DO REGIONAL DISPARITIES IN RESEARCH ON CLIMATE AND WATER INFLUENCE ADAPTIVE CAPACITY?

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Abstract. As part of a long-term effort to both improve access to information on climate change and freshwater resources, and to understand the state of the science, we compiled an electronic bibliography of scientific literature in that area. We analyzed the distribution of information on climatic impacts on freshwater resources, with an emphasis on differences between developed and developing regions as well as differences in the types and focus of research carried out among regions. There has been more research overall in developed countries than in the developing world. Proportionally more of the available research on natural and human systems pertains to developed regions, while most of the analysis done in developing countries is limited to higher-level climatology and hydrology. We argue that scientific information and understanding are important elements of the ability to adapt to potential climatic changes. The distribution of the scientific literature in our database suggests that the types of science most directly relevant to adaptive capacity are skewed towards developed countries, which may exacerbate existing disparities in adaptive capacity, and ultimately worsen the consequences of climatic impacts in developing countries.

1. Introduction

International scientific consensus states that climate change is expected to alter hydrologic regimes throughout the world, with impacts on water supply, water quality, and water management (Houghton et al., 2001). The effects of climate changes on water resources will vary regionally because of differences in climate impacts, vulnerability, and adaptive capacity, requiring widely different societal and governmental responses.

Vulnerability typically refers to the extent to which climate change may damage or harm a system, depending on both its sensitivity and adaptive capacity. Adaptive capacity refers to the ability of a system to adjust to and cope with the consequences of change (McCarthy et al., 2001). Estimates of adaptive capacity vary from region to region around the world, and these estimates inform current debates about equity in the distribution of impacts to climatic change. This paper presents a meta-analysis of the data contained in the Pacific Institute Water and Climate Database (www.pacinst.org/resources), a collection of references relating to global climate and water issues.

Reference keywords were aggregated into three main categories – Climate and Hydrology, Natural Systems, and Human Systems – and analyzed for regional

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distribution between the developed and developing world. This meta-analysis reflects potential patterns in the regional distribution of scientific study, which has broader implications for the differential adaptive capacities of developing and developed countries.

Assessments of adaptive capacity tend to focus on human or natural capital (McCarthy et al., 2001) or on a specified set of socioeconomic and political variables (e.g. Ilbery et al., 1997; Clark et al., 1998; Campbell, 1999; Hammer et al., 2000; Kates, 2000; Nelson and Finanm, 2000; Vázquez-León et al., 2003). We argue that the scientific knowledge in any region may be an important factor in adaptive capacity that has been underemphasized in the literature to this point. The distribution of scientific literature suggests that this aspect of adaptive capacity is skewed towards the developed world in ways that may exacerbate existing disparities in adaptive capacity.

2. Methods

We compiled a database of global scientific references for climate and water research. References were gathered by scanning the contents of selected journals from their inception until the end of 2002, adding any articles related to some aspects of both climate and water. Reference lists in relevant papers were also scanned for further titles and references were added through related research, online contributions, and suggestions by colleagues.

This database was expanded from a comprehensive U.S.-centered bibliography (Chalecki and Gleick, 1999), and is currently available at www.pacinst.org/resources. Keywords were assigned using a controlled vocabulary for consistency (Table I). We limited our analysis of the metadata in the bibliography to the year 2000 and earlier, because the method of gathering references biased against recent publications and the project concluded in 2002. Future versions of the bibliography will be updated with newer citations, and a re-analysis might prove interesting. The version analyzed for this paper contained 3600 references, including journal articles, book chapters, conference proceedings, and gray literature.

Our analysis of this bibliography utilizes a consistent set of subject and regional keywords on the subject of climate and water. By contrast, scientometric studies typically analyze ISI's Science Citation Index (Marx et al., 2001), and rely on searching for keywords from abstracts and titles. The ISI methodology has limits: searching an ISI database for "climate and water" will not locate many of the references with keywords "precipitation" or "hydrology," while our database includes references at the intersection of these research areas. In addition, study sites are most often described as specific locations in titles and abstracts (e.g., Sacramento River Basin), but climatic changes operate over larger spatial scales (e.g., Western United States). Thus, the bibliography also affords a unique opportunity for analysis of spatial and temporal patterns on scales relevant to climatic changes and geopolitical changes.

TABLE I
Keywords comprising the thesaurus used to analyze the bibliography, and the higher-order categories to which they are assigned. Assignment of ambiguous keywords is discussed in the text.

Climate and hydrology	Natural systems	Human systems
Modeling	Agriculture	Adaptation
Remote sensing	Biodiversity	Climate change assessment
Climate feedbacks	Coastal systems	Economics
Climate variability	Desertification	Human health
Drought	Ecology/ecosystems	Hydropower
ENSO	Estuaries	Irrigation
Evapotranspiration	Fisheries	Land use
Extreme/nonlinear events	Forests	Legal issues
Flood	Groundwater	Navigation/transportation
Glaciers	Lakes	Policy
Historical climate	Permafrost	Population
Hydrogeological cycle	Plant ecology	Recreation/tourism
Hydrology	Snowmelt	Reservoirs/storage
Ice cover	Snowpack	Security/defense
Lake ice cover	Water supply	Social issues
Lake level fluctuation	Wetlands	Urban issues
Paleoclimate		Water conservation
Precipitation		Water infrastructure
Rainfall		Water management
Rivers/streams/runoff/streamflow		Water use
Sea level rise		
Snowfall		
Soil moisture		
Storms		

In analyzing bibliography metadata, we concentrated on whether particular regions or keywords were represented in a reference. So, for example, a study that had both Natural Systems and Climate and Hydrology keywords would be counted once for each of these groupings. This may introduce pseudoreplication, but we believe that the trends reflect real and unsurprising patterns. Filtering the data in other ways gives similar results that are also highly statistically significant.

Our database contains only references in English, introducing the possibility of linguistic bias that could account for regional trends. English is widely recognized as the international *lingua franca* of science (Garfield, 1989) - almost all of the citations in the IPCC TAR are in English (Houghton et al., 2001; McCarthy et al., 2001; Metz et al., 2001). However, it is likely that European grey literature is underrepresented. In addition, this database is a relatively small (3600 references) subset of a large literature on climate change. Thus, it is with caution that broader conclusions are drawn from trends in this subset of the literature, particularly with respect to local knowledge. Though the aggregations discussed here reflect important and real trends, readers should not assume that these results are transferable to other kinds of climate impacts.

3. Results

Our data reflect the unsurprising trend that more scientific effort has been put into research into climate change and water in developed countries (UNESCO, 2001). North America has been the subject of more work in this bibliography than the sum total of all the other continental regions combined (Figure 1), followed by studies of global scope, Europe, Asia, Africa and Oceania. North America, Europe, and Oceania were taken as a proxy for the developed world (Table II), after the example of the IPCC (McCarthy et al., 2001). With some obvious exceptions, other regions represent mostly developing countries for the purposes of this analysis.

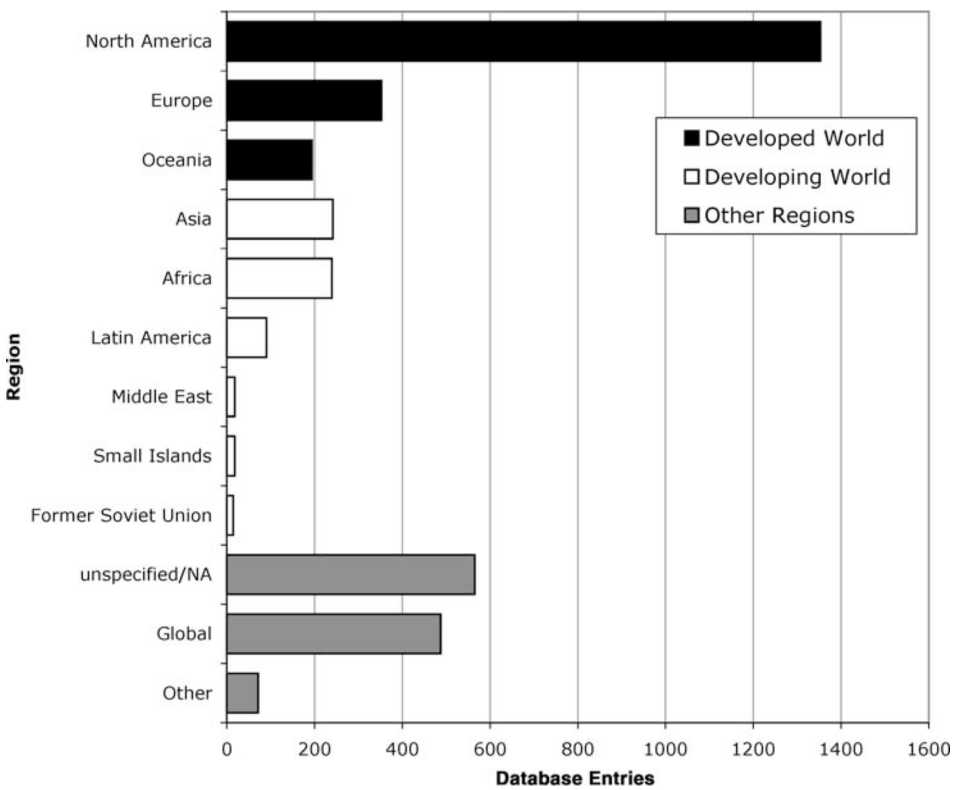


Figure 1. Regional distribution of all references in the bibliography. The "other" category includes references to regions such as "northern hemisphere" and "tropical."

TABLE II
Regional keywords grouped as proxies for development level. Developed and developing regions do not sort perfectly, but a more rigid classification would likely make the trends even more pronounced

Developing regions	Developed regions	Other regions
Africa	Europe	Global
Asia	North America	Small islands
China	Canada	Unspecified/NA
India	Great Lakes	
Former Soviet Union	Mexico	
Latin America	US	
Middle East	US East	
	US West	
	California	
	US-Mexico border	
	Oceania	
	Australia	

Figure 2 shows how the water and climate literature has been changing over time, with increasing research in all regions. This figure implies that while work on developing regions is increasing, it will take some time before the developing world can “catch up” with the level of understanding of potential effects of and responses to climate change.

Given the regional differences in *how much* science has been done, it is also appropriate to examine *what kind* of science has been done. We assigned each keyword to one of three categories: Climate and Hydrology, Natural Systems, and Human Systems (Table I). These categories are meaningful in several ways.

First, they are of ascending complexity. Climate and Hydrology articles generally relate hydrology to some aspects of general circulation model (GCM) output or historical observation. Although GCMs are complex, they are based for the most part on fundamental physics. Conversely, the workings of natural systems (e.g., ecosystems) are based on sets of relationships that are less well understood, have been less successfully modeled, and tend generally to require more empirical approaches. Human systems are still more complex.

Second, the categories are inherently nested and interrelated. Studies of climatic impacts on Natural Systems build on information from Climate and Hydrology. For example, projected changes in regional water supply might be based on modeled changes in temperature and precipitation. Likewise, the impacts of climate on Human Systems often come through changes in Natural Systems, such as how changes in water supply may affect economic or social systems through changes in hydropower or irrigation water availability (see, for example, Hanemann and McCann, 1993; Frederick and Schwarz, 1999). Conversely, human systems can impact natural systems.

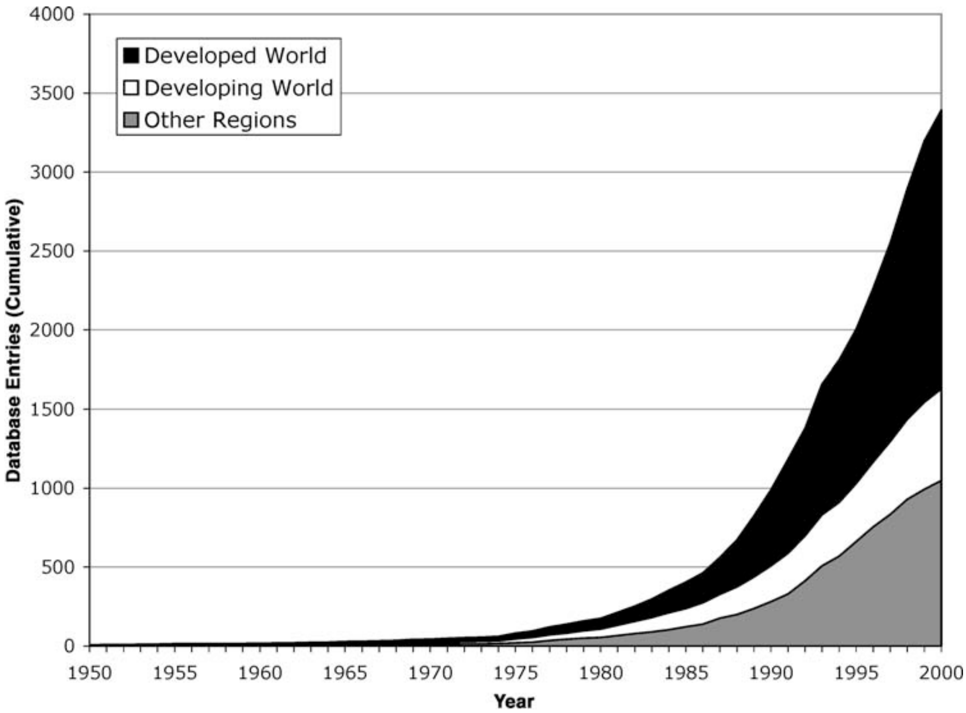


Figure 2. Cumulative distribution of all references over time by regional category. This figure may reflect the development of the field of climate and water regionally, and the disparity in the total bodies of knowledge on the subject between developing and developed regions of the world. "Other" regions include categories such as "tropical" or "northern hemisphere."

Finally, these categories generally have increasing relevance to humans and society. While humans care about the weather, its impacts on the natural systems around us are more fundamental concerns, and potential changes in social and economic structures are still more important. Thus, the Human Systems category generally has the greatest direct relevance to society. Further, elements in the Human Systems category tend to require more human management than natural systems (although natural systems may also benefit from management).

For ambiguous category choices we took into account all three of the characteristics defined above. For example, while fishing is primarily a human activity, the state of the fisheries themselves is a natural system. More questionable is including agriculture under natural systems using similar logic, but it can be justified through comparison to other keywords in each category. While some references dealt in broad terms with urban issues, there are no overviews of rural issues in the database that did not instead fall under other categories. The absence of this category makes a telling point in and of itself.

Overall, the Climate and Hydrology category has the most references (66%), followed by Natural (16%) and Human Systems (18%). In absolute terms, more work on Climate and Hydrology has been carried out in developed than in developing regions (Figure 3). However, in developed regions this category is a smaller proportion of overall work than it is in developing regions.

The most important finding from our analysis is that developing regions not only have a smaller overall body of work on climate and water, but that work in these regions to this point has been skewed away from the subjects that are of greatest importance to human societies. Work on Natural Systems and Human Systems is concentrated in the developed world in both absolute and relative terms (Figure 3). In absolute terms, developing regions have had less science done in either the Natural Systems (10%) or the Human Systems (7%) categories. They are also proportionally under-represented. An emphasis on basic hydrological research in developing regions may be appropriate given their generally less developed water resource systems, but this does not detract from the importance of higher-order studies.

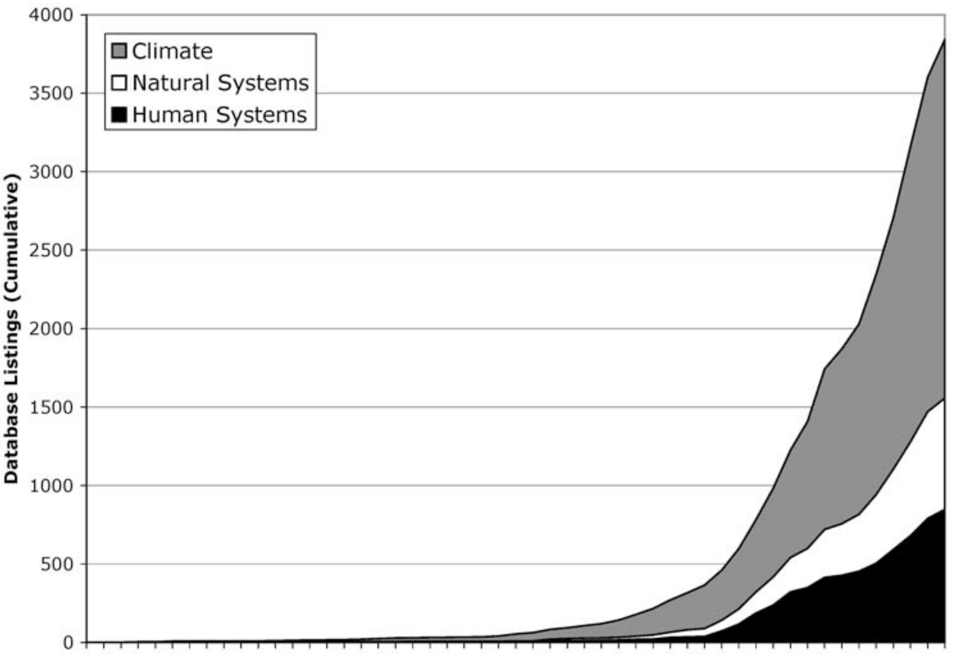
Another potential explanation for the paucity of work on Human Systems in the developing world may be that the target audience for sensitivity studies in a given locale may be less likely to speak or read English. Thus, such studies may be more likely to have local outlets in other languages than international ones in English, an artifact of our linguistic bias. However, given the internationalism of science, this is unlikely to be significant. This sample represents a particular cross section of climate work – climate and water – which may also introduce bias. A meta-analysis of the climate and agriculture literature might yield different results, for example. Despite these caveats, and given the fact that water issues are also connected to many issues of higher-order complexity, trends illustrated by this sample raise some issues of global concern.

4. Discussion

Science can in some cases help water managers adapt to climate change, while in other cases lack of a sufficient knowledge base may limit adaptive capacity. Regional differences in the *types* of existing scientific knowledge may also exacerbate such limitations. Analysis of the Pacific Institute's Water and Climate Bibliography reveals regional patterns in the distribution of scientific references. The most striking pattern is the relative paucity of research on Natural Systems and Human Systems in developing areas of the world, because these categories are most directly relevant to coping with projected climatic changes. If these results reflect a real pattern of differential scientific preparation, this finding suggests that even greater disparities may exist than are suggested by recognized issues of scientific equity such as differential scientific quantity, quality, funding and application.

Preparing for the impacts of climate change on water resources will require smart and effective management of both natural and human water systems, with water management systems capable of dealing with existing climate variability constituting one of the most basic necessities. However, scientific study and information on the nature of possible impacts is also a necessary component of preparedness. The results from this analysis indicate that developing countries are behind not only in their economic ability to cope with the potential effects of climatic change on water resources, as has been pointed out elsewhere (McCarthy et al., 2001), but also in the body of knowledge that would allow 'pre-adaptation' in the form of institutional planning and preparedness.

In addition to its influence on adaptive capacity in the sense of preparedness, scientific research is also an important component of the information leading to local perception of vulnerability to climate change (Wallner et al., 2003). Perception is a



(a) Developed regions

Figure 3. Cumulative distributions of categorized references in (a) developed and (b) developing regions show that relatively little work has been done on human and natural systems in developing countries. The figures indicate not only the absolute differences in numbers of references for each category, but also the differences in the relative amounts of work on higher-order systems. The developed world has not only had more work done on climate and water, but has had a larger proportion of work done on topics of direct interest to society (χ^2, $p < 0.001$).

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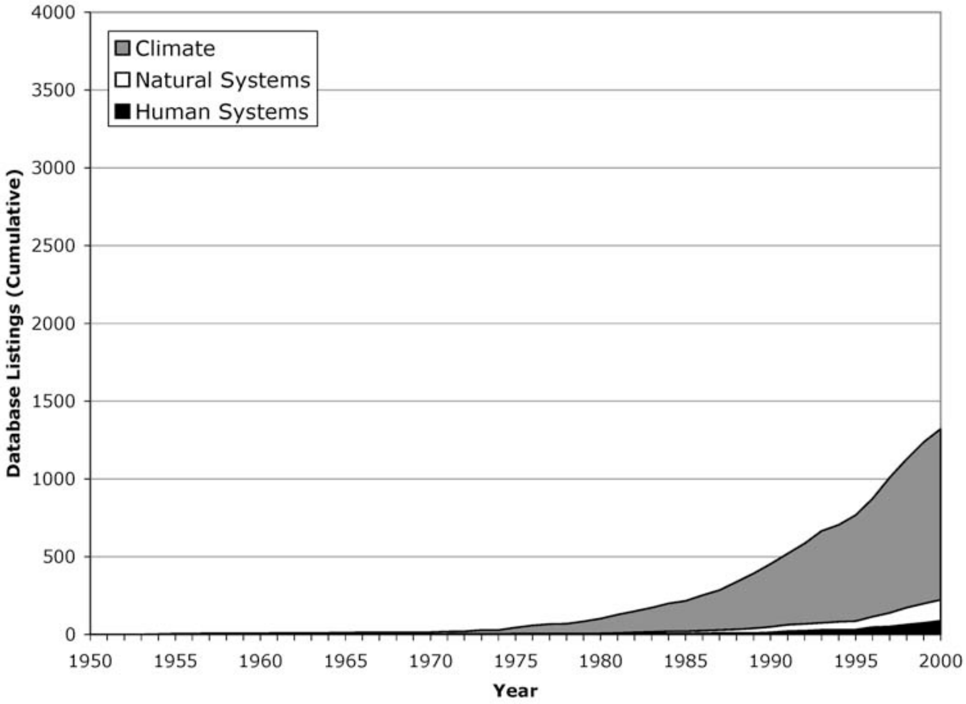

(b) Developing regions

Figure 3. (*Continued*)

critical driver of local actions (Bullock and Connor, 2003), and the lack of science in the developing world may hinder local efforts to prepare.

That more research is carried out by developed-world scientists is not a new result. In 1997 developed countries invested disproportionately in scientific research and development compared to less developed countries, both in terms of population and gross domestic product (UNESCO, 2001). Indeed, the developed world had ten times as many scientists per million people as the less-developed world (UNESCO, 2001).

Although some have alleged a "conspiracy of silence" accounting for scientific disparities (Agarwal, 2002), another explanation for the trends in Figure 3 might be a later start on the part of research institutions in developing countries to address these issues. This may reflect disparities in financial resources and the higher priority given to other more pressing scientific and social issues. A conceptual model for a temporal pattern of study of the impacts of climate change on water resources follows: (1) A research program starts with modeling of precipitation, temperature, and basic hydrological variables. (2) After these lower-level building blocks are in place, scientists build on this work to study rivers, lakes, ecosystems, and other natural systems. (3) Only then can informed assessment be made about impacts on society, management, coping, and other human systems. This would be consistent with the observed temporal disparities in research, and further suggests that rectifying this situation will require sustained and consistent national and international support over time.

In each regional breakdown of our sample, the body of research on Climate and Hydrology has historically increased more quickly since 1970, followed temporally by the other categories (Figure 3), which generally supports our conceptual model. However, our data suggest different patterns for developed and developing regions (Figure 3). In developing regions, the above conceptual model is supported by the temporal lag in the number of references to Human Systems as compared to Natural Systems. In developed countries, however, our sample suggests that research in Human Systems has more closely paralleled research in Natural Systems.

It is important to acknowledge that there may be "shortcuts," through which developing nations can learn from and apply principles explored in other areas. However, water management in the developing world is so fundamentally different from that in developed areas (e.g. Briscoe, 1996, 1999; Kahn and Siddique, 2000; World Commission on Dams, 2000) that the transferable lessons may be limited. For example, GCMs by definition have global scale, producing scenarios available for every region in the world. Interpretation and in particular downscaling these data is still a technically, computationally, and financially intensive activity. The motivation and resources necessary to produce hydrologic data at scales relevant to local problems may not be available in poor countries.

The patterns described above relate to larger issues of equity in the regional distribution of the impacts of climate change on societies. IPCC's regional analysis of the impacts of climate change acknowledges that adaptive capacity is unevenly distributed globally. It states that developing countries are expected to suffer more adverse impacts from, and to be more vulnerable to climate change than developed countries (McCarthy et al., 2001; Baer, 2002). It is important to acknowledge that scientific information and adaptive capacity are also unevenly distributed *within* individual countries (Kates, 2000), although our data do not allow an assessment of these disparities.

We argue that not only is science an important ingredient in integrating climate change to water management, but that in some cases lack of sufficient knowledge base may potentially limit adaptive capacity. IPCC emphasizes that human and natural capital are the primary resources for adaptive capacity in a society, and social studies in the developing world suggest that the actual determinants of adaptive capacity are far more complex and localized. For example, work in South Asia suggests that cultural and behavioral adaptability actually allow the poorest populations (presumably having the least access to scientific knowledge), to have better adaptability to floods and droughts through diverse livelihoods (Moench and Dixit, 2004). In addition, indigenous knowledge may be an important factor. Fundamentally, however, information is a component of adaptive capacity, and we are unaware of previous analyses that explicitly address scientific knowledge as a factor.

In addition to the limited capacity for adaptive response by developing countries, lack of science could hinder the work of international development agencies. IPCC notes that inclusion of climatic risks in international development initiatives could help mitigate disproportionate climatic impacts (McCarthy et al., 2001). However, without region-specific projections of impacts on institutions targeted for such initiatives, it will be difficult to motivate such efforts, and they may not be as effective. Lack of science to drive development initiatives could skew adaptation options in developing countries towards cultural and behavioral ones and away from legislative or technical ones.

5. Conclusion

Our meta-analysis of literature on climate change and water resources suggests that scientific effort on this subject has not been evenly distributed between developed and developing regions of the world or among the types of research done. More work has been carried out in all categories of climate and water research in the developed world. Overall, more analysis has been done on climate and hydrology than on natural and human systems, which are likely to be the subjects most relevant to adaptation of human society to climatic changes. Our main finding is that the disparity between these types of work is even greater in developing regions of the world.

IPCC and others have defined adaptive capacity as primarily related to the degree of economic resources available in a particular country. However, scientific study of the potential effects of climatic changes may be an important and underemphasized aspect of preparedness for adaptation. In addition, the disparity in the areas of closer direct relevance to human society may imply that the difference in knowledge needed to adapt to future changes in climate and water is more skewed than has previously been noted.

If the regional disparity in scientific effort revealed in our database reflects real trends, then there may be implications for estimating adaptive capacity in developing countries. These conclusions should be treated with caution because of noted biases in our data set and the complex nature and competing definitions of "adaptive capacity." However, these broad-brush quantitative results strongly suggest the need for more research on the impacts of climate change and water in developing countries, more assessments of human and natural impacts, as opposed to just higher-level hydrologic analyses, and in-depth qualitative research on the influence of scientific knowledge on adaptive capacity.

There is some hope that scientific activity in developing countries may be increasing (e.g. Holmgren and Schnitzer, 2004). Regardless, increased basic scientific research on the effects of climate change on water resources in developing countries is needed to improve preparedness for climate variability and change. It could also potentially reduce a disparity in adaptive capacity between developed and developing regions.

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