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Heterogeneity in Riverine Ecosystem Service Perceptions

**Insights for Water-decision Processes in Transboundary
Rivers**

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ABSTRACT

The objective of this study is to analyze heterogeneous perceptions of the relative importance of riverine ecosystem services to inform policy decisions. To improve allocation of scarce resources across competing uses, it is crucial to understand the values placed on various water uses. Based on electronic surveys conducted across three transboundary river basins—the Indus, Mekong, and Niger—we assess how perceptions of ecosystem services provided by these river basins differ by geography within and across basins, by type of respondent, and under alternative future conditions. The results reveal regions within each basin that are deemed to be most at risk ecologically and identify services with the most pressing need for investment. Water for irrigation and energy production are considered the most important services across all basins, with importance shifting from energy to food production from upstream to downstream.

Comparative analysis reveals that perceptions are influenced to some extent by the technical and organizational background of stakeholders. These results emphasize the need for diverse stakeholders to be involved in water resources decision-making processes. Rules derived from the electronic surveys can enhance water systems modeling, in particular, decentralized modeling approaches that use bottom-up processes with enhanced representation of the interactions between heterogeneous subsystems.

Keywords: water resources management, stakeholder survey, ecosystem services, transboundary rivers

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1. INTRODUCTION

Increasing population, coupled with rising water demands, is projected to further increase water scarcity and place tremendous pressure on various water uses (Gleick 2000). Improved water resources allocation and management have been shown to be effective at mitigating the impacts of water scarcity on economic development (World Bank 2016; Rosegrant, Cai, and Cline 2002). To ensure optimal management of water resources, it is crucial to understand the value societies place on competing water uses and to adequately incorporate all water-related benefits that people derive from water resources into decision-making processes. The objective of this study is to analyze heterogeneous perceptions of the importance of riverine ecosystem services using an electronic survey across three transboundary river basins to inform policy decisions.

Riverine ecosystem services can be defined as benefits derived by humans from a river basin. These benefits include provisioning services such as water for irrigation and hydropower, which is the traditional focus of water management (Auerbach et al. 2014); regulating services such as nutrient recycling and flood control; supporting services such as those for biodiversity and habitat; and cultural services, such as for tourism and recreation or spiritual uses. In the context of increasing demand for freshwater, riverine ecosystems are at a particularly high risk of disruption due to human intervention, such as irrigation development, reservoir construction and operation, and overfishing, all of which are expected to be further affected under climate change (Rosegrant, Cai, and Cline 2002). Maintaining an adequate level of riverine ecosystem health is crucial to ensure provision of ecosystem services in the future (Lloyd et al. 2013).

However, quantifying the levels and importance of ecosystem services in a river basin remains challenging (Nelson et al. 2009). The notion of considering social and cultural water “uses” part of ecosystem management, along with the more obvious economic uses, has received much attention recently (Reed and Brown 2003), as has a discussion of the challenges of doing so. The difficulties in measuring these diverse services can be overcome and do not justify excluding these services from

assessments (Satz et al. 2013). To enable comparison of the benefits of the different ecosystem services, they need to be translated into comparable values, such as monetary units. However, not all ecosystem service benefits can be expressed in monetary terms. The economic value provided by some ecosystem services, such as irrigation or hydropower, can be readily determined; in this article, we use the term *monetary ecosystem services* (MES) to refer to such services. For services that cannot be directly valued in monetary terms, such as value of the existence of pristine water flowing through a river, referred to in this paper as *nonmonetary ecosystem services* (NMES), environmental valuation methods can be used (Mitchell and Carson 1989).

Environmental valuation has increasingly been used to incorporate a broader range of water-based ecosystem services into the decision-making process (Willcock et al. 2016). Valuation is especially useful in resolving the tradeoff between competing uses, such as power generation and downstream rafting conditions, or dam removals for enabling fisheries to thrive. Citing the example of Mono Lake, Loomis (2000) highlights how the water allocated to the Los Angeles Department of Water and Power was reduced based on the results of a stakeholder survey. The survey results showed that society placed a high value on the Mono Lake ecosystem and the wildlife species dependent on it. As a result, flows into Mono Lake were increased, reducing flows to Los Angeles. In another application of socioeconomic evaluation for policy making, Breffle et al. (2012) document the use of surveys conducted with focus groups in the Great Lakes watershed to examine the public's concern with, and willingness to commit resources to improve, a variety of stressors of ecological services. Brouwer (2008) illustrates the use of stated preferences to derive public perceptions towards socially acceptable levels of water quality within the European Water Framework Directive. These surveys were used to complement the decision-making process and expert assessments in environmental policy formulation.

A better understanding of the preferences stakeholders place on riverine ecosystem services can aid the planning and management of water resources (van Oel et al. 2010). Extensive human intervention in the terrestrial hydrosphere means that virtually every river basin globally reflects the interaction between human and natural hydrologic processes (Vogel et al. 2015). The modeling of the interaction

among hydrologic, ecologic and human processes for assisting in water management decision-making, known as water resources systems analysis, requires a recognition of how various ecosystem services are valued by the humans that influence the system (Brown et al. 2015).

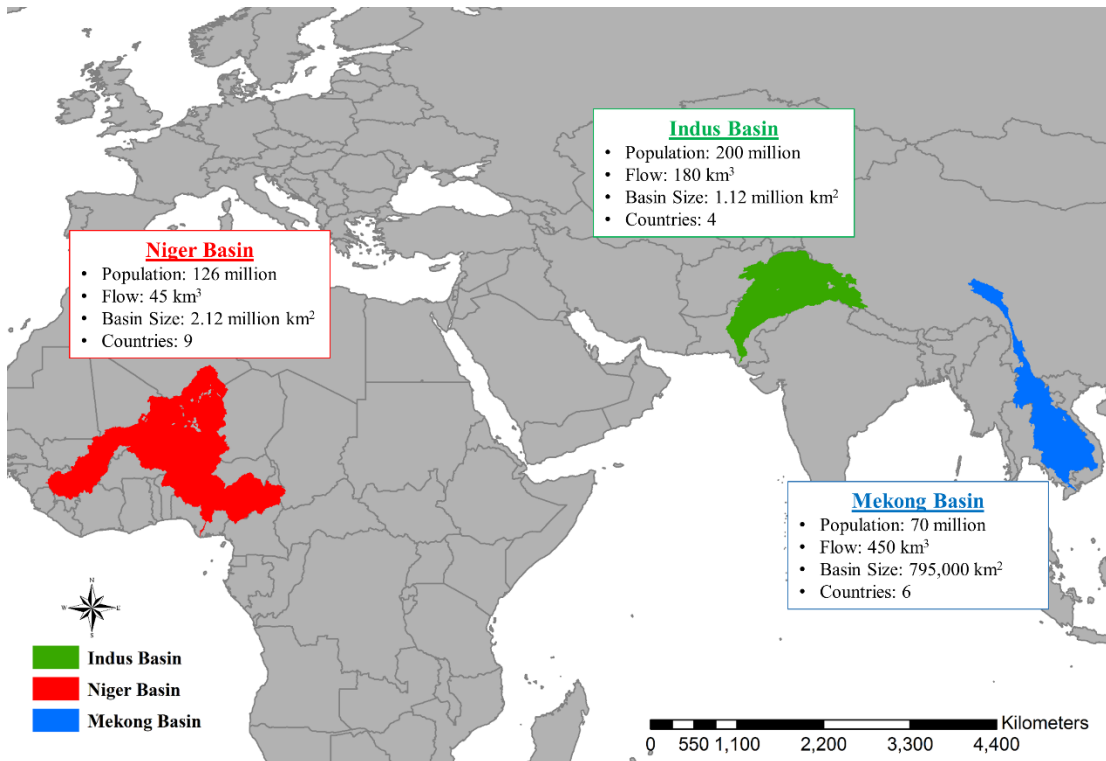
While representation of natural hydrologic processes in systems analysis has advanced considerably, human interactions with the natural system remain poorly understood. Often, human actions and societal dynamics are represented using static assumptions rarely based on empirical data. Without an appreciation of how economic and environmental issues are perceived by society and how these perceptions affect human interventions in a river basin, “we cannot understand, let alone make future projections of any long-term [human-water system] dynamics” (Sivapalan 2015). This paper addresses this research gap by eliciting ecosystem service preferences from diverse stakeholders using surveys conducted electronically and investigating the heterogeneity among the responses.

This analysis is based on surveys conducted across three transboundary river basins: Indus, Mekong, and Niger. The surveys were developed to elicit the perceived importance of various ecosystem services across each basin under a variety of economic and hydrologic future conditions. We provide an interbasin and intrabasin comparison that sheds light on the most highly valued riverine ecosystem services. We also compare how water practitioners view the most pressing issues that need to be addressed in the river basins. The results reveal regions within each basin that are deemed to be most at risk ecologically and identify services with the most pressing need for investment, as measured by stakeholder perception.

2. BASINS OVERVIEW

The river basins included in this analysis, shown in Figure 2.1, while unique in their hydrology, economy, demography, and water management challenges, share many attributes. All three transboundary basins include developing countries with rapidly growing populations, requiring substantial investment for major infrastructure to satisfy increasing water, food, and energy needs. The local economies in these countries are deeply linked with these rivers, primarily through agriculture, fisheries, or both. These basins are also home to some of the world's most diverse and productive ecosystems. The challenge, then, is to promote development of these basins to provide pathways to increased economic and social well-being while safeguarding the diverse ecology and high levels of biodiversity in these regions.

Figure 2.1 Transboundary river basins included in the analysis



Source: Produced by authors for this study.

Note: km² = square kilometers; km³ = cubic kilometers.

Indus

The Indus River originates in the Tibetan plains in China and drains an area of 1.12 million square kilometers across Afghanistan, India, and Pakistan. With a mean annual flow of 180 cubic kilometers, it is the economic lifeline for most of the 200 million people who live in its basin (Yu et al. 2012). In terms of economic activity and development of the basin, the Indus Basin can be divided into two distinct parts. The Upper Indus Basin, where the flow of the river is narrow and fast, is marked by steep topography that makes it ideal for development of storage and hydropower infrastructure (Water and Power Development Authority (WAPDA) 2013). The Lower Indus Basin is marked by extensive irrigation (largest contiguous irrigation system in the world: Indus Basin Irrigation System), which constitutes most of the water consumption from the river. Major crops grown in the Lower Indus Basin across India and Pakistan include wheat, cotton, and rice, with annual agricultural produce valued at around US\$35 billion (Yang et al. 2013). Due to extensive infrastructure on the Lower Indus for irrigation purposes, fisheries in the Indus Basin are limited to the Indus Delta. The Indus Delta is also home to rapidly dwindling mangrove forests (Kravtsova, Mikhailov, and Efremova 2009).

While boasting an extensive and complex irrigation system, the Indus River in Pakistan has few major storage facilities. The two largest reservoirs, Mangla and Tarbela, were completed more than 40 years ago, with no other major hydropower or storage facilities developed since (Laghari, Vanham, and Rauch 2012). With Pakistan suffering chronic energy shortages and large-scale flooding on an annual basis, there has been growing interest in developing new infrastructure (Mirza et al. 2008).

Mekong

The Mekong River, with an annual average discharge of 450 cubic kilometers, is the sixth largest river basin in the world in terms of runoff (Kite 2001). It is a transboundary river originating in China, and it flows through or borders Myanmar, Thailand, Laos, and Cambodia before finally draining in the Mekong Delta in Viet Nam. Flow in the Upper Mekong in China mainly comprises snowmelt, while precipitation from the two monsoon systems provide the bulk of the flow in the Lower Mekong (Ringler 2001).

Around 70 million people depend on the Mekong River for food, water, and economic sustenance, and the basin is home to several diverse and productive ecosystems. Tonle Sap Lake, among the most productive ecosystems in the world (Bakker 1999), is an example of the unique ecology and biodiversity in the basin. Agriculture accounts for 80–90 percent of total freshwater consumption in the Mekong (MRC 2002), with rice being the most widely grown crop. The Mekong River Basin is the world’s largest inland fishery, with annual fish harvests topping 2 million metric tons (Dugan et al. 2010). The Mekong Delta is another hot spot of economic activity and produces approximately half of Viet Nam’s annual rice harvest and more than half of Viet Nam’s fish exports (Kite 2001). The Mekong is currently in a phase of rapid infrastructure development (storage and hydropower). While political conflict and social unrest in the riparian countries prevented large-scale infrastructure from being realized until the 2000s, development efforts have since accelerated, particularly in the Upper Mekong (Lacombe et al. 2014) and have now also reached the lower mainstream. This has raised concerns regarding the impact of infrastructure development on downstream fisheries productivity (Urban et al. 2013).

Niger

The Niger River drains an area of more than 2 million square kilometers spanning nine riparian countries in West Africa and making it the ninth largest river basin globally in terms of area. Headwaters of the Niger are located in Guinea and Sierra Leone, from where the river flows through the Inner Delta in Mali. The river then joins the Benue River before draining into the Atlantic Ocean through the Niger Delta in Nigeria. The Niger River is spread across a wide range of ecosystem zones, and the basin is thus notable for its high spatial and temporal hydrologic variability on interannual and decadal scales (Ghile et al. 2014). Precipitation in the basin mainly depends on the Atlantic monsoon between May and November. During the past few decades, runoff into the subbasins has decreased substantially due to decreased rainfall (Laë 1994).

The current population in the basin is more than 100 million, more than 70 percent of whom live in Nigeria, with a high growth rate, which suggests a quadrupling of the basin population by 2050. Based

on gross domestic product, all nine countries of the Niger Basin fall in the bottom quartile of national incomes (Ogilvie et al. 2010). Agriculture constitutes a large part of the economic output for the region (approximately 33 percent), with livestock and fisheries also contributing substantially in some areas(Welcomme 1986). Owing to a lack of a well-developed irrigation system, most of the agriculture in the Niger is rainfed, with only 20 percent of available arable land under cultivation.

3. METHODOLOGY

An electronic survey was developed for water practitioners in the studied river basins. Lists of potential survey respondents were developed based on in-basin contacts from partner institutions (for example, Wetlands International, WorldFish). Potential survey respondents were identified based on their participation in previous in-basin workshops and stakeholder consultations. For the Mekong and the Niger River basins, the surveys were distributed to water practitioners across multiple countries in the basins. In the Indus Basin, a majority of the water use occurs in Pakistan. In addition, due to the Indus Water Treaty, the eastern and western parts of the basin are operated almost as two independent units. Due to these factors, combined with a limited number of in-basin contacts in India available to us, the survey was distributed primarily to water practitioners located in Pakistan or affiliated with institutions that focus on water resources in Pakistan. The surveys were conducted from August to October 2015. In total, 82, 74, and 80 respondents participated in the Indus, Mekong, and Niger Basin surveys, with the response rate varying approximately between 30 percent and 40 percent.

Each river basin was divided into ecologically and hydrologically similar subregions, where water management is primarily carried under the ambit of a single administrative unit. Table 3.1 lists the subregions that the three river basins were divided into. The questions included in the survey were categorized based on certain themes, with a mix of qualitative and quantitative questions. Prior to the respondents' starting the survey, they were briefed on the survey objective and definitions of various terms in the survey. The survey was designed to take approximately 20 minutes to complete, and respondents were allowed to leave questions unanswered. A copy of the survey questionnaire is available in the supplemental documents.

Table 3.1 Division of basins based on hydrologic and ecologic characteristics

Region	Subregion
Indus	Upper Indus Basin; Kabul-Afghanistan; KPK-FATA; Ravi-India; Satluj-India; Punjab; Sindh-Baluchistan; Delta
Mekong	Upper Mekong in China; Myanmar; Northern Thailand; Laos; Southern Thailand; Viet Nam Highlands; Cambodia; Viet Nam Mekong Delta
Niger	Headwater; Siguiiri-Kankan; Sankarani; Office du Niger; Bani; Inner Niger Delta–South; Inner Niger Delta–North; Middle-stream–Mali; Middle-stream–Niger; Middle-stream–Nigeria; Benue-Cameroon; Benue-Nigeria; Outlet Delta

Source: Developed by authors for this study.

Note: KPK: Khyber Pakhtunkhwa, FATA: Federally Administered Tribal Areas.

Respondents' organizational and professional backgrounds are summarized in Table 3.2. Most survey respondents consider themselves technical specialists. In both the Indus and Niger Basins, most respondents belong to government agencies, whereas in the Mekong most respondents have academic backgrounds. In all three basins, the majority of respondents operate at the national level. To gauge the level of data availability for research and management purposes, respondents were asked questions about data sources and data gaps encountered within the various water sectors. The subsequent questions on the survey asked respondents to quantify the basinwide importance of various ecosystem services under different scenarios. Respondents were then asked to rate the importance of the ecosystem services in each individual subregion of the river basin and identify the specific subregions that are most ecologically vulnerable. All three surveyed river basins are shared by several countries, and it is expected that international strategic issues would influence perceptions of ecosystem services. As shown in Table 3.2, a significant proportion of the respondents indicated the international nature of their work.

Table 3.2 Survey respondent summary, as a share of total respondents

Survey response	Indus	Mekong	Niger
Job specialization			
Project management	39.2	30.1	24.7
Technical specialist	44.3	39.7	52.0
Governance	8.9	6.8	11.7
Other	7.6	23.7	11.6
Organizational background			
Private company	6.3	12.2	1.3
Government agency	32.9	12.2	59.0
Academic	25.3	36.5	12.8
International NGO	17.7	23.0	10.3
Local NGO	8.9	2.7	2.6
Other	6.3	13.5	11.5
Regional nature of work			
International	33.3	53.8	30.0
National	74.4	63.9	66.3
Regional	37.2	44.4	43.8
District	19.2	20.8	7.5
Other	2.6	11.1	2.5

Source: Compiled by authors from e-surveys.

Note: NGO = nongovernmental organization.

4. RESULTS AND DISCUSSION

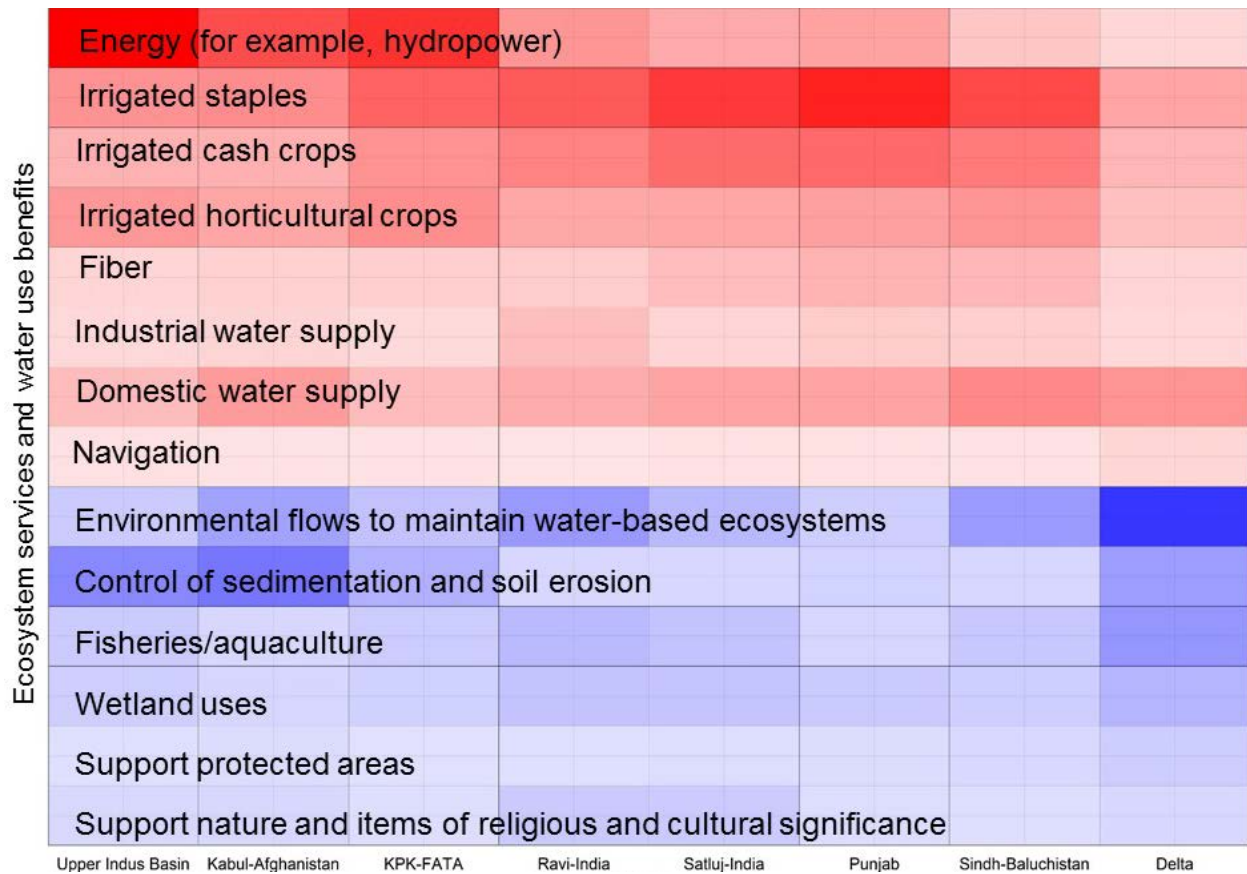
Intrabasin Heterogeneity

For each subregion in each basin, the survey asked respondents to score ecosystem services in terms of importance, with the total adding to 100. We use heat maps to display heterogeneity in responses to these questions for each basin. In heat maps, the subregions in the basin are organized upstream to downstream on the horizontal axis. The y-axis shows the various ecosystem services. MES are shaded in red, while NMES are shaded in blue. In this analysis, we designate fisheries as NMES, while recognizing the direct economic benefits they can also provide in certain areas. The intensity of the shade represents the average importance, calculated across all respondents in a river basin, for each service in each subregion.

Indus

Figure 4.1 shows that in the Indus Basin, water for energy generation and irrigated crops are the most prioritized ecosystem services. As expected, water for irrigated agriculture is the most preferred ecosystem service in the Lower Indus Basin. Water for energy generation was identified as the most important ecosystem service in the Upper Indus Basin, with its steep topography making it suitable for hydropower generation. The highest importance placed on domestic water supply is in Sindh-Baluchistan and the Delta Region (which broadly includes the Karachi metropolis). Shortages in water supply for domestic and industrial usage in these areas is well-documented (Mustafa 2007). For Punjab, the importance placed on domestic water supply is relatively low, which may be explained by the availability of easily accessible groundwater across most of the province (Khan et al. 2016).

Figure 4.1 Heat map illustrating the relative importance of various ecosystem services across different subregions in the Indus Basin



Source: Compiled by authors from e-surveys.

Note: KPK = Khyber Pakhtunkhwa, FATA = Federally Administered Tribal Areas.

Among NMES, sediment control and environmental flows emerge as the most important basinwide. The geographic distribution of NMES importance shows an interesting pattern, where the highest importance is placed in the most upstream (Upper Indus Basin and Kabul-Afghanistan) and downstream (Delta) parts of the basin. The Indus Delta is home to one of the world’s largest mangrove forests, which have been rapidly declining in area due to a combination of reduced river flows (and reduced sediment transport) and extensive logging (Memon and Thapa 2011). It is also a crucial breeding area for the fishery industry, which supports a large part of the local economy. NMES account for the top three most important services in the Delta, reflecting the Delta’s significance as an ecological hot spot.

When respondents were asked to describe the regional scale of their work, almost 50 percent of the respondents characterized their work as “international/across several countries” in the Indus Basin.

Another question asked respondents to select the countries in the Indus Basin that they focus on as part of their work. Interesting to note, only 16 percent of respondents indicated that they focused on countries other than Pakistan as part of their work. The discrepancy in the responses to these two questions may indicate that even though transboundary flows in the basin have been a topic of extensive debate (Uprety and Salman 2011), actual transboundary considerations in water resources planning are lacking.

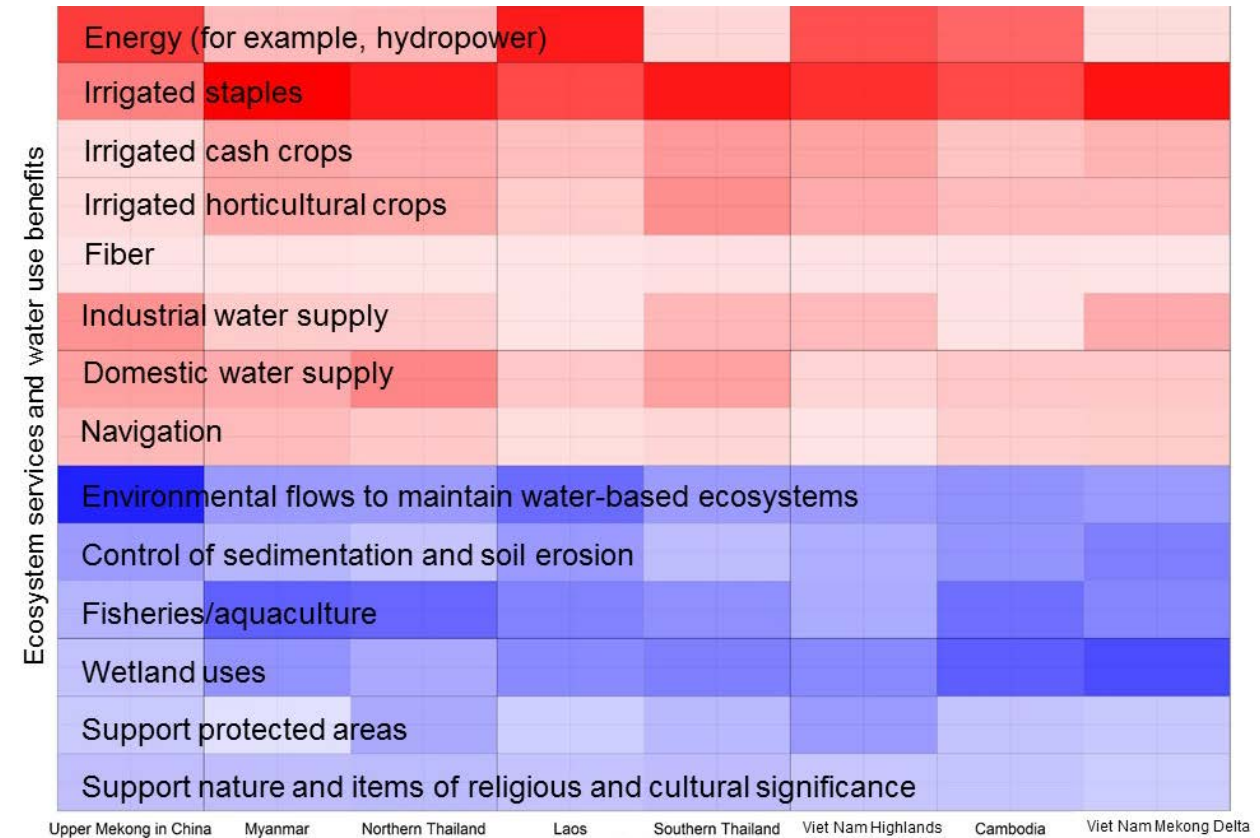
The survey results reveal the relatively low importance associated with NMES in Pakistan. While almost 40 percent of the respondents selected the “environment” as one of the sectors that they worked in, none of the NMES had an average score greater than 6 (out of a score of 100). In comparison, water for agriculture (irrigated staples, cash crops, and irrigated horticulture) had an average score of greater than 50. In another question, which asked respondents to indicate the ecosystem services most in need of increased investment, “environmental flows to maintain water-based ecosystems” scored the highest among NMES, but again with a low average score of 8. These survey results, when considered jointly, reinforce the perception that NMES provided by the Indus River are overlooked in the current decision-making paradigm in the Indus Basin, as identified in the existing literature (Meadows 2011).

Mekong

Rice production and fisheries play integral roles in food security and the overall economy of the Mekong Basin and particularly of the Lower Mekong Region where most of the basin population resides. It is no surprise then that for the Mekong, water for irrigated staples emerges as the most important ecosystem service across nearly all subregions, with the highest preference shown in the Viet Nam Mekong Delta Subregion. Figure 4.2 shows that the value placed on water for energy is highest in upstream Laos and China, with both countries viewing hydropower development as critical in national development plans (Baran and Myschowoda 2009). Among NMES, water for wetland uses and fisheries is the most valued. These services are deemed most important in Cambodia, home to the Tonle Sap, and in Viet Nam, with the highest per capita fish consumption in the basin (Hortle 2007). Water for environmental flows was selected as the most important ecosystem service for the Upper Mekong in China, possibly recognizing

the influential role these flows play for the ecosystems of downstream countries or simply admitting the reality that these flows had been affected by large-scale upstream reservoir construction.

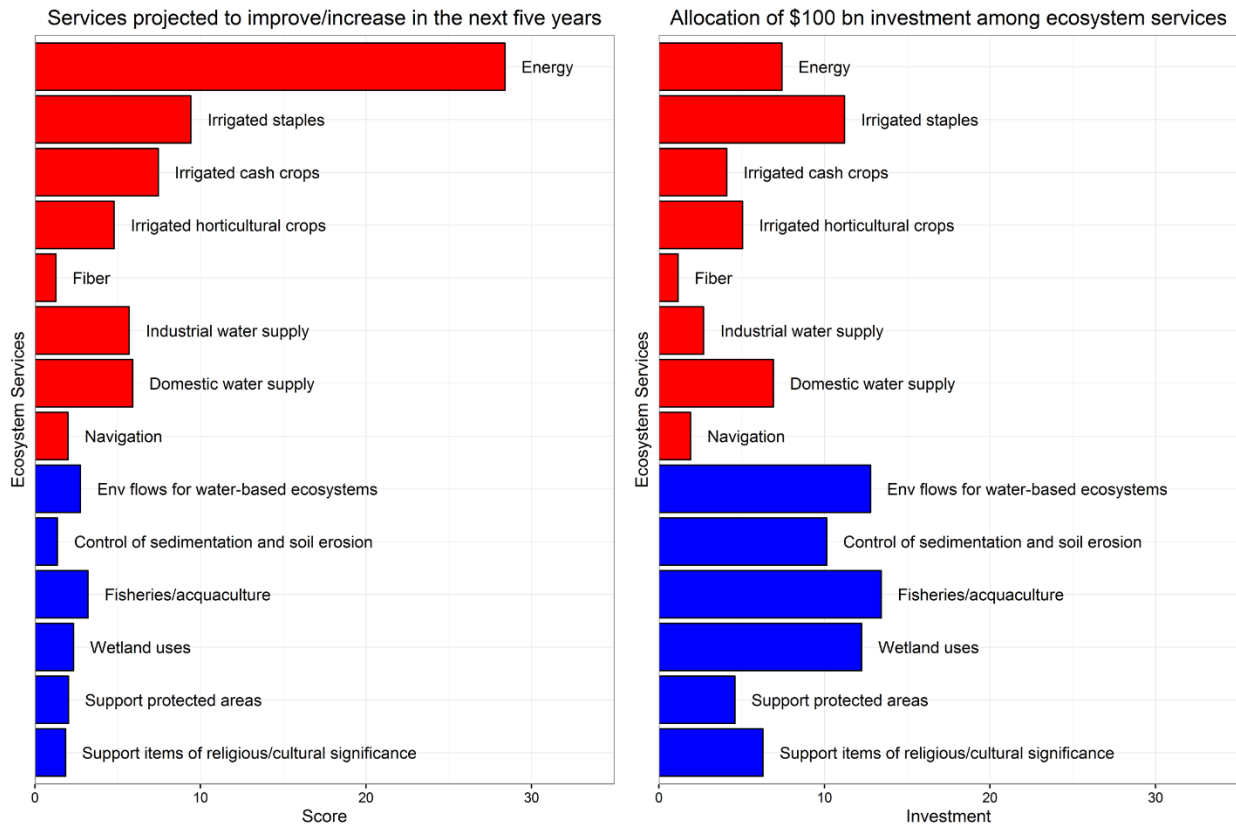
Figure 4.2 Heat map illustrating the relative importance of various ecosystem services across different subregions in the Mekong Basin



Source: Compiled by authors from e-surveys.

Provision of inexpensive and reliable energy has been identified as one of the most critical pathways to achieving economic development across the various countries in the Mekong River Basin (Grumbine and Xu 2011). The results of this survey reflect the urgency to tap the hydropower potential in the basin. Water for energy was overwhelmingly identified as the ecosystem service that is most likely to increase in quantity during the next five years, as shown in Figure 4.3, panel a. As expected, the subregions with the greatest hydropower potential and activity currently (Upper Mekong in China, Laos, and Cambodia) are correspondingly selected as places of significant activity or danger for ecosystems in another question.

Figure 4.3 Basinwide results for (a) ecosystem services projected to improve/increase during the next five years showing expected hydropower expansion and (b) identified needs for investment in the basin indicating desire to mitigate ecological consequences of hydropower expansion by ecosystem service



Source: Compiled by authors from e-surveys.
 Note: bn = billion; Env = environmental.

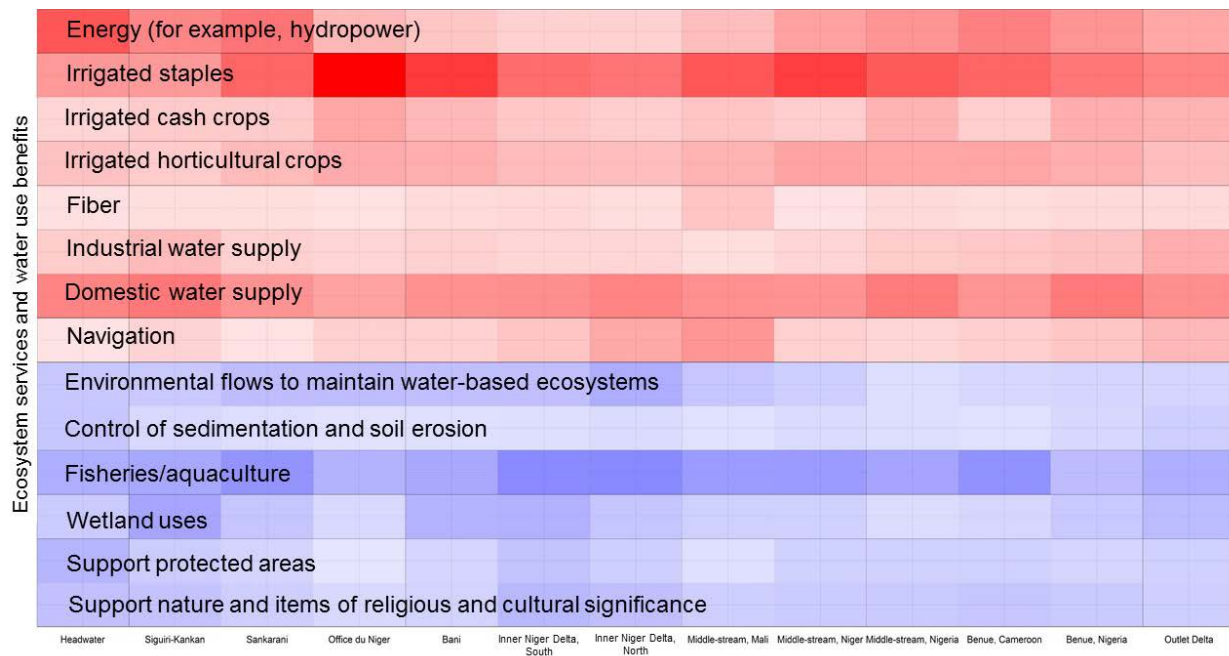
The potential expansion of hydropower energy generation in the Mekong River Basin has also led to increased fears regarding the impact of major infrastructure on the region’s ecology, especially on fisheries (Ziv et al. 2012). Survey respondents highlighted fisheries, wetlands, and environmental flows to water-based ecosystems as most likely to decline during the next five years. These same ecosystem services were identified as those that should get the largest shares of future basinwide investment, as shown in Figure 4.3, panel b. The survey results thus describe the growing awareness regarding consequences of hydropower development in the Mekong Basin as well as the desire to mitigate the associated ecological impacts. Given the integral role of NMES in the region’s economy and biodiversity, it is encouraging to see the awareness of important environmental issues and willingness to take tangible

actions to protect crucial habitats in the Mekong Basin. However, it is unclear where the hypothetical investments into these ecosystem services would come from.

Niger

Figure 4.4 shows that in the Niger River Basin, water for irrigated staples, water for domestic water supply, and water for fisheries were regarded as the most important ecosystem services. The heat map also reflects the significant spatial heterogeneity for the Niger. Fisheries are rated as highly important in the Inner Niger Delta and the Benue in Cameroon. Water for irrigated staples is most important in the Office du Niger and Bani (Mali) and the Middle-stream Niger and the Middle-stream Nigeria stretches, which also happen to have the largest share of irrigated areas in the basin. Access to potable water is low in most of the basin countries (World Bank 2014); this is reflected in the consistently high scores placed on domestic water supply across the entire basin. Water for energy is selected as the most important service in the headwaters and Sankarani where the Selingue Dam is located and the Fomi Dam is slated for construction (Zwarts et al. 2006).

Figure 4.4 Heat map illustrating the relative importance of various ecosystem services across different subregions in the Niger Basin



Source: Compiled by authors from e-surveys.

One of the survey questions asked respondents in the basin how they expected the different ecosystem services to develop in the future. In the Niger, MES are selected to be more likely to increase/improve in quantity/quality while NMES are predicted by respondents to be more likely to deteriorate in the future. In particular, fisheries and environmental flows are selected as most likely to be negatively affected, whereas the largest improvements are seen for irrigation and domestic water supplies. Set against the context of a significant increase in investment in infrastructure in the Niger River Basin (Andersen et al. 2005), this figure may reflect concerns among water stakeholders that the ecological impacts of the investments have not been properly addressed.

Interbasin Heterogeneity

Geographic Heterogeneity in Importance of Ecosystem Services

Given that agriculture accounts for more than 80 percent of water consumption across the world, it is not surprising that a comparison of ecosystem services importance between the Indus, Mekong, and Niger shows that water for irrigated staples is regarded by respondents as the most important. Compared to the Indus and the Mekong, the importance placed on irrigated staples in the Niger is slightly lower, most likely because much of the basin remains dependent on rainfed agriculture. Water for energy emerges as the second most highly scored ecosystem service. Two of the three basins in this study, Indus and Mekong, are increasingly investing heavily in hydropower facilities, a fact reflected in the survey results.

Surprisingly, domestic water supply does not feature as an important ecosystem service in the Indus and the Mekong, while it is considered somewhat important in the Niger. Domestic water supply is often cited as one of the most valued uses of water, especially in water-scarce regions and in those with poor infrastructure, as represented by all three of our study basins. It is not clear whether this low score is a result of people's expecting sufficient supply as a given or if it indicates lower importance than is commonly assumed. A possible reason for the low score assigned to domestic water supply might be related to the high use of groundwater for domestic purposes across both the Indus (Qureshi et al. 2010)

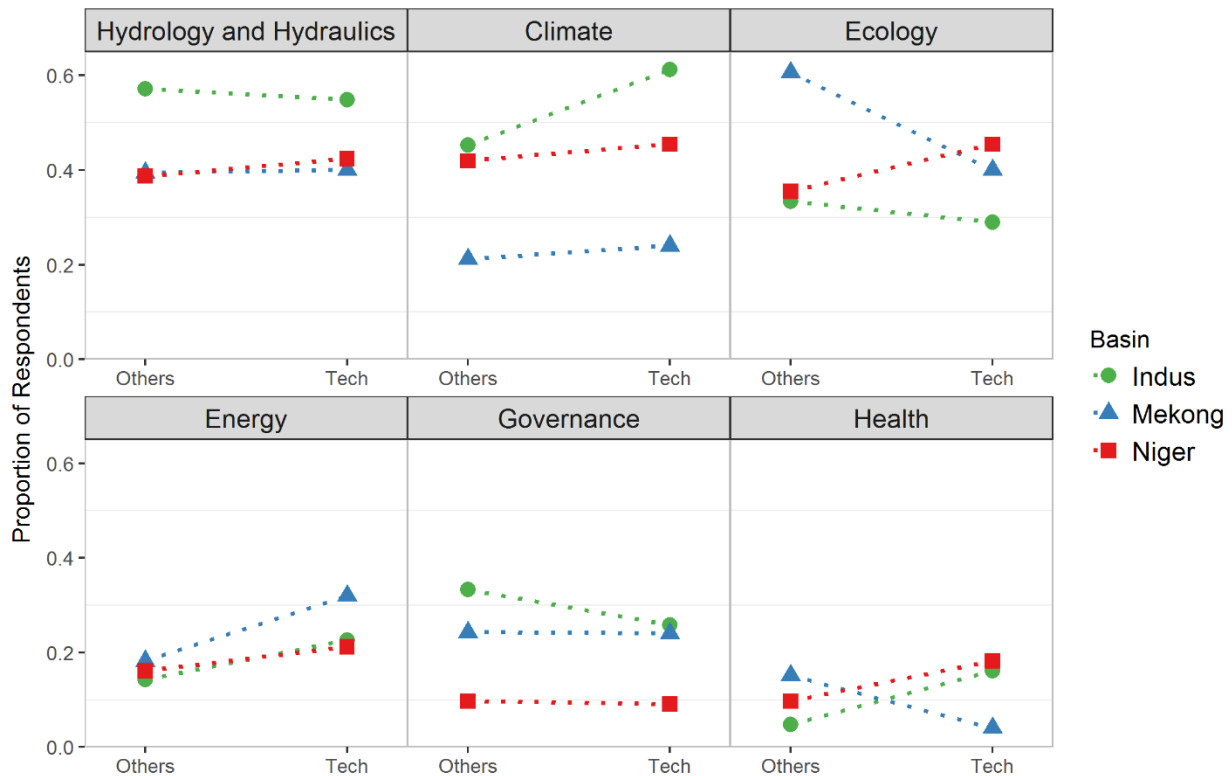
and the Mekong Basins (Ha et al. 2015) and the lack of awareness of the linkage between surface and groundwater resources.

Respondent Background and Perceived Data Gaps on Ecosystem Services

To illustrate the linkage between respondents' backgrounds and their perceptions about ecosystem services, we examine the question about identification of water-related sectors that suffer from limited data availability. The respondents were allowed to select as many water sectors as they believed suffered from data gaps. Here, we aim to assess whether respondent backgrounds influence the level of perceived gaps in datasets related to ecosystem services. Using one of the survey questions, we isolated a subset of respondents who possess a greater technical proficiency, scientific proficiency, or both. We compare the survey responses from our targeted subset with the responses from the rest of the respondents. Our initial hypothesis here is that technical specialists are generally more aware of and more affected by limited data availability. This would make them more likely to identify data gaps in the various water-sector fields.

Figure 4.5 shows the comparison between perceptions of data gaps among selected water-related sectors using slopegraphs. Each panel shows the perception of data gaps for technical specialists and the rest of the survey respondents in each basin. The y-axis shows the proportion of respondents in each group who selected a particular water sector as having limited data availability. The x-axis represents the respondent group type. The figure illustrates the patterns in recognition of data limitation across different water-related sectors in each basin by two distinct groups of respondents. Note that dash lines in Figure 4.5 are included to allow for easy comparison between the two sets of respondents; they do not imply any relationship.

Figure 4.5 Comparison between perceptions of data gaps among selected water-related sectors



Source: Produced by this study.

Note: Each panel shows the perception of data gaps for technical specialists and the rest of the survey respondents in each basin. Tech = technical specialists.

A few interesting findings emerge. Across all three basins, hydrological and hydraulic datasets are identified as being the most problematic by both technical specialists and other respondents. Limited streamflow data in river basins in developing countries are often cited as a key obstacle to performing water resources systems analysis (Akanda 2012). This limited data availability stems from both relatively insufficient gage data and restricted access to whichever data exist. Results suggest this is especially true for the Indus. On the other hand, technical specialists, more than the rest of the survey respondents in all three basins, consistently rated the climate and energy sectors as suffering from limited data. This is probably because technical specialists are more likely to be interacting with these datasets (for modeling or other research purposes) than are nonspecialists. A relatively low percentage of respondents, both technical specialists and others, identified limited health-related data as problematic. Given that several of the countries across these three basins experience high rates of water-related diseases, this result is

slightly counterintuitive. A plausible explanation for this may be that a majority of the respondents to this survey are not actively involved with research in the public health sector and thus are not aware of the state of data availability in this field.

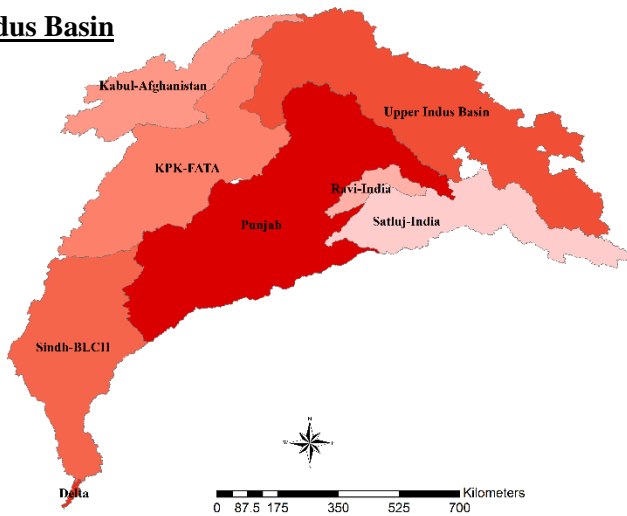
When analyzing the results from a basin perspective, across both respondent types, we observe that for the Indus and the Niger, climatic datasets (precipitation and temperature) are identified as the most significant obstacle to research. This may be because through a combination of water scarcity and relatively high interannual variability in precipitation, their economies are more vulnerable to climatic variations, which makes the availability of reliable and robust climate data particularly crucial. For the Mekong, data gaps are considered largest for ecological data, which is intuitive given the high levels of biodiversity in the Mekong Basin and its crucial role in the region's economy. It may also reflect a greater concern for ecological issues, a conclusion supported by results previously discussed. Collectively, we do not observe for these basins a predictive pattern connecting respondent background with specific water-sector issues. The absence of a trend emerging across the basins is not surprising, given the considerable diversity in the cultural, institutional, and hydrological background exhibited by the various stakeholders (as shown in Table 3.2).

Location of Ecosystem Hot Spots

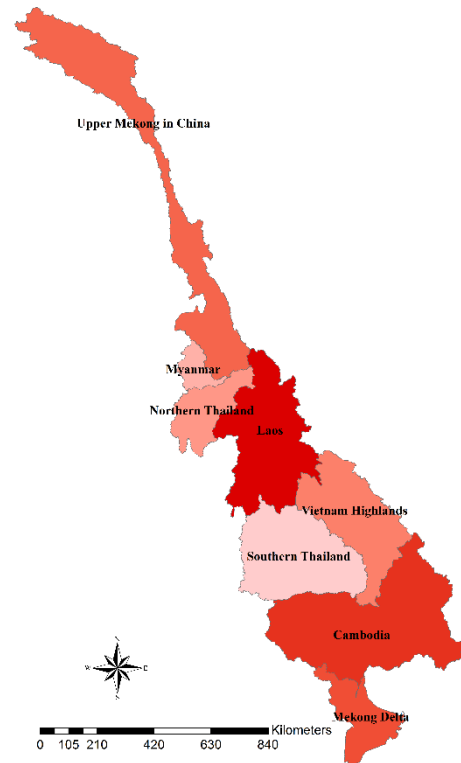
To identify areas of the basin that are perceived to be most at risk, we asked survey respondents to assign scores to the subregions that they consider to be ecosystem hot spots (that is, places of significant activity or danger), with total scores adding up to 100. In Figure 4.6, the intensity of the color corresponds to the rank assigned to each subregion in a basin with regard to risk to ecosystems.

Figure 4.6 Relative ranking of subregions as ecosystem hot spots across the (a) Indus, (b) Mekong, and (c) Niger River Basins

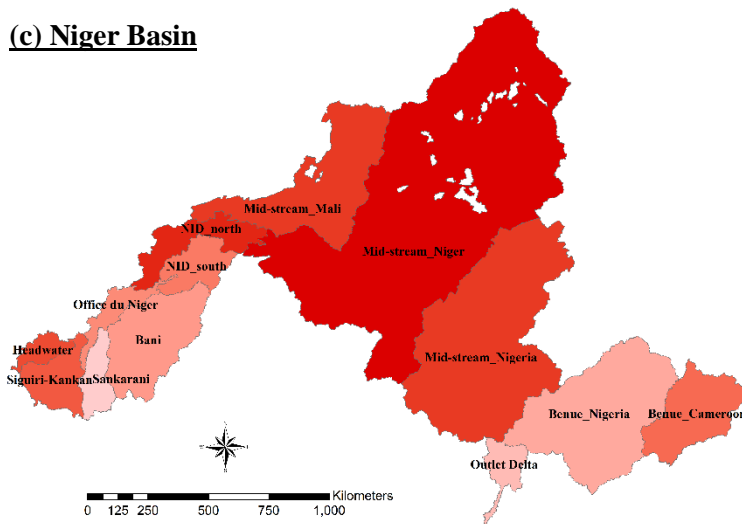
(a) Indus Basin



(b) Mekong Basin



(c) Niger Basin



Source: Compiled by authors from e-surveys.

For the Indus, Punjab Province was ranked by the respondents as the most at-risk region. Punjab accounts for the largest share of national food production in the basin, and this may reflect the high importance placed on food security relative to ecological protection by stakeholders in the basin. A similar pattern is observed for the Niger, where the Middle-stream Niger is identified as the most significant hot spot, an area that also has the largest share of irrigation in the basin. For both the Indus and the Niger, the Delta Region is ranked second in terms of danger to ecosystems. While consistent across both basins, this finding is a little counterintuitive, as deltas might be more likely contenders as ecosystem hot spots than irrigated areas. A possible reason for this result may be the interpretation of the question by

the survey respondents, an issue discussed in greater length in the following section. In the Mekong Basin, Laos and Cambodia emerge as the top two ranked ecosystem hot spots. These are areas where hydropower development is projected to increase substantially, thereby affecting the health of the fisheries downstream.

Application of Results to Decentralized Water Systems Models

Soliciting and incorporating input from stakeholders during development of water systems models has been recognized as crucial to establishing trust in modeling results, ensuring accountability and providing a realistic representation of water users' preferences (Lund and Palmer 1997). Insights gained by this inter-continental survey exercise emphasize the significant spatial heterogeneity that exists not only across but also within different river basins. In this study, we quantify the different priorities that underlie the well-documented management conflicts between upstream and downstream riparian users. Estimates of importance of various water uses can be used to inform behavioral patterns and water use needs of different water users in water systems models. Of particular interest is the decentralized modeling approach (Yang, Cai, and Stipanović 2009) that adopts a bottom-up process and enables a better representation of the interactions between heterogeneous subsystems (that is, agents).

Agent-based modeling, a decentralized modeling approach, provides a useful avenue to incorporate diverse stakeholder preferences in water resources systems analysis. The e-survey results will be used in an agent-based water management model to inform agents' behavior rules and improve its representation of differing water needs. In the simulation model, the agents make water management decisions based on the importance placed on the different ecosystem services (that is, results from heat maps). In case of conflicting uses of a limited amount of water, the agent decides to allocate water to the use with the higher importance, as provided in the surveys. This decentralized agent-based model is then coupled with a process-based hydrologic model to simulate development pathways for each of the three river basins. Incorporating measured preferences into the model enhances confidence in our simulation of development and investment pathways for these rapidly developing river basins.

Limitations

Traditionally, consideration of nonmaterial or nonmonetary services has been implicitly embedded within larger political decision frameworks. Here we advocate for the explicit integration of ecosystem values in water management decisions and policies. The survey in this study is not meant to provide a definitive framework for doing so; instead, it aims to highlight the potential benefits of increased understanding of heterogeneous water use preferences. In situations where values attached to marginal changes in ecosystem services are difficult to obtain through surveys, smaller workshops or focus groups can be organized to understand these services (Bullock and O'Shea 2016).

Surveys are prone to sometimes not being able to fully capture “true” preferences due to response effects caused by misinterpretation of the wording of the survey (Hanemann 1994). We tried to account for this limitation by including detailed explanations of the terms used in the survey and by carefully wording the survey questions, but since this survey was conducted electronically, it is impossible to entirely rule out the possibility of discrepancies between interpretations of the questions across the survey population. To further explore the underlying reasons for choices made by the survey respondents, follow-up in-person interviews with some of the survey respondents would be a useful avenue of future research. Moreover, survey responses might well include strategic considerations in addition to true reflections of perceived priorities of ecosystem services. As described well in Wolf (2001), demands on transboundary water sources are often “overwhelmed by political considerations.” Despite this, water has more often become “a catalyst to dialogue and cooperation” than the actual source of transboundary conflict. This is further supported by the existence of intergovernmental basin agencies for the Mekong and Niger and the strength of the Indus Water treaty (Rosegrant 1997).

Climate change and stakeholders’ perceptions of its impact were not explicitly investigated in the survey. The potentially significant impact of climate change on water resources in the surveyed basins could influence social values arising from management decisions. Future investigations of stakeholder perceptions would be well served to address these impacts.

Moreover, we attempt to gauge stakeholder preferences over a large spatial extent. We addressed this by including survey respondents from diverse organizational, regional, and occupational backgrounds. We recognize that the responses are from a select subset of stakeholders and that results from these surveys are not necessarily representative of the entire populations of each of the river basins. In particular, stakeholders without Internet access and those without French or English language skills were excluded. Moreover, based on the small sample size relative to the population, data are insufficient to allow for a rigorous evaluation of statistical significance. While we recognize this shortcoming, the intent of this study is not to statistically prove or disprove a particular result but rather to inform, complement, and enhance decentralized modeling in water resources systems analysis.

5. CONCLUDING REMARKS

Recognizing the importance placed on different ecosystem services provided by rivers is critical for effective water resources management. Human interactions with the natural system are not well represented in traditional water systems analysis. This is due, among other things, to a lack of information about perceptions of riverine ecosystem services that drive human interventions. Findings from this study improve our understanding of the heterogeneity of stakeholder perceptions, further stressing the need to incorporate such variations into water-related decision-making processes.

Across all basins, water for food production emerges as the most critical water use. With many countries in all three basins suffering from energy shortages, water for energy (hydroelectricity generation) is highlighted as an ecosystem service requiring investment and improvement in the future. NMES are prioritized much more in the Delta Regions of all river basins and are particularly valued in the Mekong Basin.

The results illustrate, in addition to the noticeable differences between perceptions across the three basins, significant spatial heterogeneity within each of the basins. We also observe that the responses of stakeholders to the perception of various basinwide water-sector issues are, in some cases, influenced by their technical backgrounds. These survey results can support decentralized water systems modeling that allows a representation of decision makers with locally heterogeneous conditions who act based on their unique perceptions of ecosystem services.

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