Abstract

Principles of equitable and reasonable use underpin international water agreements. Despite the potential for hydrologic information to enhance resilience to extreme events, comparable application of just principles to the distribution of hydrometeorological data is poorly established. Within the Ganges–Brahmaputra–Meghna (GBM) river basin, we find that water allocation agreements are codified into treaties or Memorandums of Understanding (MoUs). Analogous decisions regarding hydrometeorological data sharing are often internalized at the level of river basin organizations and are not upheld as MoUs. This institutional structure provides extremely limited data to the most downstream nation of Bangladesh. Available precipitation and discharge stations are well below the minimum densities recommended by the World Meteorological Organization. Forecasters in Bangladesh therefore contend with vast areas of geopolitically ungauged catchment, precluding the application of basin-wide modelling approaches driven by observed data. Thus, capacity for increasing resilience to extreme events within Bangladesh is obstructed, demonstrating the potential for perceived injustice related to distribution of hydrometeorological data. Consensus that water is a human right warrants the application of equity to water allocation. But is security from water-related disasters also a human right? As hydrometeorological data can be a powerful resource with potential to profoundly affect lives and livelihoods, enhanced awareness of justice related to data sharing is needed.

Keywords: Bangladesh; Disaster risk reduction; Human rights; Hydrologic forecasting; Hydrometeorological data; Justice; Transboundary water management

1. Introduction

Water management across administrative boundaries, including interactions at international borders, has been the topic of much work related to equitable resource management. Such dialogue is often
initiated by questions of just water allocation, with prominent issues frequently surfacing during times of unanticipated scarcity (Wolf et al., 2003; Gleditsch et al., 2006). In-depth thought and analysis has thus been applied to formulating water allocation decisions that are based on concepts of justice, including equitable use (Syme et al., 1999; Nancarrow & Syme, 2001; Tisdell, 2003). However, as capacities for modifying river flows and predicting extreme hydrologic events expand, so also does the domain of issues associating shared waters and justice.

Historically, the variability and limited predictability of hydrologic regimes and the associated consequences of drought and flooding have been largely perceived as ‘Acts of God’, or conditions existing outside the realms of justice. Yet, as the human capacity to affect water quantity and quality intensify and as causal inferences between anthropogenic activities and hydrologic conditions are better understood, such perceptions may be changing, so that too little, too much, or poor quality water is increasingly ‘blamed’ on upstream abstraction or management. In addition to allowing upstream users to store and divert water during times of low flow, increased structural capacity may allow upstream managers sufficient control to affect the timing and magnitudes of high flows released downstream. If downstream dwellers are not prepared for the flow releases, then the discharge of too much water may also be perceived as unjust. Bakker (2009a) observed a recent escalation of conflictive events related to transboundary flooding, consisting of criticism among fellow riparian nations regarding the flood-control infrastructure and management of high flows. For example, unanticipated releases from upstream reservoirs in India may have exacerbated seasonal flooding that affected south-western Bangladesh in 2000 (Ahmad & Ahmed, 2003; Thakkar, 2006). In such cases, perceptions of unjust management or inadequate notification may affect outcomes and relationships (Parks & Roberts, 2006).

Additional to issues related to upstream flow control is the growing desire for disaster-prone nations to increase their resilience to extreme hydrologic events through hydrologic prediction and early warning. The degree of transparency and openness with regard to sharing of hydrometeorological data among riparian nations of international river basins may profoundly affect the downstream nations’ capacity for planning and decision-making (Timmerman & Langaas, 2005). Geopolitically ungauged catchment areas of shared river basins, where comprehensive data observation networks may exist but data are unavailable for use due to geopolitical constraints, may pose severe limitations for downstream hydrologic forecasters (Kibler, 2014). Recalcitrance on the part of upstream nations to cooperatively support the management of downstream disaster risk may constitute a potential hotspot for perceived injustice, particularly where water hazards are severe and frequent.

1.1. Disaster risk reduction – the role of event forecasting and early warning

An accumulation of factors, notably including climate and demographic changes, are bringing people and water-related hazards together more often, resulting in increased frequency and more severe consequences of global water disasters (Takeuchi, 2001; Strömberg, 2007; Adikari & Yoshitani, 2009), including more frequent transboundary flood events (Bakker, 2009b). Researchers observe more extreme precipitation events, at both ends of the spectrum (Groisman et al., 2005; Min et al., 2011), and project that these trends will escalate in the future (Hirabayashi et al., 2013). In the developing world, extreme water events can be particularly devastating to economic and social development. Although absolute economic losses associated with disasters are often greater in developed nations, damage relative to gross national incomes (GNI) is often much higher in developing nations (Toya & Skidmore, 2007; Linnerooth-Bayer et al., 2011). Repeated disasters allow for limited recovery and tend to lower individual and societal
resilience, decreasing their capacity to cope with future disasters (Webster & Jian, 2011), potentially creating a cycle of loss, incomplete recovery, and poverty that may span generations (Webster, 2013).

To avoid the spiralling effects of recurring water hazards, managers within disaster-prone areas seek measures to prevent or ameliorate the most harmful consequences of water hazards and/or to increase resilience. Assisting these efforts, global development policies are shifting focus from investment in the relief and recovery phases of disaster management and moving towards financing preparedness and societal resilience (DFID, 2006). One of the most cost-effective and attainable measures for limiting the losses associated with floods and tropical storms, and for reducing the number of human casualties in particular, is the development of adequate early warning systems (Teisberg & Weiher, 2009). Comprehensive early warning systems, consisting of reasonably accurate forecasts delivered with sufficient lead-time for targeted response, have successfully reduced the number of human casualties related to river flooding and cyclones (Mallick et al., 2005; Paul, 2009). The lead-time of forecasts, the time between the issue of the forecast and the occurrence of the forecasted event, largely determines the level of possible response and positively correlates to the potential for loss reduction (Subbiah et al., 2008). A lead-time on the order of hours provides time for little more than immediate evacuation, while a lead-time of days or weeks allows for more comprehensive preparedness leading up to the event and can reduce economic losses (ADB, 2006).

The intrinsic effectiveness of an early warning system derives from the ability of individuals and communities to utilize information about future risk to rationally decide on the optimal course of action, taking into account the costs of possible preparations and their potential for loss reduction. In addition to sufficient lead-time, the accuracy of forecasts is particularly critical, as many resources may be mobilized and decisions made based on forecasted events. For instance, to minimize losses due to floods, farmers may make decisions to harvest crops or aquaculture products in advance of predicted floodwaters, at a cost of reduced yield. As hydrologic forecasting involves many potential sources of uncertainty, particularly at extended forecast lead-times, misunderstandings regarding the accuracy of forecasts can lead to suboptimal decisions and eventual mistrust of future forecasts (Chowdhury et al., 1993; Sharma, 2003). For this reason, it is desirable to forecast as far in advance as possible, but also to maximize the accuracy of predictions. And, importantly, it is good practice for forecasters to communicate information about the certainty of a forecasted event, for instance in probabilities of occurrence (Webster et al., 2010), or using more qualitative methods that are targeted to local communities’ perceptions of risk (Twigg, 2003). Within the scope of this article, we focus on the optimization of the forecast lead-time and accuracy; however, we do wish to emphasize that the success of an early warning system is equally influenced by dissemination of the forecast and adequate communication of risk to potentially affected populations, as well appropriate response systems (Sharma, 2003; Chowdhury, 2005; Hossain, 2009; Rahman et al., 2013).

1.2. Hydrometeorological data for forecasting extreme events

Although hydrologic forecasters may apply a range of methodologies to predicting the magnitude and timing of future flows, predictions created by the integration of meteorological observation or prediction with physically based, distributed hydrologic runoff models show much promise (WMO, 2011). Managers in disaster-prone areas want forecast systems that apply hydrologic modelling, yet the information required to run hydrologic models may often exceed existing or available data. In this article, we focus specific attention on the data used in hydrologic forecasting which are most commonly difficult for water managers to obtain or substitute. Basin-wide precipitation, water level, and/or discharge observations are particularly valuable for generating accurate hydrologic forecasts with sufficient lead-time, and for validating predictions to improve
model performance. For these items, few acceptable substitutes for observed data exist (but see Webster et al. (2010) for an example of the potential for flood forecasters to use globally generated meteorological forecasts). Observation of precipitation, water level, and river discharge is generally managed at national or local levels. Although crucial to forecasting potentially catastrophic events at the basin level, such data are often unavailable to flood forecasters outside the implementing nation or administrative district.

1.3. Water hazard management in transboundary river basins

Managing the risk of water hazards can be particularly complex in river basins shared by two or more nations. Flood disasters in shared river basins have historically been more severe, affected larger areas, and resulted in higher costs of human life and economic damage (relative to GNI) compared to floods that do not extend over national borders (Bakker, 2009b), suggesting that international river basins may be uniquely vulnerable to flood hazards. Despite evidence of this potential vulnerability, and despite the confirmation that mortality and displacement resulting from transboundary floods are lower when international institutional capacity for flood management exists, only 5% of international river basin institutions cite flooding as a principal concern and less than 4% of international water treaties list flood management within the scope of the agreement (Bakker, 2009a). The circumstances leading to more severe consequences of flooding in international river basins compared to river basins contained within one country are complex and multifaceted, so that no single variable may fully explain this trend. However, challenges related to flow prediction and forecasting extreme events given restricted access to basin-wide hydrometeorological data may be a significant obstacle preventing adequate flood preparedness within international river basins.

Given the distinctive vulnerability of international river basins and the potential for perceived injustice related to upstream management and scale of transparency, it is advantageous to build on successes and experience gained from past applications of just principles to water allocation to address a greater breadth of transboundary water-management issues. In contrast to water allocation, the sharing of hydrometeorological data and the implications for transboundary water management have been largely unexplored from the perspective of justice. In this article, we seek to fill this gap, by investigating the application of justice, including equity, to the sharing of data within transboundary river basins. We focus our investigation on the Ganges–Brahmaputra–Meghna (GBM) river basin, and specifically examine the flows of transboundary hydrometeorological data used to forecast extreme hydrologic events in Bangladesh. The objectives of this study are to: (1) investigate and compare the institutional structuring of water allocation and data sharing agreements in the GBM river basin; (2) analyse the availability of basin-wide hydrometeorological data to the most downstream nation of Bangladesh as a measure of institutional effectiveness pertaining to exchange of hydrometeorological data; and (3) discuss the concept of hydrologic data as a resource subject to equitable use, querying whether or not hydrologic data are, or should be considered, a human right, in light of findings from the GBM case study.

2. Methods

2.1. Description of study area

The GBM river basin is a large, transboundary river basin, with a total catchment area of $1.72 \times 10^6$ km$^2$ shared among five riparian nations of China, India, Bhutan, Nepal, and Bangladesh. The dominant
hydrologic processes vary throughout the basin, such that the hydrologic signatures of the major rivers comprising the GBM are in many ways unique. For instance, while monsoon-driven rainfall dominates the hydrology of almost all areas of the GBM basin, factors such as the timing of monsoon onset and the significance of Himalayan snowmelt vary spatially across the basin (Mirza, 2002; Shaman et al., 2005). Flows of GBM major rivers share a common characteristic of high annual variability characterized by predictable periods of seasonal low and high flows that may vary over several orders of magnitudes. For instance, the combined flow of the Ganges and Brahmaputra Rivers typically increases from below 10,000 m$^3$s$^{-1}$ early in the year to a peak of 80,000 to 140,000 m$^3$s$^{-1}$ by late August or early September (MWR, 1995). Seasonal flooding in many areas of the GBM basin is common.

2.1.1. Flooding in Bangladesh. Within Bangladesh, the most downstream nation of the GBM river basin, lives and livelihoods are intimately tied to seasonal hydrologic patterns. Interviews with rural villagers and farmers affected by floods indicate that many Bangladeshis perceive annual flooding as an expected and necessary part of life (Hofer & Messerli, 2006). Flooding in Bangladesh occurs with sufficient predictability that agrarian and aquaculture systems, both crucial to Bangladesh economy and livelihoods, are adapted to benefit from seasonal flooding (Paul, 1984). However, when floods exceed adaptive capacity, for instance if water levels and depths of inundation are too great, duration of inundation is too long, water rises too quickly, or floods arrive at an unusual time, the scale of losses can be considerable (Brammer, 1990). For instance, when floods in the Ganges and Brahmaputra Rivers peak simultaneously, as occurred in 1988 and 1998 (Figure 1), catastrophic flooding results (Mirza, 2002). Much of the direct economic impact of damaging floods in Bangladesh is associated with the immediate loss of agricultural productivity (Figure 2), in particular damage to rice crops (Hyder, 2013). It is noteworthy, however, that harvests following large flood years tend to reflect lagged benefits to agricultural productivity (Figure 2), perhaps related to flood-derived soil moisture and fertility.

Resilience to floods of unusual magnitude or timing in Bangladesh is closely coupled with the success of forecasting and early warning. As the difference between floods in Bangladesh that supply a desired endowment of water and soil fertility and those constituting a natural hazard or disaster may be nuanced and often difficult to define, creating a flood management system to ameliorate the negative socioeconomic impacts of flooding with minimal disturbance to beneficial flooding is challenging.

Fig. 1. Flood peak coincidence of Ganges and Brahmaputra Rivers in 1988 and 1998 led to catastrophic flooding in Bangladesh. Data provided by the Bangladesh Water Development Board.
Systems that increase resilience to low-frequency hydrologic events without significantly changing the timing and quantities of water delivered by expected and desired annual flooding characterize management objectives. Nonstructural adaptation measures, including hydrologic prediction and early warning systems, are highly cost-effective measures to increase the capacity to cope with low- to mid-frequency flood events in Bangladesh (Ahmad & Ahmed, 2003; ADB, 2006; Subbiah et al., 2008; Hyder, 2013).

2.2. Methodological approach

2.2.1. Selection of GBM water allocation and data sharing institutions and organizations. We investigated historical and existing arrangements related to cooperative water resource management within the GBM river basin, applying filtering criteria to select a specific subset of water management institutions and organizations for analysis. Ostrom (2005) defines institutions as ‘prescriptions that humans use to organize all forms of repetitive and structured interactions’. Often the terms ‘institution’ and ‘organization’ are used interchangeably; however, we adopt Polski & Ostrom’s (1999) definition of organization as ‘a set of institutional arrangements and participants who have a common set of goals and purposes’. We focus our selection on international institutions and organizations that have been highly influential for determining flows of either water or hydrometeorological data between the riparian nations of the GBM river basin. Our selection criteria allow for consideration of both documented, formalized agreements as well as less structured arrangements that regulate sharing of water and data. Included in this definition are international institutions that directly mandate and specify when and how much water or data must cross international borders, for instance by stipulating quantities, locations, timing, or methods of delivery. However, as we also consider organizations, our criteria also include key decision-making river basin organizations (RBOs), within which the specific attributes of water allocation and data exchange are negotiated, decided, and implemented (see Appendix I, available online at http://www.iwaponline.com/wp/016/007.pdf).

Fig. 2. Effect of large floods on agricultural productivity in Bangladesh. Data provided by Bangladesh Ministry of Agriculture.
We obtained full texts of treaties and Memorandums of Understanding (MoUs) from international databases (United Nations Treaty Collection (http://treaties.un.org) and the Transboundary Freshwater Dispute Database (TFDD, 2008)), as well as directly from the Government of Bangladesh. The full text of some MoU agreements proved difficult to source, and other arrangements, particularly those made within the confines of organizations, often lacked official documentation. In these cases, we obtained relevant information from published academic literature, minutes of RBO meetings, government websites, and media reports. Our resulting collection of institutions and organizations is not necessarily exhaustive, particularly with regard to RBOs, which are sometimes characterized by multifaceted, ambiguous, changeable, or undocumented objectives and outcomes. When the role played by a specific organization is unclear, we apply a set of rules for inclusion, selecting organizations which meet one or more of the following criteria: organizations established from formal agreements tasked with overseeing water or data allocation arrangements and resolving related disputes; organizations which influence decision-making, either by enabling negotiation or providing grounding scientific studies; and organizations that function as supervisory ‘umbrellas’ for sub-tier groups that meet one or more of the above criteria.

2.2.2. Analysis of current transboundary data sharing with Bangladesh. To indicate outcomes of the current institutional structure governing data sharing within the GBM river basin, we investigate the resultant data that are available to the most downstream riparian nation of Bangladesh. We identify sources of transboundary hydrometeorological data available to hydrologic forecasters in Bangladesh, as well as the method of delivery, timing, and the various institutional frameworks that specify data delivery from all upstream nations. To place the role of transboundary data sharing within the practical context of early warning systems, we trace pathways of information between stakeholders involved at all stages of hydrologic forecasting and dissemination within Bangladesh – from shared international hydrometeorological data to forecast preparation and dissemination of warnings to local communities.

3. Findings

3.1. Institutions and organizations governing water allocation and data sharing in the GBM river basin

The efforts of GBM riparian nations to anticipate and address emerging water disputes or cooperate for mutual advantage have resulted in a collection of RBOs and treaties/MoUs, composing a complex transboundary management regime which encompasses both bilateral and regional multilateral arrangements (Tables 1 and 2; Figure 3). Altogether, 33 individual bilateral arrangements (15 treaties/MoUs and 18 RBOs) have administrated water allocation between GBM nations. Additionally, 30 bilateral arrangements (eight treaties/MoUs and 22 RBOs) have facilitated the sharing of hydrometeorological data between GBM nations. The vast majority (63 out of 64) of cooperative water and data sharing arrangements within the GBM river basin are bilateral, representing accords or cooperation between two nations. There has been one multilateral cooperative platform facilitating regional data sharing, within which the roles of different GBM nations have varied with respect to the level of participation. The HKH-HYCOS (Hindu Kush-Himalayan Hydrologic Cycle Observing System) is a regional partnership coordinated by the International Centre for Integrated Mountain Development (ICIMOD) and the World Meteorological Organization (WMO). Currently, Bangladesh, Bhutan, and Nepal exchange real-time hydrometeorological data through the HKH-HYCOS Internet-based platform for real-time data.
distribution, and transfer data to China and India. China and India participate in the HKH-HYCOS project but do not currently exchange data (Figure 3).

With respect to institutions and organizations managing the water allocation of common rivers, we observe that, predictably, water allocation institutions/organizations exist only between countries that share borders. Specific allocation mandates have historically existed only between Bangladesh and India, concerning water from the Ganges and Teesta Rivers, and between India and Nepal, regarding water from the Mahakali, Kosi, and Gandak Rivers. Analogous institutions between China and India concerning water from the Yaluzangbu/Brahmaputra River are notably absent, despite India’s proposals for new institutions and dialogue focusing on transboundary water allocation. RBOs formed to address transboundary water management have often codified their key conclusions or decisions about water allocation within treaties or MoUs. In turn, the enactment of such institutions has often led to the creation of additional RBOs designed to oversee the implementation of legal agreements.

### Table 1. Water allocation. Institutions and organizations that govern or manage water allocation between GBM river basin countries.

<table>
<thead>
<tr>
<th>Cooperation</th>
<th>Treaty, MoU</th>
<th>RBO</th>
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<td></td>
<td>(2000) Terms of Reference for the Joint Committee on Water Resources</td>
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**Note:** Highlighted years of establishment indicate institutions or organizations that are currently active.

aTreaty that created the India–Bangladesh Joint Rivers Commission.
bDrafted Teesta Agreement was never signed. We list the Draft Agreement here, but do not include in assessment.
cExchanged Letters also known as ‘Sarada Treaty’.
d1978 amendment to Kosi Project Agreement does not directly address water allocation. We list this amendment here, but do not include in assessment.
eAgreement that created the India–Nepal Joint Committee on Water Resources.
Table 2. Data sharing. Institutions and organizations that govern or manage sharing of hydrometeorological data between GBM river basin countries.

<table>
<thead>
<tr>
<th>Cooperation</th>
<th>Treaty, MoU</th>
<th>RBO</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>(1989) Agreement for China–Bangladesh Technical Cooperation on Flood Control</td>
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<td></td>
<td>of the Brahmaputra River</td>
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<td></td>
<td>(2005) MoU Cooperation in the Field of Water Resources</td>
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<td></td>
<td>of Hydrological Information from Yaluzangbu/Brahmaputra River in Flood Season</td>
<td></td>
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<td></td>
<td>(2006) Joint Committee on Harnessing Water Resources and Mitigating Floods and Flood Damage</td>
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<td></td>
<td>(2004) Joint Committee on Flood Management</td>
<td></td>
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<td></td>
<td>(2008) Joint Ministerial Commission on Water Resources</td>
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<td></td>
<td>(2008) Joint Standing Technical Committee</td>
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<tr>
<td>Bhutan–India</td>
<td>(1955, 1979) Comprehensive Scheme for Establishment of Hydrometeorological and Flood Forecasting Network on Common Rivers</td>
<td></td>
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<tr>
<td></td>
<td>(1992) Joint Expert Team</td>
<td></td>
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<tr>
<td>India–Nepal</td>
<td>(1989) Flood Forecasting and Warning System on Common Rivers</td>
<td></td>
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<tr>
<td></td>
<td>(2000) Joint Committee on Water Resources</td>
<td></td>
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<tr>
<td></td>
<td>(2000) Standing Committee on Flood Forecasting</td>
<td></td>
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<tr>
<td></td>
<td>(2001) Joint Committee on Flood Control and Forecasting</td>
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<td></td>
<td>(2004) Joint Committee on Flood Management and Control</td>
<td></td>
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<tr>
<td></td>
<td>(2008) Joint Ministerial Commission on Water Resources</td>
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<td></td>
<td>(2008) Joint Standing Technical Committee</td>
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</table>

(Continued.)
The issue of transboundary hydrometeorological data exchange has triggered a more diverse set of partnerships, with agreements existing between most GBM basin dyads as well as at the multilateral level. The exchange of hydrometeorological data in the GBM river basin is governed primarily by decisions and agreements made within RBOs that are not codified into treaties/MoUs. We note that distinct geopolitical patterns exist with respect to data sharing agreements. Of the eight treaties/MoUs governing hydrometeorological data sharing between GBM nations, seven are MoUs between China and either India or Bangladesh. The remaining treaty is the Statute of the Indo-Bangladesh Joint Rivers Commission (JRC). As opposed to the MoUs signed by China, this treaty does not mandate sharing of specific data, but creates the JRC, the organization within which negotiation and decision-making regarding data sharing, among other cooperative water management issues, occurs. Therefore, all treaties/MoUs governing specific locations and timing of hydrometeorological data exchanged in the GBM river basin consist of MoUs between China and its downstream neighbours.

### 3.2. Outcomes of governance structure – hydrometeorological data available to Bangladesh

A total of 12 (five treaties/MoUs, seven RBOs) arrangements, representing cooperation with every GBM nation, have influenced Bangladesh’s access to transboundary hydrometeorological information. As governed by these institutions and organizations, Bangladesh currently has access to data observed in every GBM riparian nation (Figure 4). Specific focus on Bangladesh reveals a microcosm of geopolitical patterns observed at the scale of the GBM river basin. Decisions made by the Sino-Bangladesh Joint Expert Team, including the specification of spatial and temporal parameters of data shared from China, are detailed by formal MoU agreements and their attendant Implementation Plans. Furthermore, broader agreements framing the Sino–Bangladesh relationship with respect to cooperative water management are similarly supported by MoUs. Conversely, with respect to data shared from India, one treaty (Statute of the JRC) creates a decision-making body that manages transboundary flood concerns as one of many transboundary water-management issues under its mandate. With respect to sharing of hydrometeorological data, decisions and agreements made by the JRC are not codified by treaties or MoUs. Hydrometeorological data from Bhutan and Nepal are available to Bangladesh through the HKH-HYCOS multilateral platform.

The current institutional arrangement for data sharing results in a sparse hydrometeorological data network outside Bangladesh (Table 3). Network densities available from only one neighbouring country, Nepal, meet minimum network densities for precipitation and hydrological observation...
recommended by the WMO (WMO, 2008). As compared to the current level of sharing at the basin scale, data from four to eight times as many precipitation stations and four to seventeen times as many hydrological stations must be shared to meet WMO minimum requirements. As data requirements for operational flood forecasting may exceed the WMO minimum network density recommendations formulated for general water resources management (WMO, 2011), the current level of data sharing to Bangladesh is not likely to adequately support sophisticated hydrologic modelling approaches for accurate, extended lead-time forecasts.

Fig. 3. Current and historical institutions and organizations governing (a) water allocation and (b) sharing of hydrometeorological data between riparian nations of the GBM river basin. Arrows denoting multilateral cooperation indicate direction of data exchange/transfer.
3.3. Impact of transboundary data on the hydrologic forecasting system and early warning stakeholders in Bangladesh

The primary hydrologic forecast preparation and dissemination system in Bangladesh is structured hierarchically, in that information is exchanged between stakeholders operating at different administrative levels, beginning with international interactions (for instance, sharing of basin-wide hydrometeorological data) and ending with localized dissemination of hazard warnings to community members (Figure 5).

![Fig. 4. Results of the current institutional structure for hydrometeorological data sharing. Locations of hydrological and meteorological gauging stations within the GBM river basin that share data with Bangladesh.](https://iwaponline.com/wp/article-pdf/16/S2/36/405538/36.pdf)

Table 3. Based on data available to Bangladesh through transboundary cooperation, density of precipitation and water level/discharge gauges in upstream catchment area of Ganges, Brahmaputra, and Meghna Rivers, compared to WMO recommendations for minimum network density. Basin areas implicit within this analysis are provided by the Joint Rivers Commission Bangladesh.

<table>
<thead>
<tr>
<th>Density of upstream gauges by country and river basin (km² per gauge)</th>
<th>Precipitation</th>
<th>Water level or discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bhutan – Brahmaputra River basin</td>
<td>7,833</td>
<td>11,750</td>
</tr>
<tr>
<td>China – Ganges River basin</td>
<td>No gauges</td>
<td>No gauges</td>
</tr>
<tr>
<td>China – Brahmaputra River basin</td>
<td>90,300</td>
<td>90,300</td>
</tr>
<tr>
<td>India – Ganges River basin</td>
<td>860,000</td>
<td>430,000</td>
</tr>
<tr>
<td>India – Brahmaputra River basin</td>
<td>48,750</td>
<td>21,667</td>
</tr>
<tr>
<td>India – Meghna River basin</td>
<td>47,000</td>
<td>6,714</td>
</tr>
<tr>
<td>Nepal – Ganges River basin</td>
<td>3,138</td>
<td>1,490</td>
</tr>
<tr>
<td>Ganges River basin</td>
<td>21,688</td>
<td>10,307</td>
</tr>
<tr>
<td>Brahmaputra River basin</td>
<td>39,454</td>
<td>32,056</td>
</tr>
<tr>
<td>Meghna River basin</td>
<td>47,000</td>
<td>6,714</td>
</tr>
<tr>
<td>Minimum density of gauges recommended by WMO (2008)</td>
<td>5,750</td>
<td>1,875</td>
</tr>
</tbody>
</table>

3.3. Impact of transboundary data on the hydrologic forecasting system and early warning stakeholders in Bangladesh

The primary hydrologic forecast preparation and dissemination system in Bangladesh is structured hierarchically, in that information is exchanged between stakeholders operating at different administrative levels, beginning with international interactions (for instance, sharing of basin-wide hydrometeorological data) and ending with localized dissemination of hazard warnings to community members (Figure 5).
After receiving hydrometeorological data from upstream nations and from national meteorological, hydrological, and remote sensing units, Bangladesh’s Flood Forecast and Warning Centre (FFWC) prepares forecasts and disseminates water level tables and bulletins to different agencies and actors at the national level. Stakeholders at the national level (i.e. national government, Ministry of Food and Disaster, disaster management councils and committees, non-governmental organizations (NGOs), donors, news, and media) consecutively disseminate flood forecasts to actors at regional and sequentially at local levels to reach end-users and prepare for response and relief actions. Considering that this primary early warning system does hinge on hierarchical processes that currently function unidirectionally from the top down, the importance of international interaction and basin-wide cooperation is implicit within all levels and steps of the early warning system.

An alternative forecasting pathway is emerging in Bangladesh, which relies on the use of remotely sensed atmospheric data rather than direct observations from the upper GBM catchment. This technology-driven approach is designed to allow the application of catchment-scale hydrologic modelling while circumventing the dependence on restricted ground-based observations. The alternative forecasting system also proceeds according to a top-down hierarchy beginning with dependence on international data (from the European Centre for Medium-Range Weather Forecasts (ECMWF), US National Oceanic and Atmospheric Association (NOAA), US National Aeronautics and Space Administration (NASA)), and regional processing support from the Regional Integrated and Multi-Hazard Early Warning System (RIMES) (Figure 5).

4. Discussion

4.1. Improving hydrologic forecasting in Bangladesh through better data access

Under the current institutional framework regulating exchange of hydrometeorological data, flood forecasters in Bangladesh access data from every riparian nation within the GBM river basin. However, in many areas of Bangladesh, the performance of hydrologic forecasting is still considered unsatisfactory, most predominantly at longer lead-times and within areas close to the Bangladesh border. Realizing the potential for reducing flood losses by increasing time for preparation, it is the goal of FFWC to extend forecast lead-times beyond the current maximum 72-hour forecast horizon. However, as the current system performs inconsistently even at shorter lead-times, such goals for high-accuracy forecasts at longer lead-times seem only distantly attainable. The uneven performance of forecasting is often partially explained by insufficient levels of access to international data (Chowdhury, 2000; Faisal, 2002; Ahmad & Ahmed, 2003). At this point, it is instructive to explore specifically how shared international data are integrated into the current forecast system, to determine whether and how more open access to data could improve forecast quality.

Hydrologic forecasters in Bangladesh make use of deterministic hydrologic models to predict where and when flooding will occur. Modelled hydrological predictions are used to prepare 24-, 48-, and 72-hour flood forecasts for public dissemination. The current system provides a reasonably accurate forecast with up to a 72-hour lead-time for the central portion of the country (Paudyal, 2002; ADB, 2006, 2012; pers. comm. Professor Monowar Hossain, 17 February 2013, Dhaka). The success of forecasting in central Bangladesh can be attributed to both the hydrology of major rivers in this region and the distance from the Indian border. The main flood hazards of central Bangladesh come from the flooding of the Ganges and Brahmaputra Rivers, which have large drainage areas and long hydraulic response times.
Fig. 5. Hierarchical structure of forecast preparation and dissemination systems in Bangladesh. Key is provided in Appendix II (available online at http://www.iwaponline.com/wp/016/007.pdf).
relative to smaller, hydrologically flashier rivers that enter Bangladesh in the border regions (Mirza, 2002). The current 72-hour forecast horizon for central Bangladesh essentially corresponds to the hydraulic routing time from the Indian border (Webster et al., 2010). Data collected close to where trans-boundary rivers enter Bangladesh from India supply the boundary conditions of the hydrologic models (Hopson & Webster, 2010), and within Bangladesh, local data continually update and improve the model predictions (Paudyal, 2002). The accuracy and lead-time of hydrologic forecasting in Bangladesh therefore improves substantially with distance from the model boundary, which corresponds to the Indian border (ADB, 2006).

Despite agreements regarding data sharing with every GBM nation, results of this study indicate that hydrologic forecasters in Bangladesh contend with large areas of extremely poorly gauged catchment beyond Bangladesh’s borders. As a result, hydrologic models are currently applied only within the national borders of Bangladesh. As Bangladesh comprises between 7 and 8% of the total GBM catchment area (JRCB, 2013), rainfall within Bangladesh does not often make a significant contribution to the flows of major GBM rivers. Rather, river flows in Bangladesh correlate to a lagged precipitation received in the upper catchment areas (Chowdhury & Ward, 2004). Lacking comprehensive upstream precipitation observations and without the benefit of observed river flows to verify predictions and update the model, the application of basin-wide hydrologic modelling is challenging. Therefore, data provided from outside Bangladesh are primarily used to predict future water levels at the Bangladesh border, from which future hydrologic conditions within Bangladesh are modelled. Upstream data provided from outside Bangladesh improve the ability of forecasters to predict future boundary conditions. However, the prediction of future boundary conditions is still highly uncertain and often subjective. Improved flexibility and accuracy of the current system may be achieved by extending the boundaries of hydrologic modelling beyond Bangladesh’s borders. However, as indicated by the results of this study, the current configuration of transboundary data sharing is not sufficient to allow the application of such integrated basin-wide modelling approaches.

In addition to the number of upstream stations from which data are available, the timing of information availability and delivery are key components to successful hydrologic prediction, particularly with regard to achieving longer lead-times. Many current data sharing arrangements within the GBM river basin specify that data are only to be released during the flood season, and/or when water is already observed to be close to the danger level and precipitation exceeds a given threshold. Arrangements such as these often constrain possible lead-times (Ahmad & Ahmed, 2003), particularly in the border areas of Bangladesh. For instance, smaller international rivers, such as those entering the haor region of north-eastern Bangladesh from the Meghalaya and Tripura states of India, areas known to be globally superlative for intense precipitation, tend to have shorter hydrologic response times compared to the more gradual rises characteristically observed in the Ganges and Brahmaputra Rivers. Additionally, the most damaging floods in this region often precede the flood season, when data are not officially exchanged from upstream stations.

4.1.1. Decoupling flood forecasting from transboundary cooperation. Hydrologic forecasters in Bangladesh are actively pursuing alternative prediction and modelling approaches to combat the extensive areas of geopolitically ungauged catchment area beyond the Bangladesh border. One promising direction for improving the lead-time of forecasts is the use of downscaled global atmospheric circulation models to predict basin-wide precipitation. In a preliminary application of such methods to pilot areas of the Brahmaputra basin, Webster et al. (2010) indicate great potential for flood loss reduction from medium-range forecasts (10–15 days). Dissemination of 10-day flood warnings based on probabilistic forecasts allowed residents to prepare for oncoming floods, saving households from substantial losses. The forecasts were
created by forcing hydrologic models with bias-corrected, quantitative precipitation forecast ensembles derived from a 51-member ensemble. The probabilistic forecasting system developed, now implemented by RIMES, is expanding for wider application throughout Bangladesh.

Use of remotely sensed data products to predict basin-wide precipitation or river discharge allows downstream forecasters in transboundary river basins to extend information coverage into upstream geopolitically ungauged catchment areas. This type of technocratic approach may be one way to circumvent stalled or non-existent regional cooperation. However, as remotely sensed or predicted data will always require calibration/validation with ground-based data, the most accurate and useful solutions are likely to be found in combinations of such novel techniques and regional cooperation. For instance, observations from the upstream catchment may be used to increase the certainty of predictions made using remotely sensed data, which tend to be highly uncertain and do not account for upstream regulation. Webster et al. (2010) explain that, in 2009, unaccounted upstream water abstraction in the Ganges Plains of India led to discharge predictions that substantially overestimated observed discharges. This illustration from the Ganges River exemplifies a particularly intractable problem for flood forecasters applying hydrologic models downstream: lack of information regarding upstream regulation. Assumptions of negligible regulation may lead to misleading forecasts in highly regulated basins. Information about dam operations and flow releases from controlling infrastructure tends to be particularly sensitive and among the most difficult parameters for downstream forecasters to procure or substitute. By allowing forecasters to extend hydrologic modelling to areas outside Bangladesh, or to verify predictions made using novel modelling approaches, more open access to transboundary data, including information about river regulation, will directly improve forecasting capabilities within Bangladesh.

4.2. From hydrologic forecasting to lives and livelihoods – disasters, loss, and poverty in Bangladesh

In Bangladesh, extreme hydrologic events cause human suffering. Floods take homes and land, damage crops, aquaculture, livestock and seedbeds, consume capital and marginal investments, lead to outbreaks of waterborne disease, disrupt communication and transportation, destroy infrastructure, and cause injuries and deaths. Social cohesion and economic relationships have been disrupted by the large-scale displacement of floodplain dwellers (Shamsuddoha et al., 2012). Loss of standing crops is, for poor and subsistence farmers, one of the most serious aspects of extreme or untimely flooding. In the haor region of northeast Bangladesh, farmers typically grow one rice crop per year, and its harvest coincides with the early flood season. An added ‘ratchet effect’ arises because this pre-harvest season is also the ‘hungry season’, as household food stores and incomes are low. Loss of rice crops means loss of income and food security at the household and regional scale, for itinerant farm workers as well as farmers. Examining the effects of flooding to national-level agricultural productivity and food security is sometimes misleading, as areas that do not suffer catastrophic flooding often report high yields due to the availability of water (Brammer, 1990). Thus, national-level analysis may disguise the most insidious effects of crop losses which are the loss of investments made by farmers (Webster et al., 2010), unemployment of farm workers, and food insecurity faced by individual families (Alamgir, 1980; Mirza, 2002). Individuals who sustain losses may still be recovering when the next extreme flood occurs, pushing them into a sinking poverty trap.

Evidence of the relationship between repetitive disasters and poverty is mounting (White, 2004), particularly as trends of increasing populations and more frequent climatic extremes escalate. Recurrent extreme hydrologic events in Bangladesh illustrate the negative feedback cycle of disaster, insufficient
recovery, and reduced capacity to handle the next disaster (BBS-WB-WFP, 2009) which must be broken by increasing resilience and preparedness for extreme events (Anderson, 1991). In Bangladesh, resilience to extreme floods and early warning are closely coupled. Beyond proven life-saving capabilities, economic advantages associated with potential loss reductions are possible given accurate flood warnings with maximized lead-times (Subbiah et al., 2008; Hyder, 2013). Communities exposed to multiple disasters in each generation may perceive injustices in governance systems that do little to protect their lives and livelihoods, or that obstruct risk reduction.

4.3. Institutional structure of water allocation and data sharing agreements

Our findings indicate that agreements regulating the allocation of water between nations of the GBM river basin differ from those mandating the exchange of hydrometeorological data with respect to the instrument of agreement applied. While consensus regarding the specific quantities of water crossing international borders is without exception codified into treaties or MoUs, decisions about the exchange of hydrometeorological data are often not systemized by treaties or MoUs. With respect to both water allocation and data sharing decisions, the role of RBOs is fundamental. Information gathering, discussion, negotiation, and decision-making all occur at the level of RBOs. The essential difference between the data sharing and water allocation agreements of GBM nations is that, with respect to data sharing, the implementation of agreed actions proceeds without treaties or MoUs, while, with respect to water allocation, treaties or MoUs document decisions and outline procedures for implementation. The exception to this pattern is China. China’s approach to hydrometeorological data sharing is similar to water allocation approaches taken in other GBM nations; dialogue and negotiations take place within RBOs and key outcomes are preserved in treaties/MoUs.

The finding that water allocation and data sharing agreements are institutionalized differently may be partially explained by the differing contexts under which water allocation and data sharing decisions are often crafted. Due to the nature of flowing waters, river waters may be shared between riparian nations with no action or agreement from water managers required; water may be shared passively. Passive sharing of hydrometeorological data, by contrast, generally does not occur. Data do not passively flow from one nation to the next, but require action on the part of managers and institutional organizations to facilitate the transfer. Every instance of data sharing thereby necessitates: first, a conscious intention to share; and second, agreement as to the specific manner in which sharing occurs. While such intention and agreement is necessary for all data sharing, formal agreements regarding allocation of water often become necessary when a potential dispute or tension about allocation is perceived, or is already in progress. This may occur when quantities of water become more actively managed by one or more nations, and usually when resources are perceived to be scarce. All instances of water sharing agreements within the GBM river basin are precipitated by perceived water scarcity, new infrastructure development, or combinations of both. By contrast, levels of tension surrounding decisions of data sharing may be lower, allowing agreements to evolve with less structure and formality.

Other factors potentially explaining the differing institutional structure we observe could involve the contrasts in conceptualization of water and information. As evidenced by the UN (2010) Convention on the Human Right to Water and Sanitation, water is routinely conceptualized as a human right, or a public trust, whereas hydrometeorological data are typically understood as a proprietary resource. This difference pertains to how ownership is perceived. As a human right or public trust, ownership of water is often ambiguous, and finding ways to equitably share water is a natural extension of
these conceptualizations. By contrast, observations collected within sovereign boundaries and often using government resources are inherently the property of the collector. That institutional structures framing hydrometeorological data exchange reflect the advantage of upstream collectors who have property is probably not a coincidence.

4.4. Justice related to institutional structure of water and data agreements in the GBM river basin

The degree to which the differing institutional structures of water allocation and provision of hydrometeorological data may influence the justice of outcomes is difficult to ascertain. On one hand, documentation and processes leading to agreements upheld within treaties tend to be more visible and transparent than those managed within the confines of RBOs, allowing for a greater scope of participation and opinions. Greater visibility, transparency, and participation are often associated with outcomes that are more just. However, some treaties mandating water allocation between GBM nations have also been questioned in terms of their equity (Dhungel & Pun, 2009), indicating that the realization of a treaty does not necessarily guarantee outcomes that are considered equitable by all parties. Envisaging a treaty as a means to greater cooperation and enhanced future equity (e.g. Salman & Uprety, 1999), rather than an end goal, may be a more precise way to imagine the impact of such agreements.

The intention of proceeding in an equitable manner and striving for just outcomes is often very firmly established within the language of a treaty. Mimicking the guiding principles of transboundary water management codified within landmark documents such as the Helsinki Rules of 1966 and the 1997 framework UN Convention on International Watercourses, the language of international water treaties often references basic foundational principles which underpin customary international water law (Rahaman, 2009), including principles of equitable and reasonable utilization and no significant harm (Salman, 2007). Nearly every treaty signed within the GBM river basin addresses justice/equity at least once, and mentions of equity are numerous in many treaties. For instance, the Mahakali Treaty between India and Nepal discusses justice/equity in three different places; likewise, the 1996 Ganges Treaty between Bangladesh and India specifies justice/equity four times. It is likely that language specifically addressing equity may elevate the perception of justice related to the content of an agreement. Within the set of GBM treaties and MoUs, specific treatment of equity is less prevalent in MoUs than in treaties. Within agreements made without attendant documentation, such intentions with regard to justice cannot be determined. Although direct causation between the enactment of a treaty and equitable outcomes, or that absence of a treaty leads to less equitable outcomes, is difficult to establish, we posit that treaties epitomize the intention of applying guiding principles, including justice through equity considerations.

Upon examining the relative success of treaties/MoUs in achieving just outcomes as opposed to decisions made within RBOs, one might wish to examine factors that influence the successful implementation of both types of agreement. Assuming that both types of agreement have an equal chance of containing a just decision (which may be a false assumption, given the arguments discussed above), whether or not the parameters of agreement are effectively realized on the ground will be a determining element influencing outcomes. Treaties and MoUs tend to be comparatively successful in implementation. Often such agreements lead to the creation of designated RBOs designed to oversee a just and effective implementation of the agreement, with mandates that include dispute resolution. For example, expert teams from both India and Bangladesh measure dry season Ganges River flows at the Farakka Barrage and in Bangladesh to ensure that waters are distributed as stipulated in the Farakka
Treaty. An implementation plan often accompanies treaties/MoUs, making these institutions accountable and transparent to the involved stakeholders. This also allows stakeholders, such as media and academics, to independently monitor the implementation and express opinions as to whether the implementation is proceeding effectively.

By contrast, decisions made and upheld at the level of RBO have the potential to be less successfully implemented. For instance, organizations that make and uphold decisions about the exchange of water-related data in the GBM river basin are often tasked with several mandates and the implementation of data sharing agreements does not always receive the specific attention that is needed. For example, the Indo-Bangladesh JRC manages transboundary flood concerns as one of many transboundary water-management issues under its mandate, which also has come to include water allocation. Between June 1974 and July 1997, the issue of data exchange was not extensively discussed within the JRC, as the sharing of Ganges and Teesta River waters dominated meeting agendas. One consequence of inattentive monitoring was that in some instances data or flood notifications were not transmitted from India to Bangladesh in a timely manner. With no official implementation plan or dispute resolution procedure in place, resolving such issues in implementation proved to be challenging. Setting a primary intention within the language of an agreement to proceed in an equitable manner, creating opportunities for open and inclusive dialogue and debate, ensuring mechanisms for implementing an agreement, and providing means for dispute resolution are specific ways that decisions upheld by treaties may lead to just outcomes.

4.5. Should hydrometeorological data be a human right?

The results of this study establish that access to transboundary hydrometeorological data has the capacity to influence resilience-building efforts related to recurrent extreme hydrologic events, vulnerability to which cause poverty and human suffering. While the current institutional configuration regulating data sharing in the GBM river basin provides upstream hydrometeorological data to Bangladesh, there is an unmet potential for increasing resilience in further enhancement of regional cooperation. Restrictions to information from upstream GBM catchment areas may create a resilience ceiling with respect to early warning in Bangladesh, potentially denying citizens opportunities to prepare for oncoming floods, to protect themselves and their families, and to reduce losses. For example, in October 2000, south-western Bangladesh experienced flooding which originated from the neighbouring West Bengal and Bihar states of India. However, no warning or flood information was issued from upstream areas. People were therefore unprepared, particularly as the waters rose with uncharacteristic rapidity. Millions of people were affected and excessive losses and damage were sustained in agriculture, fisheries, infrastructure, and trade and commerce. Among many, this is one instance which justifies that hydrological information sharing could be a viable tool to secure safety of lives and livelihoods from the ravages of flooding.

The problem of access to obfuscated transboundary data that could be employed for beneficial use in hydrologic forecasting is not unique to the GBM river basin, but is a common problem in many areas of the world that is likely to come into sharper focus in the coming decades. As hydrologic forecasting technologies become more widely attainable and as the risk of water-related hazards continues to increase demand for resilience-building, more river basins will contend with injustices related to a lack of cooperation regarding hydrometeorological data. Specific global policy directions including the emerging Sustainable Development Goals, which will replace the Millennium Development Goals in 2015, are likely to direct financing and planning towards increased resilience in the post-2015 development agenda (UN, 2013; UN-Water, 2013). Indicators such as the proportion of a population with access to
effective early warning systems are proposed for monitoring resilience. Achievement of such targets may be compromised in international rivers basins by current conceptualizations of hydrometeorological data and deficient awareness of the importance of data to protect lives and livelihoods.

The perpetuation of preventable human suffering is indeed unjust. It is the right of river basin inhabitants to provide a level of security for themselves and their livelihoods against recurrent disasters. The right to security from recurrent and predictable disasters is no less profound than the human right to water. But, is hydrologic data a human right? Article 19 of the Universal Declaration on Human Rights grants every human the right to ‘receive and impart information and ideas through any media and regardless of frontiers’ and Article 3 of the same document also provides for ‘security of person’ as a human right (UN, 1948). Article 15 (1.b) of the International Covenant on Economic, Social and Cultural Rights grants each human the right to ‘enjoy the benefits of scientific progress and its applications’, for instance, the application of new technologies to enhance resilience to floods. Article 15 (4) of the same document recognizes the ‘benefits to be derived from the encouragement and development of international contacts and co-operation in the scientific and cultural fields’. As hydrologic information may be put to beneficial use in the event of extreme hydrologic conditions to prevent loss or compromise to any number of human rights, for instance, the human right to water and sanitation or to security of person, we argue that the water community should adopt and encourage a future definition of hydrologic information as a human right. Increasing awareness of associations between transboundary cooperation and social justice may be a potentially effective mechanism for affecting change. Including greater consideration of justice in international agreements for exchange of information, for example, may induce further sharing in the spirit of cooperation, as the sharing of hydrologic data would be recognized as a provision of human rights. Commitment to cooperation in the form of sharing non-consumable resources, such as beneficial information, could encourage new and productive political–technical dialogues and may become the feature around which ideas and cooperation coalesce.

Theories of absolute territorial sovereignty or integrity regarding the utilization of shared waters have been largely dismissed by scholars and water managers alike, and are not often applied in practice with regard to water allocation agreements (Rahaman, 2009). However, regarding the sharing of hydrometeorological data, absolute territorial sovereignty often reigns, with some nations classifying and severely restricting data access as a matter of national policy. Perhaps, as is accepted in customary water allocation practice, a standard of limited territorial sovereignty (sovereign equality) with regard to hydrometeorological data would be more appropriate. Analogous to application of this theory to water allocation, framing hydrometeorological data in terms of limited territorial sovereignty would acknowledge the rights and obligations of both upstream and downstream nations, discouraging data restriction that discounts the rights of downstream countries to adequate disaster preparedness.

5. Conclusions

Results of this study indicate direct links between the provision of transboundary hydrometeorological data, preparation of flood forecasts, and the timing and quality of flood warnings disseminated to affected individuals. Our results indicate limited success of the institutional structure governing transboundary exchange of hydrometeorological data in the GBM river basin. As governed by multiple RBOs, every riparian nation of the GBM river basin participates in either exchange or transfer of flood season hydrometeorological data to Bangladesh. However, the current configuration limits the application of
basin-wide hydrological modelling to flood forecasting. Vast areas of geopolitically ungauged catchment areas outside Bangladesh constrain the ability of hydrologic forecasters to predict extreme events with sufficient accuracy and desired lead-time. As information flowing from upstream nations constitutes the first step in the top-down hierarchical system that characterizes flood forecasting and early warning, every aspect of Bangladesh’s early warning system hinges on the quality of upstream hydrologic information. Thus, coverage of flood forecasting with a sufficient lead-time for response is not uniformly realized throughout Bangladesh. Comparing the institutional structure governing data sharing to that related to water allocation in the GBM river basin, we find that water allocation decisions are upheld in treaties or MoUs while agreements about data sharing often are not codified into treaties or MoUs. This differing institutional structure may reveal important information about how water and hydrometeorological data are conceptualized, with potential effects to the justice of outcomes. We propose that a lack of consciousness regarding potential inequities related to restricted access to hydrometeorological data may perpetuate such injustices; conversely, increasing understanding of the links between shared hydrometeorological data and social justice may facilitate further transparency and cooperation.

References

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