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Water Resources and Indicators of Conflict
A Proposed Spatial Analysis

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Abstract: *Analysis of current economic and environmental trends reveals increasing competition over access to and use of freshwater resources at the same time that population growth, economic development, and potential climate change are adding stress to those resources. Given these trends, it is hardly surprising that in the policy literature and the popular press the issues of water and conflict are being raised together with increasing frequency. The Transboundary Freshwater Dispute Database (TFDD) project at Oregon State University delineates 261 international river basins. Professionals concerned with security-related issues have an interest in being able to identify which of those basins may be prone to conflict over water resources, from both a perspective of intra-state and inter-state instability and conflict. Having such knowledge allows for the possibility of "preventive diplomacy," whereby diplomatic intervention prevents the escalation of disputes over shared water resources into violent conflict. Identification of basins prone to water conflict requires a framework that incorporates a wide array of physical, social, economic, and political variables, the implications of these variables at different spatial and temporal scales, and the linkages across scales. This paper proposes a methodology for defining potential indicators of international water conflict and portraying these indicators spatially within a Geographic Information System. Indicators will be defined across multiple scales in a parallel analysis of global and basin attributes. While indicators should be viewed with a healthy skepticism, they still provide value when defined through an effective analytical framework that takes into account the availability and appropriateness of relevant data and information sources.*
Keywords: *International river basins, conflict, indicators, geographic information systems (GIS).*

Introduction

Identification of basins prone to water conflict requires a framework that incorporates a wide array of physical, social, economic, and political variables, the implications of these variables at different spatial and temporal scales, and the linkages across scales. This paper proposes a methodology for defining potential indicators of international water conflict and spatially analyzing and portraying these indicators within a Geographic Information System (GIS). Indicators will be defined across multiple scales in a parallel analysis of global and basin attributes.

This paper seeks only to propose a framework and analytic model; the empirical research is an ongoing project of the Transboundary Freshwater Dispute Database (TFDD) at Oregon State University. Many problems are foreseen with regard to the quality and applicability of available data, as well as to the use of GIS to analyze and display the data. Nonetheless, while indicators should be viewed with a healthy skepticism, they also offer a means to weave together understandings from case studies and theoretical literature into a model of the relationships between water resources and social, political, economic, and environmental patterns and processes across regions. This proposed research would offer a means to explore those linkages and to compare the importance of specific linkages from region to region, river basin to river basin. This research also offers the chance to explore the use of GIS for social science research and the problems and applicability of incorporating social science data related to water into a GIS system. Such experimentation may provide useful insights for the use of GIS in the management of international freshwater resources.

A comprehensive analysis requires a global comparison. Given the time and effort, not to mention computer memory, required to gather and analyze (spatially and statistically) data for the globe's 261 international river basins and their riparian countries (Figure 1), research has begun with a pilot project to test the feasibility of the analytic framework. Four basins, each representing different histories and levels of river basin development, are being examined – the Salween, Mekong, Indus, and Ganges-Brahmaputra-Meghna (Figure 2). The Salween offers an undeveloped and sparsely populated river basin

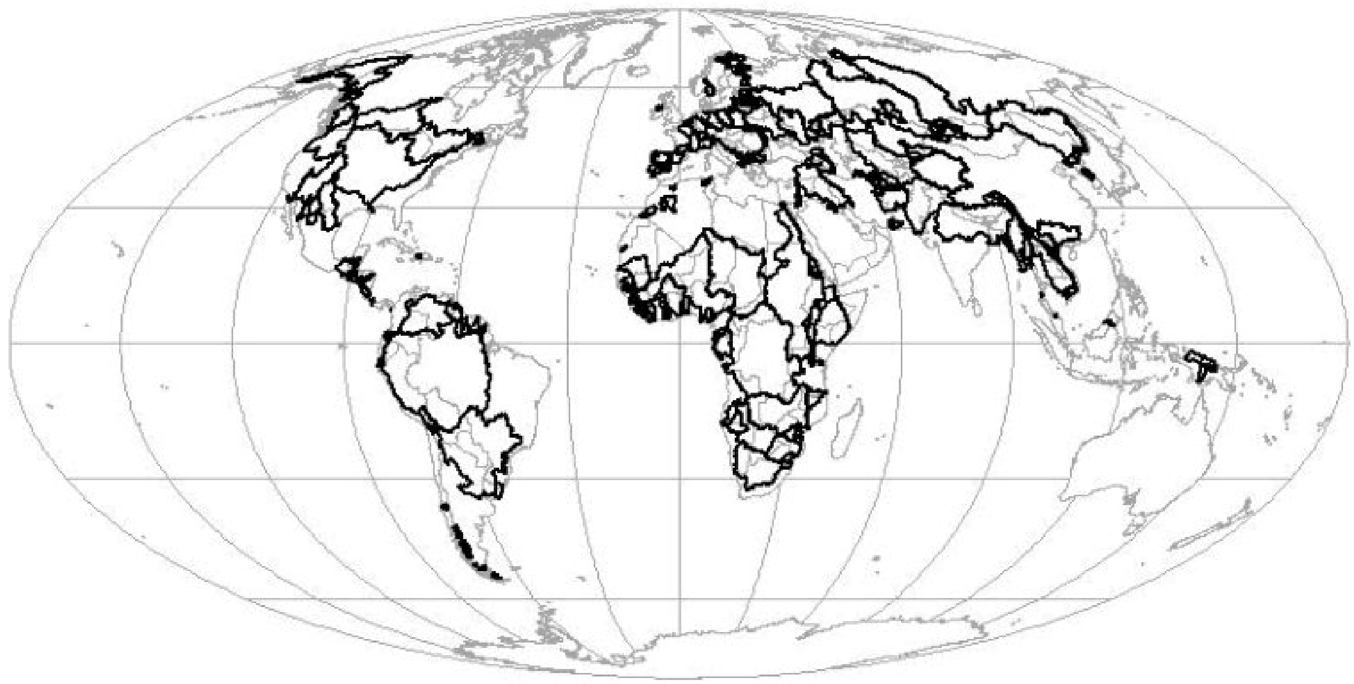

Figure 1. International River Basins of the World. Source: Wolf, Kinsler, et al., 1999; ESRI, Inc., 1993.

that lacks a treaty among the riparian states, which all have different and conflicting development plans for the basin. The Mekong is similar in climate and topography to the Salween, but has a greater population and, although it remains relatively undeveloped, does have a treaty and a structure for joint international management. In contrast, the Indus and Ganges-Brahmaputra-Meghna represent highly developed and populous basins in which there have been recent or ongoing conflicts over water resources. From these four basins, the research project will be expanded to include all 261 international river basins. This expansion will allow for broader and more complex statistical and spatial analyses, as well as for cross-regional comparisons of the driving forces associated with the allocation, management, and use of freshwater resources.

Methodology

The river basin was chosen as the key unit of research for a number of reasons. A river basin is defined as "a topographically delineated area drained by a stream system - that is, the total land area above some point on a stream or river that drains past that point" (Brooks, Ffolliott, et al., 1997). A river basin, as defined by the TFDD, comprises all the land that drains through that river and its tributaries into an ocean or internal lake. Since it represents a hydrologic unit, incorporating both freshwater and groundwater, the river basin is often used as a physical, biological, or socioeconomic unit of management. As a unit of research, the river basin fits well within the framework of the TFDD, which is designed around the concept of international river basins. Using the river basin as the frame of reference also fits well with the trend in changing definitions of transboundary water in international law. Such definitions frame future debates and agreements concerning the joint management of transboundary freshwater resources. Most importantly, however, framing questions in terms of river basins avoids the problems associated with the fact that most data are classified by country and fail to account for within-country variation. By focusing on the water resource, water basins offer a natural unit of analysis for the study of the relationship between conflict and freshwater resources.

The approach combines global level analysis with basin-specific information (see Table 1). At the global level, country data are available that describe attributes specific to countries and to country boundaries. Indicators at these levels might include: the degree of democratization within a country, the existence of disputed boundaries, Gross National Product, a country's rank in the United Nations' Human Development Index, or freshwater availability per capita. Since national data often mask regional or intrastate differences, basin- and river-specific information and analysis will also be incorporated. Such indicators may include: population levels and land use within a basin; the quantity, quality, and timing of river flow; or the existence of treaties for the river basin.

Parallel analysis of global and basin level attributes also offers the potential to examine inter-scale interactions. It may be that some indicators are relevant at one scale, but not at others. The purpose of this analysis is to understand the physical, political, environmental, and socio-economic patterns and processes that impact, or are impacted by, water resources and to find those combinations of attributes, or indicators, that provide some indication of the potential for water conflict. Having identified regions or basins prone to conflict over water, further, specific information can then be added to the area in order to provide additional context within which the level of potential for conflict may be evaluated. The basin-specific information may also offer further insights as to how water is, or should be, managed in a region.

A list of potential indicators, including data sources, data caveats, and how to obtain data, has been compiled. Specific indicator selection will be informed by theoretical and empirical literature on causes of water conflict and the relationship between water resources and environmental, social, demographic, economic, and political processes (e.g., Elhance, 1999; Homer-Dixon, 1994; Moldan, Billharz, et al., 1995; Ohlsson, 1999; Toset and Gleditsch, 1998). As indicator data are obtained, the list of indicators will be further refined using statistical and spatial analysis techniques. The validity and credibility of indicators will be evaluated by backtesting the indicators against both existing water treaties and incidents of water conflict.

If it is assumed that every water treaty represents an attempt to address an existing (perceived or potential future) conflict, then selected indicators from the time period prior to a treaty can be examined, and statistical methods can be used to evaluate the relationship among those indicators and the incidents of conflict (Wolf 1999a). There are, however, problems associated with this method. Data for many of the indicators are only available for the latter half of the 20th century. It may not be possible to examine indicators for treaties signed prior to the 1950s. Moreover, the past is not necessarily a good predictor of the future. This caveat will need to be taken into account when developing indicators and their ranges for predicting future water conflict. It should also be noted that this method of backtesting will not allow for testing of indicators regarding internal, i.e., sub-national, conflict. There are databases of internal conflicts, however, and such datasets, while not without their own limitations, offer a backdrop against which to test indicators of intrastate conflict. The initial focus of the project, however, is on international conflict. Intra-national conflict will be considered in terms of how such conflict may contribute to larger scale instability and conflict.

A database of water-related treaties is available through the Transboundary Freshwater Dispute Database Project (TFDD), directed by Dr. Aaron Wolf, at the Department of Geosciences, Oregon State University (Wolf, Kinsler, et al., 1999). The TFDD is a searchable database of summaries and the full text of 150 water-related treaties, with plans for the addition of approximately 100 more over the course of the coming year. Dates covered by the treaties range from 1874 to 1996, although treaties signed before the mid-20th century are often incomplete, and some sources contain only excerpts or annotated treaty summaries. The database also contains condensed treaties, some with direct quotes from the treaty text. Treaties in the TFDD address the freshwater needs of the signatories and, for the most part, do not include transportation, fishing, or boundary treaties. The treaties do deal with one or more of the following issues: water rights, water allocations, water pollution, principles for equitably addressing water needs, hydropower/reservoir/flood control development, and environmental issues and the rights of riverine ecological systems.

Table 1. Attributes (Indicators) at Various Scales

Country Attributes	*Country Boundary Attributes*
GNP	Trade flows
Relative power	Worker flows (long term, seasonal)
Level of democratization	Level of friendship (high, med, low)
Vote on UN Convention on Non-Navigational Uses of International Water Courses	Border sections under dispute
Per capita water availability	
Ranking on Index of Human Insecurity	
River Basin Attributes	***River Attributes***
Population density	Quality
Land use (industry vs. agriculture)	Quantity
Urbanization	Timing
Minority populations	Existing works
Presence/absence of water agreement	Proposed works
Timing of treaty in relation to basin development	Uses
Strength of treaty (i.e., does it mitigate/address dispute; were key issues addressed?)	Navigation, fisheries, flood control, irrigation, hydropower
Transportation lines	International or not
Electricity lines	

In selecting indicators, care is taken that each indicator answers a potential question or questions that ask what purpose the information serves. Much of the research will involve exploring the relevance of various indicators to answering the question of what conditions favor conflict over water. Some data "set the stage," that is, provide a description or situational context. Other data are actual indicators whose presence, absence, or patterns indicate the likelihood of conflict. By patterns, one can explore whether certain trends and discontinuities in the data indicate the likelihood for conflict.

Indicators

Indicators are proxy variables, used to simplify and amalgamate large quantities of data. They represent a compromise between accuracy and precise information,

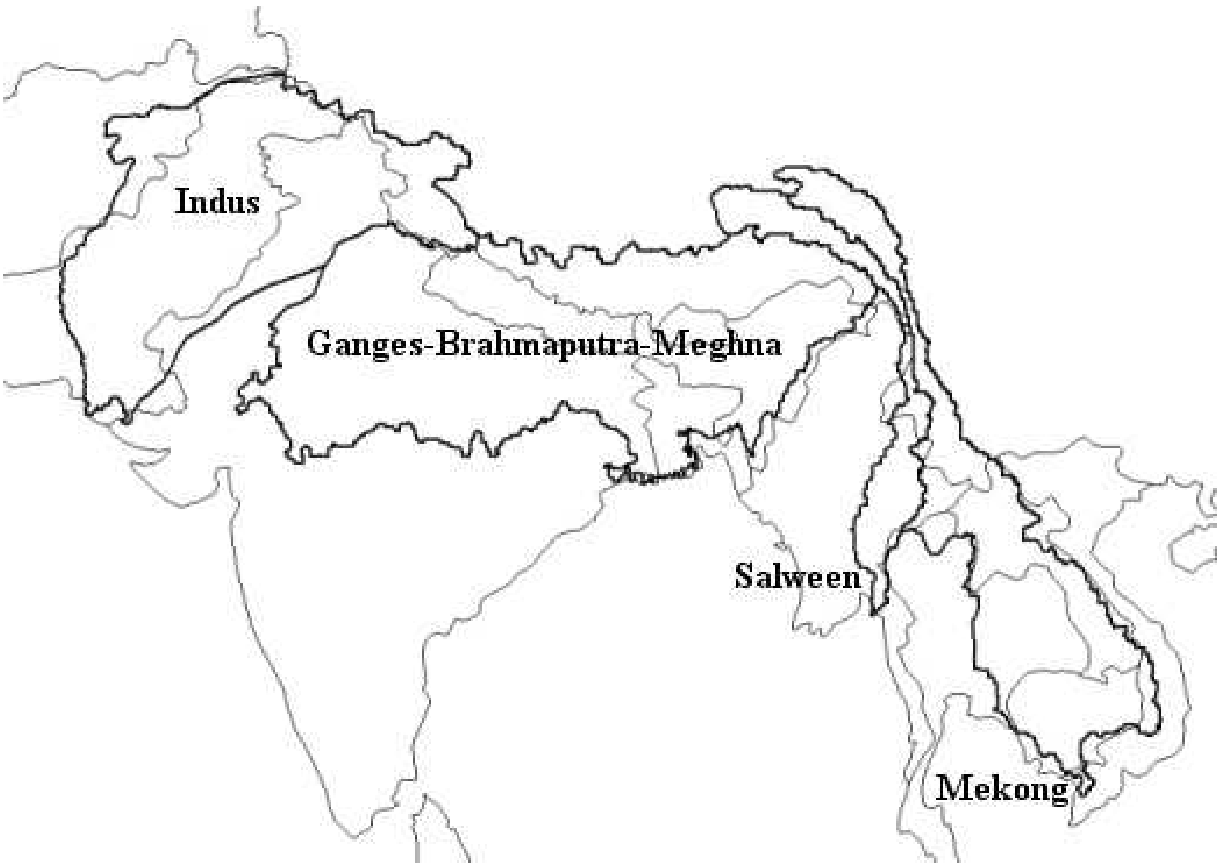

Figure 2. The four pilot project basins. Source: Wolf, Kinsler, et al., 1999; ESRI, Inc., 1993.

but provide a simplification of complex systems that facilitates evaluation of those systems. Indicators are used for a variety of purposes, including: assessment of states, determining linkages, and improving decision making and planning (Gustavson, 1999). For the purposes of this project, indicators will be selected that point to potential areas of water-related conflict.

A key element in selection of indicators is an understanding of the scale at which those indicators will be used. Indicators of potential water-related conflict represented at the global scale, for example, should be viewed with skepticism, since it is impossible to represent accurately complex relationships between states at such a broad scale. Given this, other indicators will be used to examine relationships at the regional and basin scale. It may be that different indicators will be more effective at different scales, since the same indicators may not have equal relevance across scales.

In general, good indicators should satisfy the following conditions, although these properties might vary depending on the situation. A good indicator should:

- correspond to the selected application,
- have an explicit value,
- sufficiently simplify the target system characteristics, (Gustavson, 1999)
- have an empirical or theoretical link with the issue at hand, and
- have an adequacy of spatial and temporal coverage so that it can be effectively represented and modeled (Lonergan, Gustavson, et al., 1999).

In addition, there should also be a means for testing an indicator's accuracy and relevance. In part, an indicator's relevance may be supported by the existence of empirical or theoretical links with water resource conflict or related issues. For instance, the indicators used in this project will be predictive of conditions that might lead to dispute. The Jordan, Indus, Nile, and Aral basins have all been sites of conflict. They also all represent internationalized basins. If it is assumed that there is a causal link between the internationalization of a basin and incidents of conflict among the states that now share that basin, the presence of ethnic minorities with nationalistic aspirations becomes a potential indicator of water-related instability (Wolf, 1999b).

This example reiterates the need to study past situations that have brought about disputes or led to instability, in order to determine what indicators might be useful. There are a number of potential indicators that could point to water-related instability, both at the basin and country level. Access to clean water supplies, for example, has

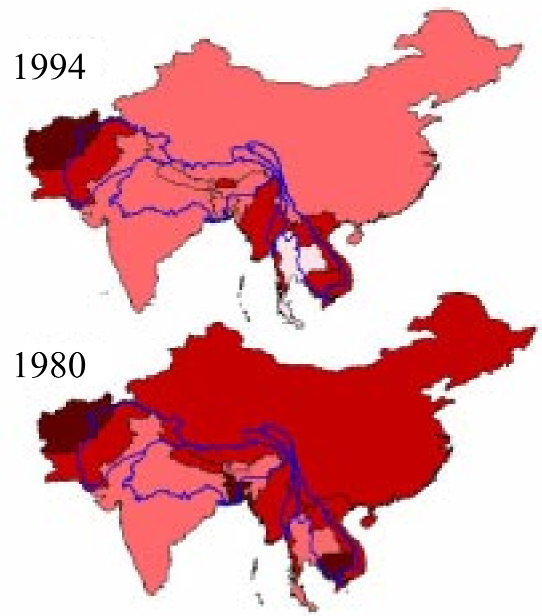

Figure 3. Index of Human Insecurity: darker areas indicate countries with higher insecurity. Source: Lonergan, Gustavson, et al., 1999; Wolf, Kinsler, et al., 1999; ESRI, Inc., 1993.

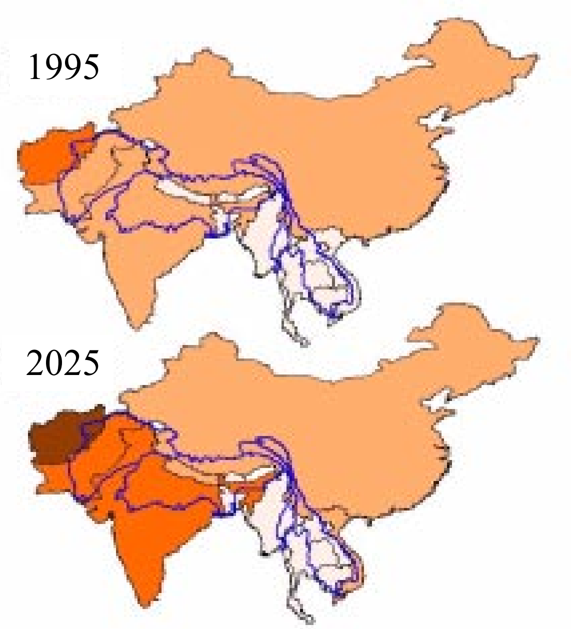

Figure 4. Social Water Stress Index, 1995, 2025: darker areas indicate higher levels of Social Water Stress. Source: Ohlsson, 1999; Wolf, Kinsler, et al., 1999; ESRI, Inc., 1993.

historically been tied in with political stability (Wolf, 1999b), and water-related problems exist in many areas of the world. Much of the developing world falls below the "basic water requirement" (BWR), as outlined by Gleick (1998), meaning that people of these countries are not getting sufficient clean water to meet their daily water needs. Worldwide, nearly 250 million people suffer from water-related diseases and 5-10 million die from them each year (Gleick,1998). It would be difficult to argue that these data are not evidence of the potential for instability, if not for conflict.

At the global level, the Index of Human Insecurity (IHI) is an example of a set of indicators developed to facilitate identification of vulnerable or insecure regions, in order to aid decision makers in development assistance efforts. It is considered an "aggregate measure of human welfare that integrates social, economic, and political exposures to and capacity to cope with a range of potentially harmful perturbations" (Lonergan, Gustavson, et al., 1999). The IHI identifies four "key system components" – the environment, the economy, society, and institutions. Within each of these four indicator categories are four variables, each of which measure either a key structural relationship (e.g., linkages, defining characteristics) or a key functional relationship (e.g., processes, flows) of the system. Where data in a time series are missing, IHI developers utilize statistical techniques to establish a complete time series for all indicators and all countries where there are sufficient initial data. The IHI presents a model upon which water-specific indicators might be framed. There are, however, problems associated with using the IHI for certain types of analysis. The index for each year is specific to that year, making it difficult to compare changes in a country's IHI from across years. It may also be that there are one or two indicators, such as GDP, that account for the majority of variation in the IHI (Figure 3).

Another water-specific, global-level indicator is water stress, which measures freshwater availability per capita within a country. This measure, however, does not account for a country's ability to adapt to water stress, such as with more efficient irrigation technology. Ohlsson (1999) has developed a Social Water Stress Index (SWSI) to incorporate a measure of a country's adaptability (Figure 4). The SWSI is a water stress index (freshwater availability per capita) divided by UNDP's Human Development Index and then divided by two (rounded to nearest wholes).

While the SWSI is an improvement, neither of its key components, the Human Development Index nor the Water Stress Index, incorporate measures of percentage of population with access to freshwater or sanitation services, incidence of water-related disease, water quality/pollution trends, and/or efficiency of existing water uses and water delivery systems. These measures provide more accurate representations of water stress and are increasingly important as the analysis moves from large scale to small scale. In addition, since data often overestimate or underestimate freshwater availability or use, a country's adaptive capability may be a more accurate indicator in terms of future trends. As a further caveat, freshwater availability, also measured as total renewable surface and groundwater, typically includes flows from other countries. That is to say, not all of the annual renewable water supply may be available to a country to which it is cred-

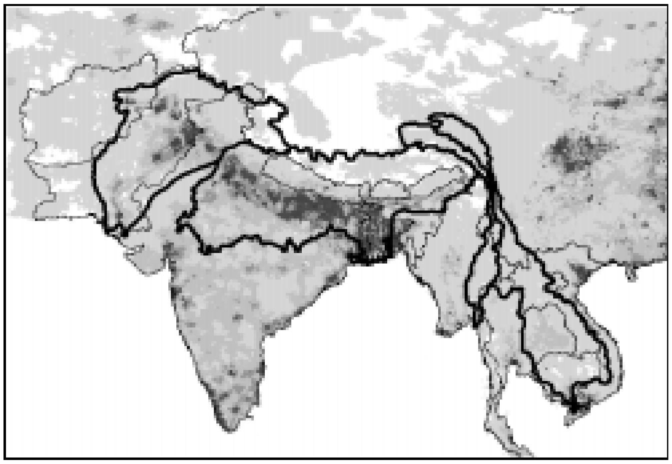

Figure 5. Population density: darker areas indicate high population densities. Source: Tobler et al., 1995.

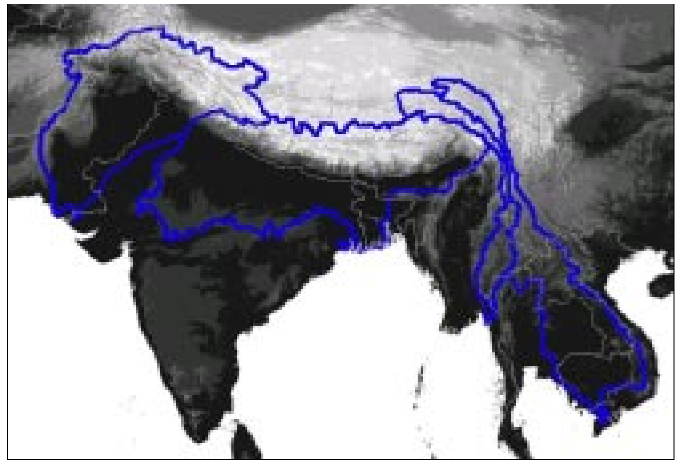

Figure 6. Elevation within the basin: lighter colors indicate higher elevations. Source: GTOPO30, 1996; Wolf, Kinsler, et al., 1999; ESRI, Inc. 1993.

ited, as some flows are committed to downstream users. The annual average figures also hide large seasonal, inter-annual, and long-term variations.

There are a number of other potential indicators, each of which requires more detailed research in order to evaluate their theoretical and empirical validity. Overall population growth rates within a country may indicate infrastructure development pressures on that country. Population density within a basin can indicate the degree of direct pressure on the water resources of that basin. Population density outside a basin may also be an indicator of development pressure, particularly if that population is looking for new sources of freshwater (Figure 5). Relative power and position of riparian countries within a basin can indicate the likelihood for international conflict. Weaker nations, for example, are unlikely to attack upstream hegemons and upstream nations would not have cause to attack (Wolf, forthcoming). Internationalization of a basin is also an impetus for conflict. The degree of democratization of countries sharing a river basin is also an indicator of conflict, as political science research indicates that democracies are unlikely to go to war against each other.

Also telling are basic physical and topographical variables. Areas of high elevation make good dam sites (Figure 6). High seasonal and annual precipitation fluctuations can indicate pressure to build water projects that would regulate and improve the predictability of flow, particularly if other variables indicate that a country is looking to expand its irrigated agriculture or its hydropower capacity.

Other layers of information that would potentially be incorporated include the following spatial and attribute data: land cover or land use classification, areas of irrigated agriculture, areas prone to flooding or drought, location of major freshwater fisheries, location and size of urban areas, internal administrative boundaries, major roads and railways, the portion of government money spent on defense versus education and health spending, incidence of waterborne disease, and water quality (as measured by the presence of organic and inorganic chemicals in river systems).

The data listed above represent a broad range of information. The key to these layers is to ask what their relevance is to indicating water conflict. As one moves from global level indicators to the regional or basin scale, the need for context increases. For instance, it becomes important to understand at greater length the past and current relationships between co-riparian states within a watershed. It is also important to note, for example, existing and planned water development projects among the riparian states. Projects in conflict with each other may create tensions. More generally, by understanding the specific socio-political situations, and by incorporating them into watershed scale indicators, the factors at play within a region or watershed can be understood better.

Last, another potential area of study is that of internal basins within a state. By looking at the amount of stress within an internal basin, information about the potential pressure for development of international resources might be learned, since it is likely that a given country would look to develop its internal sources before dealing with the development of shared resources.

Representing Indicators Using GIS

A number of the attribute data mentioned above can quite effectively be represented within a Geographic Information System (GIS), such as Environmental Systems Research Institute's Arc/INFO, and much of the spatial information mentioned previously would be extremely difficult and at times impossible to analyze without the use of a GIS. Key water-related indicators can be defined through the use of various GIS processes. Examples of this include: studying areas that are prone to flooding or drought using remote sensing technologies, performing spatial analysis on road networks within watersheds and countries to determine areas of high industrialization, analyzing differences in variables (e.g., power, population growth, and river development) between upstream and downstream riparians within an international basin, and the relationship between river development and water-borne diseases.

GIS technologies are designed to capture, store, manipulate, analyze, and visualize disparate sets of geographically referenced data. While GIS has its advantages, however, there are also certain limitations to the technology. These limitations include problems of temporal analysis, multiple scales, and data quality and interpretation. The examination of indicators at an international, national, and sub-national level introduces questions of scale that will need to be further addressed, as well-tested methods for translation across scales are lacking. Linked to problems of scale is a lack of frameworks for understanding the interaction of human and environmental systems that do not require high levels of abstraction. A model that is too abstract loses its interpretive value (Goodchild, 1996).

Another difficulty associated with this project, and with understanding human-environment interactions in general, is the incorporation of temporal change into the GIS. GIS mechanisms build on those of cartography and produce static maps. Incorporating representations of temporal change into GIS is still in its infancy and represents an area of further research for the field of GIS (Langram, 1993).

While a wide range of data are available for this project, socioeconomic and demographic data are difficult to collect, span a range of temporal and spatial scales, may have incomplete coverages, are not systematically checked for error, and may have unsuitable archiving or retrieval formats (Committee on the Human Dimensions of Global Change, 1992). Moreover, data quality is not just a measure of data accuracy, it also includes the interpretation placed on the data. GIS technologies rarely capture the uncertainty associated with maps, presenting them as being uniform in the availability and accuracy of their data. Given the often coarse nature of the data (geographic, biophysical, socioeconomic) that are examined in this project, some way of measuring error and uncertainty would be extremely useful. Unfortunately, uncertainty modeling is a recent GIS development and not broadly supported.

Conclusion

Water is a critical resource at an international level, with 261 international rivers covering almost one-half of the total land surface of the globe. It is linked to a variety of socio-economic factors, and has become prominent in literature on environment and international conflict. This paper presents an approach to parallel analysis of variables related to water-related conflict on both a global- and basin-level scale, with the hope of finding combinations of attributes, or indicators, that provide an indication of potential water conflict. It is important not only that these indicators have an empirical or theoretical link with conflict or related issues, but that there is also a means for testing their usefulness and accuracy. A possibility for testing indicators exists in studying historical evidence surrounding past water conflicts, particularly those that were resolved through treaties.

Such indicators, even when tested against historical evidence, should be viewed with some skepticism, since it is difficult to establish causal relationships between variables and water-related conflict. It is also potentially errant to assume that by studying historical evidence, one can accurately predict what future events will take place. Previously unexperienced pressures, such as increased resource scarcity and rapidly increasing populations, particularly in areas that are already faced with water stresses, are difficult to account for because there is a lack of comparable historic situations.

This skepticism, however, does not suggest that water-related indicators of potential instability or conflict are without value. Through research, access to potentially useful information, effective spatial representation and analysis of that information, and contact with various regional experts, reasonable indicators can be developed. It simply is important to note that an indicator or set of indicators, no matter how well thought out and planned, cannot predict potential conflicts with complete reliability.

With the proper approach, effective analytical framework, and access to appropriate data sources, there is great potential for establishing water-related indicators of conflict. A strong base of information and research has been gathered and can now be built upon to create a series of water-related indicators that will be valuable in the 21st century.

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