Freshwater Availability Anomalies and Outbreak of Internal War: Results from a Global Spatial Time Series Analysis

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Abstract

We investigated the relationship between water availability and internal war outbreak. This work constitutes the first test of climate-security connections utilizing global subnational time series data. We created harmonized spatial time series databases on a subnational global grid of internal war, renewable freshwater surface water resources (in the form of runoff), rainfall deviations and population for the period 1980-2002. We utilize national-level data on infant mortality, political institutions, and trade openness as controls. We find that at the global scale there is a highly significant relationship between rainfall deviations and the likelihood of outbreak of a high-intensity internal war. When rainfall is significantly below normal, the likelihood of conflict outbreak is significantly elevated in the subsequent year. We do not find a similar effect for the mean annual runoff at the global scale, but find some evidence at the continental scale. We also find no significant relationship between rainfall deviations and the onset of low-intensity internal wars. The capacity to geographically reference social science and biogeophysical data sets will create new opportunities for hypothesis testing with respect to the sources of internal conflict in the fast of climate change invariability

Introduction

For the most part quantitative research on the causes of civil war has been progressive, cumulative and analytically rewarding (Fearon and Laitin 2003). However, the area of environment and natural resources represents an exception when it comes to the general progressive trend in civil war scholarship. Whether or not environmental conditions contribute to the outbreak of civil war remains a central and unanswered question, and a source of debate among civil conflict scholars. Most of the earliest claims that environmental conditions contributed to civil war outbreak (e.g. Homer Dixon, 1994) relied on ad-hoc case study evidence, on speculations about likely future trends, or on unsystematic procedures for identifying environmental causal forces (Gleditsch 1998, Levy 1995a). Not surprisingly, these weaknesses limited the ability of the social science community to make progress on determining the degree to which such factors make a difference, or the conditions under which they make a difference.

In recent years a small number of studies has found, using more robust methods and data sources, that significant relationships between civil war outbreak and environmental conditions exist (Ross 2004a). In large part the ability of these studies to identify a relationship between civil war outbreak and environmental conditions derives from the calculation of innovative indicators. Hauge and Ellingsen (1998) constructed a measure of soil degradation and found it to be a significant correlate of civil war outbreak. De Soysa (2002) tested whether World Bank estimates of "natural capital," comprising soil and forest asset measures, were significant predictors of civil war outbreak but found no relationship. Collier and Hoeffler (2002) calculated a measure of demographic dispersion using georeferenced population data sets; they also calculated a measure of mountainous terrain using spatial elevation data

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[1] **Acknowledgements:** Darcy Shiber-Knowles assisted with much of the GIS processing of the conflict data; Glenn Deane provide valuable advice on spatial regression analysis; we also thank Bethany Ann Lacina; Brad Lyon, Emily Grover Kopec, Susan Woodward and Nils Petter Gleditsch for helpful discussions.

sets. Fearon and Latin (2003) utilized the same mountainous terrain variable as Collier and Hoeffler. Miguel et al (2004) made use of a global monthly rainfall data set to calculate measures of temporal variability.

Although these results are highly suggestive, they collectively remain ad hoc. Although Collier and Hoeffler's mountainous measure has been used in other civil war models, their demographic dispersion measure has not. De Soysa's experimentation with natural capital estimates has not been replicated by others. The soil degradation data used by Hauge and Ellingsen is utilized sporadically (e.g. Esty et al 1998b, Stalley 2003) but soil degradation experts have discredited the measure and no longer recommend its use (Niemeijer and Mazzucato 2002). Moreover, quantitative studies of environment-conflict connections vary in the degree to which they test hypotheses that link abundant natural resources to conflict because they create incentives for looting and plunder; or, on the other hand, hypotheses that link scarcity of natural resources to conflict because they exacerbate social tensions and diminish coping capacities. All of the above studies are limited by an inability to exploit the rich information found in spatially explicit environmental data sources, relying instead on gross national averages which obscure potentially meaningful variation.

Miguel et al's use of water data is surprisingly rare in quantitative studies of internal war, although advances have been made in exploring the role of water resources in interstate conflict (Toset, Gleditsch and Hagre 2000; Wolf, Yoffe and Giordano 2003). Among rural poor populations vulnerable to internal war, water is a vital natural resource with clear potential links to violence. The emerging technical capabilities for high resolution mapping geophysical variables make it possible to articulate a more clear geography of resource constraints (NRC 1998). The next challenge in water resource assessment is to create a practical merger of social dimension data sets (typically at the administrative level) and hydrodynamic data sets that can be mapped in pixellated form and at high geospatial resolutions (Vörösmarty et al. 2002 , 2005b; Sanderson et al 2002).

Our study therefore aims to make a systematic advance in understanding the role of water availability in contributing to civil war outbreak, and to produce a set of robust indicators that can be utilized among civil war modelers and policy-makers.

Parallel advances in data sets on civil war, on climate, water, and demography make it possible to formulate a research design that will subject the proposition that scarcity and variability in water availability contribute to the likelihood of civil war to a rigorous test. Because we think advances will come from combining data carefully, we have assembled a partnership of three complementary research centers that have played central roles in creating pivotal data. The Center for International Earth Science Information Network (CIESIN) at Columbia University is a leader in global spatial demographic data, and at interdisciplinary data integration. It produces a global spatial data set on the distribution of the world's population that has been widely used in a range of research activities. It produced the first integrated collection of state failure variables under contract to the State Failure Task Force, which helped support the analysis of that group (Esty et al 1998a). The University of New Hampshire Water Systems Analysis Group is a world leader in global hydrology data analysis, modeling, and interdisciplinary research, contributing to synthesis studies of global change and the water cycle (Meybeck and Vörösmarty 2004), the Millennium Assessment chapter on freshwater rsources condition (Vörösmarty et al. 2005), the interdisciplinary Global Water System Project (GWSP 2004) and global water resources theme for Phase-VI of UNESCO's International Hydrological Programme (www.unesco.org/water). It has produced a global monthly time series of water availability dating back fifty years based on hydrology models and water indicators designed specifically for large-scale regional and global application (Federer et al. 2003, Fekete et al. 2002, Vörösmarty et al. 2005b). The Center for the Study of Civil War (CSCW) at PRIO (International Peace Research Institute, Oslo) is an internationally recognized leader in the quantitative study of civil war, and has been appointed by the Research Council of Norway as one of its 13 national Centers of Excellence. CSCW was instrumental in extending the Uppsala Conflict dataset to cover the entire period after World War II and in transforming it from a conflict list into a database for statistical analysis. While Uppsala University takes care of the annual update (published every year in *Journal of Peace Research*), CSCW is currently in the process of adding three important elements to the database: more accurate start and end dates for all conflicts, more precise data for battle-deaths by conflict and by year, and more realistic data for geographic battle areas (polygons instead of circles).[2]

By bringing these three centers together in direct collaboration, we will ensure that the state of the art in different scientific fields is well represented, that wise choices are made in constructing variables and statistical tests, and that the publications that result are seen as credible within multiple disciplines.

Hypotheses

There are three core clusters of theoretical perspectives from which to derive hypotheses linking water and civil conflict. One perspective emphasizes *capacity*, and holds that low levels of wealth make it difficult for societies to construct political institutions that are robust enough to avoid violent conflict (Laitin 2001). From this perspective, water scarcity is easily conceived as a form of wealth deprivation, logically leading to greater propensities to violence and low coping capacities. Another perspective emphasizes *deprivation*, and holds that low levels of wealth foment perceptions of injustice, thereby increasing the likelihood of rebellion. Finally, a competing perspective emphasizes the *political economy* of rebellion, and holds that the distribution of wealth affects patterns of civil conflict by shaping the incentives of social groups to engage in rebellion; under this perspective water scarcity could increase the likelihood of violence because it reduces the return from economic production and therefore increases the relative rates of return from rebellion. Similarly, disparities in water resources could increase the likelihood of civil conflict if the disparity motivates a disadvantaged group to displace another group from a more water-rich territory, or induces a water-rich region to secede or otherwise distance itself from central government control.

We have chosen to formulate hypotheses that are stark, clear and testable, as well as relevant to ongoing theory building. For a similar approach that utilizes a set of small-n comparisons, see Ross (2004b).

We can think of conflict as linked to lack of water (i.e. dryness per se (*Level Effects*) or as linked to deviations from the local normal water conditions (*Variability Effects*). Similarly, we can think of effects that are felt in absolute terms by their direct consequences on regions or populations, or

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[2] Together, these three centers have applied for research funding to carry out a multi-year research program along the lines outlined here. The research results presented here have been carried out on an exploratory basis by the Columbia and UNH teams.

effects that are felt in relative terms, by the impacts they convey on inter-region or inter-group competition. For the sake of exposition we can simplify this proposition focusing on a two-by-two matrix, as summarized in **Table** 1.

Table 1: Hypotheses linking water availability and civil conflict

	Level Effects	Variability Effects
Absolute effects	**H1**: Regions with low levels of baseline water availability are more prone to conflict than other regions	**H3:** Regions with high levels of variability in available water are more prone to conflict than other regions.
Difference effects	**H2**: Contiguous or near-contiguous regions that exhibit significant disparities in baseline levels of water availability are more prone to conflict than other regions	**H4**: Deviations from baseline water availability that result in significant disparities across regions will experience more conflict than other regions.

H1: Regions with low levels of baseline water availability are more prone to conflict than other regions. Dryer regions, ceteris paribus, are poorer. The economic base is less likely to be sufficient to maintain centralized political structures, there are lower levels of investment in human capital and three this is less capacity to resolve conflicts. In this case water availability is largely serving a similar function as wealth.[3] This hypothesis can be tested using both national-level data and data at the subnational administrative unit.

H2: Contiguous or near-contiguous regions that exhibit significant disparities in baseline levels of water availability are more prone to conflict than other regions. When dryer regions are near regions of greater water availability, economic growth rates will tend to diverge, ceteris paribus. Producers in dry regions will becoming increasingly isolated from other parts of the economy; as economic growth takes place their productive capacity becomes relatively more marginal. This will lead to rising inequality between regions and rising frustrations. In this case differences in water availability serve the same function as differences in economic growth rates.

H3: Regions with high levels of variability in available water are more prone to conflict than other regions. We expect this effect to be most pronounced in areas where the downswings in water availability are sharp enough to affect economic production. Ceteris paribus, such regions will find it harder to develop institutional mechanisms that are effective under such a broad range of physical conditions, and therefore are more likely to experience gaps between social conflict and institutional mechanisms to manage conflict.

H4: Deviations from baseline water availability that result in significant disparities across regions will experience more conflict than other regions. Communities in water poor areas may

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[3] We also expect that families and groups are more likely to be operating at the margins of viability in dry regions, and therefore are more dependent on conflict resolution mechanisms to avoid violence than populations in water-rich areas.

compete to secure water resources from water rich areas—for example through diversion of rivers or land-grabs. We expect that this is especially likely where such deviations are consistent with baseline disparities – that is, where a dry region experiences an unusually dry year while a wet neighbor suffers less. In a similar vein, uneven water shocks may spark migration that generates competition over land and other resources and social upheaval. Finally, areas hit with disproportionate water shocks may be tempted to raid resources from neighboring regions, for example livestock; such behavior may escalate into internal war.

The present study is designed primarily to test the broad relationship between water and conflict. It focuses primarily on Hypotheses 1 and 3.

Data

Our approach relies on geospatial statistics developed from spatially and temporally harmonized data sets. We will begin utilize existing water and climate archives from the University of New Hampshire Water Systems Analysis Group and from the International Research Institute on Climate Prediction to produce spatial indicators of water stress. Our full research methodology calls for creation of such indicators over a 50-year period, the interim results presented here cover only the period 1979-2002. over a 50-year time period at monthly increments. The period of record from 1979-200 is analyzed at monthly increments.

Conflict Data

The PRIO/Uppsala Conflict Database (Gleditsch et al 2002; www.prio.no/cwp/armedconflict) was utilized in this study. This database is the first civil war database to provide explicit geographic information, indicating latitude and longitude of the conflict's center along with an estimate of the wars' geographic extent (as length of radius).

We worked with the internal wars identified in the PRIO database, processing each of the three intensity levels. For the present we have processed conflicts covering the period 1975-2002. Our full research plan calls for processing back to 1955. We limited our database to conflicts which were ongoing in the years 1975 to 2002 (the most recent year available at the time of this project's beginning). Côte d'Ivoire 2002 was omitted because of missing geographic information. Geographic extent data concerning some Balkan conflicts were modified in consultation with Susan Woodward, because of the complexities of the shifting national boundaries during the 1990s.

Conflict centroids were mapped according to the longitude and latitude given in the PRIO dataset. Buffers of given radii were generated for each conflict (Figure 3). These buffers were then merged with country boundary data and clipped to the borders of the appropriate country. Country boundaries were taken from Digital Chart of the World; historic boundaries for countries that changed boundaries over the study period were obtained from an internal CIESIN data set. These files were converted to raster grid format at 0.25-degree resolution. The resulting data set is organized by grid-year, with conflict summaries for each data point (intensity 0, 1, 2 or 3).

We opted not to do detailed analysis on level-2 conflicts, out of concern that the timing of the outbreak of such conflicts may be less precise than for level 1 and level 3.

Figures 1 and 2 provide a summary for the whole historic period. They map the total number of conflict years, by grid cell, for the period 1979-2002.

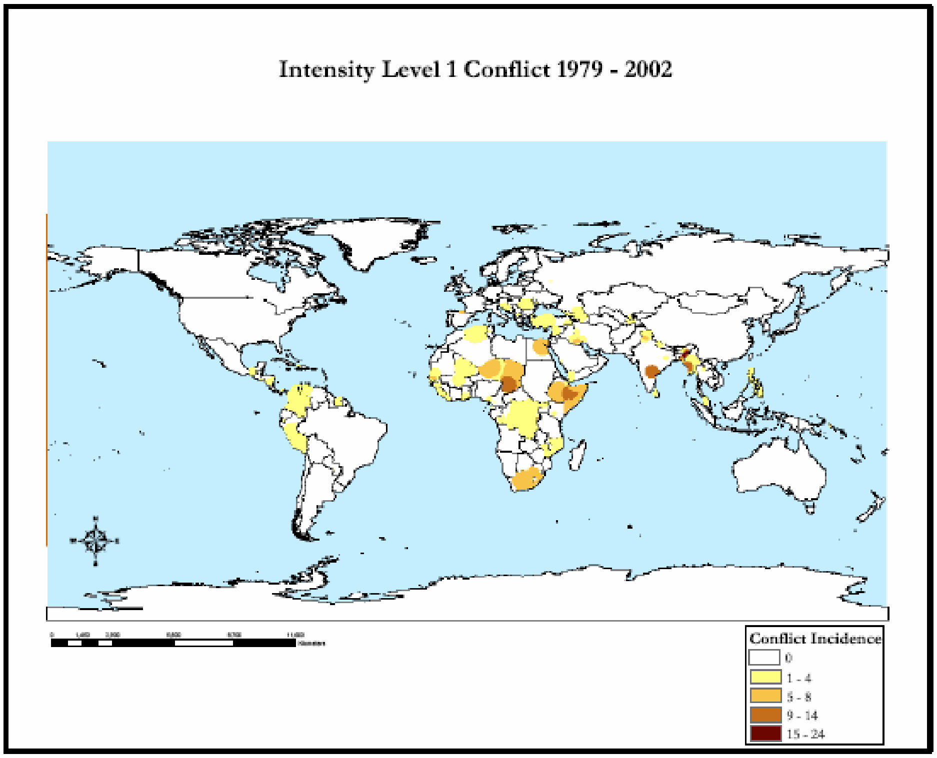


Figure 1: Conflict Years in Low-Intensity Internal War

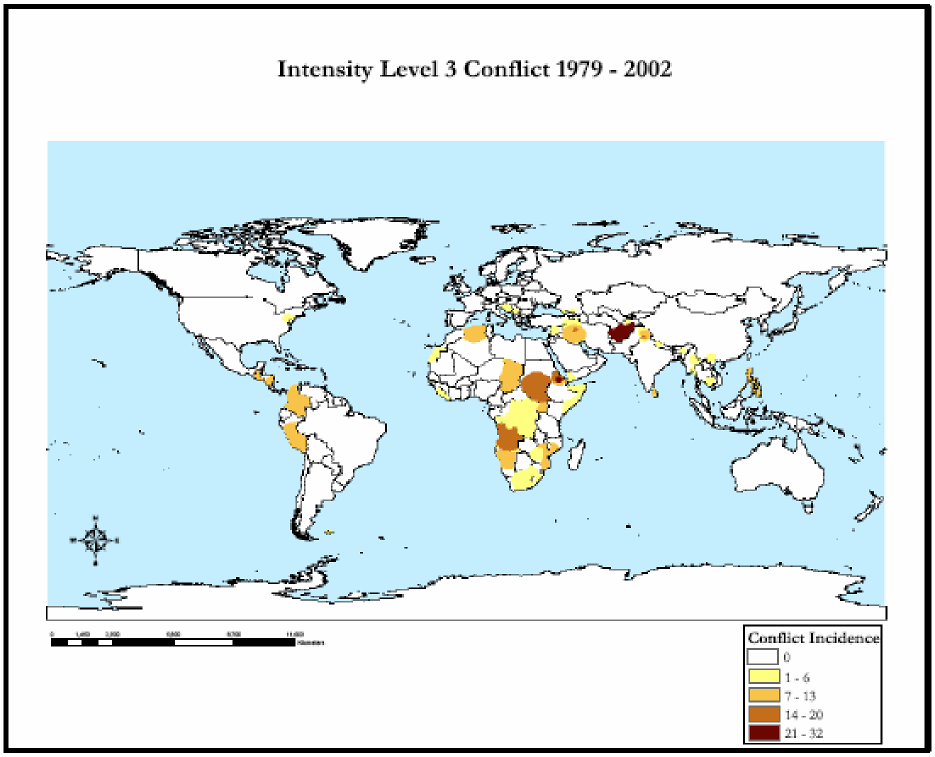


Figure 2: Conflict Years in High-Intensity Internal War

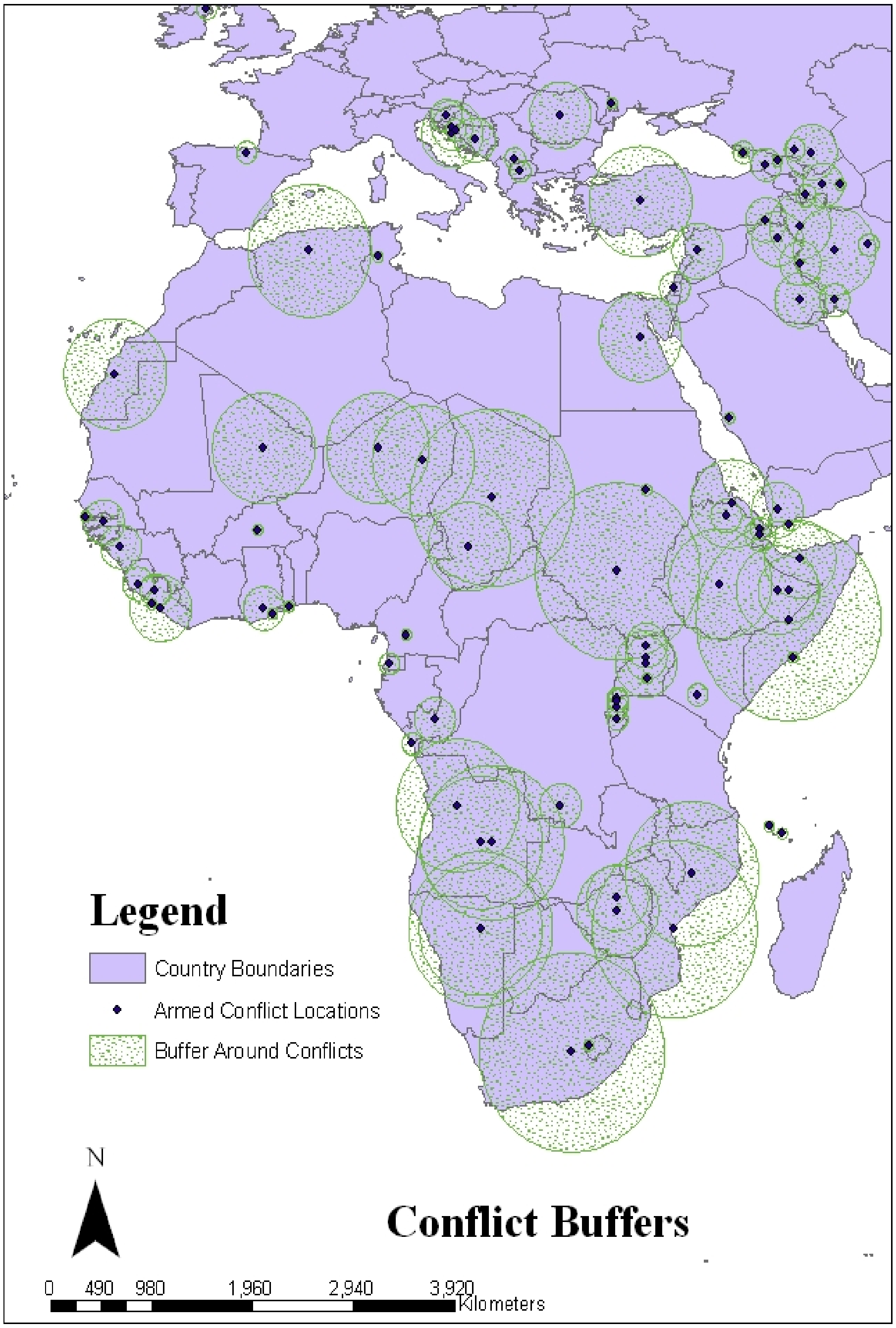


Figure 3: Illustrative sample of conflict centroids and circles, as determined by attributes in PRIO Internal War database.

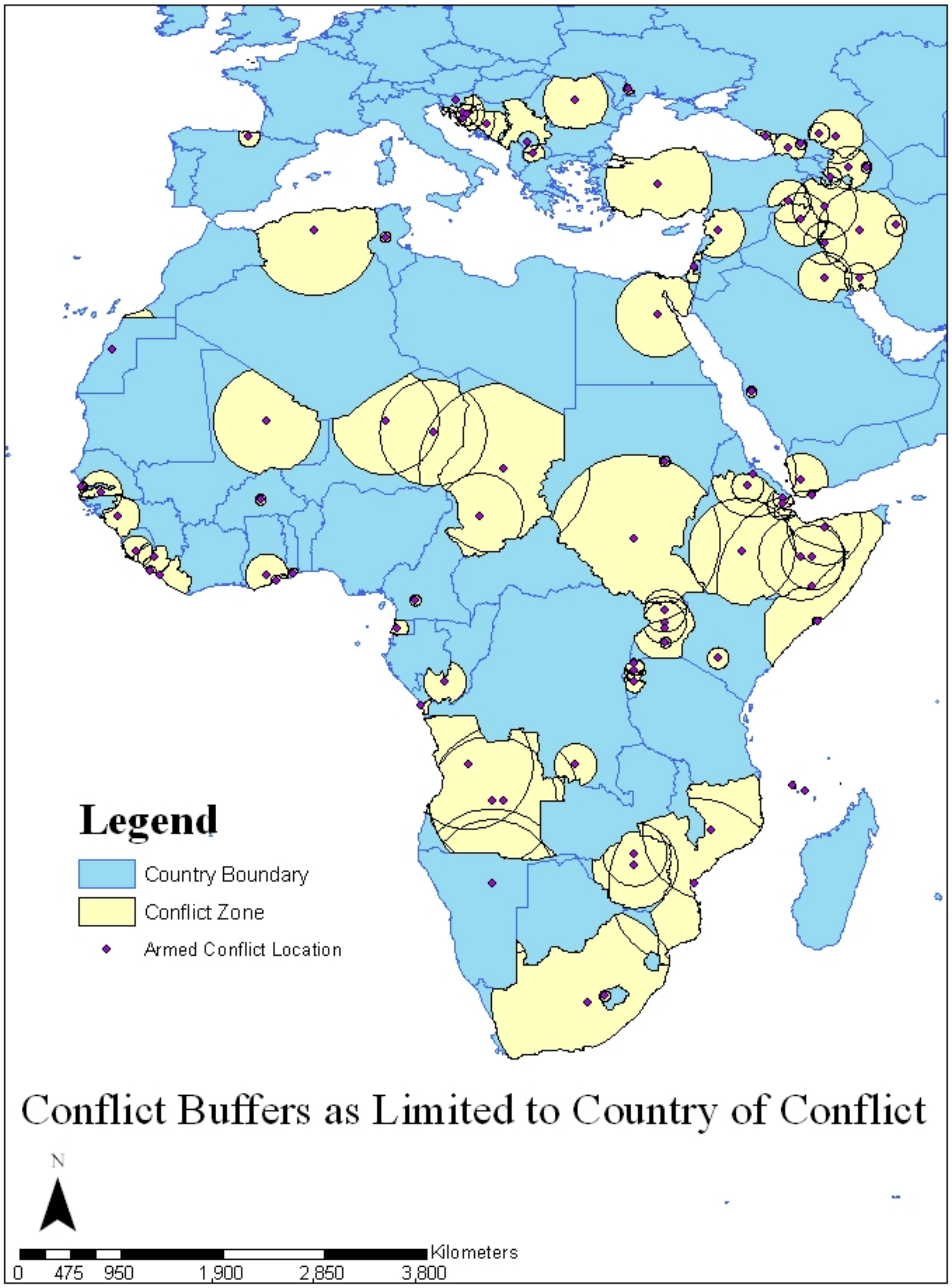


Figure 4: Conflict zones following "clipping" to country borders.

From a database indicating presence or absence of conflict, we computed a conflict outbreak variable. The outbreak variable was set to 1 in relevant grid cells for the first year in which a conflict was recorded. For grid cells experiencing no conflict, the outbreak variable is set to 0. For years subsequent to the outbreak year, in an ongoing conflict, the grid-years are censored out of the analysis (set to missing in the database).

Table 2: Conflicts included in the analysis

Location	Start Year	End Year	Percent of territory coded as outbreak grid	Percent of conflict zone already in prior conflict, excluded from outbreak code
China - Vietnam	1979	1979	0.8	
China - Vietnam	1979	1979	21.3	
Iran	1979	1980	11.4	
Uganda	1979	1979	31.6	
Iran - Iraq	1980	1988	11.6	11.4
Iran - Iraq	1980	1988	83.9	
Lebanon	1980	1982	43.8	
South Africa	1980	1983	74.5	
El Salvador	1981	1990	85.2	
Mozambique	1981	1992	70.8	
Peru	1981	1985	70.9	
Philippines	1981	1981	50.0	
Uganda	1981	1988	93.7	
Argentina - United Kingdom	1982	1982	100.0	
Philippines	1982	1986	50.0	49.5
Syria	1982	1982	69.5	
Nicaragua	1983	1988	100.0	
Sudan	1983	1992	58.1	
Yemen (South)	1986	1986	1.0	
Chad - Libya	1987	1987	1.9	97.1
India	1988	1992	2.8	
Iraq	1988	1988	5.9	83.9
Cambodia	1989	1989	81.1	
Colombia	1989	1990	97.7	
Somalia	1989	1992	98.9	
South Africa	1989	1993	80.0	
Sri Lanka	1989	1989	100.0	
Sri Lanka	1989	1993	100.0	
Angola	1990	1994	3.3	79.7
Chad	1990	1990	26.0	
India	1990	1993	4.5	2.8
Liberia	1990	1990	100.0	
India	1991	1991	2.5	7.3
Kuwait	1991	1991	100.0	
Rwanda	1991	1992	66.7	
Yugoslavia	1991	1991	22.4	
Azerbaijan	1992	1993	12.3	
Bosnia and Herzegovina	1992	1993	19.8	
Burma	1992	1992	11.2	
Guatemala	1992	1992	100.0	
Tajikistan	1992	1992	32.2	
Turkey	1992	1997	8.6	
Algeria	1993	2001	29.4	
Georgia	1993	1993	17.9	
Burma	1994	1994	28.6	

Table 2: Conflicts included in the analysis

Location	Start Year	End Year	Percent of territory coded as outbreak grid	Percent of conflict zone already in prior conflict, excluded from outbreak code
Yemen	1994	1994	28.6	
Russia	1995	1996	0.1	
Congo/Zaire	1997	1997	98.1	
Congo-Brazzaville	1997	1997	31.6	
Angola	1998	1998	58.0	
Burundi	1998	1998	83.3	
Eritrea	1998	2000	90.2	
Ethiopia	1998	2000	10.1	
Guinea-Bissau	1998	1998	27.9	
Rwanda	1998	1998	100.0	
Sierra Leone	1998	1999	82.7	
Yugoslavia	1998	1998	33.5	
India	1999	2002	6.2	
Pakistan	1999	1999	9.0	
USA	2001	2001	1.4	
Nepal	2002	2002	53.2	

Demographic Data.

Population data are gathered through a variety of mechanisms, including population, housing, and agricultural censuses, civil registration systems, government and administrative sources, and sample surveys. These data are often collected and integrated at irregular intervals with widely varying objectives, levels of resources, quality control, breadth of data, and degrees of spatial and temporal resolution and referencing. Through preparation of the Gridded Population of the World (GPW), CIESIN has developed a unique collection of subnational administrative boundary data and corresponding population estimates for the world covering approximately a 20-year period from the late 1980s to the present. Whereas the first version of GPW was based on approximately 19,000 subnational units, GPW Version 3, now available in preliminary form, incorporates more than 350,000 subnational units, each with georeferenced boundaries and at least one corresponding population estimate (Balk et al 2004). GPW is based on application of standard GIS gridding algorithms to these data to produce population estimates for "spherical quadrilaterals" with the dimensions of 2.5 minutes latitude by 2.5 minutes longitude, approximately 21 km^2 at the equator. GPW is widely utilized in interdisciplinary research because of its ability to place human activity in a spatial context; it has been cited in over 100 published articles (http://sedac.ciesin.columbia.edu/plue/gpw/papers.html).

Rainfall Deviations

We utilized the Weighted Anomaly Standardized Precipitation index (WASP) as a measure of the rainfall deviations from normal (Lyon, 2004). The WASP index measures, on a monthly basis, the difference between observed rainfall totals and persistent averages over the period 1980-2002. It weights monthly anomalies according to the average monthly rainfall's fraction of annual rainfall (http://ingrid.ldeo.columbia.edu/maproom/.Global/.Precipitation/WASP_Indices.html, 4/15/05.) The WASP index is calculated on a 2.5 degree grid.

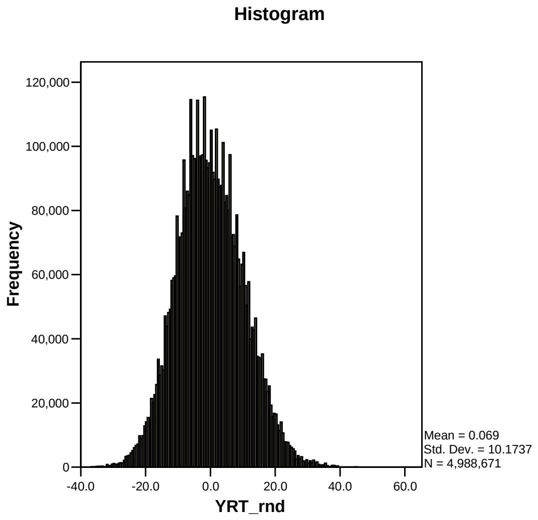
$$WASP_N = \frac{1}{\sigma_{WASP_N}} \bullet \sum_{i=1}^{N} \left(\frac{P_i - \overline{P_i}}{\sigma_i} \bullet \frac{\overline{P_i}}{\overline{P_A}} \right)$$

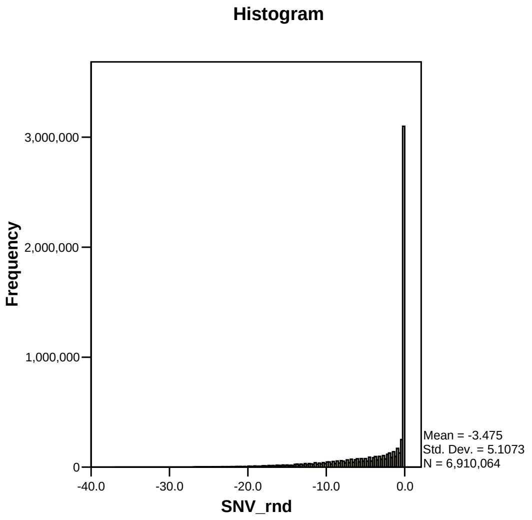
where P_A is the average total annual precipitation; P_i is the observed monthly precipitation in the i^{th} month in the sum; $\overline{P_i}$ is the climatological average value for that month; $\frac{\overline{P_i}}{\overline{P_A}}$ is the average monthly fraction of annual precipitation; and σ_i is the standard deviation of anomalies of monthly precipitation.

To make the data compatible with our annual conflict data, we converted the monthly WASP index into an annualized index. We explored a number of alternatives.

1. The sum of WASP values over a twelve month period (YRTOT).
2. Sum of negative monthly anomalies only (SNV).
3. Number of months with negative WASP value (NEG_MOS).
4. Number of months with WASP values below -1. This indicator counts up the number of months in a given year that precipitation fell to one standard deviation below expected, or less. [UNDER1].
5. Number of months with WASP values below -2.

Histograms for four of these alternatives are provided below. The normal distribution of the sum of the 12 monthly WASP values made it attractive for present modeling purposes. In ongoing we will continue to experiment with alternative formulations.





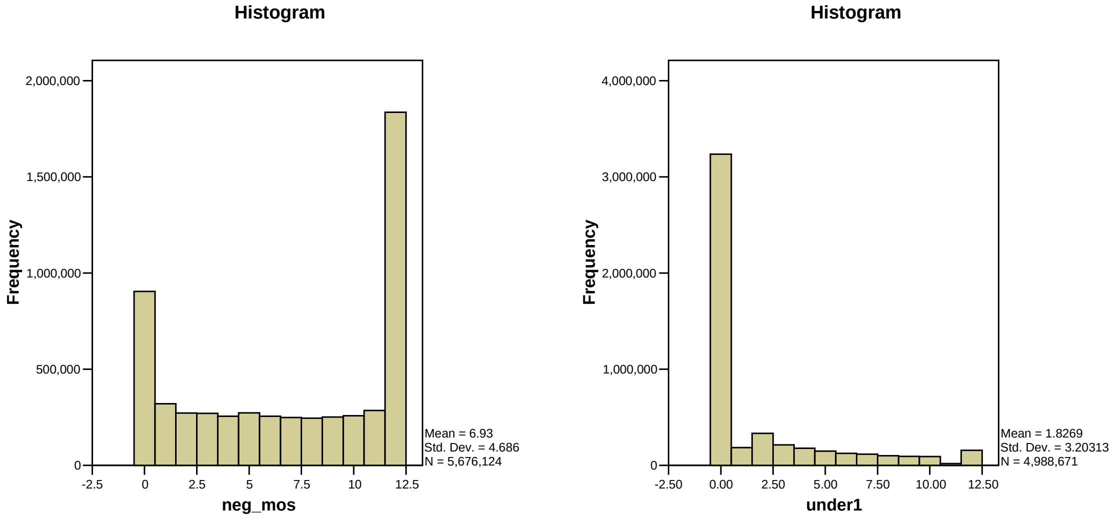


Figure 5: Histograms of alternative annual WASP aggregations

Hydroclimatic Datasets

For this preliminary work, we used mean annual locally-derived runoff to represent renewable water available within each grid cell. Locally-derived runoff can be thought of as the amount of precipitation that remains after vegetation, soil moisture and atmospheric demands have been met. This runoff was generated from a geographically-referenced Water Balance and Transport Model (WBM/WTM) will be used to determine the spatial distribution of renewable water supply, specifically as the expression of local runoff as discharge in river corridors at a 30-minute (30') spatial resolution (longitude x latitude). While the model version used in this study shows <10 mm yr^{-1} bias in runoff (Vörösmarty et al., 1998; Fekete et al., 2002), WBM/WTM estimates are constrained where possible by observed hydrographic information. Atmospheric forcings (i.e., rainfall, temperature, solar radiance, etc.) are from New et al. (1998) comprising monthly data from 1960 to 1995 at a 30-minute (30') resolution, which is the best resolution available for globally consistent climatological model inputs. All water supply estimates are georegistered to a 30' potential river flow topological network (STN-30p, Vörösmarty et al., 2000b; 2000c) using a river network rescaling algorithm (Fekete et al., 2001) based on 1 kilometer (km) digital streamlines (USGS, 1998). Grid cells in which the upstream average runoff was < 3 mm yr^{-1} represent areas where the river network is considered to be inactive (Vörösmarty et al., 2000b, Meybeck, 1995). Basin boundaries were derived from this algorithm and compared to a hand-corrected version of the database provided by the Food and Agricultural Organization (Jippe Hoogeveen, FAO/AGL, Rome Italy). Data sets for domestic and industrial water demand (Vörösmarty et al., 2000a, Vörösmarty et al., 2003a) were resampled from the original 1-km resolution and co-registered to the 30' grid and river network. Demand was apportioned by urban/rural population densities. The agricultural water demand layer are developed using water statistics provided by FAO (Jippe Hoogeveen, FAO/AGL, Rome Italy) at the sub-basin level. Irrigation water use within each sub-basin as defined by FAO is distributed by sub-basin across a data set of irrigation-equipped lands developed by Siebert et al. (2002).

We also calculated a measure of average water availability per capita, by dividing the above runoff measure by our gridded population estimate.

Methodology

To evaluate the relationship between the variables of interest, we implemented a logistic regression model, with grid cell as the unit of analysis and conflict outbreak as the dependent variable. Ongoing conflict grids subsequent to the year of outbreak were censored from the analysis as noted above.

For control variables, we sought to implement a simple version of the Political Instability Task Force model (Esty et al 1998), utilizing measures of infant mortality, trade openness, and democratic institutions (Polity). Following the Political Instability Task Force, infant mortality and trade openness were measured relative to world mean. Similarly, the Polity measure that was used was a binary variable set to 1 for Polity scores in the intermediate range of -5 to 7. Each measure applies to country-year observations. Grid cells within a country-year were assigned identical values uniformly. We utilized the public version of the Political Instability Task Force database (ref).

As an additional control variable we added grid cell population. Many national-level models of civil war have found that country population size is directly related to probability of civil war outbreak (e.g Fearon and Laitin 2003), although not all published models incorporate the variable. In our case, dealing with subnational grid cells, including a population variable seemed especially important because of the great variation in population distribution within countries. Conflict is unlikely in subnational regions that are largely empty of people. Although ideally we would like subnational time series data on population, such data do not exist. For this study we used the 2000 population count derived from CIESIN's Gridded Population of the World, version 3 (ref). Within the limits of precision afforded by the spatial conflict boundaries we are working with, this proxy is sufficient. To the extent more spatially precise definitions of conflict zones become available it would become increasingly important to identify more precise time series data on subnational population. Our variables possess multiple forms of spatial autocorrelation that complicate the application of conventional regression analysis (Anselin 1988). Infant mortality, trade openness, and Polity have what can be called "pseudo-replication." They are measured at the national level, but implemented in the data set at the subnational grid cell. Therefore within a single country year the value of any one cell is absolutely identical to that of its neighbors. Alternatively, the population, rainfall and conflict measures are not identical within a country-year unit, but they are spatially correlated.

We sought to implement a GEE model to help cope with these dependencies, specifying a correlation matrix that included time and space. However, with our data set of 4.5 million observations it was not possible to implement such a model within either SAS or Stata. We also explored implementation of a spatial regression model using libraries written for Matlab (Smirnov and Anselin 2001) but these also failed because of problems emerging from the very large size of the intermediate matrices employed.

As a next best alternative, we utilized Stata's robust standard error option, selecting country as the sampling cluster. This approach explicitly recognizes that variables are correlated within countries but not necessarily across them. It is less than optimal because it does not allow for specification of an explicit customization of the spatial correlation matrix, however we deemed it adequate for our exploratory analysis. The effect of these dependencies on our results will be explored and quantified in greater detail in future work.

In ongoing planned work we plan to experiment with alternative units of analysis, including river basins and subnational administrative units (Provinces and Districts).

Results

We discovered a quadratic relationship between population and conflict outbreak. The probability of conflict increases through about the 75th percentile of population, then declines. The model includes a value for log(population) and $[\log(\text{population})]^2$.

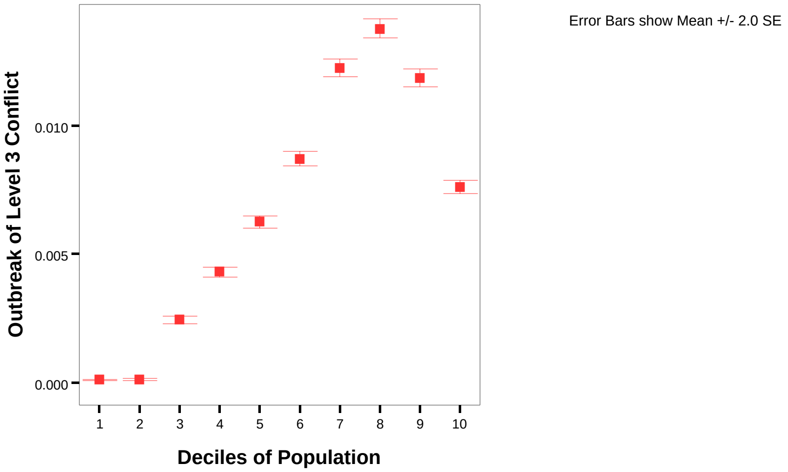


Figure 6: Mean High-Intensity Conflict Outbreak by Population Deciles

This global pattern is also seen within Africa and Asia. In South America, by contrast, the relationship is linear. In regions with few internal wars, no discernible pattern is present.

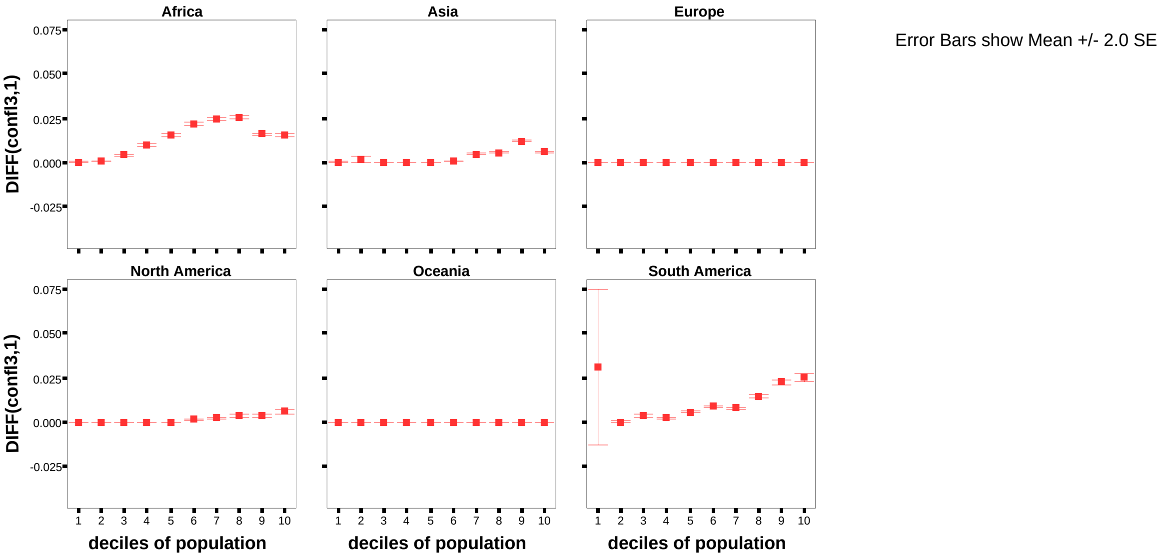


Figure 7: Mean High-Intensity Conflict Outbreak by Population Deciles by World Region

Table 3: Logistic Regression Results
Dependent variable: Outbreak of High-Intensity Conflict. All independent variables lagged one year.

	Base Model		**Model 1**		**Model 2**	
Variables	**Coefficient**	**z**	**Coefficient**	**z**	**Coefficient**	**z**
Infant Mortality	.6066303***	3.70	.555298**	3.15	.5626645**	3.17
Trade Openness	-.0056111	-1.00	-.0061467	-1.02	-.0065039	-1.10
Polity -5 to 7	.5972534	1.12	.6185404	1.10	.6194272	1.09
Population (natural log)	1.544352***	3.43	1.370418**	3.12	1.402548**	3.08
Square of population	-.0753709**	-3.07	-.0661139**	-2.74	-.0683341**	-2.74
Rainfall Deviations			-.0433752***	-5.06	-.044599***	-5.56
Average Surface Freshwater per capita 1979-2000					-.0002359	-0.35
Constant	-13.35957***	-6.10	-12.51891***	-5.90	-12.63071***	-5.78
Number of observations	4031955		3373403		3179202	
Wald chi^2	42.33***		76.28***		146.52***	
Pseudo R^2	.1152		0.1240		.1206	

*** = significant at .001 level, all standard errors adjusted for clustering on country ID
** = significant at .01 level
* = significant at .05 level

The results for the base model show some difficulty in replicating the Political Instability Task Force results. The coefficients for Trade Openness and mid-range Polity scores are not significant. At this stage we cannot conclude for certain whether this is attributable to the alteration of the unit of analysis (grid-year as opposed to country-year) or to the truncation of the time period (the Task Force results are built primarily on the period 1955 onward , as opposed to 1979 onward). However, preliminary tests suggest that the time period may be the primary culprit; running the model with country-years as the unit of analysis seems to generate similar results to those presented here. We leave Trade Openness and Polity in subsequent models as controls in spite of their low significance.

Model 1 shows a strong relationship between rainfall deviations, lagged one year, and the likelihood of high-intensity conflict outbreak. We experimented with alternative lag specifications, including a 2-year lag, no lag, and cumulative 2-year totals. The simple one-year lag proved the most significant in all comparisons.

In Model 2 we introduced average surface freshwater availability (in the form of mean annual runoff) per capita. It is not significant in this test. We investigated whether removing the rainfall deviation variable from the equation affected this result, and it did not – the freshwater availability measure remained insignificant. However, Figure *8* indicates a relationship between the interannual variability of water resources (in the form of river discharge) and the spatial occurrence of internal conflict. The lesser significance of water availability in this preliminary work could be a result of two factors: 1) unlike precipitation, runoff integrates the effects of land-based biophysical processes, such as land cover, soil properties, and terrain which may have confounded the runoff "signal"; 2) we did not treat land-based water availability in the same manner as atmospheric water availability (precipitation). In future work, we will evaluate the significance of mean annual discharge (cumulative runoff for each grid cell, which represents available river flow) and a WASP-like index computed from a time series of monthly runoff.

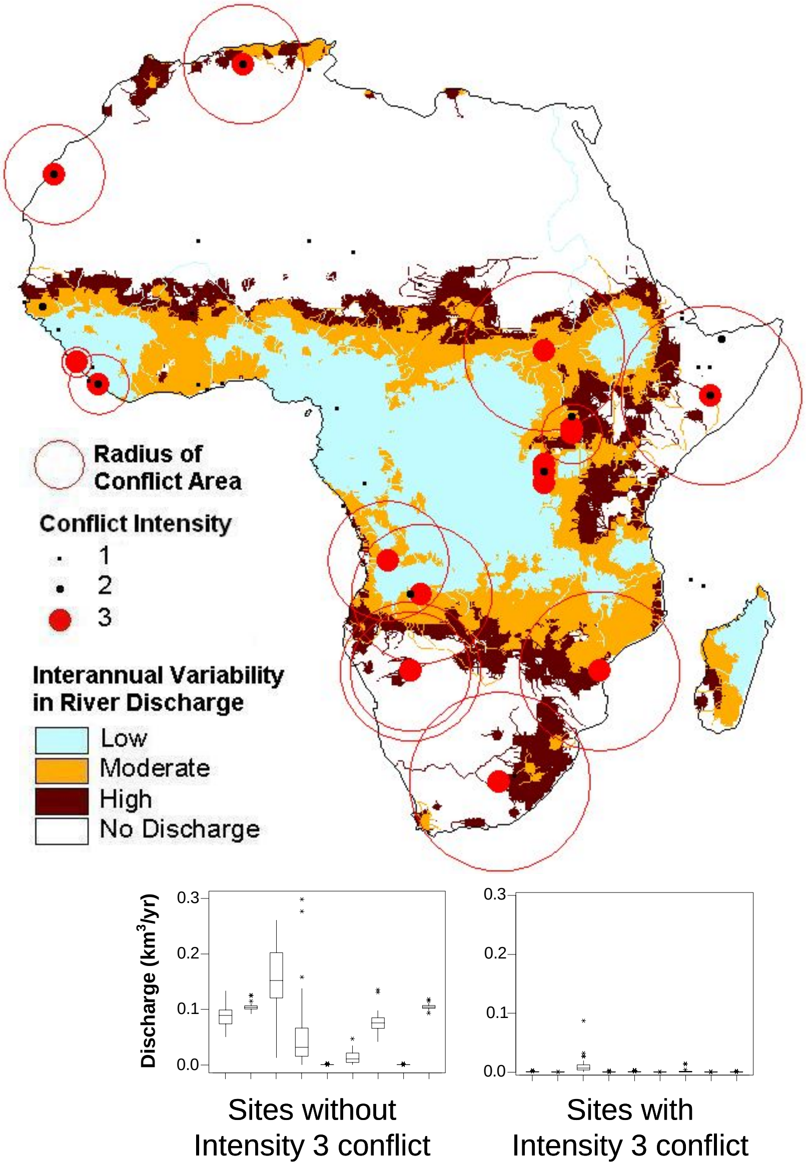


Figure 8. Preliminary analysis of the spatial coincidence of internal conflicts and river discharge availability and variability. The box plots (bottom) compare the range of river discharge at sites that have experienced high intensity internal conflicts and sites outside of the areas of these conflicts. They imply that river discharge is a potential discriminatory variable in evaluating the risk of internal conflicts.

These results, therefore, support Hypothesis 3 but not Hypothesis 1. Regions with high levels of variability in rainfall are more prone to conflict than other regions, although regions with low levels of baseline water availability are not more prone to conflict than other regions.

To test whether our results might be overly influenced by a single case we carried out a simple sensitivity analysis. We calculated partial correlations between rainfall deviations and high-intensity conflict outbreak, controlling for infant mortality, trade openness, polity, population, and the square of population. The results show that the results are not dependent on any single case but are robust across all possible single-case deletions. The results are shown graphically below in Figure 9.

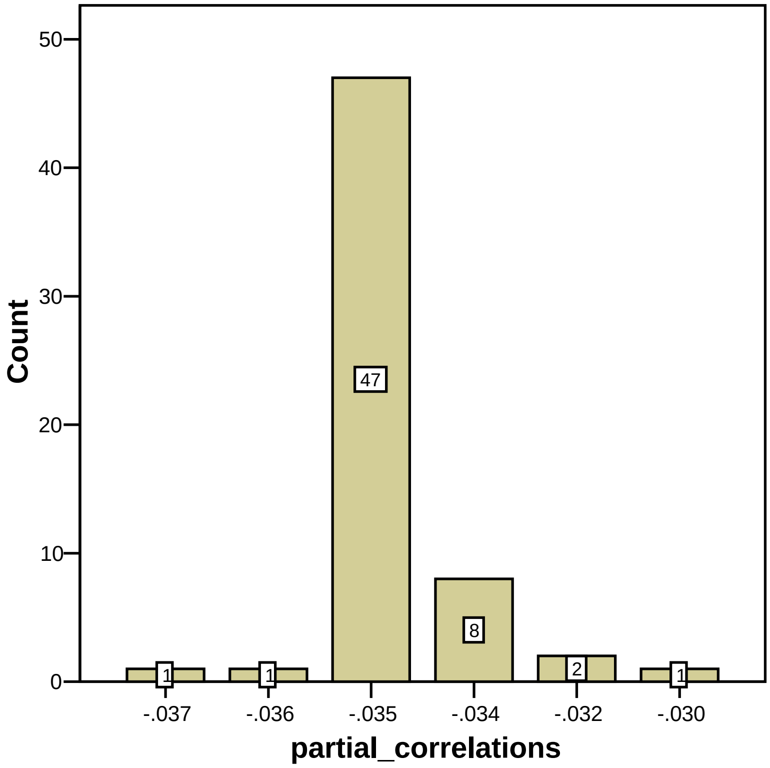


Figure 9: Correlations between Rainfall Deviations and Conflict Outbreak (controlling for other model variables), upon selective removal of individual cases. The reference correlation coefficient (when all cases are included) is -.035).

There are two cases which, if removed, slightly increase the effect of rainfall deviation on drought, but only by very small amounts. Eleven slightly decrease the measured effect. The largest such effect is from Zaire 1997. It alters the partial correlation coefficient from -.035 to -.030, a difference of about 13%. Although this effect is tangible, it does not affect the significance of the overall results – the sign of the coefficient and its significance level remain the same. We conclude that the results presented here are not sensitive to the presence or absence of any peculiar cases.

We further explored the impact of rainfall and water variables on low-level conflicts (intensity 1). We found that both the rainfall deviations and total freshwater availability per capita were not significant predictors of such conflicts.

An illustration

The case of Nepal's Maoist insurgency, which crossed the threshold to level-3 conflict in 2002, helps illustrate the patterns uncovered by the global model. We are not arguing that this single case is "explained" by drought patterns. Rather we think it provides an illustration of the plausibility of the statistical relations identified in the global logistic regression. In our planned joint research we will carry out thorough case studies in a way that subjects them to robust testing. This discussion of Nepal does not constitute a test but rather an illustration.

In Figure 10 we see that the area of the country in which the internal war was concentrated was also the area where there was a serious drought during the prior year.

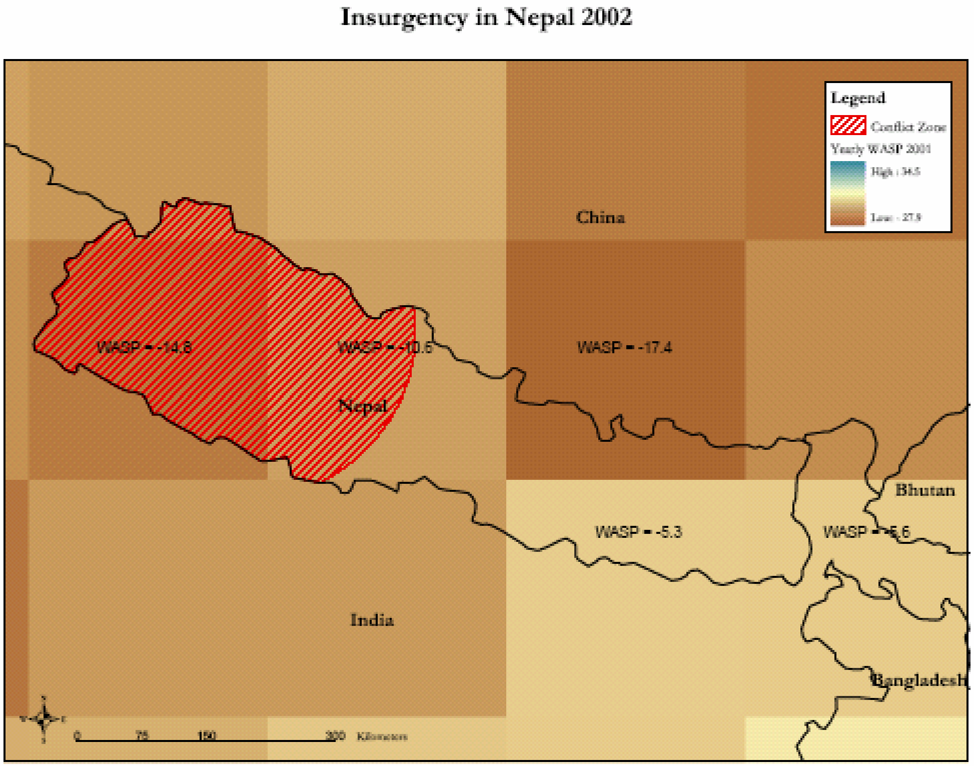

Insurgency in Nepal 2002

Figure 10: Nepal 2002 Conflict Zone and 2001 Rainfall Deviation

The following graph we show the trends leading up to the 2002 high-intensity outbreak. It compares values for the rainfall deviation measure within the area that erupted in conflict and the rest of the country. Points below the line are drier than average and points above are wetter. Each unit corresponds to a monthly standard deviation. We see that up to 1994 there was more or less a fluctuation around zero, both inside and outside the conflict zone. However, from 1994 onward a period of long-term shortfalls ensued which were consistently more severe within the conflict zone than outside it.

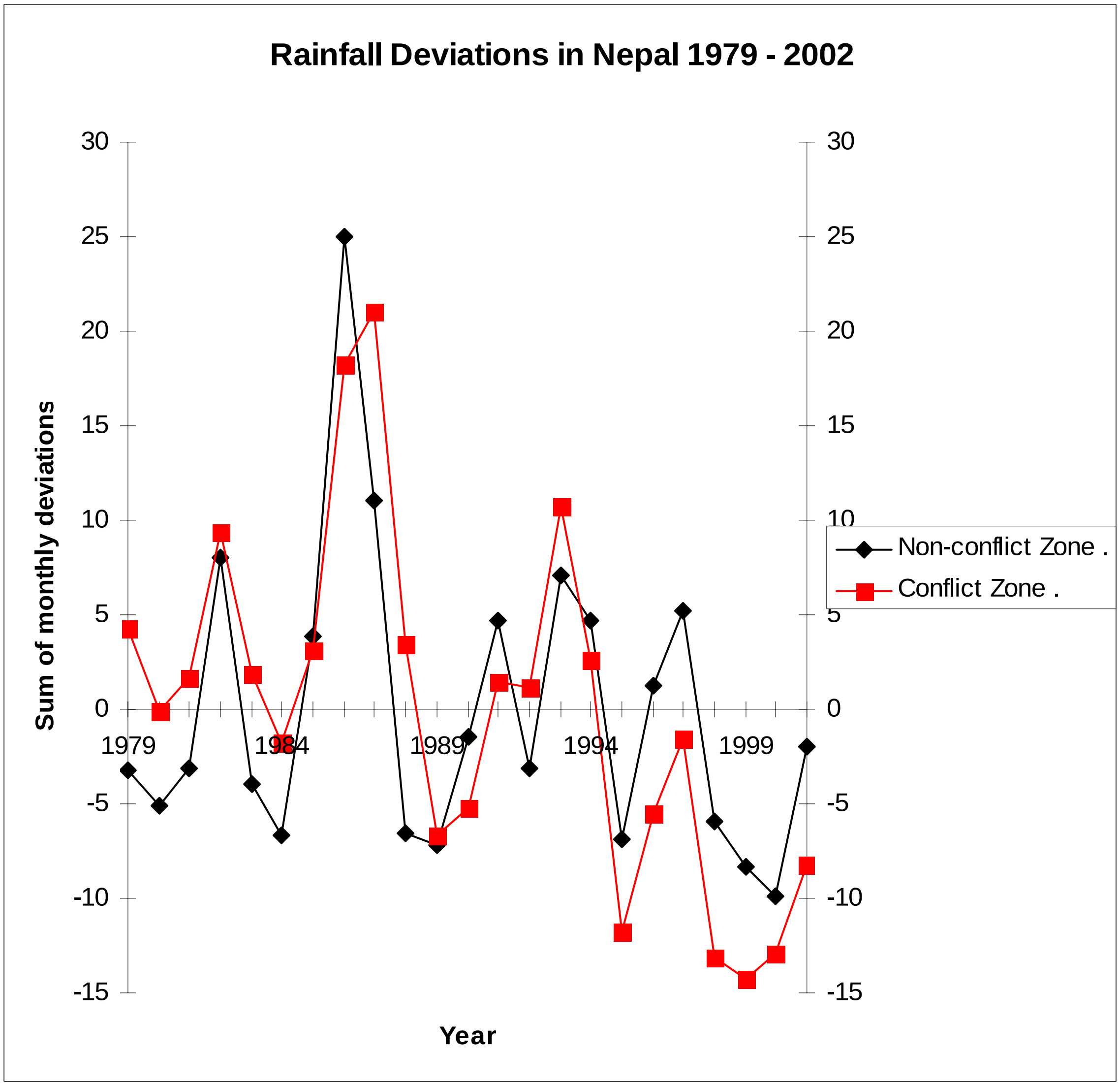


Figure 11: Rainfall Deviations in Nepal, 1979-2002, in Conflict and Non-conflict Zones

The fact that these areas experienced a significant drought in the years leading up to the conflict is consistent with the finding that the conflict areas experienced greater levels of inter-group inequality than other areas (Murshed and Gates 2003). We intend to explore in the next phase of our work whether the apparent statistical correlation between horizontal inequality and levels of drought is accompanied by a plausible causal connection – is there evidence that droughts exacerbate inter-group inequality.

Conclusions

We have demonstrated a technique for exploring the relationship between low water availability (in the form of meterological drought) and political conflict that makes use of subnational time series data. Controlling for other variables, we find a strong relationship between rainfall deviations below normal and the likelihood of high-intensity conflict. We do not find such a correlation for low-intensity conflicts.

One can posit two competing explanations for a correlation between drought and conflict. One the hand, drought may decrease levels of capacity and increase levels of grievance. Such a view is consistent with the implicit models of Homer-Dixon and Kaplan. On the other hand, drought may alter the incentive structure facing potential rebel recruits, in a framework consistent with Collier and Hoeffler; droughts reduce the return from agricultural labor and therefore improve the relative returns from rebellion. We expect that multiple causal paths are likely to be operating, and that many omitted variables are likely to be important, including political institutions and regional coping mechanisms. Under the circumstances, further progress is likely to require a careful combination of large-n statistical modeling and structured in-depth comparison of cases.

We find differences in these relationships between world regions. What explains these differences constitutes an interesting puzzle for further work. Prior to engaging in such investigation we think it would be valuable to extend the spatial data set to cover earlier time periods.

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