1960s to the 1980s (Table 2). For the Interior Basin (northwestern arid region) the change is more obvious. For example, discharges of the majority of rivers in Xinjiang have been reduced drastically (or even dried up), river courses have been shortened, and inland lakes have contracted or dried up (Wang and Cheng 2000). The drying up of rivers in north China has been frequent in recent years. For example, the Huanghe ran dry for the first time in history in 1972, and water failed to reach the sea for 226 days in 1997 (Brown and Halweil 1998); the same happened to the Liaohe in Liaonin Province for 148 days in 2001. The emerging water shortages are threatening the country’s food production as rivers are drained and aquifers are depleted by the soaring water needs (Brown and Halweil 1998). In 2000 alone it was reported that economic loss was US$16 billion as a result of drought in the north China plain. The severe droughts shut down the Xiaolangdi power station, which is the largest and most expensive hydro-electric scheme on the river.

The Changjiang has displayed a stable value in the annual mean and the annual maximum discharge, but a significant decrease in the annual minimum at Yichang has been observed (Fig. 5). This is in contrast to its major tributaries in the upper reach, namely the Yalong, the Dadu-Min, the Jianlin and the Wu, which have increased or decreased in importance as suppliers of water and sediment during the last 50 years (Lu and Higgitt 1998; Chen et al. 2001; Lu et al. 2003). For the other rivers in south China, the Xijiang at Wuzhou showed a downward trend only in the minimum water discharge (Fig. 5). The Yujiang at Nanjing is the only river in south China which has experienced significant change in all the three variables of the water discharge. The rivers in the Southwestern region, such as the Yaluzangbu and Lancangjiang, have more or less stable water discharges, based on the studies of Liu and Qimeidouji (1999) and You (1999).
The monthly discharge of the Changjiang is expected to be modified further with the full operation of the Three Gorges Project (TGP) in 2009. The TGP’s regulation may prevent further reduction in the trends of the minimum water discharge at Yichang station, but the South-North Water Transfer Project will significantly reduce the water discharge of the Changjiang. The proposed diversion project will divert water from the Changjiang via three different routes: the eastern route, middle route and western route (Liu and Zheng 2002), with a total supply of 48 billion m$^3$ of water per year (around 5.5% of the total annual water discharge of the Changjiang) to the main rivers of Huanghe, Huaihe and Haihe. Due to this, the largest river in China with abundant rainfall in the catchment area may soon follow a similar drying up trend as the rivers in North China.

Although there are less obvious changes in the aggregate data, south China has been frequently hit by severe floods in recent years. For example, the disastrous Changjiang floods in 1998, the worst since the 1950s, cost China a total economic loss of over 2 billion US$, and damaged around 5 million houses and affected about 223 million people, with 1320 casualties (Zong and Chen 2000). The Changjiang basin was also hit by droughts, though most of its area covers a sub-tropical region with abundant rainfall. In 2000, for example, over 1000 industrial enterprises have suspended production due to the drought in Sichuan Province alone.

The results in Table 2 indicate that water discharge in the rivers of the semi-arid regions (e.g. northern China) and the dry regions (e.g. northwestern China) are more vulnerable and sensitive to environmental changes than those in the humid regions (e.g. northeastern and southern China). This is consistent with previous studies (Xu 1998; Ying 2000; Wang and Cheng 2000; Guo et al. 2002). Xu (1998), for example, found that human activity impact ($I_m$) on runoff was negatively related to precipitation ($P$) ($I_m=1.816 \times 10^6 P^{-2.53}$), and positively related to the aridity index ($I_a$, defined as evaporation divided by precipitation) ($I_m=0.539I_d^{0.42}$). Human activity impact ($I_m$) is defined as ($Q_n-Q_m$)/$Q_n$, where $Q_n$ is water discharge without human disturbance and $Q_m$ is the actual measurement of water discharge (Xu 1998). $I_m$ will increase 49.3% if the aridity degree increases by 10%, or $I_m$ will increase 75.8% if the annual precipitation decreases by 20%. The environmental changes considered in this paper include climate variation/change, water consumption by domestic, industrial and agricultural sectors, construction of reservoirs/dams, and land surface disturbance and subsequent soil erosion and sedimentation.

### Water discharge vulnerability

Climate variability or change is expected to alter the hydrological processes and balance. Global warming, for example, is expected to increase evapotranspiration and change precipitation, and subsequently affect the timing and magnitude of water discharge. Over the past century, most of the dramatic climate changes were observed in

---

**Fig. 3**

Mean monthly water discharge for the five rivers from north to south: Songhuajiang at Haerbin, Yongding at Guanting, Huanghua at Huayuankou, Changjiang at Yichang and Zhujiang at Wuzhou. Vertical bars represent minimum and maximum values.

---

**Vulnerability to climate change**

Climate variability or change is expected to alter the hydrological processes and balance. Global warming, for example, is expected to increase evapotranspiration and change precipitation, and subsequently affect the timing and magnitude of water discharge. Over the past century, most of the dramatic climate changes were observed in
Table 2
Summary of the annual water discharge changes of major Chinese rivers (shaded is the rivers in north China, whereas unshaded the rivers in south China)

<table>
<thead>
<tr>
<th>System Regions</th>
<th>Main Rivers</th>
<th>Stations</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Drainage Areas (km²)</th>
<th>Years</th>
<th>Annual min.</th>
<th>Annual max.</th>
<th>Annual mean</th>
<th>Authors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeastern</td>
<td>Songhuajiang</td>
<td>Harbin</td>
<td>45°77’N</td>
<td>126°58’E</td>
<td>391000</td>
<td>1898–1987</td>
<td>Δ</td>
<td>○</td>
<td>○</td>
<td>Ren et al. (2002)</td>
</tr>
<tr>
<td></td>
<td>Lancang</td>
<td>Changdu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
<td>You (1999)</td>
</tr>
<tr>
<td></td>
<td>Lancang</td>
<td>Jiuzhou</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
<td>You (1999)</td>
</tr>
<tr>
<td></td>
<td>Lancang</td>
<td>Gejiu</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
<td>You (1999)</td>
</tr>
<tr>
<td></td>
<td>Lancang</td>
<td>Jinhong</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>△</td>
<td>△</td>
<td>You (1999)</td>
</tr>
</tbody>
</table>

Note: Those data without specifying authors were obtained for this study. Δ increase, △ decrease, ○ no change.
monsoon climates (Varis and Vakkilainen 2001). Zhai et al. (1999) and Shen and Varis (2001) reported that temperatures have increased and precipitation has decreased in most of north China, in particular in the north China Plain, while in south China, Tibet and Xinjiang, precipitation has increased. Mou (1996) reported that precipitation in the 1970s was less in north China. Xu (2002) also reported that the Huanghe basin experienced a period of relatively low precipitation in the 1970s. The significant decrease in the mean monthly water discharge in north China could be attributed to increased temperatures and decreased precipitation.

Despite the high spatial and temporal variation in precipitation, the overall volume of the annual precipitation in China has remained relatively unchanged since 1956 (unpublished report, Nanjing Institute of Hydrological and Water Resources). The report on the reduction of precipitation in north China also contrasted recent simulation studies with regards to the impact of the projected climate change on river discharge and water resources (Ying 2000; Chen and Liu 1996; Guo 1995). These simulations were based on projected global annual temperature increases about 1.5 to 3.5 °C within the next few decades. For example, Ying (2000) predicted that if the annual temperatures increase by 0.88–1.2 °C in the year 2030, precipitation will increase in China, including northern China, but more notably in northeastern and southern China (Table 3). The combined impact of the increased temperatures and the increased precipitation will significantly decrease runoff for the northern rivers, and increase runoff for the southern and northeastern rivers (Table 3). This projection is consistent with the water discharge change of the rivers listed in Table 2.

Vulnerability to water consumption

Direct water consumption by domestic, industrial and agricultural sectors in China have significantly increased over the past decades due to rapid economic development (United Nations 1997; Heilig 1999). Water diversion from the Huanghe for irrigation as well as industrial and domestic uses has also increased since the 1970s. Water was transferred from the Luanhe to the Tianjing and the Huanghe to the Qindao in the 1980s. The trans-basin water diversion from the Huanghe to the Luanhe, the Taiyuan and the Huhehot is currently in process. However, these water diversion projects can not fully ease the shortage problem since these rivers themselves do not have much water left. The well-known Duiyangyan Irrigation System, with a history of over 2000 years, is another example showing the impact of agricultural irrigation on the seasonal water discharge. The irrigation area of the System was increased from 1,920 km² in 1949 to 6,670 km² in the 1990s. The System, vitally important for agricultural
irrigation in the Sichuan Basin, is under threat from the decreasing monthly and daily water discharge in the Min tributary (Lu et al. 2003).

Water stress is defined as the ratio of the combined water withdrawal or water use by the domestic, industrial and agricultural sectors (DIA) to the annual mean of water discharge (Q) (Vörösmarty et al. 2000). It was calculated for major Chinese rivers (Table 4). The water stress ratio determines the degree of direct human consumption of water supplies and thus provides a local index of water stress. Values in the order of 0.2 to 0.4 indicate medium to high stress, whereas those larger than 0.4 reflect conditions of severe water limitation (United Nations 1997). The ratio in 1980 was above 0.1 for most of the regions, with Haihe-Luanhe basin, Huaihe basin and Huanghe basin being at the top. The water stress ratio further increased in 1993, in particular in the northeastern, southern and southwestern regions. However, it is noted that such a simple water stress index has its limitations because it is influenced by the use of water discharge (averaged or observed), excessive water discharge (i.e. flood) and the storage of water in reservoirs before being observed as water discharge.

For the combined effect of climate change and population increase, Vörösmarty et al. (2000) demonstrated that the Huanghe can derive an apparent beneficial effect from climate change, as the climate change will lower values of the water stress and thereby counteract the increases associated with future population growth. This estimate was made on the basis of data collected in 1985; the current condition is that the water stress is more severe because of a rapid increase in water use, rather than a water discharge increase as a result of climate change as they estimated.

**Vulnerability to construction of dams and reservoirs**

China had built over 80,000 reservoirs by 1990, which account for about half of the world’s large dams (i.e. dams over 15 m in height). The majority of these reservoirs has been built since the Great Leap Forward (1958–60) (Dai 1998). Almost all of China’s major rivers have been dammed. Major dams in the Huanghe include Sanmenxia, completed in 1960, Liujiaxia in 1969, Longyangxia in 1986 and recently Xiaolangdi. The operation of these reservoirs has resulted in an uneven distribution of the monthly water discharge (Ren et al. 2002). For example, the increase in the minimum monthly discharge since the 1960s in the Huanghe, e.g. at Shanmenxia and Huayuankou (Table 2), was a likely effect of the operation of the Sanmenxia Dam. Unfortunately, further down the river (e.g. to Lijin in Fig. 1) this increase could not compensate water consumption and hence the river stopped its flow in 1972 and since then, this has become almost an annual phenomenon.

Though the reservoirs and dams can regulate seasonal water discharge, their overall impact is a reduction of water discharge. The significant decrease of water discharge in the Huanghe basin, for example, arose partly from large scale soil conservation measures such as the construction of small dams and terraces in the Loess Plateau (Mou 1996; Xu 2002). Ying (2000) calculated the water storage index which is defined as the ratio of the reservoir water storage capacity and river water discharge. The Haihe and Huaihe had indices of 0.87 and over 0.60, whereas the Changjiang and the Pearl River had indices below 0.11. The rivers which displayed higher water storage indices as calculated by Ying (2000) have also experienced the greatest changes as shown in this paper. Major dams in the Changjiang basin include the Danjiangkou and Gezhouba Dams. The Gezhouba Dam, the first dam in the main Changjiang channel, has affected the water discharge at Yichang station in the dry season (Dec. to March) (Lu et al. 2003).

### Table 3

<table>
<thead>
<tr>
<th>Regions</th>
<th>Songhua</th>
<th>Liaohe</th>
<th>Jing-Jin-Tang</th>
<th>Huanghe</th>
<th>Huaihe</th>
<th>Hanjiang</th>
<th>Dongjiang</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980 Water Stress (D/Q)</td>
<td>0.148</td>
<td>0.118</td>
<td>0.172</td>
<td>0.198</td>
<td>0.146</td>
<td>0.153</td>
<td>0.135</td>
</tr>
<tr>
<td>1993 Water Stress (D/Q)</td>
<td>0.171</td>
<td>0.143</td>
<td>0.152</td>
<td>0.202</td>
<td>0.148</td>
<td>0.145</td>
<td>0.136</td>
</tr>
<tr>
<td>Change (%)</td>
<td>16.1%</td>
<td>19.1%</td>
<td>16.2%</td>
<td>35.5%</td>
<td>11.2%</td>
<td>10.9%</td>
<td>10.7%</td>
</tr>
</tbody>
</table>

### Table 4

<table>
<thead>
<tr>
<th>Regions</th>
<th>Water Stress (D/Q)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980</td>
<td>0.184</td>
</tr>
<tr>
<td>1993</td>
<td>0.258</td>
</tr>
<tr>
<td>Change (%)</td>
<td>40.84</td>
</tr>
</tbody>
</table>

**Original article**

Vulnerability to land surface disturbance

Land surface disturbance includes land use alteration, mainly deforestation and agricultural expansion and its consequences of soil erosion and sediment deposition. Land use alteration can cause water discharge changes. However, identification and interpretation of such impacts can be much more difficult for large basins due to interference of other human activities and hydrological time lags throughout the examined periods. Attempts to analyze precipitation, stream flow and sediment transfer data from the Himalayas region, for example, have been inconclusive (Carson 1985; Hamilton 1987; Ives and Messeri 1989; Hofer 1993). With the loss of tree cover on slopes, the natural capacity of the trees to store water that might otherwise be lost to evaporation or rapid flow downstream is reduced. The decrease of the water discharge in the upper stream of the Huanghe was largely due to extensive deforestation and grassland desertification upstream, especially in the Qinghai Plateau. It was reported in 1998 that the quantity of Huanghe water leaving the source area in Qinghai has fallen by 23% over the past few decades. The impact of land surface disturbance on water discharge was demonstrated by the seasonal water discharge and sediment transport in the major tributaries of the upper Changjiang (Lu and Higgitt 1998; Chen et al. 2001; Lu et al. 2003). For example, the water discharge and sediment flux in the Dadu-Min tributary of the Upper Changjiang have been significantly modified (Fig. 6) due to the reduction of forest cover from 32% in 1949 to only 14% in the 1990s (Winkler 1996).

Sediment deposition elevates the riverbed relative to the surrounding landscape. The elevated riverbed in the Huanghe, for example, may play a role in the declining water discharge, as both surface runoff and groundwater flow could not contribute to the lower 600 km of the river, though there is considerable leakage of water out of the leveed banks (Yang et al. 1998). Sedimentation in water bodies and flood plains significantly reduces the water storage capacity in the Changjiang basin (Chen et al. 2001; Du et al. 2001). The river bed along the Jinjiang area in the middle reach of the Yangtze River, for example, is a few meters higher than ground level. The surface area and the water storage capacity of the Dongting Lake and the Poyang Lake have been reduced. More silt and less water storage capacity imply that with less water floods can become more serious than ever before. During the 1998 Yangtze flood, for example, most of the hydrological stations measured lower water discharge but higher water levels as compared to some historical flooding events (Zong and Chen 2000). The encroachment onto the natural flood retention areas by local farmers and onto scarce agricultural land due to urban development also significantly disturbed the land surface. Studies have shown that over the past decades, there have been increasing numbers of farmers moving into the most flood-prone areas such as wetlands, lakes and even river beds (Du et al. 2001), and previously designated flood-diversion areas in Jinjiang in the middle reach of the Yangtze River, which are currently farm and factory sites, thus making diversion impossible. The encroachment has also significantly reduced the water storage capacity and hence increased water levels as evident around the Poyang Lake (Xiang et al. 2002).

Summary and Conclusion

This paper provides an overview of the water discharge change in major large rivers in China over the past decades. The time series data indicates that most of the rivers have experienced significant changes in the monthly water discharge (mean, minimum and maximum). The rivers in North China generally have experienced decreases in water discharge, while the rivers in South China show less changes. This indicates that water discharges in the
semi-arid regions (e.g.

North China) and the dry re-

gions (e.g.

western China) are more vulnerable and sensitive to environmental changes than in the humid regions (e.g.

eastern and southern China). It can be argued that North China has been or will be getting hotter and therefore will experience less precipitation. Appar-

tently, the impact of climatic variations on water discharge in China has not been fully understood yet. Evidence 

suggests that the significant changes of river discharge were due to increasing water consumption by domestic, 

industrial and agricultural users, land surface disturbance such as logging, deforestation, agricultural expansion, 

reservoir construction and regulation.

These profound changes have significant implications for

the management and utilization of water resources across the country. China’s waterscape will be further changed 

with the construction of projects such as the on-going 

Three Gorges Project (TGP) and South-North Water 

Transfer Project. Thus, the variable response of the large 

rivers to environmental change and the variable stages of 

large river engineering projects pose many challenges to 

rivers and water resources management. A detailed analysis 

of the impact of climate change and human activities on 

hydrological regimes should be given further attention. 

The consideration of an entire river system including 

runoff generation in mountain areas and transport 

through middle and lower reaches, will further improve 

understanding of the links between potential factors and 

water discharge change in large river basins. A holistic 

approach, apart from the water saving measures in north 

China, should be taken to ease the increasing problems 

throughout the country.

Acknowledgements This research is funded by the National 

University of Singapore (Grant number R-109-000-034-112).

Acknowledgements go to Mrs. Lee Li Kheng for preparing Fig. 1.

References


(accessed in August 1999).

Carson B (1983) Erosion and sedimentation processes in the 

Nepalese Himalaya. International Centre for Integrated 


Guo SL, Wang JX, Xiong LH, Ying AW, Li DF (2002) A macro-

scale and semi-distributed monthly water balance model to 


Hamilton LS (1987) What are the impacts of Himalayan defor-

estation on the Ganges-Brahmaputra lowlands and delta? 

Assumptions and facts. Mountain Research and Development 

7:256–263.

Heilig GK (1999) China Food: Can China Feed Itself? IIASA LUC 

Project CD, Version 1.1, IIASA, Laxenburg.

Hofer T (1993) Himalayan deforestation, changing river dis-

charge, and increasing floods: myth or reality? Mountain 


Shiklomanov I (1996) Assessment of water resources and water availability in the world: scientific and technical report (State Hydrological Institute, St. Petersburg, Russia).


