Analysis of climate change trend and possible impacts in the Upper Brahmaputra River Basin – the BRAHMATWINN Project

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EXTENDED ABSTRACT

The overall objective of the study is to enhance capacity to carry out harmonized integrated water resources management (IWRM). For headwater river systems of alpine mountain massifs, impacts from climate change will be modelled and appropriate mitigation measures will be developed in twinning Danube and Upper Brahmaputra River Basins (UBRB).

The focus of the research study emphasize on system responses on climate change like cryogenic phenomena as glacier retreat, permafrost thawing and avalanches; the implications for water supply, ecosystems, and hazards; and how these threaten regional populations. Therefore, the relevant knowledge needs to be enhanced concerning key policy areas and strategies to improve the adaptive capacities of communities. The present state is evaluated through a hierarchical approach in four levels:

- Assessment and holistic analysis of the natural environment to derive the interactive dynamics of the system components.
- Assessment of the system's human dimension accounting for water related issues of socio-economic vulnerability to environmental stress in respect to water allocation and demand, and considering the political structures and policies pertaining to the basins.
- Analysis of present, traditional and conceptual IWRM practices and its potential for adaptation to cope with impacts of changing flow regimes.
- The development of scenarios relies on downscaling predictions from Global Circulation Models to a basin scale coupled with a DPSIR (Driving forces, Pressures, States, Impacts and Responses) approach. The spatial concept in both mapping the vulnerability and building adaptive IWRM scenarios is the regionalization of Response Units.

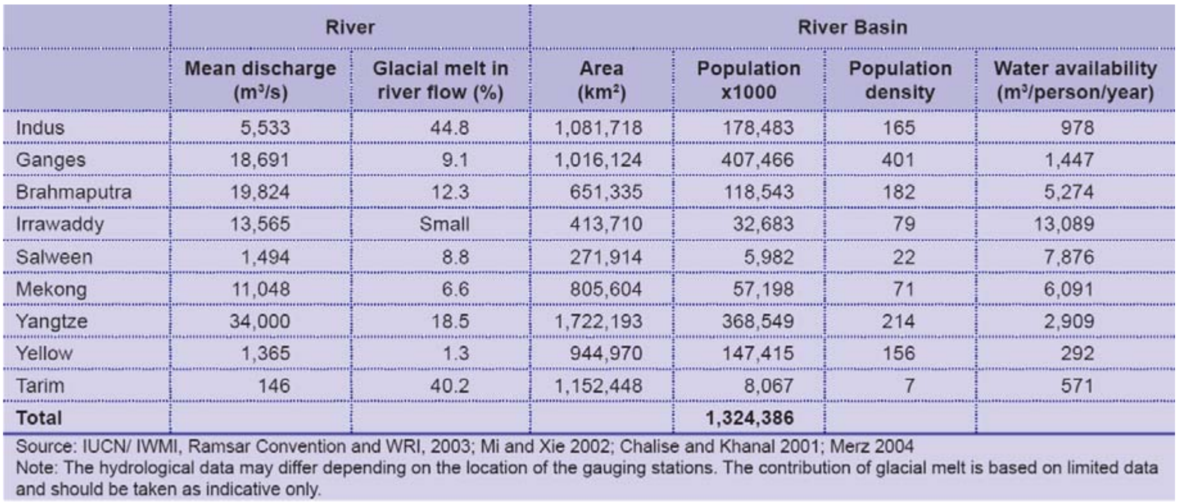
1. INTRODUCTION

The Himalayan Region plays an important role in global atmospheric circulation, biological and cultural diversity, water resources, and the hydrological cycle, apart from the beauty of its landscape and provision of other ecosystem amenities (Bandyopadhyay and Gyawali 1994). The region is the source of the nine largest rivers in Asia, the basins of which are home to over 1.3 billion people (Table 1).

Environmental change in the greater Himalayans affects most of Central and South Asia, and the mainland of Southeast Asia. The Himalayan region is the most critical region in the world in which melting glaciers will have a negative affect on water supplies in the next few decades (Barnett et al. 2005). Moreover, the impacts of climate change are superimposed on a variety of other environmental and social stresses, many of them already recognised as severe (Ives and Messerli 1989), causing uncertainty (Thompson and Warburton 1985), and leading to contradictory perceptions (Ives 2004). Continuing climate change will cause changes in the strength and timing of the Asian monsoon, inner Asian high pressure systems, and winter Westerly's, the main systems affecting the climate of the Himalayan region. The impacts on river flows, natural hazards, and the ecosystem, as well as on people and their livelihoods can be dramatic, although not the same in rate, intensity, or direction in all parts of the region.

Snow and Ice: A substantial proportion of the annual precipitation in the UBRB falls as snow, particularly at high altitude (above 3000m). In the higher reaches, snowfall builds up from year to year to form glaciers that provide long-term reservoirs of water stored as ice. The high Himalayan and inner Asian ranges have the most highly glaciated areas outside the polar region, although accurate data are lacking (Dyurgerov and Meier 2005).

Table 1: Principal Rivers of the Himalayan Region – basic statistics



	River		River Basin			
	Mean discharge (m^3/s)	Glacial melt in river flow (%)	Area (km^2)	Population x1000	Population density	Water availability (m^3/person/year)
Indus	5,533	44.8	1,081,718	178,483	165	978
Ganges	18,691	9.1	1,016,124	407,466	401	1,447
Brahmaputra	19,824	12.3	651,335	118,543	182	5,274
Irrawaddy	13,565	Small	413,710	32,683	79	13,089
Salween	1,494	8.8	271,914	5,982	22	7,876
Mekong	11,048	6.6	805,604	57,198	71	6,091
Yangtze	34,000	18.5	1,722,193	368,549	214	2,909
Yellow	1,365	1.3	944,970	147,415	156	292
Tarim	146	40.2	1,152,448	8,067	7	571
Total				**1,324,386**		

Source: IUCN/ IWMI, Ramsar Convention and WRI, 2003; Mi and Xie 2002; Chalise and Khanal 2001; Merz 2004
Note: The hydrological data may differ depending on the location of the gauging stations. The contribution of glacial melt is based on limited data and should be taken as indicative only.

There are around 10471 glaciers in the upstream region of the UBRB at elevations of more than 4800m a.s.l. covering a total area of 10335.6km² (Mi and Xie 2002).

Climate controls river flow and glacier mass balance in the Himalayan region, and these vary considerably from west to east. The monsoon from the Bay of Bengal, further developed in the Indian subcontinent, produces heavy precipitation – predominantly in the southeast. The main melting occurs in midsummer but, when this coincides with the monsoon, it may not be as critical for water supply as when the melting occurs in the shoulder seasons: spring and autumn. When the monsoon is weak, delayed, or fails, meltwater from snow and ice may limit or avert catastrophic drought.

The contribution of snow and glacial melt to the major rivers in the region ranges from less than 5% to more than 45% of the average flow (Table 1). Glacial melt provides the principal water source in dry season - for 23% of the population living in western China (Gao et al. 1992).

Permafrost: Areas in the high mountains not covered in perennial snow and ice are underlying by permafrost. Recent studies showed that the extent of permafrost is shrinking and that active layer thickness (the upper portion of soil that thaws each summer) is increasing, and this has altered the hydrological cycle, vegetation composition, and carbon dioxide and methane fluxes that appear linked to permafrost degradation (Lawrence and Slater 2005). The areas of permafrost are much larger than those covered by glaciers or perennial snow, especially in the UBRB the permafrost covers about of 40 % the drainage area. This factor plays a critical role in terms of slope stability, ecology, erosion processes, surface waters, and such areas will be sensitive to degradation with climate warming. Disappearance of permafrost and expansion of non-permafrost areas would accelerate desertification in the highlands (Ni 2000). Notwithstanding, there is almost no information about the full extent and behaviour of high mountain permafrost areas in this region.

Extreme events: Climate change involves changes in the frequency and magnitude of extreme weather events. There is widespread agreement that global warming is associated with the most severe fluctuations, particularly in combination with intensified monsoon circulations. Global El Niño/Southern Oscillation (ENSO) events have directly affected the regional annual precipitation in the Yellow River Basin and resulted in an approximately 51% decrease in river discharge to the sea (Wang et al. 2006). Although, many other factors are involved. The growing incidence and tribute of related natural disasters, such as floods and droughts in the UBRB, are of particular concern.

Large fluctuations in the melting of snow and ice can result in excessive or insufficient water supplies: heavy snowfalls can block roads or overload structures. Snowfall on steep slopes and associated conditions give rise to avalanches. The most destructive hazards, and those that can have impacts far beyond their mountain sources, tend to be the direct consequences of changes in the cryosphere. These include ponding of water by glaciers and subsequent glacial lake outburst floods (GLOFs), and can involve much more water than the amount generated by climatic events alone. Fluctuations in glaciers, especially retreat and thinning, destabilise surrounding slopes and may give rise to catastrophic landslides (Ballantyne and Benn 1994; Dadson and Church 2005) which can dam streams, and sometimes lead to outbreak floods. Excessive melt waters, often in combination with liquid precipitation, may trigger flash floods or debris flows.

2. OBJECTIVE

The overall objective of this study is to enhance and improve capacity to carry out a harmonised IWRM approach as addressed by the European Water Initiative in headwater river systems of alpine mountain massifs in respect to impacts from climate change, and to transfer professional IWRM expertise, approaches and tools based on case studies carried out in twinning European and Asian river basins. In realizing the overall objective holistic case studies will be carried out in two twinning macro-scale basins: Upper Danube River Basin (UDRB) in Europe, and Upper Brahmaputra River Basin (UBRB) in Southeast Asia. By means of innovative technologies applying integrated approaches, techniques, and experiences gained from former and ongoing EU-projects.

The following IWRM related general objective will be jointly elaborated in this study: (i) Comprehensive assessment of the present systems and (ii) change detection of their natural environments (NE) and (iii) its human dimensions (HD) by a set of recognized IWRM indicators.

3. STUDY AREA

The Brahmaputra River Basin, the mainstream of which originates from the Chamyungdung glacier on the Tibetan plateau, is the biggest trans-Himalayan river basin (A = 651.334km²; L = 2.896km), encompassing parts of the territory, ecosystems, people, economies and politics of China, Bhutan, Nepal, India and Bangladesh. The UBRB in this study is defined upstream of the town Guwahati in NE-India and drains about 500.000km² shared mainly by China (293.000km²), Bhutan (45.000km²) and NE-India (195.000km²), where the slope of the river forms a flood plain in front of the Himalaya with a braided channel pattern. The geography of the UBRB is characterized by the alpine mountain system of the Himalaya and the tropical Monsoon climate. Topographic units are (1) the Tibetan plateau reaching up to 6000m, (2) the Greater Himalaya (Himadri) with mountain peaks exceeding altitudes of 6000m; (3) the Lower Himalya (Himanchal) between 1800 - 3000m, (4) the Sub Himalaya (Shivalik) as a foreland zone ranging from 300 – 1800m, and (5) the flood plain (< 300m) of NE-India.

4. HYDROLOGICAL SYSTEMS ANALYSIS

4.1. Precipitation

Associated with two paths of the South Asian Monsoon across the Tibetian-Himalayas from Indian Ocean, the precipitation decreases to the west and northwest of the UBRB. The observed mean precipitation is quite inhomogenous, the maximum rainfall occurs near the outlet into India with about 5317mm, and the minimum is in the west of the headwater only about 75.0mm shown in Figure 1. However, the monsoonal precipitation in summer (June to September) contributes 80% of annual precipitation.

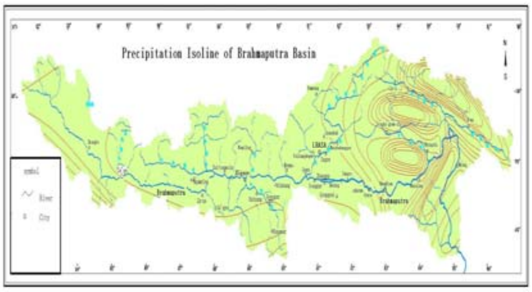


Figure 1: Precipitation Isolines of Brahmaputra Basin

4.2. Evaporation

The evaporation shows the same spatial inhomogeneity as the precipitation. The highest annual evaporation within the UBRB occurs in the dry western and northwestern part of the basin near Lhazi with maximum evaporation rates of about 1500mm, the minimum annual evaporation is in the wet monsoonal influenced region near the outlet into India with about 950mm.

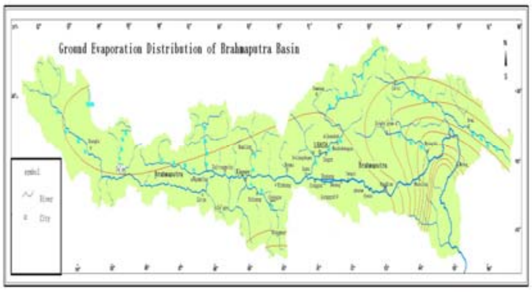


Figure 2: Evaporation Distribution of Brahmaputra Basin

4.3. Runoff

There is a strong seasonal pattern of runoff driven by meltwater and the monsoonal rainfall accounting for about 80% of the annual total runoff. The maximum monthly runoff in the UBRB occurs in August and constitutes about 24.0-30.0% whereas the minimum occurs in February with below < 2% due to low temperatures and the frozen active layer. However, there is considerable inter annual variability within this pluvio-glacial runoff regime. During winter (mid-October to mid-April) soil freezing and thawing occur periodically for about 170 days at lower elevations and for up to 210 days in the high mountains. Snow cover persists from November to May with the greatest snowpack thickness in the high mountains. In winter, the river discharge is fed by groundwater which is greatly affected by the freezing and thawing of seasonally frozen ground and the active layer over permafrost.

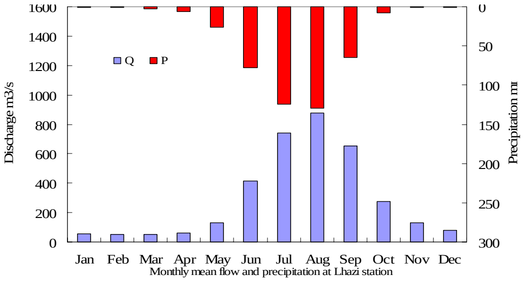


Figure 3: Precipitation and Discharge at Lhazi station

4.4. Temperature trends

The mean linear trend on annual basis as well as on seasonal basis has increased during the period 1961-2005 in the UBRB (see Figure 4). All seasons and annual values are significant at the 95% significance level. The annual temperature trend is +0.28°C/decade. This trend is greater than the calculated trend for China and the Northern Hemisphere. The greatest increase was found in winter with +0.37°C/decade, which was slightly larger than in fall (+0.35°C/decade). For spring and summer an increasing temperature trend of +0.24 and +0.17°C/decade has been defined.

Table 2 presents the distributions of the trends for seasonal and annual temperature in that region. It shows that most of the stations are following the temperature trends, while Jiali is an exception. Jiali has a negative trend in spring and summer.

We conclude that warming trends observed in seasonal and annual temperature is largely contributed by increasing temperature in winter, fall and spring. The dotted line in Figure 4 represents the linear trend during 1961-2005; the red curve shows the 9-year moving average for 1961 to 2005.

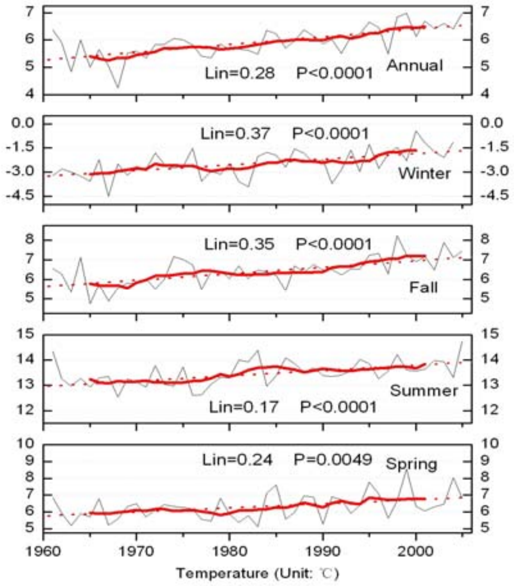


Figure 4: Regional trends of mean annual and seasonal temperature in the UBRB 1961-2005, the unit is °C/decade per season and per year

Table 2: Spatial distribution of seasonal and annual temperature trends in the UBRB during the period 1961-2005, unit is °C per decade, per season, and per year

Station Name	Annual	Spring	Summer	Fall	Winter
Jiangzi	**0.22**	**0.22**	0.06	**0.27**	**0.40**
Dangxiong	**0.28**	**0.21**	**0.16**	**0.35**	**0.37**
Lhazi	**0.45**	**0.59**	0.10	**0.43**	**0.56**
Xigaze	**0.22**	**0.25**	**0.16**	**0.22**	**0.28**
Nimu	**0.23**	**0.30**	0.12	0.14	**0.40**
Lhasa	**0.43**	**0.39**	**0.31**	**0.46**	**0.58**
Zedang	**0.32**	**0.22**	**0.30**	**0.41**	**0.37**
Jiali	0.04	-0.09	-0.08	0.14	0.31
Bomi	**0.20**	**0.18**	**0.13**	**0.22**	**0.30**
Linzhi	**0.24**	**0.28**	**0.23**	**0.27**	**0.25**

4.5. Precipitation trends

Figure 5 depicts the variation of precipitation of four seasons and annual mean from 1961 to 2005. The red curve represents the 9-year moving average from 1961 to 2005. It shows that precipitation increased slightly and exhibited no statistically significant trends during that period. The mean annual precipitation has a non-significant positive trend of 6.75mm/decade whereas the increase amounted 3.74mm/decade in fall, 3.38mm/decade in spring and 1.71 mm/decade in summer. This trend in annual precipitation was observed in all stations except for Jiangzi. It has to be notably pointed out that trends in most stations have a larger magnitude (see Table 3).

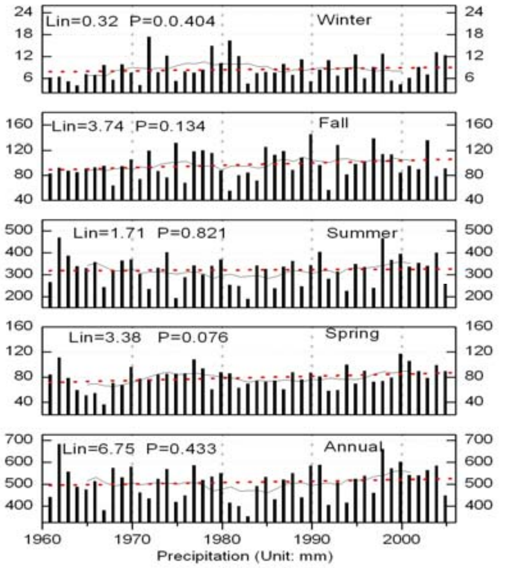


Figure 5: Precipitation variance 1961 to 2005

Table 3: Distribution of seasonal and annual precipitation trends in the UBRB during the period 1961-2005, unit is mm per decade, per season, and per year

Station Name	Annual	Spring	Summer	Fall	Winter
Jiangzi	-3.42	2.60	-2.9	-2.02	0.08
Dangxiong	14.66	**5.95**	1.24	**6.00**	**1.53**
Lhazi	**48.59**	1.89	**40.46**	6.16	0.09
Xigaze	0.63	3.88	-1.67	-1.45	-0.16
Nimu	**33.32**	2.66	22.04	9.13	-0.57
Lhasa	12.28	3.94	2.16	**6.82**	0.68
Zedang	7.83	**6.79**	-0.71	1.66	0.08
Jiali	**27.88**	**10.89**	1.53	**13.53**	2.28
Bomi	**73.46**	**33.06**	16.19	**21.24**	2.95
Linzhi	**28.65**	0.28	20.11	8.57	-0.17

5. POTENTIAL IMPACTS

5.1. Agriculture

According to UNDP (2006), the rising temperatures accompanied by water stress are will lead to a decreasing crop yield of about 30% in Central and South Asia in the mid-21st century. On the other hand, due to the reduction of frost and cold damage it will be possible to grow rice and wheat at higher latitudes which is currently happening in China.

5.2. Forest Ecosystems

Impacts of climate change on forest ecosystems include a shifting of forest boundaries in latitude, the upward movement of the tree line to higher elevations, changes in species' composition and vegetation types and an increase in net primary productivity (NPP) (Ramakrishna et al. 2003). In the eastern part of the basin, it is expected that forest vegetation will expand significantly, forest productivity will increase from 1-10%; and that forest fires and pests will increase as consequence of dryness and warming (Rebetez and Dobbertin 2004).

5.3. Fresh Water

Glacial melt is the essential freshwater resource for ecosystems, particularly in arid areas of the Himalayans during critical periods from the dry season to monsoon. The supply of water resources, based on the snow and ice meltwater, is projected to increase over the following decades as perennial snow and ice decrease. In a study by Yao et al. (2004) the glacial retreat caused an increasing glacial-melt runoff by more than 5.5%, examined in the 1990s for the past decade in northwest China. The impact of warmer climates on the melt from snow-fed basins has been converse to the impact on glacier-fed basins: snow-fed basins are more sensitive in terms of reduction in the availability of water due to a compound effect of increase in evaporation and decrease in melt (Singh and Bengtsson 2005). Most scenarios, however, suggest a water scarcity even of catastrophic proportions in the 2050s resulting from population growth, climatic change, and the increase of water consumption (Oki 2003).

5.4. Biodiversity

Mountain ecosystems host a series of climatically different life zones over short distances and elevations and have a range of micro-habitats and ‘niches’. Therefore mountains are hot spots of biodiversity and priority regions for conservation (Körner 2004). Mountain biodiversity is also most sensitive to global warming and is now showing signs of fragmentation and degradation caused by exogenous forces such as temperature increases and human activities (Xu and Wilkes 2003; Körner 2004). Species in high-elevation ecosystems are projected to shift higher. However, the rates of vegetation change are expected to be slow, and colonisation constrained by increased soil erosion. Alpine plant species on mountain ranges with restricted habitat availability above the tree line will experience severe fragmentation, habitat loss, or even extinction if they cannot move to higher elevations, particularly after an increase of 2ºC (Dirnbock et al. 2003).

5.5. Infrastructure

Valuable infrastructure, such as hydropower plants, roads, bridges, and communication systems will be increasingly at risk from climate change. Entire hydropower generation systems established on rivers will be in jeopardy if landslides and flash floods increase and if a reduction of low flow during the dry season. Mountain engineers have to consider how to respond to extreme events in the mountain context (OECD 2003). For instance, permafrost melting was the main challenge for designing a railway connection to Lhasa.

5.6. Tourism

Although there will be benefits, trekking and mountaineering may be affected adversely by reduced snow and glacial cover. Tourism could, become more profitable as post monsoon dry periods increase and warm winters come to high elevations. However, increases in natural hazards, endangering transportation on high-altitude routes could be have negative affects on tourism.

6. SUMMARY AND CONCLUSIONS

We evaluated the spatial and temporal variations of temperature and precipitation in the UBRB based on monthly and daily climate extremes from 10 meteorological stations (China Meteorological Administration) during the period 1961-2005. Quality control was performed on data, which was processed into climate extremes indices for releasing to the global community. Temperature extremes showed patterns consistent with warming trends over most of the study region.

Precipitation indices, despite the large and expected spatial variability, indicate that regionally averaged total precipitation has increased by 6.75mm/decade but is not statistically significant.

Work on evaporation changes and glacier retreat will be done next as basis for regional hydrological modelling.

The Himalayans cover one of the most dynamic and complex mountain ranges in the world and they are vulnerable to global warming and increasing human activities (Bandyopadhyay and Gyawali 1994). Uncertainties about the rate and magnitude of climate change and potential impacts prevail, but there is no question that it is gradually and powerfully changing the ecological and socioeconomic landscape in the Himalayan region, particularly in relation to water. Business as usual is not an option. Floods are the main natural disaster aggravating poverty in the Himalayans where half of the world’s poor live. Technical advances in flood forecasting and management offer an opportunity for regional cooperation in disaster management. Regional cooperation in transboundary disaster risk management should become political agenda. Disaster preparedness and risk reduction should be seen as an integral part of water resource management. IWRM should include further climate change scenarios and be scaled up from watersheds to river basins.

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