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Dependence on agriculture and ecosystem services for livelihood in Northeast India and Bhutan: vulnerability to climate change in the Tropical River Basins of the Upper Brahmaputra

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Abstract The Upper Brahmaputra River Basin is prone to natural disasters and environmental stresses (floods, droughts and bank erosion, delayed rainfall, among others) creating an environment of uncertainty and setting the basin back in terms of socio-economic development. The climate change literature shows that agriculture and ecosystems and their services are highly climate sensitive, yet they are the main sources of livelihood that supports a large proportion of residents of the tributaries of the Brahmaputra River Basin. The continuous depletion of ecosystems and loss of agricultural outputs resulting from environmental stressors has a substantial impact on the socio-economic wellbeing of the basins residents, particularly the vulnerable rural poor. This paper uses spatially explicit data from Census, Household Surveys and Earth Observation to develop a transferable methodological approach which investigates the extent of dependence on agriculture and ecosystems as a source of livelihood in the contrasting sub-basins of the Brahmaputra River in the State of Assam, India and Bhutan, and the risk to these livelihood dependencies in these sub-basins due to potential environmental impacts of climate change. The results from this study constitute a case study in the development of a systematic and spatially explicit set of tools that inform and assist policy makers in the appropriate interventions to secure the livelihood benefits of sustainably managed agriculture in the face of environmental change.

1 Introduction

Climate change and its impact on resources affect the socio-economic wellbeing of individuals, households, communities and nations. The impacts are mainly adverse, with some

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being irreversible, while a small number of others may be beneficial (O'Neil et al. 2001). The effects vary greatly and are felt more among the poorest of the poor and vulnerable communities due to limited resources and infrastructure available to these groups (O'Brien and Leichenko 2000). The Brahmaputra River and tributaries in Assam and Bhutan are examples of areas under intense environmental risk due to climate changes and resultant man-made activities. The effects of climate change on the environment are already being experienced in these basins. These Basins are exposed to numerous environmental stresses including increasing floods, droughts, river bank erosion, glacier lake outburst, landslides among others and are highly sensitive to changes in precipitation patterns, with wide impacts on the socio-economic systems of the region. These include impacts on livelihoods, human health, water availability and quality, ecosystems and infrastructure loss (Sharma et al. 2010).

In this study, using a stakeholder based approach, the authors investigate:

i. the impacts of environmental hazards and stressors on the socio-economic wellbeing of the basin's residents with a particular focus on dependence on agriculture and non-agricultural ecosystem services (where agriculture is identified as an ecosystem service in the Millennium Ecosystem Assessment 2005);
ii. the resilience of communities to cope with the stressors; and,
iii. using appropriate statistical techniques, Census and remote sensing data as well as information gathered from the basin's residents, stakeholders and experts to analyse the spatial patterns in dependence on agriculture and ecosystems to identify the most vulnerability communities.

The study is not intended, within the specific research context, to allow for a direct comparison of indicators between the study sites so much as mapping and comparison at the higher domain level only. Indeed, it is at the domain level that the expert weightings are elicited.

2 Study site

The study sites (the Brahmaputra River Basin of the Assam State of India and its tributaries in the Kingdom of Bhutan) are reflective of a substantive and diverse, predominantly rural agricultural communities living within the corridors or tributaries of a river of international significance. The river and its tributaries dominate the regions environment and provide directly or indirectly the livelihoods and ecosystem services (water, soils, food and transport) of many of its residence. Of course the river is also a source of much of the hazards to which the population are exposed.

The literature shows that within the selected basins (Fig. 1), communities live at great risk of environmental hazards; exacerbated by human-activities and climate change (Sarma and Saikia 2010; Biswas 1986). Agriculture and ecosystems which form the main sources of livelihood for the Basin's residents are also the most sensitive to the impacts of environmental stresses (Policy and Planning Division 2004; Reuveny 2007). In the Assam State of India, agriculture accounts for 35.1 % of the state's Gross Domestic Product (GDP) and employs about 70 % of the total work force (Planning Commission 2002). Agricultural practices in the Basin tend to revolve around the monsoon rainfall and the annual water logging of the floodplains (Gadgil and Kumar 2006). However, the monsoon rains have been associated with annual floods, changing patterns of rainfall with far-reaching social and economic impacts (Gadgil and Kumar 2006). Deficits in the monsoon rains, on the other hand results in prolonged dry spells, confronting families with unprecedented hardships

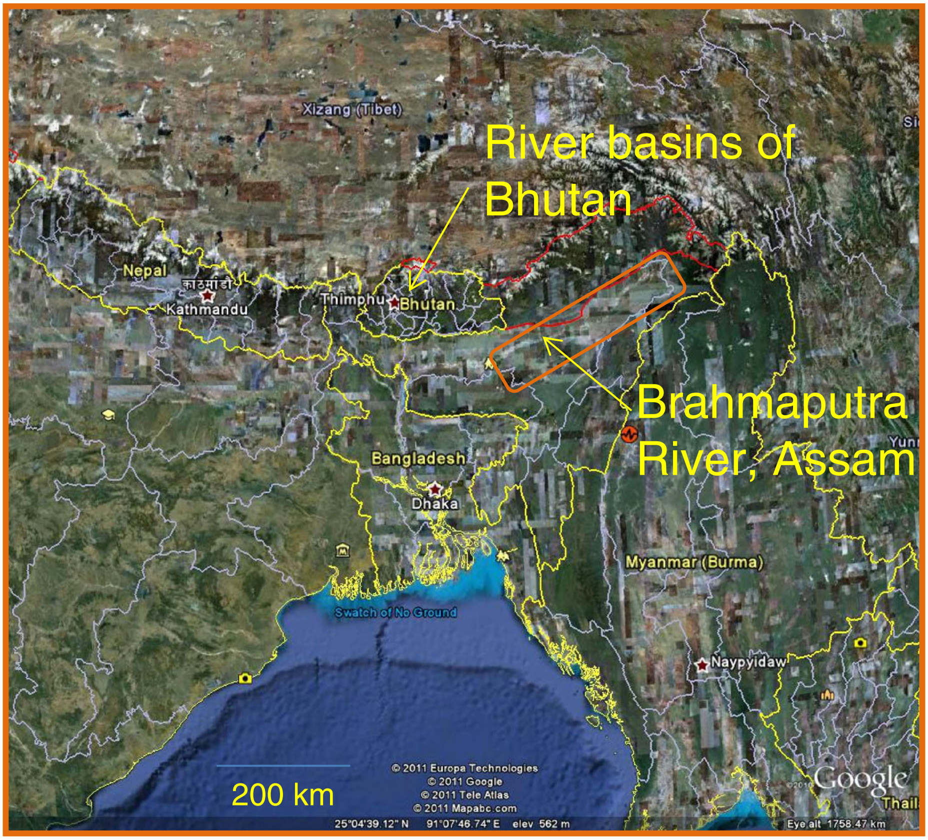

Fig. 1 Location map showing the river basins selected for study in Bhutan and Assam, North East India

(Sharma et al. 2010). Glacier retreat and changes in precipitation patterns have increased flood flows in the Basin, which in its wake create greater inundation and river bank erosion (Sharma et al. 2010) and disturb economically sensitive agricultural calendars with consequential loss of resources, economic confidence and agricultural outputs (Das 2002).

In the river basins of Bhutan, agricultural practices revolve around the movement of livestock between pastures (transhumance) with majority of cultivation tending to be small scale and subsistent (Young 1991; Alam and Murray 2005). Nonetheless, it is the main source of livelihood for 90 % of the population and contributes 41 % of the country's GDP (Alam and Murray 2005).

Despite the high dependence on agriculture, growth in the sector has been very slow. In Bhutan, high pressure on agricultural land (only 7.8 % of Bhutan's land is arable due to mountainous terrain), exacerbated by the steep slopes of the region (Tobgay 2005; National Statistics Bureau 2004) and limited mechanisation of farming in the test basins, has contributed to the limited growth in the sector (Roder et al. 2007). A point exasperated by the high input cost of mechanized farming which the majority of the basin's residents may not be able to afford. To compound the limited access to suitable agricultural land, persistent flooding and glacial lake outburst have resulted in the loss of further agricultural land and livestock (Tshering 2009). With rapidly increasing environmental changes, more agriculture land in the basins could be lost, shifting cultivation to steeper and higher elevations often not suitable for agriculture (Huq and Reid 2005). The nature of the terrain also limits both supply and marketing of agricultural products, restricting opportunities for commercial farming (Tobgay 2005).

In addition to the more formally managed ecological service of agricultural production in the basins, other ecosystems are also essential for service provision of food, medicine, energy and water (International Centre for Integrated Mountain Development 2010; Rasul et al. 2011; Millennium Ecosystem Assessment 2005). These ecosystems are also highly affected by environmental stresses (International Centre for Integrated Mountain Development 2010; Rasul et al. 2011), with variations in precipitation, temperature, atmospheric composition and increasing pollution having a substantial impact on the availability of ecosystem services within the basins (Brenkert and Malone 2005). In the past, environmental hazards have affected the composition and distribution of ecosystems and the services they provide and projections show that there will be further shifts in these ecosystems in response to the rate and magnitude to climate change (Brenkert and Malone 2005).

3 Data

One of the innovations of the authors approach has been to include Earth Observation data to augment the Census. This remote sensing based approach utilises the spatial relationships between communities and the environment to develop proxies for socio-economic status. This includes road density networks, settlement type and specific land use. The data for the analysis are derived from Census and Land Remote Sensing Satellite (Landsat) data. For Assam, the data comes from the 2001 Indian Population and Housing Census and 2001 Land Remote Sensing Satellite data. The Land Remote Sensing Satellite data include data on road density, agricultural land use and distance to main settlements. For Bhutan, the 2005 Population and Housing Census and Renewable Natural Resources (RNR) Statistics data were used. In both countries, these were the most recent datasets that were representative at the lowest administrative level. Using data from different time periods may raise issues of comparability, however, using a combination of indicators to derive composite indices minimises these effects, since not all the estimates for the selected indicators will change significantly over a short period of time. Selection of indicators and issues of comparability are discussed in detail in section 4.

The analysis was conducted at the lowest administrative units that were possible based upon the available data. In Assam, the analysis was conducted at the Tehsil level and for Bhutan at the Gewog level. Tehsils also referred to as sub-Districts, Talukas or Mandals is the fourth-tier of the local government administrative structure in India, after Zones (which comprise of a group of States), States/Union Territories and Districts (Government of India 2009; Office of the Registrar General 2009). The analysis covered 71 Tehsils within the Brahmaputra River Basin. Bhutan is governed by a three-tier system—the Central Government, Dzongkhags (District) and Gewogs also known as Blocks (Office of the Census Commissioner 2006). A Gewog is made up of several villages (Office of the Census Commissioner 2006). The analysis covered all 201 Gewogs documented in the 2005 Bhutan Population and Housing Census.

4 Methods

The conceptualisation of vulnerability in this study is based on the Intergovernmental Panel on Climate Change (2001a) working definition of vulnerability to climate hazards. Although, this may lack some of the sophistication of the conceptual literature, it provides a pragmatic route towards a realistic target for assessing vulnerability in data scare regions. The Intergovernmental Panel on Climate Change's implicit definition of vulnerability is the degree to which a system is susceptible to or unable to cope with the adverse effects of climate change (Intergovernmental Panel on Climate Change 2001b). It is a function of the character, magnitude and rate of climate change to which a system is exposed, its sensitivity (degree to which a system is affected, adversely or beneficially, by climate-related stimuli) and its adaptive capacity (the ability of a system to adjust to climate change, moderate potential damages, take advantage of opportunities or cope with the consequences). The relation can be expressed as:

$$\text{Vulnerability} = f(\text{Hazard, Sensitivity, Adaptive capacity}) \quad (1)$$

The literature is sated with a range of possible formulations of Equation (1) (Sharma et al. 2010). Although, most of the relationships propagated in the literature provide a viable working definition, in practice it is difficult to implement locally in data-poor regions because it includes the full range of both bio-physical and socio-economic factors (hazard and adaptive capacity). However, it can be suggested that the Hazard term in Equation (1) in effect serves mainly to scale the variability of vulnerability, spatially and temporally. Thus, for any one particular place and time, it may be possible to simplify the relationship to:

$$\text{Vulnerability} = f(\text{Sensitivity, Adaptive Capacity}) \quad (2)$$

In this form, the level of vulnerability is seen to be driven mainly by socio-economic factors. The reader is referred to Sharma et al. (2010) for a more detailed discussion on the conceptualisation of socio-economic vulnerability to climate hazards.

To identify the importance of agriculture and ecosystems services as sources of livelihood and the indicators to quantify them in Assam and Bhutan, a participatory process involving residents, stakeholders and experts was employed. Through literature review, field observation and discussions with residents, stakeholders and experts a set of domains were identified that mediate the immediate impacts of climate change (sensitivity domains) and the ability of communities to moderate potential damages, take advantage of opportunities or cope with the stresses (adaptive capacity domains). The sensitivity domains identified include contamination of drinking water, impact on agriculture, poor sanitation, access to health and outbreak of diseases, destruction to housing and road infrastructure, ecosystem loss, impact on women, immigration and urbanization. The Adaptive Capacity domains identified were availability of economic alternative, economic capacity, human capital and social networks. From this process an inventory of domains of sensitivity and adaptive capacity was developed.

A two stage Delphi process was used in this case to reach a consensus on the domains which directly impact sources of livelihood. The Delphi technique is a systematic and interactive technique for obtaining individual opinions and building consensus on a particular issue (Thangaratinam and Redman 2005). The first stage of the Delphi process was then used as consensus building process to identify the importance and severity of the domains. In both regions, government officials, representatives of Non-Governmental Organisations, academics and representatives of the basin's residents were in attendance and after extensive discussions were asked to rank the domains according to their importance in mediating the impacts of specific hazards and environmental stressors (flood, drought, bank erosion). In both study areas, each participant at the workshop was asked to score the domains to sum up to a total score of 40, with the most important domain receiving the highest score and the least important receiving the lowest score. The scores were then averaged over the number of participants. The results were presented to participants and further deliberations undertaken to ensure that at least 95 % of the participants agree with the ranking. Following this process it emerged that the top two livelihood sources which are most climate sensitive in both Assam and Bhutan were agriculture and provisioning of ecosystems services. This illustrated how the basins residents, stakeholders and experts perceive the importance of agriculture and ecosystem services relative to other systems at risk of climate change related stressors.

A second Delphi process was then initiated to identify the importance of agriculture and ecosystem services as sources of livelihood, relative to the level of human capital and availability of economic alternatives. In the second Delphi process, each participant was again asked to score agriculture, ecosystem services, human capital and availability of economic alternatives to sum up to a total score of 40, with the most important domain receiving the highest score and the least important receiving the lowest score.

Following components of the contribution of the authors outlined in Sharma et al. (2010), a statistical technique that incorporates local knowledge to quantify vulnerability was adopted to investigate the spatial disparities in dependence on agriculture and ecosystem loss and the ability to deal with or cope with risk. A multi-dimensional matrix of indicators was selected to represent each domain. A maximum likelihood factor analysis was then used to derive a single factor score for each domain. The motivation for using maximum likelihood factor analysis is that it circumvents the problem of multicolinearity (Jones and Andrey 2007). The factor scores generated are then ranked, scaled to the range between 0 and 1 by R where R=1/N is the least sensitive or least adaptive community and R=N/N is the most sensitive or most adaptive community; N being the number of areas.

To ensure comparability between the domain scores, it is appropriate that the domain scores are derived to have identical distributions with similar minimum and maximum values, with emphases on the tail of the distribution. This helps to clearly distinguish most sensitive and least adaptive communities. The exponential transformation has been widely used in this respect. The ‘cancellation property’ of the exponential transformation ensures that high scores in one domain do not cancel out low scores in others (Social Disadvantage Research Centre 2003). This property is highly desirable when combining scores from different domains. Equation (3) is used in this regards.

$$d_k = -23.026 * \log\left\{1 - R * \left[1 - e^{\frac{-\lambda}{23}}\right]\right\} \tag{3}$$

Where d_k is the transformed domain score which ranges between 0 and 100 (d_i for sensitivity domains and d_j for adaptive capacity domains), −23.026 is a mathematical constant which gives a 10 % cancellation property, log is the natural logarithm, *R* is the ranked scores, *e* is the exponential transformation and the parameter λ controls the degree of progression of the score. In this case λ=100. This transformation approach is employed for the analysis because it satisfies all the statistical requirements stated earlier (Social Disadvantage Research Centre 2003).

The next stage of the analysis requires combining the scores derived for each domain to create an overall score of livelihood sensitivity and also adaptive capacity. This process requires weighting the indices to reflect their severity and or importance. Determining weights to attach to different indices to generate an overall index could be an intricate task. There are a number of prepositions in the literature—theoretical, empirical, policy driven, consensus or purely arbitrary. To ensure that the weights applied to the scores in this study reflect the severity or importance of the domains based on the views of the basin’s residents, stakeholders and experts working in the area, the Delphi scores were used to generate the weights— $w_k = t_k/n$. Where t_k is the total score for domain k and n is the number of participants. In this regard, the weights reflect residents, stakeholders and experts knowledge and are based on consensus of people living and working in the area. The results of the ranking are presented in section 5. An overall exponentially transformed livelihood sensitivity and adaptive capacity scores are then derived using equations (4) and (5) respectively:

$$S = -23.026 * log\left\{1 - R\left(\frac{1}{n_l}\sum_{l=1}^{l} d_i w_k\right) * \left[1 - e^{\frac{-\lambda}{23}}\right]\right\} \tag{4}$$

$$AD = -23.026 * log\left\{1 - R\left(\frac{1}{n_h}\sum_{h=1}^{h} d_j w_k\right) * \left[1 - \mathrm{e}^{\frac{-\lambda}{23}}\right]\right\} \tag{5}$$

Where $\frac{1}{n_l}\sum_{l=1}^{l} d_i w_k$ and $\frac{1}{n_h}\sum_{h=1}^{h} d_j w_k$ are the livelihood sensitivity and adaptive capacity scores averaged over the respective number of domains—n_l is the number of livelihood sensitivity domains and n_h is the number of adaptive capacity domains.

Having derived the indices of sensitivity and adaptive capacity, the next stage of the analysis is to derive an overall index of livelihood vulnerability. Following the Intergovernmental Panel on Climate Change's conceptualisations of vulnerability (Intergovernmental Panel on Climate Change 2001b) we assumed an inverse relationship between sensitivity and adaptive capacity in deriving an overall index of vulnerability. Equation (6) is then used to derive an exponentially transformed index of livelihood vulnerability (V).

$$V = -23.026 * log\left\{1 - R\left(\frac{S}{AD}\right) * \left[1 - e^{\frac{-\lambda}{23}}\right]\right\} \tag{6}$$

Where S and AD are the livelihood sensitivity and adaptive capacity scores. The indices generated from Equations 3–6 can then be mapped to reveal the spatial variation in the livelihood sensitivity, adaptive capacity and vulnerability, respectively. The scores range from 0.1 to 100, with an increase in score showing increasing sensitivity, adaptivity and vulnerability. Thus, sensitivity, adaptive capacity and vulnerability are measured on a scale of 0 to 100.

The indicators used to profile the domains are shown in Tables 1 and 2. The indicators selected to represent each domain were what local resident, stakeholders and experts deemed appropriate within each country. It has to be noted that the indicators adopted for Assam and Bhutan are not the same, though they share similar characteristics. For comparative purposes, the indicators have been grouped to reflect their characteristics (see Tables 1 and 2). As mentioned earlier, not all indicators identified by participants are included in the final analysis due to data limitations. Throughout the development of this method certain unavoidable limitation were placed upon the research in terms of availability of data. This includes differences in year, content questions and resolution of data made available for use by researchers. However the methodological approach developed is intentionally designed to limit the impact of such inevitable variation by gathering variable indicators into common domains for analysis. Indeed to limit such variation is, in part, the motivation for such a study. After the map outputs have been produced a stakeholder validation workshop was convened, to enable them validate the representativness of the outputs and share opinions on the spatial disparities identified.

Table 1 Indicators for quantifying dependency on agriculture and ecosystem services

	Assam	Bhutan
Agriculture		
Engagement in agriculture	1. % workers engaged in agriculture	1. % households that are farm households
	2. Main to marginal agricultural workers (ratio of agricultural worker who work for more than 6 months to those who work less than 6 months)	
Constraints to land and production	3. Subsistence crop land (in km^2) per 100 HH	2. % farm HH reporting shortage of land
	4. Commercial crop land (in km^2) per 100 HH	3. % farm HH limited access to market
		4. Average months with food shortage
		5. % farm HH reporting food shortage
		6. % farm HH borrowing food
		7. % farm HH exchanging labour for food
		8. % farm HH constrained growing crops by wild animals, pets and diseases, drought, excessive rain and hail storm
		9. % farm HH constraints to livestock by predation, diseases, shortage of feed
Ecosystem services		
Forest resources	1. % farm HH dependent on forest resources: firewood/ crop residue/grass/thatch/ bamboo	1. % farm HH dependent on forest resources: firewood, bamboo, fodder
Non-forest resources	2. % farm HH using cow dung cake as source of cooking fuel	2. % farm HH collecting non-wood forest products: mushroom, fern top, cane shoot
Constraints in accessing forest resources		3. % farm HH increasing difficulty in collecting firewood due to: increasing population, diminishing forest cover, stricter forest rules

HH Household

5 Results

5.1 Dependence on agriculture and ecosystems for livelihood

Figure 2 shows the ranking of the domains in Assam and Bhutan. This figure shows a clear contrast of how residents of lowland Assam test Basin rank the importance and severity of the domains when compared to those of the upland Bhutan Basin. Although, agriculture and ecosystem services are essential sources of livelihood in the two Basins, the relative importance place on them vary substantially between the Basins. The people of Assam place a higher relative importance on agriculture, while those in Bhutan place relatively greater importance on ecosystems and the services they provide. From discussions in the workshops this is thought to be reflective of the high dependency on rice farming in Assam with little ecological service alternative other than adding to heavily pressurised fishing

Table 2 Indicators for quantifying availability of economic alternatives and human capital

	Assam	Bhutan
Availability of economic alternatives		
Urbanization and access to services	1. % of non-agricultural workers	1. % farm HH within a motor road by : less than 30 min, 30 min to 1 hour, 1 to 3 h, more than 3 h
	2. Distance to the nearest city or town	2. Standard deviation of the terrain
	3. % of roads that are: metalled, national roads, track paths, un-metalled roads, cart tracts	
	4. foot paths	
Human capital		
Education	1. Adult literacy rate	1. Adult literacy rate
		2. % of the population (6+ years) in school
		3. % of the population (6+ years) who have never been to school
Economic dependence	2. % of the population (7+ years) who are working	4. Dependency ratio
	3. Ratio of workers to non-workers (dependency ratio)	
	4. Ratio of main workers to marginal workers	

HH Household

activities. This contrasts with the more diverse utilisation of ecosystems in Bhutan where forestry (non-timber forest products) and pasturelands are utilised alongside arable agriculture. With regards to mitigating the impact of environmental stresses, the people of Assam consider availability of economic alternatives as essential, while those in the Bhutan consider human capital (skills, health and education) to be of greater importance. As such it is possible to see that hazard dominated Assam is a more "Sensitivity" dominated society whereas in the absence of Assam scale hazards the more ambient environmental pressure experienced in Bhutan (e.g. late

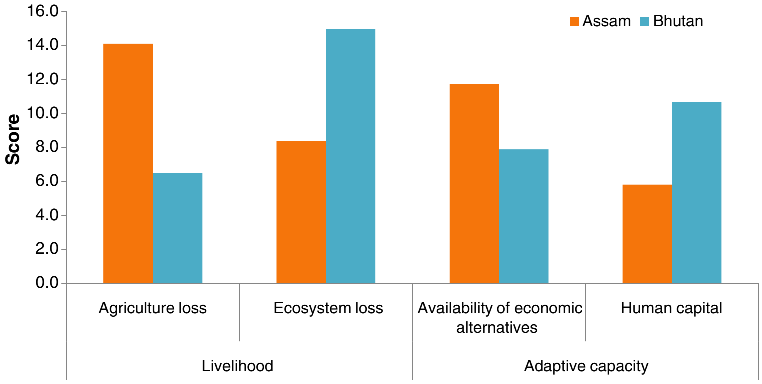

Fig. 2 Perception of the importance of agriculture and ecosystem loss and adaptive capacity

monsoon) dominate, producing a society dominated by “Adaptive Capacity”. Again this is reflective of the discussion during the workshops where it was clear that the critical issues associated with climate change in Assam tend to be spatially specific incidents such as flood or bank erosion which result in an immediate need for an alternative. This gives the sense of a binary state of either work on the land or an alternative, usually in local settlement (pulling a rickshaw, work at the brick factory). Whereas, in Bhutan the climate change impacts are more “ambient” across a whole region and can not be avoided simply be internal re-location and settlements and alternative employment are far less dominant in the landscape. As such a more gradual adaptation process exploring alternative ecosystem services and crop alternatives is favoured, a process reflected in the higher ranking of human capital.

Further discussions with residents of both Basins revealed that subsistence agriculture is the main source of income and livelihood in Basins. As such both are highly susceptible to environmental stresses which lead to crop yield instability, loss of production and quality (due to variable rainfall, temperature, etc.), increased risk of loss of diversity in of already threatened crop species and demand for expensive or unavailable hybrids; loss of soil fertility due to erosion of top soil and runoff, loss of land due to flash floods, land slides and rill and gully formations and soil nutrient loss through seepage; Where perishable crops were destined for market, particularly in Bhutan, deteriorating produce quality by untimely incessant heavy rains and hailstorms; delayed sowing due to late rainfall, damage to crops by sudden early and late spring frost, outbreak of pests and diseases in the fields and during storage; and damages to roads restricting commercial production were all raised as issues.

5.2 Spatial variations in agriculture and ecosystem service sensitivity

Figure 3 shows spatial variations in agriculture and ecosystem sensitivity in Assam and Bhutan. The map ties in well with the findings of the workshops. In Assam the map reflects the distribution of the known poorer sections of rural society. These are dominantly the Bangladeshi immigrants, although not exclusively who have a high reliance upon agriculture and fisheries (ecosystem services). In essence the red areas representing high sensitivity represent the communities that are living directly on the river banks and in wetland areas on what is often marginalised land. The green areas are known to represent substantial areas of urban and peri-urban development and well established tea plantations, both of which have low direct reliance on agriculture or have strong anti-flood and bank erosion measures in place. In Bhutan, agricultural is split between the lowland plane in the south and valley based agriculture further north and pastoral activities in the highland areas. Whereas ecosystem service provision and sensitivity is dominated by the forested areas of the southern lowland areas with non-timber forest product and other ecosystem services provided in these regions.

5.3 Spatial variations in availability of economic alternatives and human capital

Figure 4 shows spatial variations in availability of economic alternatives and human capital. In Assam this is heavily dominated by the access to a series of main settlements and towns where alternative employment is available. The occurrence of the human capital distribution owes its form to both the distribution of the poorer Bangladeshi immigrant population distribution as seen in Fig. 3 in both a rural setting and in association with poor settlements on the periphery of larger settlements. In Bhutan, where there is little migration to urban settlements due to their relatively small size and low potential provision of employment potential, the maps of economic alternative still reflect the significance of market access in the main settlements in this mountainous country. The main urban settlements located in the central

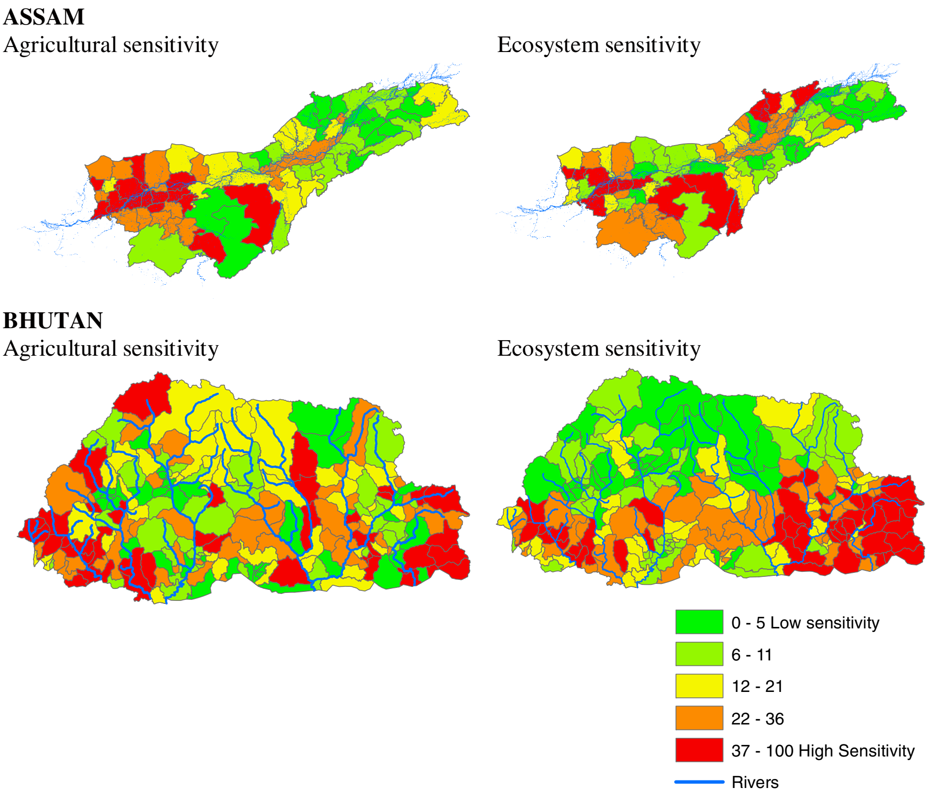

Fig. 3 Spatial variations in agriculture and ecosystem sensitivity

west and east of the country are the regions dominated by clusters of high economic alternative potentials. A similar halo pattern occurs with reference to the human capital map with education and other elements of this domain decreasing away from the cities.

5.4 Spatial variations in livelihood vulnerability

Figure 5 shows spatial variations in livelihood vulnerability. These maps represent a combination of the sensitivity and adaptive components defined in the earlier figures. In a broad sense they are very much reflective of the distribution of rural poverty in both the regions of study. In Assam the red areas are coincident with the poorest Assamese populations but dominantly of the Bangladeshi immigrant populations which are know to be amongst the poorest and most vulnerable populations. In Bhutan, the pattern is reflective of the increased vulnerability away from the main settlements which sit centrally in the west and east with the poor and vulnerable forming a halo around these centres.

6 Discussions

It was identified through the literature review, field trips, field observations and discussions with local people, stakeholders and experts that agriculture and animal husbandry remains the main

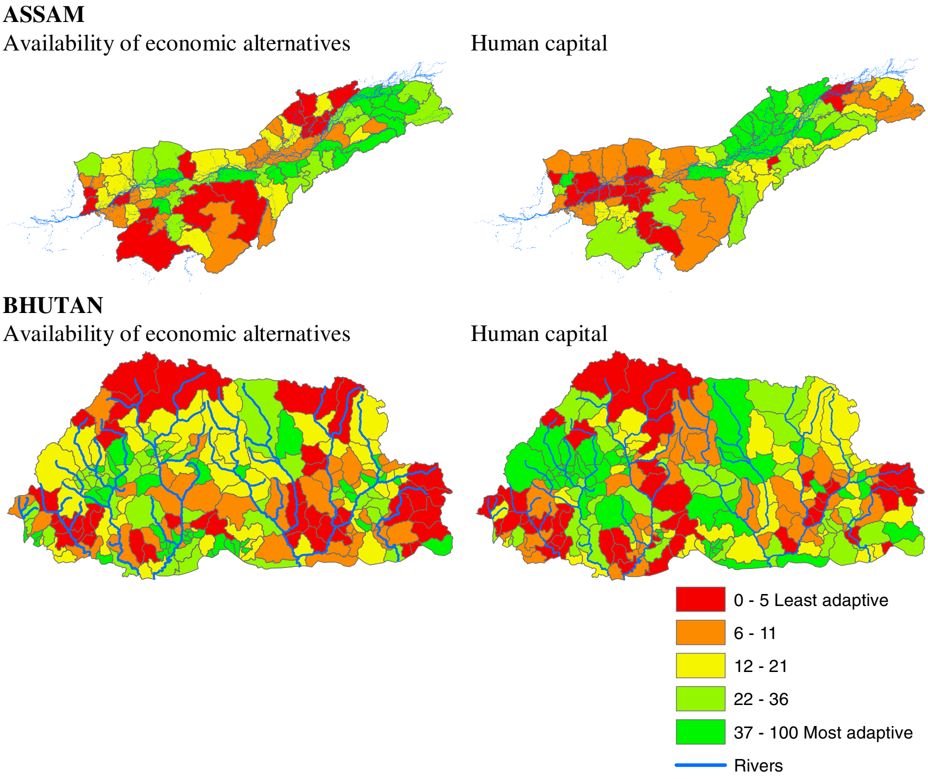

Fig. 4 Spatial variations in availability of economic alternatives and human capital

sources of income/livelihood for the majority of the people in the study area. Both subsistence and commercial agriculture are very important to the people. The agricultural sector however, is very susceptible to environmental stresses. Local people, stakeholders and experts indicated that communities with high dependency on agriculture are more sensitive to the impacts of

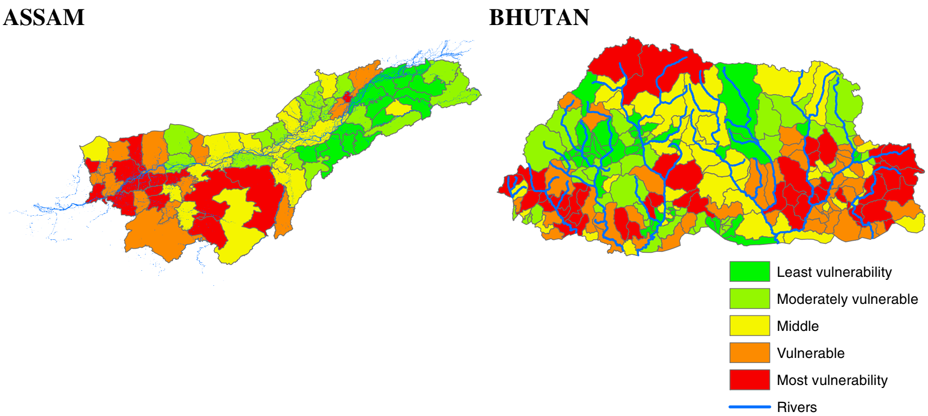

Fig. 5 Spatial variations in agriculture and ecosystems livelihood vulnerability

environmental stresses. They are most at risk of floods, droughts and bank erosion and land-slides. Although the industrial and tourism sectors are also important sources of income/ livelihood for some sub-groups of the people, this is not covered in the analysis due to data limitations. The dependence on these sectors is minimal compared to agriculture.

An interesting finding from the study is that, while the people of the Assam basin place more importance on agriculture for their livelihood, those of Bhutan place importance on non-agricultural ecosystem services. It is widely reported that while most states of India are gradually moving away from traditional agriculture-based economy towards a more service or industry-oriented economy, Assam is still heavily dependent on agriculture (Sarma and Saikia 2010; Bhowmick et al. 2005; Planning Commission 2002). The importance of the agriculture sector to the people of the Assam Basin, despite the sectors sensitivity to the regions environmental stresses is reaffirmed in this study. As this study revealed, the lower valleys towards the west of the Basin, bordered by Bhutan and Bangladesh and the Indian states of West Bengal and Meghalaya, are most vulnerable with regards to dependence on agriculture. This region is significantly populated by poor Bangladeshis immigrants who occupy marginalised land and are exposed to uncertain land tenures and risk of environmental hazards (Shrivastava and Heinen 2005; Swain 1996). Indeed, the region is prone to tribal and ethnic conflict due to scarcity of fertile agricultural land (Swain 1996; Homer-Dixon 1994).

The people of Bhutan, on the other hand are highly dependent on the country’s non-agricultural ecosystems services not only for their livelihoods but also for religious purposes, food and medicine among others (Wangchuk 2007; Tobgay 2005). Population pressures and environmental stresses on ecosystems services are increasing rapidly, with anticipated future challenges which include rising poverty, hunger and malnutrition (Wangchuk 2007). This study has confirmed the importance of ecosystem services to the people of Bhutan, identified and mapping areas where dependence on ecosystem services are high and where resilience to the impacts of environmental stresses on ecosystems could be most felt.

A critical outcome of the study is the emphasis placed upon the role of access to settlements in the development of adaptively to climate change. Economic alternatives and human capital are both heavily influenced by the proximity or effort requirement to access the main cities and towns. With further investigation this may represent a key issue in the development of policy to enhance adaptively with the development of transportation and communication in the forefront with access to settlements being differentiated from migration

The comparison between the basins of Assam and Bhutan is valuable in that it shows two rather contrasting dominant climate risks, spatially specific and catastrophic in Assam (flood) and more ambient and dispersed in Bhutan (late monsoon). Clearly, Assam does experience the same environmental pressures as Bhutan. A late monsoon impacts both countries; however the presence of the major hazards comes to dominate for obvious reasons. This contrast is then reflected in the choice of domain properties with a sensitivity focus in Assam and an adaptive capacity focus in Bhutan.

7 Conclusion

A methodology is presented which allows for the effective spatial mapping of vulnerability of diverse and extensive agricultural communities to climate change over a large geographical area utilising selected interviews with local communities, extensive engagement and integration of the opinions of local stakeholders with readily available secondary household and remote sensing data. Using the approaches outlined in this work, the study has gone some way to substantiating that agriculture and the ecosystems which most of the poorest people are dependent on for their livelihood are highly sensitive to the impacts of climate change and environmental stressors. This study has also highlighted that these impacts are not evenly distributed spatially within the Brahmaputra River Basin of Assam, India and Bhutan but have socio-economic and environmental associations that need to be considered by policy makers. The results from interviews with stakeholders and the quantitative analysis both highlights the need for targeted policy interventions to reduce the impacts of climate change and environmental stresses on the poor in these basins The results are congruent with the stakeholder's experiences.

The utilisation of household survey, Census and remote sensing (Landsat) data to provide a series of indicators for fulfilling a given domain provides a valuable context for the utilisation of readily available and comparable data on a regional scale. As such, this method offers an approach which can be utilised on a large scale for planning and informing policy decisions, emphasising that it is possible to weight specific components of vulnerability in the light of given environmental stressors or hazards. Within the study it became clear that there is a requirement for clear definition when considering the specifics of vulnerability. As such vulnerability, which is often used as a general term, needs to be defined in the context of who is vulnerable and to what specific pressure or hazard. This differential has implications for developing specific policy responses which acknowledge the complexity of the relationship between poverty, vulnerability and environmental pressure.

In the context of decentralised approaches to development planning, the demand for understanding spatial inequalities in social, economic and environmental issues have grown tremendously. This is particularly the case in the developing world, where there is considerable spatial inequalities with regards to availability and distribution of resources. In many settings of the developing world such information is non-existent mainly due to the lack of representative and comparable data at the local level. These include differences in year, content questions and resolution of data. The methodological approach developed in this study is intentionally designed to minimise the effect of such inevitable limitations and augment more standard metrics of welfare and poverty such as census with available spatial data. Thus, an additional emphasis from this work is the value of mapping data and findings, even on a large scale, where general trends and patterns can begin to be discerned in relation to key spatial variables such as land cover, administrative boundaries and populations. The authors strongly encourage decision makers to consider the value of utilising spatial data as a way of maximising the utility of various datasets such as census and modelled outcomes and to consider the synergy available from this process.

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