Minimizing "geopolitically ungauged" catchment area of transboundary river basins to support disaster risk reduction

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Abstract Water managers across the globe comprehend the vital importance of adequate hydrological information to support water policy creation and decision-making. In addition to the spatial and temporal resolution of physical observations, data distribution (where data are available for use) and timing (when data are available for use) may determine the utility and benefit of observed data, e.g. in forecasting extreme hydrological events. Within transboundary river basins, it is too often the case that flows of hydrological information stall or halt at national boundaries. The result is that decision-making relying on use of real-time hydrological observation is often compromised by partial, untimely, or uncertain flows of information from "geopolitically ungauged" catchment areas. For this reason, much potential for improving data-driven decision making lies within opportunities to fully utilize existing data networks. Regional platforms for sharing hydro-meteorological data may be a potential pathway to improve management capabilities and a point of coalescence for sharing the benefits of regional cooperation.

Key words transboundary water management; hydro-meteorological data; geopolitically ungauged catchment area; hydrological forecasting; disaster risk reduction

INTRODUCTION

Geopolitically ungauged catchment area

Within the context of disaster management, timely dissemination of flood and drought warnings may allow for enhanced preparedness, enabling communities to become more resilient to extreme events (WMO, 2009; WMO-GWP, 2011). In preparing accurate hydrological forecasts, direct observations of hydro-meteorological conditions are indispensable. Yet within transboundary river basins, many downstream, flood and drought-prone nations lack adequate institutional arrangements guaranteeing access to basin-wide data. Due to the unavailability of data collected beyond national borders, water and disaster managers within shared river basins may contend with areas of upstream catchment that are, for the purpose of hydrological prediction, ungauged. The term "geopolitically ungauged" may be applied to describe such areas. A comprehensive observation network may exist in geopolitically ungauged areas, but from the perspective of downstream managers with limited, untimely, or uncertain access to these data, such catchment areas are effectively ungauged or poorly gauged. When hydrological forecasting is constrained by flows of information from upstream geopolitically ungauged catchment areas, capacity to manage extreme events may be severely limited.

HYDROLOGICAL FORECASTING FOR DISASTER RISK REDUCTION

An accumulation of factors, notably including climate and demographic changes, are bringing people and water-related hazards together more regularly, resulting in increased frequency of global water disasters (Takeuchi, 2001; Strömberg, 2007), including more frequent transboundary flood events (Bakker, 2009a). Researchers observe more extreme precipitation events at both ends of the spectrum (both high-intensity precipitation and prolonged dry periods), and project that these trends will escalate in the future (Groisman *et al.*, 2005; Min *et al.*, 2011). With the prospect of more frequent and severe floods and droughts looming, practitioners seeking to minimize critical impacts agree that cooperative and equitable water management is an essential mechanism for adaptation.

Disasters and development

In the developing world, extreme hydrological events can be particularly devastating. Although absolute economic losses associated with disasters are often greater in developed nations, damages relative to gross national incomes (GNI) are often much higher in developing nations (Toya & Skidmore, 2007). As losses are much less likely to be insured, costs are also felt more acutely in developing areas (Linnerooth-Bayer *et al.*, 2011). Moreover, development specialists recognize that disasters are a hindrance to economic and social development, as infrastructure, capital, and stocks are damaged and productivity and growth stalled (Anderson, 1991; White *et al.*, 2004). In addition to acute losses or mortality incurred during or immediately following an event, many crippling losses may occur as secondary and tertiary effects after the disaster has passed. For instance, effects such as famine due to loss of crops or fodder (Islam, 2010), outbreak of diseases (Kondo *et al.*, 2002; Ahern *et al.*, 2005), or political unrest (Olson & Drury, 1997) may lag well behind the actual triggering event and may be substantial.

Repeated disasters allow for limited recovery and tend to lower individual and societal resilience as capacity to cope with future disaster decreases (Webster & Jian, 2011). The sequence of disaster, partial restoration, and lower resilience to subsequent events has the potential to create a cycle of loss, incomplete recovery, and poverty that may span generations (Webster, 2013). To avoid such spiralling effects of recurring water hazards, managers within disaster-prone areas seek measures to prevent or ameliorate the most harmful effects of water hazards and/or reduce vulnerability. Assisting these efforts, global development policies are shifting focus from investment in relief and recovery phases of disaster management and trending towards financing preparedness and societal resilience (DFID, 2006).

Critical components of hydrological forecasting and early warning systems

One of the most cost-effective measures for limiting losses associated with water-related hazards, and for reducing numbers 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 numbers of human casualties related to river flooding and cyclones (Mallick *et al.*, 2005; Paul, 2009). Lead time of forecasts, the time between the issue of the forecast and occurrence of the forecasted event, largely determines the level of possible response and positively correlates to 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 lead times of days or weeks allow for more comprehensive preparedness leading up to the event.

Intrinsic effectiveness of an early warning derives from the ability of individuals and communities to utilize information about future risk to rationally decide upon the optimal course of action, taking into account the costs of possible preparations and their potential for loss reduction. In addition to lead time, the accuracy of forecasts is particularly critical, as many resources may be mobilized and decisions made based upon 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 hydrological 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. For this reason, it is desirable to forecast as far in advance as possible, but also to maximize accuracy of predictions. Importantly, it is good practice for forecasters to communicate information about certainty of a forecasted event, for instance in probabilities of occurrence (Webster *et al.*, 2010).

Hydro-meteorological data for hydrological forecasting

Although forecasters may apply a range of methodologies to predicting magnitude and timing of future hydrological events, forecasts created by the integration of meteorological information with physically-based, distributed hydrological runoff models show much promise (Takeuchi, 2001). Development of forecast systems based on hydrological modelling are a target for many flood-prone nations. Primary inputs of geophysical data, including hydro-meteorological observations, are necessary to build, parameterize, calibrate, and force such hydrological models. Meteorological data such as observed or predicted precipitation, temperature, humidity, and wind speed, are used to compute water balance relationships that drive hydrological simulations. Observed water level and/or river discharge are used to calibrate hydrological models and to validate predictions, or are input directly to specify boundary conditions. Data used to build and parameterize river basin and flow network models, such as digital elevation models (DEMs), information about soil depth and texture, or land cover data are also necessary inputs to a flood forecasting hydrological model.

Hydro-meteorological data utilized in hydrological forecasting that are most commonly difficult for water managers to obtain or substitute include basin-wide precipitation, and water level or discharge observations. For these key data, few acceptable substitutes for observed data exist (but see Webster *et al.*, 2010 for an example of the potential for forecasters to predict floods using globally-generated meteorological forecasts). Spatial datasets with global coverage of terrain, land cover, and soils are available, thus modelling is not often limited by availability of these parameters. There is always potential to improve model quality with localized, high-resolution data, particularly high-quality DEMs. However, event-based hydrological models are less sensitive to accuracy of these parameters and globally-available data may often be of sufficient quality for the purpose of flood forecasting. In contrast to these globally-available datasets, observation of precipitation, water level, and river flow is generally managed at national levels. Though critical to forecasting potentially catastrophic events, such data are often unavailable to forecasters outside of the implementing nation or administrative district. Even within nations, complex administrative procedures are often necessary to allow sharing of data between institutions.

FLOOD MANAGEMENT IN TRANSBOUNDARY RIVER BASINS

Managing risk of water hazards can be particularly complex in river basins shared by two or more nations. Flood disasters in transboundary river basins have historically been more severe, affected larger areas, and resulted in higher costs of human life and economic damages (relative to GNI) as compared to floods that do not extend over national borders (Bakker, 2009a), 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 principle concern and less than 4% of international water treaties list flood management within the scope of the agreement (Bakker, 2009b).

The circumstances leading to more severe consequences of flooding in international river basins as compared to river basins contained within one country are likely complex and multifaceted, such 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 hydro-meteorological data may be a significant obstacle preventing adequate flood preparedness within areas of international river basins.

Regulation in upstream catchment areas

River regulation may pose a particular challenge to accurate modelling of flows from geopolitically ungauged upstream catchment areas. As upstream capacity for controlling and modifying flows expands, the need for direct observations to anchor modelled downstream flow predictions becomes imperative. In addition to allowing upstream users to harness and divert water during times of low flow, increased infrastructure and storage capacity also may allow upstream managers sufficient control to affect timing and magnitudes of high flows released to downstream areas. For example, unanticipated releases from upstream reservoirs in India may have exacerbated seasonal flooding that affected southwestern Bangladesh in 2000 (Ahmad & Ahmed, 2003; Thakkar, 2006). Information about dam operations and flow releases from controlling infrastructure tends to be particularly sensitive, and the most difficult for downstream forecasters to procure or substitute.

Lack of information regarding upstream regulation presents a particularly intractable problem for flood forecasters applying hydrological models downstream. Unless river regulation is detailed by the modeller, hydrological models used in flood forecasting will route water through a geopolitically ungauged catchment with no regulation, modelling natural flow patterns driven by catchment characteristics. However, upstream management may control and modify flows such that assumptions of negligible regulation may lead to misleading forecasts. For instance, hydrological conditions downstream may be directly affected by decisions about upstream dam operations, such as timing and quantities of water released from reservoirs. Flood forecasters downstream who are not privy to information about upstream regulation are thus unable to predict downstream hydrological conditions. In this situation, there are few substitutes for observed data. In this way, prediction of flows from geopolitically ungauged catchments may be even more challenging than the well-studied conundrum of hydrological prediction in ungauged basins (Sivapalan *et al.*, 2003) which, almost by definition, are characterized by little or no regulation.

Timing constraints for flood forecasting data

Information used for flood prediction is extremely time-sensitive. In order for forecasters to create predictions at times scales that are relevant to desired response activities, timely hydrological information is essential. One of the greatest challenges to sharing data across international boundaries may be delivering data within a timeframe that is useful for forecasters. Despite the importance of timely delivery of hydro-meteorological data to maximize forecast lead time, current data-sharing agreements are sometimes structured such that this importance is under-represented. For instance, a data-sharing arrangement may specify that hydrological information may only be released to downstream countries when the river is approaching flood stage, e.g. when water levels are within with one metre of a pre-determined danger level. While data observed close to an extreme hydrological event are undoubtedly helpful, data collected in the days and weeks leading up to the event are also very important for crafting flood warnings with sufficient lead times to allow for meaningful response.

Even when data-sharing agreements allow for exchange of longer data time series leading up to extreme events, it is often the case that the method of data delivery is insufficient to provide information in a timely manner. Transmission of hydro-meteorological information for flood forecasting should ideally proceed in near real-time and the transmission medium should be robust to the extreme hydro-meteorological conditions that are being observed.

CONCLUSIONS: BENEFITS OF REGIONAL COOPERATION

In the context of disaster preparedness, hydro-meteorological data used to forecast extreme hydrological events for early warning systems can be a powerful resource with the potential to affect lives and livelihoods. However, lack of basic hydrological information from upstream geopolitically ungauged catchment areas truncates forecast lead time and elevates uncertainty of downstream forecasts in many disaster-prone transboundary river basins. While expansion of hydro-meteorological data acquisition networks is a priority, there is also much opportunity to fully utilize existing data networks through enhanced cooperation and basin-wide sharing of hydrological information. Following the United Nations International Year for Water Cooperation, minimizing geopolitically ungauged catchment areas by improving data access and connectivity of data networks is a timely direction for improving data-driven water management. Enhanced awareness and conceptualization of information as a resource may allow for expansion of justice considerations in international water agreements to include equitable sharing of data to benefit disaster risk management.

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