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Development of adaptive IWRM options for climate change mitigation and adaptation

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Abstract. Adaptive Integrated Water Resources Management (IWRM) options related to the impacts of climate change in the twinning basins of the Upper Danube River Basin (UDRB) and the Upper Brahmaputra River Basin (UBRB) are developed based on the results obtained in the different work packages of the BRAHMATWINN project. They have been described and discussed in Chapter 2 till Chapter 9 and the paper is referring to and is integrating these findings with respect to their application and interpretation for the development of adaptive IWRM options addressing impacts of climate change in river basins. The data and information related to the results discussed in Chapter 2 till 8 have been input to the RBIS as a central component of the IWRMS (Chapter 9). Meanwhile the UDRB has been analysed with respect to IWRM and climate change impacts by various projects, i.e. the GLOWA-Danube BMBF funded project (GLOWA Danube, 2009; Mauser and Ludwig, 2002) the UBRB has not been studied so far in a similar way as it was done in the BRAHMATWINN project. Therefore the IWRM option development is focussing on the UBRB but the methodology presented can be applied for the UDRB and other river basins as well. Data presented and analysed in this chapter have been elaborated by the BRAHMATWINN project partners and are published in the project deliverable reports available from the project homepage http://www.brahmatwinn.uni-jena.de/index.php?id=5311&L=2.

1 Introduction and objectives

The development of IWRM adaptation options to account for impacts from climate change must apply a holistic system's approach (Flügel, 2009) comprising a thorough hydrological system analysis (Flügel, 2000). Both require a methodology that integrates tools provided by Geoinformatics (Flügel, 2010) and a central data and information platform. The latter was established for the BARAHMATWINN project by implementing the River Basin Information System (RBIS) developed by the FSU-Jena (Flügel, 2007; Kralisch et al., 2009). The IWRMS (Chapter 9) provides the means to analyse the deliverables of the BRAHMATWINN project, like the measured data time series, the results of the climate modelling exercises (Dobler and Ahrens, 2008, 2010), modelled data time series as output from the DANUBIA modelling system (Mauser and Bach, 2009), socio-economic vulnerability studies (Kienberger et al., 2009), and the analysis done by means of the NetSyMod – mulino decision support system (mDss) (Giupponi et al., 2008).

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The *overall objective* of the IWRM adaptation options development was to demonstrate the knowledge based potential of such an integrated system analysis using the results obtained from interdisciplinary research cooperation between natural, socio-economic and engineering sciences. This will be demonstrated by examples derived from the

- climate modelling studies presented in Chapter 2,
- natural and socio-economic system assessment done in Chapter 3 and 4,
- IWRM assessment given in Chapter 5,
- DANUBIA hydrological modelling results given in Chapter 7,
- socio-economic vulnerability analysis discussed in Chapter 6, and the
- development of stakeholder approved "what-if?" scenarios in Chapter 8.

The ILWRMS presented in Chapter 9 has been used to carry out the analysis based on the data and information provided by the numerous BRAHMATWINN deliverables available from the RBIS database.

2 Role within the integrated project

The development of alternative IWRM options to adapt to impacts of climate change is the integral component of the BRAHMATWINN project. It relies on the IWRMS development that provides the software techniques and methodologies for such an integrated analysis and the results obtained from the natural and socio-economic system assessment complemented by the scenario based modelling studies. They are presented and discussed in Chapter 2 till Chapter 9.

3 Scientific methods applied

Neither does the design of adaptive IWRM options appear from the holistic systems approach applied in the BRAHMATWINN project per se nor is there a "perfect" strategy to be proposed as the optimum solution for IWRM options adapting this process to climate change impacts. Instead professional expert knowledge is required to properly define IWRM challenges related to climate change and identify the appropriate project results to be applied and analyse them in an integrated way. The IWRMS in this regard provides the technical means from Geoinformatics but needs the expert knowledge and professional expertise that is required for the integrated analysis.

In result such an exercise will deliver a set of alternative IWRM options that have to be discussed with stakeholders and decision makers to find a solution to the defined IWRM challenge. The selected option should receive the broadest level of acceptance by the stakeholder communities that have to implement and support the respective IWRM strategy.

4 Results achieved and IWRM options proposed

4.1 IWRM options due to climate change

The climate modelling results and their discussion and analysis presented in Chapter 2 of this publication for the UDRB and UBRB shows that both twinning basins have a temperate climate. In the UBRB it is dominated by the monsoon system which supplies the region with up to 80% of the annual total rainfall meanwhile the UDRB has a rainfall pattern distributed over all months of the year. Both basins have in common to receive winter precipitation as snow that is melting in the following spring time and summer season.

4.1.1 Model projections

The modelled projected temperature confirm average temperature increase up to 5 °C in 2100 in the UBRB with the higher values in the region of the Tibetan Plateau and up to 4 °C in the UDRB. Thus, processes that directly dependent on temperature, like potential evapotranspiration melting of snow and glacier ice will show similar trends with consequent impacts on the hydrology of the river basins.The annual average precipitation in the UBRB is without a significant trend because an increasing trend in the summer is compensated by opposite trends in others seasons. The results of the modelled rainfall projections for the IPCC scenarios A1B and B2 are aggregated in Table 4 of Chapter 2 and reveal:

1. Precipitation trends in both basins are negative with a higher trend in the UDRB than in the UBRB.

2. Different climate change indicators, like the length of the longest dry periods, indicate more frequent and prolonged droughts.

3. The projected increasing amount of (1-day and 5-day) spring precipitation in the UDRB in combination with increased spring snow melt due to higher temperatures in the Alps is likely to increase the magnitude and frequency of floods.

4. In Assam the positive trend in the number of consecutive dry days in the monsoon season indicates longer monsoon breaks in the forthcoming decades.

5. An increase in the number of consecutive dry days and in the maximum 5-day precipitation amount in the region of the Tibetan Plateau for the monsoon season. The complement temperature impacts of trends indicate the UBRB as a highly sensitive region to future climate changes.

4.1.2 Analysis of measured climate

An intensive climate data collection was done during the course of the BRAHMATWINN project and hundreds of stations have been input into the BrahmaRBIS and DanubeRBIS respectively. For the UBRB the quality assessment revealed that most of these stations unfortunately have significant data gaps and therefore cannot be used for a comparative assessment. After a thorough screening the remaining stations presented the regional climate trends for the UBRB in Fig. 1. They can be described as follows:

1. Throughout the UBRB, i.e. from the semi-arid western till the monsoon driven eastern part of the basin there is a positive trend projected for air temperature.

2. The precipitation trend is negative in the arid western and Tibetan part of the UBRB and turns into a positive trend in the eastern part of the UBRB, i.e. in Assam and the windward located slopes of the Himalaya mountain ridge.

As showing in Figs. 2 and 3 for the station Dibrugarh (India/Assam) the increase of temperature and precipitation has also been measured in Assam. Both trends are significant on the annual and monthly scale, as the monthly averages after 1990 show considerably higher values as those from the previous 15 year time span.

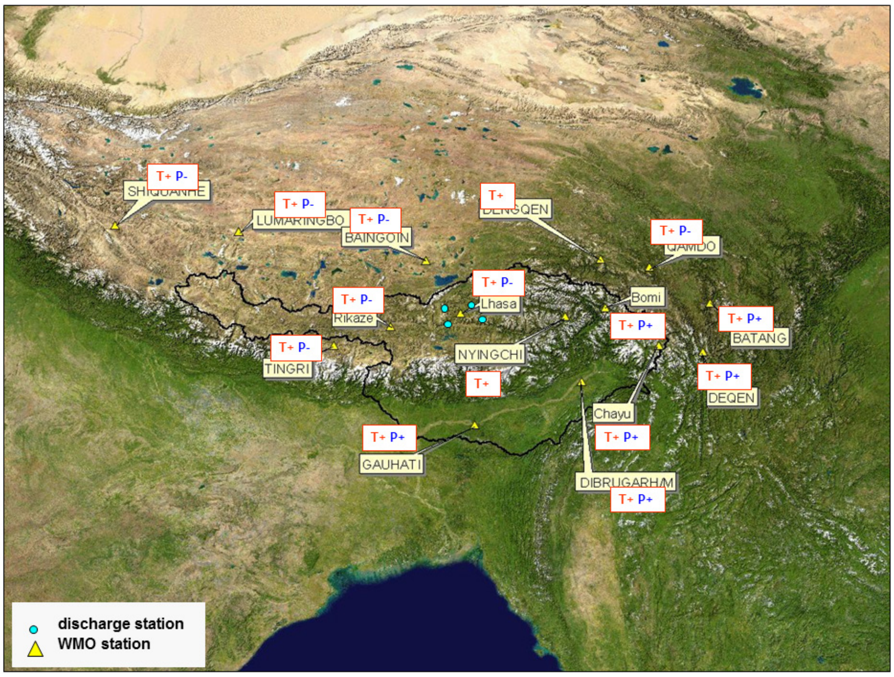

Figure 1. Trends of temperature and precipitation measured at stations in the UBRB.

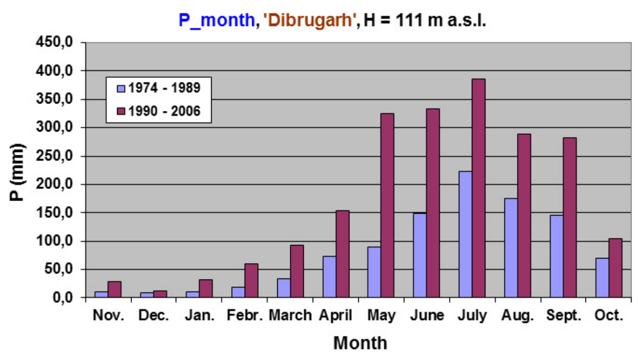

Figure 2. Positive trend of annual precipitation at Dibrugarh, Assam, NE-India.

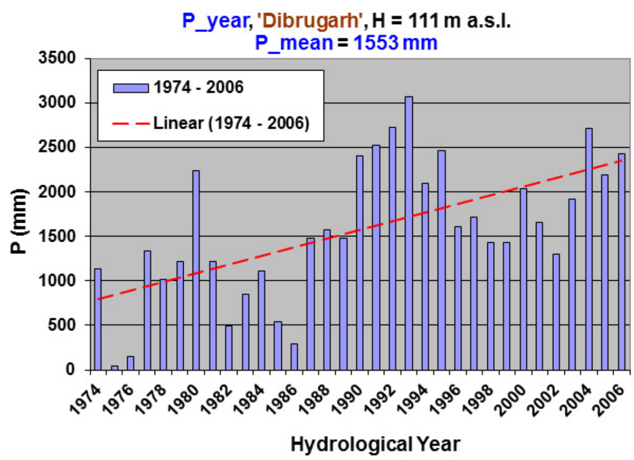

Figure 3. Positive trend of monthly mean precipitation at Dibrugarh, Assam, NE-India.

4.1.3 Consequences for adaptive IWRM options

Although the climate projections are still coarse in resolution and are not directly of use for IWRM planning they can be analysed together with the measured climate trends with respect to IWRM as follows:

1. There is a clear indication that climate warming is most likely to continue further and evapotranspiration will increase resulting *firstly* in increasing melt of glaciers, permanent snow fields and permafrost, and *secondly* in a reduction of runoff generation in the hot summer months.

2. Precipitation has a declining trend in the north-western part of the UBRB and complemented by the increasing temperatures the presently semi-arid climate of this region will most likely get dryer and more arid. As a result the annual runoff yield will decrease as well so that less water can be expected for distribution to irrigation schemes and for hydropower generation.

3. In the monsoon driven North Eastern Region (NER) of India, i.e. in Assam the climate modelling results indicate longer dry spells during the monsoon period.

Table 1. Modelled scenario trends till 2080 for precipitation in the UDRB and UBRB (adapted from Dl_2, 2010).

Acronym	Description	UDRB		UBRB	
		A1B	B2	A1B	B2
PFRE	Number of precipitation days	−27	−19	−19	−11
PRECIP	Mean annual precipitation	−22	−16	−11	−6
PX5D	Max. 5-day precipitation period	0	−5	6	6
PCDD	Longest period of consecutive dry days	34	22	24	16

Table 2. Glacier reduction in the UBRB and UDRB between 1970 and 2000 (adapted from Dl_3, 2010).

Area of glacier cover (AGC)	River Basin (RB)			
	Lhasa River	Wang Chu	UBRB	Salzach
1970 (km^2)	535	60	17580	95
2000 (km^2)	429	50	14400	79
ΔAGC (km^2)	−106	−10	−3180	−16
ΔAGC (%)	−19.8	−16.7	−18.1	−16.8

4. Higher precipitation is projected for the NER during the monsoon period and this is supported by station time series from this region. They can exaggerate the already threatening flood inundations and consequent bank erosion. Both will further put valuable farm land at risk and call for the implementation of effective river training measures.

4.2 IWRM options due to melting glaciers and permafrost

Melting and retreating glaciers are obviously associated with the positive temperature trend in both twinning basins and this has been validated from change analysis done by means of satellite images between 1980 and today (Chapter 3).

The results of such an change detection analysis are listed in Table 2 and reveal that glacier melt and their retreat is almost of the same magnitude in the alpine mountains of the UDRB and the UBRB respectively ranging between 16.7% and 19.8%. The following interpretation can be derived from the results given in Table 2:

1. The glacier area in the Lhasa river catchment is about 8 times larger than in the Wang Chu catchment. The glacier area change, however, is similar in both catchments with a decline of about −7% per decade. The significant debris cover of the glacier tongues in the Wang Chu is buffering this process that reduces glacier mass loss and retreat.

2. The glacier area loss in the Salzach catchment during ~1970 to ~2000 was similar, and altogether glacier loss in the four catchments between the 1970s and 2000 ranged between 16.7% and 19.6%.

Consequences for adaptive IWRM options

The consequences for IWRM can be described as follows:

1. Discharge from glaciers and permanent snow fields will increase due to progressive melting of these permanent storages till a new balance between precipitation input and consequent melting is reached.

2. Melt water from glacier ice and snow is stored in glacier lakes in front of ice core moraines and significantly enhances the threat of glacier lake outburst floods (GLOFs) which frequently occurred in the past in both twinning basins (Subba, 2001).

3. After a new ice and snow balance has been established their contribution to river runoff most probably will be considerably smaller than in the 20th century.

4. Especially during the summer time consequent water shortages for irrigation agriculture are likely and farmers either need to adapt in their cropping pattern or additional infrastructures must be built to provide the storage capacity to sustain irrigation during that period.

5. Melting permafrost is reducing the slope stability as the ice that is cementing the weathered debris is disappearing. Consequent landslides, mudslides, and rock falls can dam rivers and add further sediment to the rivers threatening irrigation infrastructures and reservoirs.

Table 3. Vulnerability of wetlands to socio-economic development (SED) and climate change (CC) in river basins in Assam, Bhutan and India (adapted from Dl_3, 2010).

<table>
<tr><th rowspan="2">River Basin</th><th rowspan="2">Vulnerability to</th><th colspan="6">Type of Wetland classified</th></tr>
<tr><th>alluvial</th><th>floodplain</th><th>swamp</th><th>lake</th><th>alpine meadow</th><th>beel</th></tr>
<tr><td>Lhasa River, Tibet</td><td>SED
CC</td><td rowspan="3">low</td><td rowspan="3">high</td><td>low
high</td><td rowspan="3">medium</td><td>low
high</td><td></td></tr>
<tr><td>Wang Chu, Bhutan</td><td>SED
CC</td><td>low
high</td><td rowspan="2"></td><td rowspan="2">high</td></tr>
<tr><td>Assam, North-East India</td><td>SED
CC</td><td></td></tr>
</table>

4.3 IWRM options due to the transfer of wetlands

Types and functions of wetlands have been described and classified according to their distribution and hydrological dynamics for the Lhasa River, the Wang Chu and for Assam in India in Chapter 3. Projected climate change (Chapter 2) indicates that runoff variability will increase in terms of extremens, i.e. floods and dry weather runoff. Increased sediment load is likely due to landslides slipping off from slopes that became instable due to melting permafrost (Chapter 3). These are negative impacts on wetlands which need a sufficient period of flooding of water with little sediment load for fish breeding.

In addition wetlands are under continuous pressure by getting transferred into settlements or agriculture fields to satisfy the needs to accommodate and feed the ever growing population. Although the importance of wetlands for the buffering of floods and the support of dry weather base flow as well as for the biodiversity are often appreciated by planners and water managers these destructive processes are continuing in unchanged dynamics.

Consequences for adaptive IWRM options

Draining of wetlands to generate new areas for settlements or agriculture has impacts for IWRM that cannot completely be quantified at present. In cases that small wetlands are destroyed the impact on biodiversity outweighs the impact on the hydrological dynamics. This might be the case in the Wang Chu in Bhutan and to a certain degree also for the flood plains in the western part of the Yarlung Tsangpo.

In the flood plains of Assam, however, adaptive IWRM initiatives are required to ensure that their hydrological as well as their environmental functions and services can be sustained. Otherwise it is likely that essential ecosystem functions (ESF), i.e. flood retention or biodiversity regeneration will be impacted. Furthermore vital livelihood capacities for the local population that depend on respective ecosystem services (ESS), i.e. food supply from fishery and the purification of flood water for rural water supply will become at risk.

The risk matrix for the wetlands classified in the BRAHMATWINN project is listed in Table 3 derived from detailed weighting analysis done in Chapter 3 applying the Millennium Ecosystem Assessment (2005). Table 3 defines the ranked magnitudes of likely impacts that can be expected from climate change and consequent socio-economic pressure on ESS and ESF. Especially the *Beels* which are permanent flooded wetlands representing the majority of wetlands in Assam are under strong pressure and in almost all aspects will be impacted in terms of ESS, ESF, biodiversity and flood peak buffering if impacts from climate change continue and are progressively exaggerated by human activities.

4.4 IWRM options due to water balance modelling and bank erosion

The results of the water balance modelling exercises done by means of the DANUBIA model have been reported in Chapter 7. The maybe most alarming result is the projected decline of the runoff in the Brahmaputra River at Guwahati (Fig. 10 of Chapter 7), and this trend is obvious in all four IPCC scenarios applied. They are corresponding to the projected temperature increase and the respective decline of precipitation and for the snow precipitation in particular (Fig. 12 of Chapter 7). Projected lower rainfall input (Table 1) and increasing temperature (Fig. 4 of Chapter 2) result in higher evapotranspiration that in turn is reducing runoff generation and discharge height.

This process is not only impacting the already semi-arid western part of the Yarlung Tsangpo in Tibet but also the monsoon dominated runoff generation in the NER of India, i.e. in Assam. According to the model results shown in Fig. 13 of Chapter 7 the A1B and B1 scenarios agree in this trend and both areas are expected to show more severe dry periods with related impacts to agriculture, fisheries and socio-economy in general. If compared with the historical past (1971–2000) the magnitude of the projected discharge decline for the A1B scenario ranges between 15% for the period 2011–2040 and 28% for the period 2051–2080 meanwhile the B1 scenario has projected declines of 15% and 23% respectively (Table 4, line 2).

Table 4. Integrated indicators to evaluate quantifying SRES based model projections for climate change impact on sustainable IWRM (adapted from Dl_7, 2010).

Integrated Indicator		Scenarios and Projections		
Domain (subdomain)	Indicator	Base Line (1971–2000)	A1B	B1
env (climate)	air temperature (T) precipitation (P) evapotranspiration (ET)	Different regional trends depend on seasonal dynamics	$T+2$–$6\,^\circ$C $P+$ in Bhutan $P+$ in Tibet $P-$ in Assam	$T+2$–$3\,^\circ$C $P+$ in Bhutan $P+$ in Tibet $P-$ in Assam
env (hydrology)	surface runoff (Sr) interflow (Int) groundwater flow (Gf) snow and glacier melt (SGM)	Changes of flow volume and seasonal flow distribution	15% till 28% less mean annual discharge and changing runoff regimes	15% till 23% less mean annual discharge and changing runoff regimes
env (glaciology)	Δ Area of Glacier Cover (AGC)	ΔAGC (1970–2000) −17% till −20%	glaciers and permafrost will melt away	less pace of glacier and permafrost melt
env (hydrobiology)	wetlands with eco-system services (ESS) and ecosystem functions (ESF)	regional diversity with functioning ESS and ESF	strong pressure from GDP and population growth on ESS and ESF	less pressure from GDP and population growth on ESS and ESF
soc-econ (vulnerability)	Gross domestic product (GDP) population pressure (PP)	high vulnerability in flood prone areas with high PP	high GDP development decreases vulnerability	lower plus of GDP reduces decrease of vulnerability
soc (governance)	governance and policy	IWRM is not in place but first attempts are made on a transnational level	less good with respect to sustainability but governance levels as good as in B1	best setup for management of the whole river basin and IWRM

4.4.1 Changing runoff components

If one compares the modelled mean monthly discharge distribution shown in Fig. 15 of Chapter 7 of the historical past from 1971 to 2000 with the modelled runoff projections of the A1B scenario the following IWRM relevant information can be extracted:

1. Meanwhile the monthly runoff is almost normal distributed in the historical past it becomes skewed in the projected period 2011–2040 but still reaches similar peak discharge in July.

2. The rising limb of the monthly hydrograph for the A1B scenario in the projected period 2011–2040 has significant lower discharges if compared to the historical past, which indicates less precipitation input and a smaller contribution of snow and glacier melt from reduced snow and glacier storages in the alpine mountains.

3. In the second projected period of the modelled A1B scenario the reduced rainfall and the increased temperatures are becoming fully effective and reduce the hydrograph peak but keep the shape skewed towards the end of the monsoon period.

The modelled change of snow and glacier melt runoff components have been discussed in Chapter 7 for the Lhasa River basin and are shown in Fig. 16 of Chapter 7. Significant changes in the contribution of glacier melt runoff can be expected according to the modelled projections. The modelling results are supported by measured discharge values given as monthly averages from 1957 onwards for the gauging station at Lhasa in Fig. 4 and reveal:

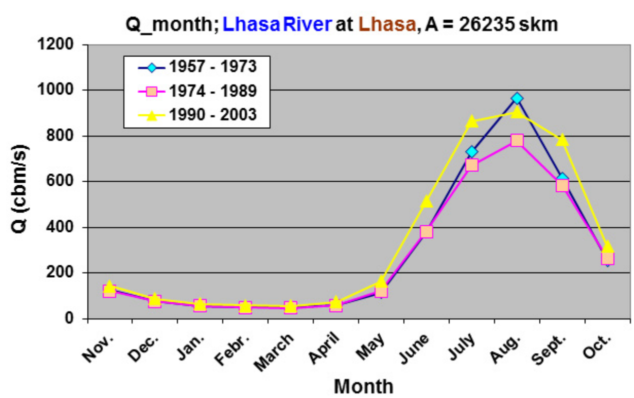

Figure 4. Mean monthly discharge of the Lhasa River at the gauging station Lhasa.

1. For the two time periods 1957–1973 and 1974–1989 the distribution of mean monthly discharge is almost the same and only the peak discharge is different most likely due to variations in rainfall.

Figure 5. Bank erosion from slipping unstable river banks (left) and unfertile flood sand deposits destroying fertile farm land (Photo: Nayan Sharma).

2. The third time period 1990–2003 is giving a different distribution, as the hydrograph has higher values in the rising and falling limb and is of a broader shape.

This obvious change in runoff dynamics and seasonal distribution can be accounted for a higher contribution of snow and glacier melt in the past 14 years which due to climate warming is starting earlier, contributes more runoff then in previous decades and supports runoff even after the summer rainfall season.

4.4.2 Bank erosion

Bank erosion is an obvious threat in the floodplains of the Brahmaputra River and its tributaries. Especially after the last severe earth quake in 1950 this process has reached disastrous extremes eroding about 4000 km^2 of rural farmland and leaving almost a million of people home- and landless. The erosion process in many cases is related to the changing hydrostatic pressure between high and low water levels during flood and low flow respectively. This change of pressure balance is destabilizing the steep sandy banks which then slip down into the river (Fig. 5, left). If floods inundate fertile farm land they deposit thick layers of unfertile sands thus making this former farm land unfertile for years (Fig. 5, right).

As shown in Fig. 6 the Brahmaputra River had broadened its river bed considerably during the last three decades and at present is having an uncontrolled dynamics with the tendency of extending towards the southern banks bordering fertile farm land regions.

4.4.3 Consequences for adaptive IWRM options

The hydrological modelling of the UBRB water balance is integrating the results obtained from Chapter 2 and 3 and confirms to a large extent the findings from the glacier and permafrost studies. They clearly show the need for additional validation and require the access to hydro-meteorological station time series, which at present are still ranked as classified and are not available to the research community. Especially the regional distribution of precipitation is crucial for the water balance and runoff modelling studies.

Declining discharge of the Brahmaputra River is most alarming and calls for further validation concentrating on the NER of India, which at present is receiving the bulk of the monsoon rainfall and generates a large portion of the Brahmaputra discharge. In this region adaptive IWRM options must be focussing on the following components which have to be combined in an integrated way:

1. A comprehensive hydrological system analysis is required to obtain enhanced understanding of the Brahmaputra River system in the NER of India complemented by more detailed hydrological modelling of the tributary runoff dynamics contributing to the discharge and sediment load along the main river stretch.

2. The hydrological system analysis and modelling exercises must be complemented by a respective computational hydrodynamic flow analysis linked with the hydrological modelling into an integrated river basin model of the Brahmaputra River in the NER of India.

3. The buffering of flood peaks and the support of base flow is essential and must include the exploration of wetland retention potential, i.e. the flooding management of *Beels* integrating aspects of biodiversity and socio-economic development.

4. Complement flood retention infrastructures should be considered and respective conceptions must integrate in a balanced way aspects of hydro-power generation, irrigation water supply, environmental flow requirements, and biodiversity. Scale and distribution of infrastructure concepts must account for the prevailing geo-tectonic activity in the NER of India.

5. Bank erosion must be addresses and to a large extend can be prevented by means of properly designed and

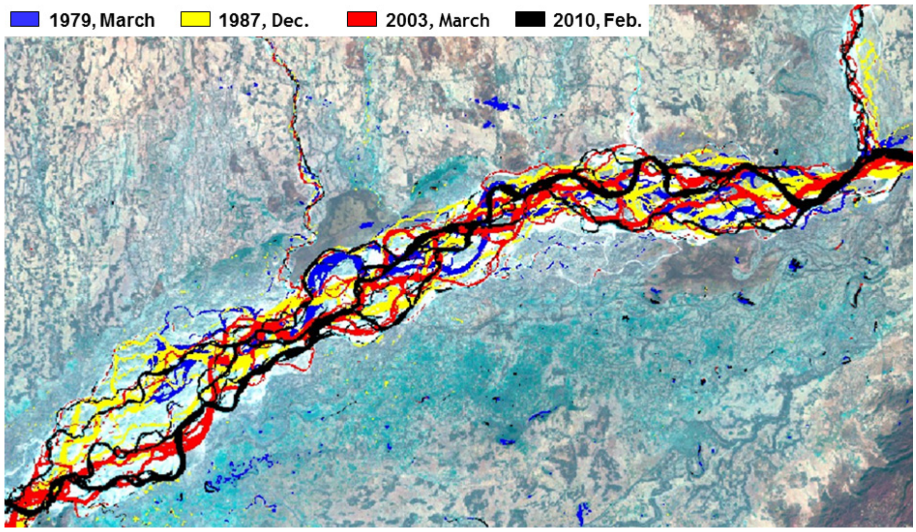

Figure 6. Braided flow paths of the Brahmaputra River system between 1979 and 2010 (analysis and graphic provided by Bettina Böhm).

effective river training measures. The installation of these measures has to apply the findings from the thorough hydrological system analysis and complement hydrodynamic flow studies.

6. River training measures should be based on expertise obtained from Indian rivers, i.e. the Ganga River. They must be designed in such a way that they are easy to build, make use of locally available resources, i.e. bamboo, and create jobs for the rural poor when being implemented and maintained.

4.5 Vulnerability and governance analysis

Vulnerability against floods was analysed in Chapter 4 and a comprehensive governance analysis was discussed in Chapter 8.

4.5.1 Vulnerability analysis

The vulnerability against floods was established for the UDRB and UBRB using the test regions of the Brahmaputra River floodplain in Assam and the Salzach River in Austria for the UBRB and the UDRB respectively. The results are discussed in Chapter 4 and here Fig. 6 reveals:

1. High vulnerabilities are strongly related to population centres like in the west of Assam at the city of Guwahati in Assam and of the city Salzburg in Austria.

2. Higher vulnerabilities can be found along the main stem of the Brahmaputra River and its tributaries because of bank erosion and flooding of the *Beels* which are used for complement food supply and grazing.

Vulnerability projection modelling for the SRES (A1, B1) was done for both case regions in the UDRB and UBRB and discussed in Chapter 8. They show that GDP and population growth impacts both household and community factors that control socio-economic vulnerability to climate hazards. Factors that are relevant in this regard are the proportions of the population working in agriculture, of households with a television, houses with burnt brick walls and of households using firewood for cooking.

4.5.2 Governance analysis

Each of the storylines for the SRES scenarios A1B and B1 makes certain assumptions about the balance of the socio-economic drivers in place in 2050 but fails to make comments regarding the governance regimes expected to support the scenarios. Governance scenarios might be difficult to project but there is no doubt that the extent to which IWRM options adapting to impacts of climate change will be effective or not depends on the governance and policy positions in place (Ministerial Declaration, 2000). It is therefore necessary to assess the characteristics and suitability of the governance system that would be needed to support adaptive IWRM options as proposed response options.

4.5.3 Consequences for adaptive IWRM options

Adaptive IWRM options must account for socio-economic developments and constraints as it is the human dimension in which they will be implemented. Moreover their successful implementation and effectiveness strongly depends on the appreciation and willingness of people to accept them as a valuable support for socio-economic development and sustainable use of water resources that both account for environmental preservation. Accounting for these findings should be done as follows:

1. IWRM as a process must support the growth of GDP which contributes to reduce the flood vulnerability, i.e. by a better maintenance and management of protection measures and management operations.

2. Substantial growth in GDP is supporting the slowing down of the present growth in population, thus must be a complement objective of IWRM options in reducing levels of vulnerability.

3. It is necessary to assess the suitability of adaptive IWRM options with respect to their functional potential within the governance system to support its implementation.The characteristics of the governance system that would be needed to support the storylines must be determined and addressed by the IWRM strategy design.

5 Contributions to sustainable IWRM

The analysis given in this chapter is interpreting the findings from the research studies presented in Chapter 2 till Chapter 9 by an integrated approach towards sustainable IWRM. They have been quantified by numerous indicators out of which by means of an expert assessment (Chapter 6) those have been selected that quantify climate change impacts for the "what-if?" scenarios developed in Chapter 8 for the A1B and B1 scenarios. They have been named "integrated indicators" as they comprise meanings for interdisciplinary interpretation of the natural environment and its socio-economic development. Furthermore they are considered relevant for vulnerability and governance analysis and the development of adaptive IWRM options respectively. They have been grouped in three domains of sustainability: environmental (env), socio-economic (soc-econ) and social (soc) indicators and are listed together in Table 4.

Required data for the indicator calculation have been collected and analysed in the work packages (WP) WP2 till WP5 and WP7 of the BRAHMATWINN project and respective information is available for the A1B, B1 and B2 scenarios from the IWRMS BrahmaRBIS and DanubeRBIS (http://www.brahmatwinn.uni-jena.de/) both implemented for the twinning basins in WP9. Data and information also originates from the modelling exercises in WP2 and WP7 as well as from the stakeholder workshops and expert assessments done in WP4 till WP6 and WP8.

6 Conclusions and recommendations

Climate change is a complex problem and the assessment of respective impacts requires a holistic system's approach comprising the interdisciplinary cooperation and integration of natural, socio-economic and engineering sciences. Summarizing the discussions presented herein the following conclusions are presented:

1. When applying the holistic system's approach it is necessary to address the problem of scales. Data and information provided relate to different scales and it is necessary to appreciate the potential and limitations of downscaling procedures.

2. Modelling is an essential methodology and used in almost all disciplines that have been involved in the BRAHMATWINN project. However, the types of data which are produced by the natural and socio-economic models are not always compatible and need expert interpretation.

3. Applied Geoinformatics via the RBIS has provided data and information to all disciplines and research teams involved, and is implementing the knowledge obtained in Decision Information Support Tools (DIST) like the Integrated Water Resources Management System (IWRMS).

4. "What-if?" scenario based model projections are essential tools for IWRM analysis and respective options development. The storylines of the "what-if?" scenarios must include the human dimension based on stakeholder integration.

5. Socio-economic and governance analysis are as important as the natural and engineering studies as they provide the information about the human dimension to implement IWRM options successfully within a given governance system.

From these experiences and the constraints met during the BRAHMATWINN project the following recommendations can be formulated:

1. There is still a lack of hydro-meteorological information in the UBRB. This situation could be significantly improved if measured hydro-meteorological data time series are not any longer classified but made available to research projects like BRAHMATWINN.

2. Downscaling of climate data that are relevant for hydrological modelling studies is an essential part of a climate impact assessment study and needs further research. Software packages that have been developed for this purpose should be well documented with respect to their input data demands and constraints. They should be available to the scientific community for testing and evaluation. Impact analysis of climate change on river basin water resources must be based on a holistic approach comprising land and water resources management to develop adaptive ILWRM strategies applying innovative software toolsets like the Integrated Land Management System (ILMS) described by Flügel (2010).

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