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The Role of the Himalayan Mountain Systems in Food Security and Agricultural Sustainability in South Asia

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Although South Asian countries made impressive progress in food production during 1960s, 1970s and 1980s, the dynamism in the agricultural sector has, however, lost recently. Productivity of major food grains has slowed down and even declined, for some crops and food production is failing to keep pace with population growth. Therefore, food security has remained a major concern in South Asian countries.

The linkage between food production and the Himalayan mountains is poorly understood though the Himalayan mountains are the major source of dry season water in Pakistan, Nepal, Bangladesh and Bhutan for irrigated rice and wheat, which are the staple food in South Asia. In view of that this article briefly examines the role of the Himalayan mountain systems in food production and agricultural sustainability in South Asian countries looking at the emerging challenges posed by the increasing water stress and climate change.

The analysis suggests that a common challenge is being faced by all South Asian countries—for increased food production to meet the demand of burgeoning population, the growing stress of water as rice and wheat , the staple food in South Asia, require huge amounts of water. Moreover, the increased food production in South Asia has to come from the same amount of land, by increasing productivity through bringing additional land under irrigation, as the frontier for expansion of agricultural land has almost been exhausted. The availability of irrigation water is, therefore, critical for increased food production and agricultural sustainability in entire South Asia. Climate change introduces a new challenge to agriculture and food security in South Asia. Recent studies suggest that the impact of climate change on cereal production in South Asia could be negative and that may be as high as 18.2–22.1 per cent.

Our analysis reveals that the Hindu Kush-Himalayan mountain systems play a significant role in agriculture and food security in South Asia through water supply, climate and wind regulation, groundwater recharge and in sustaining wetland ecosystems. It is the major source of dry season water for several large river systems, such as the Indus, the Ganges and the Brahmaputra from the snow and glacier melt of the Himalayas, which provide the main basis for surface and groundwater irrigation. These three rivers form the largest river basins (Indo–Ganga–Brahmaputra) which are the major source of rice and wheat in South Asia. Besides surface water, the contribution of mountain discharge to groundwater is also significant, which makes it an important resource for agriculture and food security in South Asia. In addition to providing surface and groundwater, the Himalayan mountain system provides huge inputs to agriculture through regulating micro-climates as well as wind and monsoon circulation, and by supporting river and wetland ecosystems in South Asia. It is estimated that the Ganges river ecosystem alone supports 25,000 or more species, ranging from micro-organisms to mammals, which support agricultural sustainability and provide livelihoods for millions of people.

This article concludes that the long-term agricultural sustainability and food security of South Asia is heavily dependent on the water and other ecosystem services it receives from the Himalayan ecosystems. Attention therefore must be paid to conserve the Himalayan ecosystems in order to ensure sustained flow of ecosystem services required for agriculture, food production and overall well-being of Himalayan and downstream population. Options and opportunities for enhancing the agricultural sustainability and food security by sustainable utilization of Himalayan resources and ecosystem services are briefly analyzed and suggestions have been made.

Keywords: Himalayan ecosystems services; water; irrigation; agricultural sustainability; food production; food security; South Asia

INTRODUCTION

Food is fundamental to all living organisms, including human beings. South Asia—Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka—is one of the most densely populated regions in the world. But with only 3.3 per cent of the world's land area, this region has to feed one-fifth of the world's population.

South Asia has the largest number of poor and malnourished people in the world—446.2 million (46 per cent) out of 969 million in the world who live on less than US$ 1 a day (Ahmed et al. 2007). According to the Global Hunger Index (GHI), Sub-Saharan Africa and South Asia are the world's two hunger 'hot spots'. In terms of food-energy deficiency (defined as per capita calorie availability below the average requirement for light activity) South Asia is at about the same level as that of Sub-Saharan Africa. In South Asia 51 per cent of the populace is food-energy deficient while in Sub-Saharan Africa the figure is 57 per cent (Smith and Wiesmann 2007).

The foundation of agriculture is land, water, weather, climate, biodiversity and other environmental and ecosystem resources. Although green revolution technologies have increased agricultural production to a remarkable degree and have contributed to enhancing food security, these technologies have also affected land, water, and the environment and have reduced the diversity and resilience of the agricultural system—essential for long-term sustainability. Degrading land quality, depleting water resources, increasing soil salinity and water logging, as well as expanding biotic and abiotic stresses are now evident in the entire region. This has raised serious concerns in South Asia.

The degradation of the resource base combined with the increased stresses and uncertainties arising from global warming and the increased melting of ice and snow (the primary source of water for irrigation during the dry season) have posed a serious development and environmental challenge to South Asia. Recently, the Prime Minister of India, Dr Manmohan Singh, said, 'Agriculture in many parts of the country [India] is in a state of crisis'. Similar concerns were raised by Dr M.S. Swaminathan, 'The farming sector is fast heading for a total collapse if no rapid remedial measures are taken' (Agoramoorthy 2007). Such disquiet is also echoed in Afghanistan, Bangladesh, Nepal and Pakistan (Kumar et al. 2008). The problem is more serious in mountain areas due to remoteness, inaccessibility, the fragile environment, the limited area of arable land and high transportation costs (ICIMOD 2008). All the countries of South Asia are confronted with the challenge of how to grow enough food to meet the ever-increasing demands of a burgeoning population without degrading the natural resource base and the environment.

So, what is the relevance of the Himalayan mountain system in agricultural productivity and sustainability, and how can this mountain system influence food security in South Asia? In order to answer this question we must first examine the challenges and opportunities of agricultural productivity, particularly in the context of increasing water stress stemming from global warming, climate change, and other socio-economic and demographic factors.

As the Himalayan mountains are a major source of dry season water for irrigated rice and wheat in India, Pakistan, Nepal, Bangladesh and Bhutan, which are the staple food in South Asia, the linkage between food security and mountains is very strong. This article briefly examines the challenges and opportunities of enhancing food security and agricultural sustainability in South Asian countries from the mountain perspective, focusing on environment and resource constraints.

While, generally, the mountains are seen as a food deficit area or as a source of food items such as fruits, vegetables, spices and other niche products (ICIMOD 2008; Jodha 1995, 2009), we will argue that the role of the mountains in food security is much more than just as a source of food when we take into account its indirect contribution in terms of water, ecosystem services and mitigating natural hazards. Of the eight South Asian countries, this article concentrates on Afghanistan, Bangladesh, Bhutan, India, Nepal and Pakistan as they are part of the Hindu Kush-Himalayan (HKH) region, where the International Centre for Integrated Mountain Development (ICIMOD) works. Although the concept of food security includes both physical availability and economic and social access to food, this article focuses on food production, that is, the physical availability of food at the national level, as rural people's food security is often threatened when food production is unstable and the country has to depend on external sources due to global market uncertainty and price instability (Chand 2009). The article is organized into five sections. After giving the context in the first section, the second section presents the status, trends and concerns of food security. The third section deals with the critical issues and challenges of agricultural production from the resource perspective followed by the role of the Himalayan mountain system in agricultural sustainability and food security in South Asia. The fifth section briefly examines the options and opportunities for enhancing food security and draws conclusion and recommendations.

FOOD SECURITY AND AGRICULTURE IN SOUTH ASIA: TRENDS AND CONCERNS

South Asian countries made tremendous progress in food production during 1960s, 1970s and 1980s. With an impressive growth of food production, India, Pakistan, Bangladesh and Nepal transformed themselves from countries with a chronic food deficit to countries that were almost self-sufficient in the early 1990s. Except Afghanistan, all these countries had exported some quantity of food grain during late 1990s. This dynamic growth in the agricultural sector has, however, recently been lost. Productivity of major food grains has slowed down and has even declined for some crops (Kumar et al. 2008) with food production failing to keep pace with population growth. As a result, South Asian countries are now finding it difficult to meet their populations' most basic food and nutritional needs and remain vulnerable to food insecurity.

Afghanistan is the most vulnerable country in South Asia in terms of food security. Wheat is the staple food in Afghanistan, as well as the major crop. Due to its mountainous terrain and an arid to semi-arid climate, crops are cultivated on only about 14 per cent of the country's total area. In 2006, consumption in each income group was estimated to have fallen below minimum nutritional requirements. The unstable political and security environment combined with limited resources and very high population growth (more than 2.0 per cent per year) may force per capita consumption to continue to decline over the next decade.

Bangladesh is another highly vulnerable country in the region. Rice is the country's staple food. Despite significant progress in food production, food grain production often lagged behind domestic demand as it failed to cope with population growth. The per capita food consumption here is close to the minimum nutritional requirement (2199 calories per day in 2004). Only the top two income groups were estimated to have exceeded the nutritional target in 2006. The situation has worsened due to floods and cyclones—almost regular phenomena that damage crops and affect food production. Bangladesh has to import 3–5 million tonnes of cereal per year on average, depending on weather conditions.

Bhutan is also vulnerable in terms of food insecurity. Only 3.4 per cent of its land is suitable for arable agriculture, although more than 80 per cent of the population depends on agriculture for its livelihood. Productivity is low and variation in cereal production is very high. More than one-tenth of the cereal consumption in the country comes from imports and food aid.

Although India has made significant progress in food production since the 1960s, becoming self-sufficient in food grain and exporting a sizeable amount of food grain in the late 1990s, production started declining from 2000 while population continued to increase. In 2000, net cereal production was 172 million tonnes, which decreased to 163 million tonnes in 2001 and in 2003 it further declined to 143 million tonnes. As per estimates made in 2006, about 20 per cent (222 million) of India's population fell short of nutritional requirements. As the major producer and consumer of food in South Asia, India must not only maintain its own self-sufficiency in food production but must also meet the additional requirements of its neighbouring countries.

Nepal's food security situation has improved slightly as growth in food production has increased, although food security has remained a serious concern in remote areas. Generally, those in the lowest income quintile fall short of the minimum needed to fulfill their nutritional requirements. According to UN report, 2.5 million people in Nepal need urgent food assistance (Pyakuryal 2009).

Although the performance of the agricultural sector in Pakistan improved in the early 1960s and the country achieved near self-sufficiency in food during the 1980s, Pakistan's food production has remained erratic and has failed to keep pace with high population growth (2.4 per cent). As a result, food security has remained a persistent concern. In 2006, 10 per cent of the population was estimated to have less food than required and the situation could deteriorate further over the next decade due to the gap between population growth and food production.

The key characteristics of the agriculture and food security situation in South Asia are presented in Table 1.

Per capita availability of land is relatively scarce in South Asia, varying from 0.1 ha per person to 0.3 ha per person (Table 1). The lowest amount of agricultural land per capita is in Bhutan (0.08 ha). Likewise, for Bangladesh the amount of agriculatural land per capita is Bangaldesh (0.1 ha); and the highest is in India

Table 1
Key Features of Agriculture and Food Security in South Asia

Country	Population: 2007 (Millions)	Population: Population Growth Rate (%)	Agricultural Land: Total Land Area ('m ha) in 2003	Agricultural Land: Agri Land % of Land Area	Agricultural Land: Arable Lands (% of Agri. Land)	Agricultural Land: Hectares Per Capita 2003–05	Agricultural Land: Irrigated Cropland (2002) (%)	Cereal Production (m Tonnes)*	Cereal Production (kg Per Capita 2003–05)	% of Under-nourished Pop.	% GDP Agriculture (2004)	Total Economically Active Population in Agric (%)
Afghanistan	28.1	1.36	65.2	N/A	20.8		29.6	0.12	N/A	35	36	23.36
Bangladesh	142	1.9	14.4	69.6	88.2	0.1	54.5	25.95 (11.2)	285	30	20	28.53
Bhutan	0.71	2.2	4.7	N/A	26.9	0.08	24.2	0.10 (12.4)	N/A		26	50.47
India	1,095	1.6	328.7	60.9	88.6	0.3	33.6	196.84 (4.5)	219	21	20	25.45
Nepal	27	2.1	14.718	34.8	55.8	0.1	34.5	4.6 (8.5)	288	17	39	42.93
Pakistan	156	2.0	79.6	35.2	78.6	0.3	80.5	25.0 (8.4)	203	20	22	17.24
Maldives	0.3	2.5	0.3	N/A	28.6		–	0	N/A		8	10
Sri Lanka	21	0.9	6.561	36.4	38.9	0.2	33.3	0	155	22	15	19.17

Source: World Development Report 2008; Allauddin and Quiggin 2008; Atapattu and Kodituwakku 2009.
Note: *Figures in parenthesis shows variation in domestic cereal production.

and Pakistan (0.3 ha) per person. The corresponding figures in 1961 were 0.16 (Bangaldesh) and 0.35 (India) in the same countries (Alauddin and Quiggin 2008: 112). Per capita agricultural land has thus been declining very sharply over the years due to population pressure.

Population growth coupled with limited land supply has forced populations to bring as much land as possible under agriculture. As a result, the ratio of agricultural land to total land is high in South Asia and varies from about 35–70 per cent. The figure is highest in Bangladesh (around 70 per cent) and lowest in Nepal (around 35 per cent). In India, the ratio is around 60 per cent and in Pakistan, it is 35 per cent. This suggests that the scope for increasing food production by bringing additional land under cultivation is limited, as most of the suitable land is already under cultivation. Table 1 presents some other features of agriculture and food security in South Asia.

The rapid decline in per capita availability of land resources has put serious pressure on agriculture and food security in South Asia. It is estimated that in 2025 there will be 2.02 billion people in South Asia, and cereal demand will be 549.7 million tonnes due to increased population and higher incomes (Dyson 1999). But this higher agricultural production has to come from the same amount of land, maybe from even less, because land will be needed for other uses resulting from population growth, urbanization and industrialization. Thus, the scope for increased productivity by bringing additional land under agriculture has almost been exhausted.

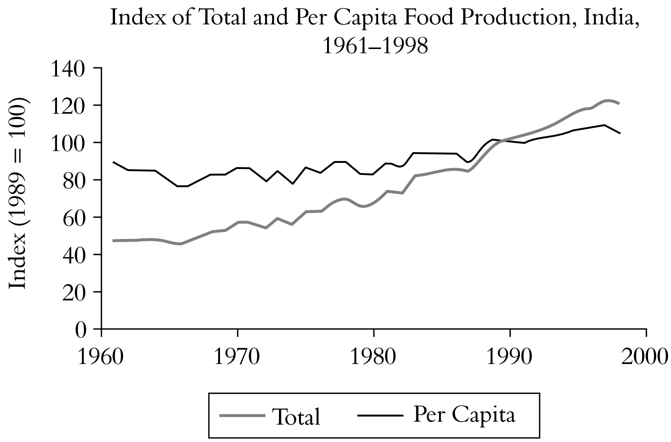
Although the growth of cereal production in South Asia is positive in all countries, the concern remains that the yield's growth trend has become stagnant or negative (Figure 1). In addition, there is an increasing trend of needing higher inputs for the same level of production. Rising production costs and falling profit margins at the farm level have pushed some farmers to the point of abandoning agricultural land (ICIMOD 2008). High input costs (Table 2) include irrigation and transportation, and the ever-growing need for more fertilizers (Figure 2) and pesticides to maintain the same level of productivity. In addition, unstable prices, poor credit facilities, and a lack of insurance to cover risk combine to push farmers to abandon agricultural land and even to commit suicide in some parts of South Asia.

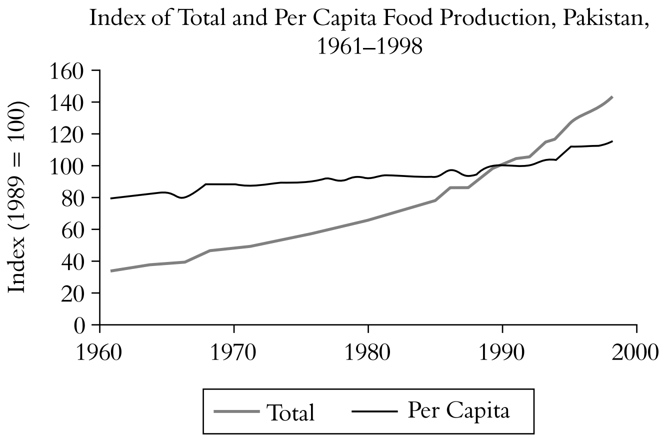
Issues and Challenges in Agricultural Sustainability and Food Security in South Asia

Increasing water stress

Rice and wheat, the staple food in South Asia, require huge amounts of water. About 1,000 tonnes of water is required to produce just 1 tonne of grain (Brown 2000; Ximing 2007). The production of these staple food grains is critically

Figure 1
Trend of Per Capita Food Production in India and Pakistan





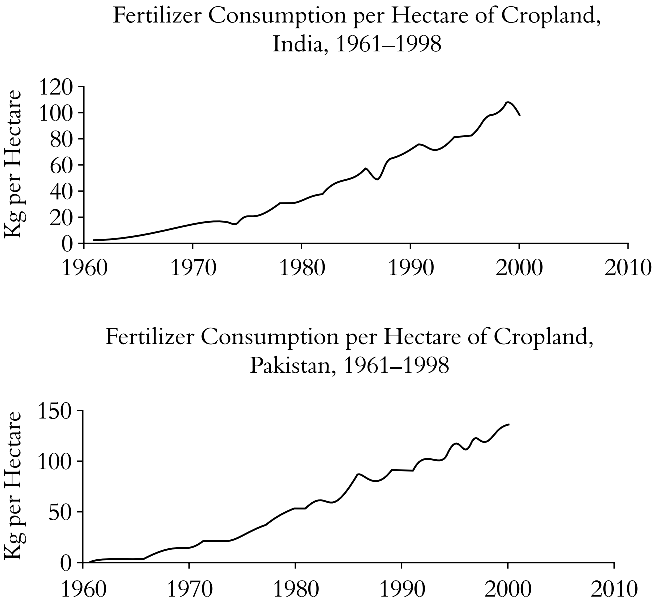
Source: WRI 2008.

Table 2
Global Prices of Fertilizer from 2003–07

Year	*Urea US$/Tonne*	*Price Increase*	*% Increase*
2003–04	138.9		
2004–05	175.29	36.39	26.20
2005–06	219.04	43.75	24.96
2006–07	222.95	3.91	1.79
2007–08	309.4	86.45	38.78

Source: Chand 2008.

Figure 2
Trend of Fertilizer Use in India and Pakistan



Source: WRI 2008.

dependent on the availability of water in the dry season and on irrigation facilities. Higher food grain production in South Asian countries in the last several decades has been driven primarily by the expansion of irrigation facilities that allowed the growing of high-yielding varieties (HYV) of rice and wheat with intensive management through the application of inorganic fertilizers, pesticides and insecticides. Every year new areas have been brought under irrigation and the area under rice and wheat cultivation has expanded in all South Asian countries since the 1960s (Table 3). From 1965 to 2002 the area under irrigation has increased nine times in Bangladesh, more than two times in India, about fifteen times in Nepal, and about two times in Pakistan.

Although the South Asian region is generally perceived as rich in water resources due to the great Himalayan snows, a vast network of perennial rivers, high monsoon rainfall and rich groundwater aquifers, increased demand for water in the last century has led to shortage of water particularly in the dry season in most parts of South Asia. Per capita water availability in South Asia has decreased by nearly 70 per cent compared to 1950 as a result of population growth, economic growth, rapid urbanization, changing consumption patterns and industrialization. If this trend continues, the region will face widespread water

Table 3
Expansion of Irrigation and Cereal Production in Selected South Asian Countries

	Bangladesh			*India*			*Nepal*			*Pakistan*		
	1965	*1985*	*2002*	*1965*	*1985*	*2002*	*1965*	*1985*	*2002*	*1965*	*1985*	*2002*
Irrigated area in '000 ha*	501 (100)	1,841 (367)	4,509 (900)	25,523 (100)	40,637 (159)	57,178 (224)	77 (100)	673 (874)	1135 (1474)	11,139 (100)	15,548 (140)	17,810 (159)
Irrigated land as % of arable land	5.8	20.8	56.0	16.2	24.9	35.4	4.3	29.4	36.0	62.9	77.6	83.0
Rice area in '000 ha*	8,955 (100)	10,281 (115)	10,940 (122)	15,626 (100)	40,502 (259)	42,908 (275)	1,096 (100)	1,333 (122)	1,537 (140)	1,287 (100)	1,963 (155)	2,183 (170)
Wheat area in '000 ha	60	369	764	13,402	23,246	25,654	109	440	563	4,984	7,241	4984
Rice area as % of arable land	103.6	116.0	135.9	22.7	24.8	26.5	60.6	58.3	48.8	7.3	9.8	10.2
Wheat area as % of arable land	0.7	6.4	9.5	8.5	14.3	15.9	6.1	19.2	21.0	28.1	36.1	37.7

Source: Adapted from Alauddin and Quiggin (2008: 113).
Note: *Figures in parentheses show percentage of change compared to 1965; base year 1965 is considered 100..

scarcity by 2025 (FAO 2006). As irrigated rice and wheat is highly dependent on water availability, the shortage of water will affect food production and food security unless appropriate measures are taken.

Farmers in different parts of South Asia are already experiencing a shortage of water and are adapting by moving from surface water to groundwater irrigation. As a result, groundwater irrigation has increased enormously in all of the South Asian countries and the area under surface irrigation has been declining gradually (Table 4). At present, groundwater irrigation accounts for 69 per cent of all irrigated areas in Bangladesh, 53 per cent in India, and 31 per cent in Pakistan (Jaitly 2009: 23).

Table 4
Changing Irrigation Sources in South Asia

	Net Irrigated Area Under Surface Irrigation (000' ha)			*Net Irrigated Area Served by Groundwater (000' ha)*			*Groundwater Irrigation as a % of Surface Irrigation in 2000–01*
	1993–94	*2000–01*	*Change %*	*1993–94*	*2000–01*	*Change %*	
Key Indian states	15,633	11,035	–29.4	17,413	21,760	+25	197
Pakistan Punjab	4240	3740	–11.8	8760	10,340	18	276
Sindh	2300	1960	–14.8	140	200	42.9	
Bangladesh	53.7	480	–10.7	2,124	3,462	63	721
All areas	22,709	17,215	–24.2	28,437	35,762	25.8	207

Source: World Development 2005.

Today in Bangladesh, India and Pakistan, groundwater irrigation accounts for the larger part of additional irrigated areas. In Bangladesh, which had hardly any groundwater irrigation until 1960, the area irrigated by wells expanded from 4 per cent in 1972 to 70 per cent in 1999 (Table 4). The over-extraction and indeed 'mining' (tapping deeper aquifers) in many water zones is taking a heavy toll on both the quantity and quality of fresh water. In several places in Pakistan and India, groundwater levels are falling by 1–3 metres a year.

While groundwater has been a major contributor to the increase in agricultural productivity and food security, the increased extraction of groundwater has lowered the groundwater table in some parts of South Asia (Jaitly 2009: 23). This is causing environmental problems and has raised concerns for the long-term sustainability of food production and food security.

The cost of inputs (particularly external inputs, which farmers have to buy) in food grain production has been increasing steeply in many parts of South Asia.

Table 5
Increased Cost of Food Grain Production Due to Elevated Input Costs in the Indo-Gangetic Basin of India

Year	*Kg of Wheat to Buy 1 Litre of Diesel*	*Kg of Wheat to Pay for 1 hr of Pump Irrigation*	*Kg of Rice to Buy 1 Litre of Diesel*	*Kg of Rice to Buy 1 hr of Pump Irrigation*	*Pumping Cost (₹/m³)*	
					South Bihar	*Easter Uttar Pradesh*
1990	1.24	3.14	1.45	3.67	0.41	0.47
1995	1.61	4.04	2.17	5.43	0.51	1.31
2000	3.71	8.00	5.30	11.43	0.95	1.63
2005	5.63	10.00	6.75	12.00	n/a	n/a
2006	n/a	n/a	n/a	n/a	1.60	2.47

Source: Shah et al. 2008.

For example, the pumping cost of irrigation water in Bihar and Uttar Pradesh in India has more than doubled in just a decade (Table 5). Moreover, the terms of trade are going against farmers, that is, the prices of agricultural inputs are increasing at a much faster rate than the price of agricultural outputs. As a result, farmers' profit margins are becoming increasingly eroded, and this may affect the production of cereals production and food security as farmers may move to other crops, as reflected in many parts of South Asia (ICIMOD 2008).

In some parts of Bangladesh, particularly in the northern districts, problems with the 'mining' of groundwater are already evident. The energy costs of irrigation in Bangladesh are increasing. Furthermore, the uncertainty of the energy supply as a result of frequent power failures is a serious cause for concern.

Climate change

South Asia is a region of diverse climates. From the Arctic temperatures of the Himalayas covering the northern parts of Afghanistan, Bhutan, India, Nepal and Pakistan; through to the arid areas of south-eastern Pakistan and Western India; to the intense tropical humidity of Bangladesh, Southern India, the Maldives and Sri Lanka; these varying climatic conditions have a direct bearing on production patterns, livelihoods and socio-economic structures. Climate is a major determinant of water availability in South Asia.

The Himalayas are described as the 'water towers' of South Asia since the three largest river systems—the Indus, the Ganges and the Brahmaputra—originate from the Himalayas and are partially fed by the snow and ice reserved there. Climate change introduces a new challenge to food security. The impact of climate change on rainfall patterns, river flows dependent upon glacial melt and sea levels have only recently begun to be scientifically assessed with some degree of accuracy.

Nevertheless, a recent report of the Intergovernmental Panel on Climate Change (IPCC) concludes that it is very likely that most river basins are likely to become drier, leading to persistent water shortages. Moreover, the contribution of snow and glacial melt to the dry season flow of the major northern rivers of South Asia may be reduced substantially.

Changes in water availability in the monsoon, pre-monsoon and post-monsoon seasons, as well as erratic rainfall, have a direct impact on Himalayan agriculture. While climate change may affect the entire world, its impact in the Himalayan region is more severe because of the dependence of the majority of the people in the region on climate-sensitive sectors such as agriculture, forestry and fishing for their livelihoods. Recent studies conclude that the Himalayan region and its downstream areas, including the Indo-Gangetic plains (IGP), the grain basket of South Asia, are also particularly vulnerable to climate change resulting from the effects of the atmospheric brown cloud and its radiative forces (Ramanathan et al. 2005).

Based on a simulation study (von Braun 2007) on the impacts of climate change on global cereal production, the International Food Policy Research Institute concluded that the negative impact of climate change on world cereal production may vary from 0.6 per cent to 0.9 per cent, but that in South Asia the impact could be as high as 18.2–22.1 per cent (Table 6). Similarly, United Nations Development Programme (UNDP) (2006) warns that increased temperatures and water stress may lead to a 30 per cent decrease in crop yields in South Asia by the mid 21st century. Although increased temperatures may offer for the opportunity to grow cereal crops at certain altitudes in the Himalayas, the environmental costs of this could be very high due to accelerated soil erosion.

Table 6
Expected Impacts of Climate Change on Global Cereal Production

	1990–2080 (% Change)
World	0.6 – –0.9
Developed Countries	2.7 – 9.0
Developing Countries	–3.3 – –7.2
Southeast Asia	–2.5 – –7.8
South Asia	**–18.2 – –22.1**
Sub-Saharan Africa	–3.9 – –7.5
Latin America	5.2 – 12.5

Source: von Braun 2007:4.

Climate change may further reinforce the pressure on available resources and ecosystem services and trigger the process of a vicious circle of poverty, resource degradation, environmental deterioration and social unrest.

OPTIONS AND OPPORTUNITIES FOR FOOD SECURITY AND AGRICULTURAL SUSTAINABILITY

Although South Asian agriculture presently faces difficult challenges, there are still promising opportunities for diversifying production to high-value market products such as fruit, vegetables, fish and livestock. Despite visible improvements in the productivity of food grains in South Asia, the region has not been able to fully utilize its agricultural potential for a variety of reasons. As a result, levels of productivity have remained much lower than in neighbouring regions; for example, China (Table 7). Scholars suggest that food production in South Asia could be increased significantly by reducing potential and existing yield gaps.

Table 7
Cereal Productivity in Selected Countries in Asia

Country	*Cereal Yield Kg/Ha*
Afghanistan	N/A
Bangladesh	3,551
Bhutan	1,614
India	2,367
Nepal	2,282
Pakistan	2,562
Maldives	1,000
Sri Lanka	3,432
China	5,106
Egypt	9,135

Source: World Bank 2008.

The IGP spread over the region's four countries—Pakistan, India, Nepal and Bangladesh—is agriculturally of high potential, with good water resources and fairly good weather. There is great potential to enhance rice and wheat production in the IGP if water and other inputs are properly managed and infrastructure and marketing facilities are developed properly. The average potential yield in the IGP per hectare of rice is 9.88 metric tonnes and 6.82 metric tonnes of wheat (FAO 2002: 28). Even half of this potential yield has not been produced as yet. There is also great potential to enhance food production by narrowing the yield gaps of crops, livestock and fishery products by removing supply constraints and providing the necessary support in terms of technology, inputs, infrastructure and marketing. Tapping these opportunities requires new thinking, new ways of looking at agriculture, and new approaches and strategies, as well as new technologies and innovations. This section briefly examines some of such options and opportunities.

Increasing agricultural productivity by developing water resources

Given the increasing water stress, the future growth of agriculture and food production will depend on the management of water and land resources. The shortage of water in the dry season for irrigation is a major constraint to the expansion of irrigation and food production in many parts of South Asia. The issue of increasing water stress in South Asia can be addressed through better management of water resources, including storing monsoon rainwater in lakes, reservoirs, and through multipurpose river development in South Asia. There is tremendous potential in South Asia to increase food production by expanding irrigation and reducing dependency on monsoon weather for agriculture. Besides water storage, there is great scope for enhancing efficiency in irrigation and water resource management, which is very low in South Asia. In India, for example, water use efficiency compared to China varies from 41–64 per cent (Table 8). Scholars (for example, Saleth 1996) suggest that a 10 per cent improvement in the efficiency of water use could allow 14 million hectares of land to be brought under irrigation.

Table 8
Water Use Efficiency in Indian Agriculture

	Average Amount of Water (in Cubic Metres Per Tonne)			
Crops and Crop Products	India	China	US	*India's Water Efficiency Compared to China (%)*
Rice	4,113	1,906	1,840	46
Wheat	1,654	690	849	42
Maize (corn)	1,937	801	489	41
Soya beans	4,124	2,617	1,869	64

Source: Adapted from Kapur et al. 2009: 41.

The opportunity exists to increase food production by bringing new areas under irrigation in South Asia by improving irrigation and water use efficiency. It is also possible to enhance agricultural sustainability and productivity by improving the management of Himalayan watersheds, an important source of dry season water in most South Asian countries.

Increasing productivity of hills, mountains and other rainfed areas

While irrigated areas need to be expanded further through better water resources, the diversification of agriculture in favour of high-value products such as fruit, vegetables, dairy products, poultry, fish and so on, is necessary to augment the income of farmers located in the hills, mountains and other rainfed areas. In the past, the focus was mainly on prime agricultural areas suited to green revolution technologies, with the mountain areas receiving little benefit. As a result, the productivity of the mountains and other rainfed areas has not increased much over the past three decades. Due to their specific environments and their diversity, the mountain areas of the HKH region have comparative advantages and niches for certain products. Mountain areas can contribute significantly to food and nutrition security by growing the fruit, vegetables, nuts, oilseeds, pulses, meats and spices required for nutritionally balanced food (Jodha 1995; Chand et al. 2008). For example, Himachal Pradesh in India and the North West Frontier Province (NWFP) in Pakistan have witnessed an upsurge in the production of fruit and vegetables in the last two decades. The area under apple and apricot farming grew by 2.37 per cent and 2.36 per cent per annum respectively in NWFP, Pakistan, between 1981 and 1994. Likewise, the area under citrus fruit and apples increased by 3.4 per cent and by 1.6 per cent respectively per annum between 1981 and 1992 in Himachal Pradesh, India. Similarly, in Bhutan the area under apples increased by more than 30 per cent between 1986 and 1995. The considerable expansion of horticultural crops, particularly apples and citrus fruit, also took place in Nepal during the same period. Besides horticultural crops, the growing of ginger, turmeric and tobacco is also becoming popular in the HKH region. The potential of mountain areas can be further developed by improving post-harvest management, agro-processing and value-addition of mountain products; and by reducing post-harvest losses through proper storage, packaging, handling and transportation.

Moreover, mountain farmers are the custodians of agricultural germ plasm, which is the basis for enhancing agricultural sustainability and resilience. Increasing the productivity of rain-fed crops can be an option along with a seed revolution for oilseeds, pulses, fruits and vegetables for food security.

Increasing agricultural productivity by removing supply constraints

Agricultural productivity can be increased by removing supply constraints such as agricultural inputs, power, irrigation, fertilizers and infrastructure facilities. South Asian countries do not produce enough electricity to sustain agriculture productivity. In India, Pakistan and Bangladesh, farmers suffer heavily from a shortage in the power supply for irrigation. For example, farmers in Madhya Pradesh, India, get electricity for only 2–4 hours a day for irrigation, and for

6–8 hours a day in Rajasthan (Jaitly 2009). Agricultural productivity could be improved considerably by improving the supply of inputs and infrastructure facilities.

Enhancing agricultural performance and sustainability by improving knowledge, technologies, innovations and their effective dissemination

Since the 1980s, investment in agricultural research and investment both from overseas development assistance (ODA) and government spending have gradually decreased. The proportion of ODA to agriculture went down from 30 per cent in early 1980s to 10 per cent in 2005 (Global Crop Diversity Trust 2008). The majority of the farmers in South Asia are poor, and depend mainly on the public sector for the knowledge, information and support they require. Investment both by the national government and international agencies in agricultural research has been declining recently. Research and extension should be strengthened further to increase productivity. Agricultural research should not only be limited to crops and animals but should also be undertaken in hydro-meteorological prediction. If the monsoon in South Asian countries could be predicted earlier, farmers could adjust their crops accordingly. This could save millions of dollars worth of crops and reduce farmers' misery. It is, therefore, important to increase the level of public investment in agricultural research, technology and rural infrastructure. Given the changing conditions, water availability and climatic conditions, the focus of the research should not only be HYV crops, but also on drought-tolerant crops, water saving technologies, and hydro-meteorological analysis.

Bridging the gap between science and practice

Agricultural extension has remained poor in most South Asian countries. As a result, the adoption of many research findings and technologies has remained low. There is scope to reduce yield gaps and increase productivity through improved extension services to bridge the gap between farmers and researchers.

Making agriculture more stable by minimizing risks and uncertainties

Agriculture is a high-risk undertaking due to the absence of insurance arrangements; this has made the food security situation more fragile. Greater stability can be brought to agriculture by developing policies and instruments to mitigate risks arising from natural disasters and other changes such as increased input prices and reduced product prices, as well as market fluctuations.

Developing the non-farm sector

Options for food security should not be confined to the agricultural sector. As nearly 70 per cent of the rural population depend on agriculture for their primary or secondary means of livelihood, rural jobs should be generated in the non-farm sector so that people's dependency on agriculture as their main source of income and livelihood is reduced.

Improving policy support to address the mountain issues and needs of the mountain communities

The majority of the producers in these regions are resource-poor and income-poor, and therefore, technologies, policies and institutional support need to be tuned to their socio-economic needs and the local bio-physical conditions.

THE ROLE OF THE HIMALAYAN MOUNTAIN SYSTEM IN AGRICULTURE AND FOOD SECURITY IN SOUTH ASIA

The question arises as to what role the HKH mountain system can play in sustaining agriculture and food security in South Asia. Traditionally, policymakers and development practitioners see only a limited role for mountains in sustaining food security due to the bio-physical constraints of growing arable crops such as rice, wheat and other cereal crops intensively. Generally, the role of the mountains is seen as complementary in supplying mountain niche-based products such as fruit, spices, nuts and other high-value products. The policymakers and scholars, however, often ignore the indirect role of the HKH mountain system in sustaining agriculture and food security.

The HKH mountain system as a whole plays a significant role in agriculture and food security in South Asia through water supply, climate and wind regulation, groundwater recharge, and in sustaining wetland ecosystems. There are more than 16,000 glaciers in the Himalayan range, forming the largest body of ice outside the polar caps and a huge natural reservoir where more than 12,000 km^3 of freshwater is stored (Eriksson et al. 2009). Table 9 shows the glaciated areas in the Himalayan range.

The Himalayan mountain system is the source of water for several large river systems, such as the Indus, the Ganges and the Brahmaputra. These three rivers form the largest river basins (Indo–Ganga–Brhamaputra) which is the major

Table 9
Glaciated Areas in the Himalayan Range

Drainage Basin	*No. of Glaciers*	*Total Area (sq. km.)*	*Total Ice Reserves (km.^{3})*
Ganges River	6,694	16,677	1,971
Brahmaputra River	4,366	6,579	600
Indus River	5,057	8,926	850
Total	16,117	32,182	3,421

Source: Eriksson et al. 2009.

source of rice and wheat in South Asia. These rivers receive significant contributions from the snow and glacier melt of the Himalayas, which provide the main basis for surface and groundwater irrigation. Although hard data on the contribution of mountain discharge to dry season water is limited, available evidence suggest that this may vary from more than 90 per cent to about 30 per cent, depending on a number of factors. In arid and semi-arid regions, the contribution may vary from 50 per cent to more than 90 per cent, while in the humid tropics it ranges from 30–60 per cent.

Similarly, the contribution of Himalayan discharge to the dry season water flow of major rivers in South Asia such as the Indus, Ganges and Brahmaputra (including their hundreds of tributaries) is enormous. Water from the Himalayas also forms the main source of dry season irrigation water in terms of surface and groundwater. However, the degree of contribution varies, generally reducing as it moves from west to east. A simulation study conducted in the western Himalayas found that the contribution of glacial melt in total runoff was 87 per cent (Pratap et al. 2006). Similarly, Winiger et al. (2005) found that the Indus Irrigation Scheme in Pakistan receives about 50 per cent of water from snow and glacial meltwater from the eastern Hindu Kush, the Karakoram and the western Himalayas. However, the contribution of snow and ice meltwater may reach 70 per cent of the flow of the Ganges, Indus, Tarim and Kabul rivers in the dry season, when rainfall is minimal and water requirement for irrigation is at its most (Kattelmann, 1987 cited in Eriksson et al. 2009).

Besides surface water, the contribution of mountain discharge to groundwater is also significant, which makes it an important resource for agriculture and food security in South Asia. In addition to the use of groundwater for irrigation and for various forms of human use, groundwater sustains many wetland ecosystems. Groundwater is also an important supplier to surface water resources, making significant contributions to streamflow and sustaining flows during the long, dry season. Mountains, being relatively wetter and cooler, contribute significantly to groundwater recharge in adjacent basins (Earman and Dettinger 2006).

In addition to surface water and groundwater, the Himalayan mountain system provides huge inputs to agriculture through regulating micro-climates as well as wind and monsoon circulation, and by supporting river and wetland ecosystems in South Asia. It is estimated that the Ganges River ecosystem alone supports 25,000 or more species, ranging from micro-organisms to mammals. This supports agricultural sustainability and provides livelihoods for millions of people. The Himalaya has a unique ecosystem and an environment that plays a critical role in agriculture and food security in South Asia. For long-term agricultural sustainability and food security, attention must therefore be paid to the better utilization of Himalayan resources and services that so often go unrecognized and unaccounted for. It is, therefore, important to protect the Himalayan ecosystems and environment so that agriculture and food production can be sustained in the long run.

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References

Agoramoorthy, G. 2007. 'Can India Meet the Increasing Food Demand by 2020?', *Futures*, 40 (5): 503–06.

Ahmed, Akhter U., Ruth Vargas Hill, Lisa C. Smith, Doris M. Wiesmann and Tim Frankenberger. 2007. The World's Most Deprived: Characteristics and Causes of Extreme Poverty and Hunger', *Discussion Paper 43,* Washington DC: International Food Policy Research Institute.

Alauddin, M. and J. Quiggin. 2008. 'Agricultural Intensification, Irrigation and Environment in South Asia: Issues and Policy Potions', *Ecological Economics*, 65 (1): 111–14.

Atapattu, S.S. and D.C. Kodituwakku. 2009. 'Agriculture in South Asia and its Implications on Downstream Health and Sustainability: A Review', *Agricultural Water Management*, 96 (3): 361–73.

Brown, L.R. 2000. 'Population growth sentencing millions to hydrological poverty', *World Watch Institute*, accessed on 27 September 2009 http://www.sdearthtimes.com/et0700/et0700s8.html

Chand, R. 2009. 'Heavy Dependence on Trade for Food Can Prove Dangerous', *Trade and Development Quarterly*, 4 (2): 9–10.

Chand, R.S.S. Raju and L.M. Pandey. (2008). 'Progress and Potential of Horticulture in India'. Paper prepared for the 68th Annual Conference of the Indian Society of Agricultural Economics to be held in November 2008 in India.

Dyson, T. 1999. 'World Food Trends and Prospects', *Proc. Natl. Acad. Sci. USA*, 96 (11): 5929–936.

Earman, S..and M. Dettinger. 2006. Possible Impacts of Warming-induced Changes in Ground Water Recharge in Western Mountains on Surface water resources. *American Geographical Union*, Fall meeting, 2006.

Eriksson, M., X. Jianchu, A. Shrestha, R. Vaidya, S. Nepal, K. Sandrom. 2009. 'The Changing Himalayas: Impact of Climate Change on Water resources and Livelihoods in the Greater Himalayas', *ICIMOD Technical Paper*, Kathmandu: ICIMOD.

FAO (Food and Agriculture Organization of the United Nations). 2006. *The State of Food Insecurity in the World 2006*. Rome: FAO.

———. 2002. *World Agriculture: Towards 2015/2030*. Rome: Food and Agriculture Organization of United Nations.

Global Crop Diversity Trust. 2008. 'Crop Diversity Topics no. 14 2008'. http://www.croptrust.org/documents/newsletter/newsletter_croptrust_v14_final.htm (accessed on 16 December 2008).

ICIMOD. 2008. *Food Security in the Hindu Kush-Himalayan Region: A Position Paper*. Kathmandu: ICIMOD.

Jaitly, A. 2009. 'South Asian Perspectives on Climate Change and Water Policy', in D. Michael and A. Pandya (eds), *Troubled Waters: Climate Change, Hydropolitics, and Transboundary resources*, pp. 17–31. Washington DC: The Henry L. Stimson Center.

Jodha, N.S. 2005. 'Adaptation Strategies against Growing Environmental and Social Vulnerabilities in Mountain Areas', *Himalayan Journal of Sciences*, 3 (5): 33–42.

———. 2009. 'Mountain Agriculture: Development Policies and Perspectives', *Indian Journal of Agriculture Economics*, 64 (1): 1–14.

Kapur, D.R. Khosla and P.B. Mehta. 2009. 'Climate Change: India's Options'*, Economic and Political Weekly*, XLIV (31): 34–42.

Kumar, P., S. Mittal, and M. Hossain. 2008. 'Agricultural Growth Accounting and Total Factor Productivity in South Asia: A Review and Policy Implications', *Agricultural Economics Research Review*, 21(2): 145–72.

Pratap, S., A. Manohar, and N.K. Goel. 2006. 'Effect of Climate Change on Runoff of a Glacierized Himalayan Basin', *Hydrological Processes*, 20 (9):1979–992.

Pyakuryal, B. 2009. 'Food Security in Nepal: Need for Increased Investment', *Trade and Development Quarterly*, 4 (2): 11–14.

Ramanathan, V., C. Chung, D. Kim, T. Bettge, L. Buja, J.T. Kiehl, W.M. Washington, Q. Fu, D.R. Sikka and Wild, M. 2005. 'Atmospheric Brown Clouds: Impacts on South Asian Climate and Hydrological Cycle', *Proc. Natl. Acad. Sci. USA*, 102: 5326–33.

Saleth, R.M. 1996. 'Water Markets in India: Economic and Institutional Aspects', in K. William Easter, Mark W. Rosegrant and Ariel Dinar (eds), *Markets for Water*, pp. 187–205. US: Springer.

Shah, T., M. Hassan, M.Z. Khattak, P.R. Banerjee, O.P. Singh and S. Rehman. 2008. 'Is Irrigation Water Free? A Reality Check in the Indo-Gangetic Basin', *World Development*, 37 (2): 422–34.

Smith, L.C. and D. Wiesmann. 2007. 'Is Food Insecurity More Severe in South Asia or Sub-Saharan Africa?', *IFPRI Discussion Paper* 712. Washington DC: International Food Policy Research Institute.

von Braun, J. 2007. *The World Food Situation: New Driving Forces and Required Actions*. IFPRI's Biannual Overview of the World Food Situation presented to the CGIAR Annual General Meeting held in Beijing, China, in December 2007.

Winiger, M., M. Gumpert and H. Yamout. 2005. 'Karakoram-Hindu Kush-Western Himalaya: Assessing High-Altitude Water Resources', *Hydrological Processes*, 19 (12): 2329–338.

World Bank. 2008. *World Development Indicators*. Washington, DC: World Bank.

World Development Report. 2008. *Agriculture for Development*. Washington DC: The World Bank.

WRI (World Resource Institute). 2008. *EarthTrends: Agricultural Production Indices*. http://earthtrends.wri.org/pdf_library/country_profiles/agr_cou_356.pdf (accessed on 12 December 2008).

Ximing, C. and M. Rosegrant. 2007. 'Future Prospects for Water and Food in China and India: A Comparative Assessment', in Ashok Gulati and Shenggen Fan (eds), *The Dragon and the Elephant: Agricultural and Rural Reforms in China and India*, pp. 207–33. Baltimore, MD: Published for the International Food Policy Research Institute (IFPRI) by Johns Hopkins University Press.