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MAPPING GLOBAL CLIMATE-RELATED RISK AND VULNERABILITY IN A GEOGRAPHIC INFORMATION SYSTEM

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ABSTRACT: *International global climate change policy requires a nuanced approach. A theoretical model of human vulnerability to weather-related risk was developed recently that correlates human loss and suffering to specific extreme events in developing nations. The model includes a diverse set of paths to climate risk and vulnerability designed to assess wealth, inequality, urbanization, the environment, political structures, and civil societal strength. A geographic information system (ArcGIS) is used to illustrate the spatial distribution of risk and vulnerability to atmospheric hazards related to climate change for all countries, not just developing nations. ArcGIS provides the user capabilities to synthesize and meld data, develop digital shapefiles and layers to allow for wider dissemination and use of the data, classify data and create thematic maps of an index for climate-related risk and vulnerability, and preliminary spatial analysis at a variety of scales: global, regional and national. The index model used in this study is compared to the multi-criteria Environmental Sustainability Index for verification. The results indicate that vulnerability to climate-related risk is not solely related to any broader, more established, traditional nation-scale assessments of environmental or socio-economic vulnerability. While developing countries of the global south are significantly exposed, this analysis reveals potential issues in the mid-latitude developed world. The resulting GIS maps can be used to frame the issue of climate-related risk and vulnerability at the national scale and illuminate potential differences in how institutional capacity and visualization influence climate policy and perception.*

Keywords: *Climate, Risk, Vulnerability, GIS*

INTRODUCTION

Maps are powerful tools for understanding risk and vulnerability to hazards (Monmonier, 1997). The geographic implication of risk and vulnerability, hazards and disasters has been widely and thoughtfully discussed by geographers for decades in emergency and environmental management (Cutter, 2003a and 2003b), geographic regions and disaster (Hewitt, 1997), models of risk, exposure, response and mitigation (Mitchell et al., 1989); environmental hazards (Smith, 1992); seminal works in response and adjustments and response to flood hazards (White, 1975 and Ward, 1978) and more broadly in the context of vulnerability science (Cutter, 2003b), multidimensional social contexts related to the use of geospatial tools such as GIS (Pickles, 1995) and hazard perception and persistent human occupancy in areas of recurrent hazard (White, 1974). These discussions have led to paradigms, models, and definitions which can be broadly summarized as the following: risk is a measure of the probability of a hazardous event of significant magnitude occurring in a place; vulnerability is a measure of the likelihood of people to be exposed to risk; hazards exist at the junction of risk and vulnerability; and disasters occur when significant populations are affected by a hazard, inclusive of and influenced by response, mitigation and social and political contexts. According to the International Panel on Climate Change (2007) increases in the risk of weather related hazard events, including drought, heat waves, heavy precipitation and the intensity of tropical cyclones are related to anthropogenic climate warming.

Recent work in the area of climate-related risk and vulnerability has utilized a quantitative methodology for defining risk and vulnerability on a global scale. Kahn (2005) uses the average number of natural hazards that a country experiences and the deaths from these hazards to evaluate risk and vulnerability. Roberts and Parks (2007) use deaths, homeless or otherwise affected by climate-related hazards to evaluate risk and vulnerability which is synthesized in this paper into a single digital database for climate risk and vulnerability focusing on the social context of environmental change. Risk and vulnerability to global environmental change are a function of political economy and biophysical variables. Environmental effects such as anthropogenic climate change due to greenhouse gases are embedded within the framework of increasing economic and social interdependence of countries across the world (White, 1991). Some countries will suffer more and more quickly to global environmental change and some will benefit (Liverman, 1994), and specific populations are more vulnerable based on natural and socioeconomic conditions (Hugo, 2007).

Geographic Information Systems (GIS) can be used to determine indicators from sources such as remotely sensed imagery, Global Positioning System (GPS) and field data (Zeilhofer and Topanotti, 2008) and ultimately couple environmental and socio-economic indicators for spatial analysis. GIS is also a social actor that can function as a legitimizing tool for representing evidence and has been successful at shaping agendas in the areas of climate change and risk (Pickles, 2006). Geospatial technologies used in the context of a social actor can be harbingers of hope by creating more informed and interdisciplinary research related to environmental, health and social justice issues (Klinkenberg, 2007). GIS facilitates the accessibility of relevant and usable data for associated domains such as emergency management, although realization in the field has not been widely documented (Cutter, 2003a). The coupling of seasonal population data with hurricane tracks and evacuation routes for local emergency management resonates with the work of assessing global risk to climate change, specifically, by providing better integration of social dynamics and physical models and better representation of data to evaluate vulnerability to hazard.

Climate-related hazards and geographic analysis using GIS has been explored, especially in constructing maps of coastal change due to sea level rise (Boruff and Cutter, 2007 and McGranahan et al., 2007). Research in the social dimensions of issues that affect people and the environment (see Kahn 2005 and Roberts and Parks 2007) has not taken advantage of the capabilities of GIS perhaps to avoid generalizations. Others have concerns that GIS is too technocratic, as in the view of GIS as a cyborg capable of improving human performance (Piper, 2002) or in fear associated in the broader context of surveillance by geospatial technologies (Klinkenberg, 2007). While many works use statistical methods, maps and digital geospatial data are not ubiquitously used to support their detailed accounts and arguments. GIS has become a widely used tool for visualizing spatial climate data and for analysis of global climate change (Chapman and Thornes, 2003) and for regional ecosystem modeling (Dockerty and Lovett, 2003). The multiple works of Cutter and others couple geospatial analysis using GIS with the broader conceptual frameworks of vulnerability on local scales (Cutter et al., 2000). The utility of GIS is demonstrated in this paper by editing country digital shapefiles, classifying and ranking variables to create an index model, and producing choropleth maps at the national scale. This paper provides an example of how GIS, the tool and GI Science (Goodchild, 1997), can be implemented to provide solutions to complex issues such as in the work of Ueland and Warf (2006) in analyzing environmental justice and race. Specifically, by using the abilities of a GIS to create an index model of the parameters, classify and portray vulnerability in a thematic map, places other than the global south are revealed as vulnerable.

METHODS

Eight interdisciplinary factors: GDP per capita, population in cities and near coasts, ecosystem wellbeing index, press freedom, civil societal pressure, social justice and property rights (Roberts and Parks, 2007) are correlated to climate-related risk and vulnerability by Roberts and Parks (2007) and Kahn's (2005) summation of disaster and death per country. A GIS based methodology is used to create thematic maps that reflect these factors at the country scale. GIS shapefiles provided by Environmental Science Research Institute (ESRI) were analyzed to determine if the necessary demographic data existed to either match or provide a surrogate for the data in previous studies to create a new index model that could provide spatial representation and analysis of climate-related risk and vulnerability at the global scale. ESRI provides a world geography file which includes a country shapefile with total population and area and a separate database file with demographic data compiled from CountryWatch.com from ESRI, Series 2006.

GDP per capita, a match to the previous study, and percent urban population, a surrogate for number of people living in cities, are the only two variables directly utilized from the existing ESRI GIS databases. The source of the remaining six variables and their relation to the previous study (Roberts and Parks, 2007) are summarized in Table 1. These data are added manually as new fields to the existing Countrywatch database and connected to the country shapefile using the 'Join' command in ArcMap to allow for future edits and updates. In addition to the eight variables, new fields are created for average annual disasters and deaths from Kahn (2005) and the 2005 Environmental Sustainability Index from the Socioeconomic Data and Applications Center (SEDAC).

Table 1. Eight Variables Related to Climate Risk and Vulnerability

Variable	*Roberts & Park 2007*	*CVI*	*Data Classes*	*Rank*	*Source*
National Wealth	GDP per Capita	GDP per Capital	< 4951	5	ESRI Countrywatch
			4952-7962	4	file
			7963-15954	3	
			15954-23,487	2	
			23,288-31,880	1	
Geographic	Percent population < 100 km	Percent population in the	<7	1	SEDAC
Vulnerability I	from coast	LECZ	8-19	2	http://sedac.ciesin.
			20-34	3	columbia.edu/
			35-56	4	gpw/lecz.jsp
			>56	5	
Geographic	Percent population living in	Percent Urban	<30.28	5	ESRI Countrywatch
Vulnerability II	cities		30.29-50.35	4	file
			50.36-67.00	3	
			67.00-81.28	2	
			>81.28	1	
Environmental	Ecosystem Wellbeing Index	Ecosystem Wellbeing	0-14	5	The Wellbeing of
Vulnerability		Index	15-35	4	Nations
			36-47	3	http://sustainability.ca/
			48-58	2	Docs/wonrank.pdf
			59-72	1	
Civil Societal	Total NGOs in 2000	Cap_Gov index from ESI	< (-0.8)	5	The Environmental
Pressure			(-0.81) - (-0.34)	4	Performance
			(-0.35) – 0.21	3	Measurement Report
			0.21 – 0.92	2	http://www.yale.edu/esi
			> 0.91	1	
Institutional	Press Freedom Index	Press Freedom Index	Good	1	Internet:
Quality I			Satisfactory	2	Reporters without
			Problems	3	Borders(poster)
			Difficult	4	Already classified.
			Very Serious	5	
Institutional	Property Rights	IPRI	<3.8	5	http://
Quality II			3.9-4.9	4	internationalproperty
			5.0-6.1	3	rightsindex.org
			6.2-6.8	2	
			> 6.8	1	
Social	Inequality GINI index	Inequality GINI index	<31.0	1	http//en.wikipedia.org/
Vulnerability			31.1 - 38.0	2	wiki/
			38.1 - 46.1	3	List_of_countries_by
			46.2 – 56.4	4	_income_equality
			>56.4	5	Used U.N. coefficients

Thematic maps were made in GIS for each variable using five classes based on natural breaks, the default classification in ArcMap GIS based on Jenk's Optimization. Jenk's Optimization has been argued to be more efficient in data visualization for thematic mapping and "most consistent with the goal of data classification, forming groups that are internally homogenous while assuring heterogeneity among classes" (Dent, 1999). Some published maps for individual variables such as GINI and press freedom use quantiles, a classification scheme in which each class contains an equal number of features through a sorting and mathematical process. Thematic maps based on quantile classification can be misleading when only a few classes (5 or less) are used because countries with similar attributes may fall into different classes to fit the sorting scheme. Similarly, countries with extreme differences in attributes may be placed in the same class to fit the sorting scheme. Thematic maps that use Jenk's Optimization may produce a classification scheme that represents spatial regions that are most similar according to the attribute values and not contingent on a systematic but mostly random use of some measure of equality. These statistical methods are not unique to GIS and available in commercial database software, however a GIS provides a single platform for database manipulation and thematic mapping.

Each class was assigned a rank between 1 (low) and 5 (high) and a new field was created in the database for the integer values for the ranked variables (Table 1). An arithmetic linear model was created based on the sum of each ranked variable and the data classified and mapped using ArcMap (Figure 1). The technique is consistent with index modeling methods which weigh, standardize and sum values (Chang, 2008) which is commonly used for analyses of vulnerability and suitability as in the Habitat Suitability Index. A sum value was used to have a cumulative index value, not an average, which would be more comparable to the Environmental Sustainability Index. Table 1 lists the data classes and ranks for each variable. Classification was performed after countries with no data were removed. Ranks were assigned based on the criteria in the table and countries with no data were ranked with a 5 for the missing variable. The variables with the highest amounts of non-reported "no data" are assessments of GINI (70) or Press Freedom. Therefore, the rationale to use the highest rank for a variable with no data is warranted because the no data is a result of data not being available or reporting of data and in these two areas is an indication of suppression of freedoms and rights. Studies of climate change vulnerability such as SEDAC (Yohe et al., 2006a) ignore many countries that would be of interest to geographers, such as Greenland and Mynamar, by simply indicating "No Data". The GINI, SEDAC, and Press Freedom works are useful but limited in acquiring a complete world map of these issues and more work is needed to better address including all countries in global analyses.

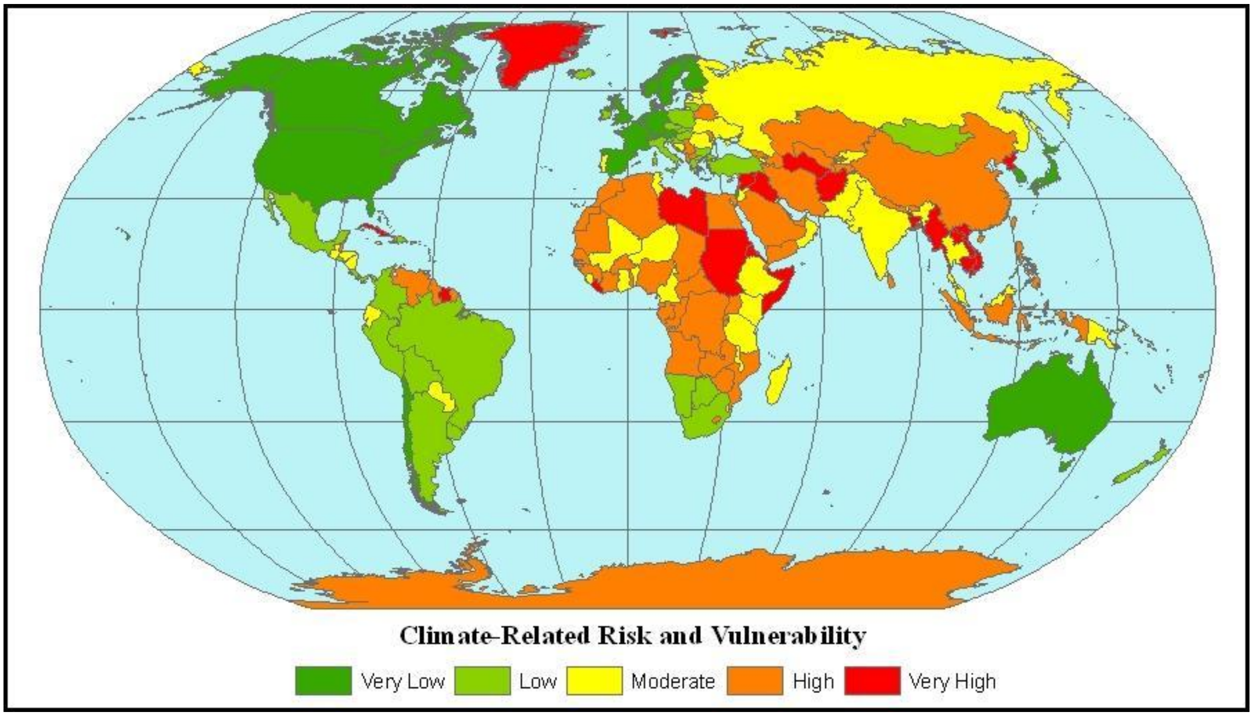

Figure 1. World map (Robinson Projection) of the climate risk and vulnerability index using natural breaks in ArcMap GIS.

RESULTS

The data classes and rank for each variable for each country are summarized in Table 1. Maps for these variables are usually available in the source material and therefore not represented here. A total of 177 countries are evaluated in the climate risk and vulnerability index (Figure 1) which is more than the number of countries analyzed in the SEDAC database. The countries placed in the lowest vulnerability class based on the natural breaks computation are listed in Table 2. Nineteen countries with values from 10-17 are placed in the lowest climate vulnerability class, with Sweden ranked the lowest with a value of 10 and Spain at the threshold with a value of 17. 139 countries are in the environmental sustainability index (Figure 2) and the lowest class grouped by natural breaks in ArcMap and compared in Table 2 to the climate vulnerability index. The 2005 ESI report places the lower end of that class at 59.7 and would include 17 countries. Only six countries were placed in the highest index with values between 64.4 and 75.1, compared to nineteen in the CVI. The countries that are "missing" in the ArcMap analysis are high ranking non-OECD (Organization for Economic Co-operation and Development) countries such as Uruguay and Guyana. There are 29 countries in the Moderate to High class which is cut at 55.2. The United States, ranked 44 with an ESI value of 53.0 is placed in the Moderate Sustainability class.

Table 2. Low Climate Risk and Vulnerability Countries by Rank Compared to ESI Score

Country	*CVI (lowest)*	*ESI (class)*
Sweden	**10**	**71.1 (high)**
Germany	11	56.9 (moderate-high)
Finland	**13**	**75.1 (high)**
Norway	**13**	**73.4 (high)**
Austria	13	62.7 (moderate-high)
Switzerland	13	63.7 (moderate-high)
Denmark	14	58.2 (moderate-high)
Canada	**14**	**64.4 (high)**
United Kingdom	14	50.2 (moderate)
Australia	15	61.0 (moderate-high)
France	15	55.2 (moderate-high)
Israel	16	50.9 (moderate)
Chile	16	53.6 (moderate)
Belgium	16	Not listed
Netherlands	16	53.7 (moderate-high)
South Korea	16	Not listed
Japan	16	57.3 (moderate-high)
United States	16	52.9 (moderate)
Spain	17	48.8 (moderate)

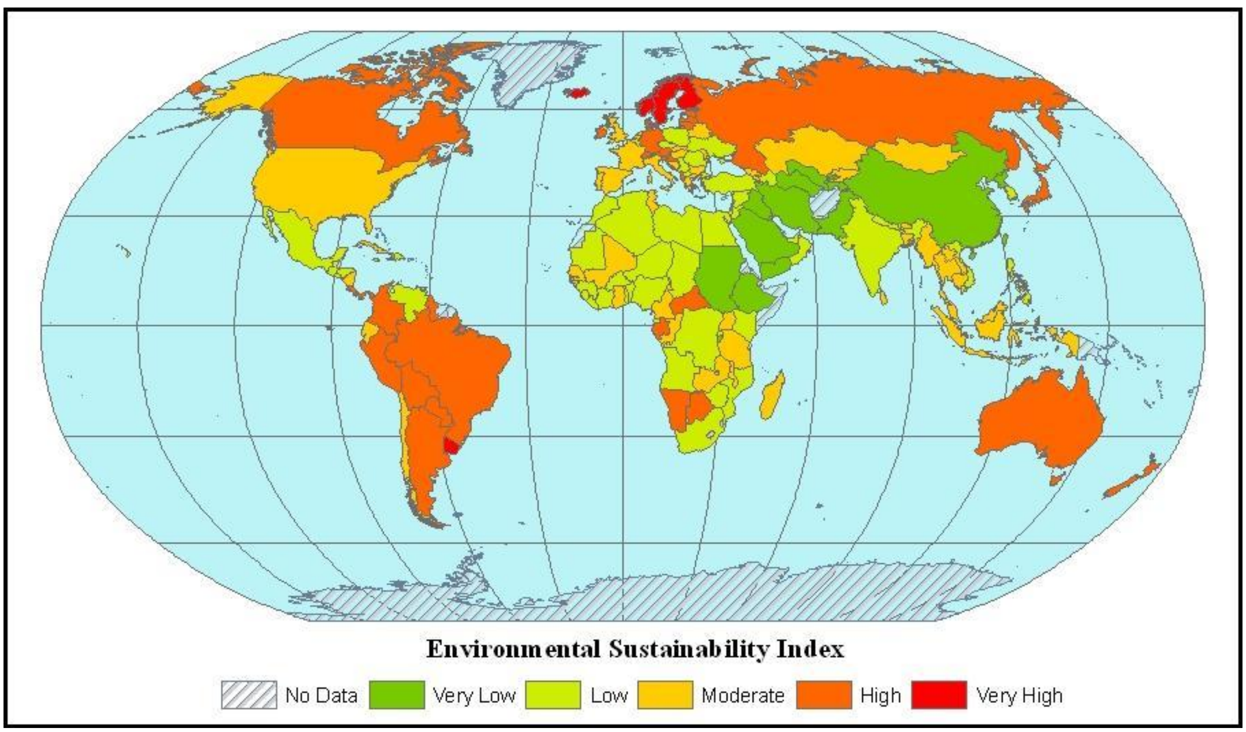

Figure 2. World map (Robinson Projection) of the environmental sustainability index classified using natural breaks in ArcMAP GIS.

The climate vulnerability index is statistically correlated (correlation coefficient R^2=0.3419) to the elaborate environmental sustainability index (Figure 3) with a significant correlation at the 95% confidence level. High environmental sustainability values are inversely correlated to low climate vulnerability values. However, the classification of individual countries can be quite varied (Table 2). Only four countries are classified as both high ESI and low CVI. The other high ESI countries (values from 64.4-75.1) are Uruguay (71.8) a non-OECD country and Iceland (70.8), a country with missing data for the eight variables used in the CVI, resulting in a poorer climate vulnerability index (CVI).

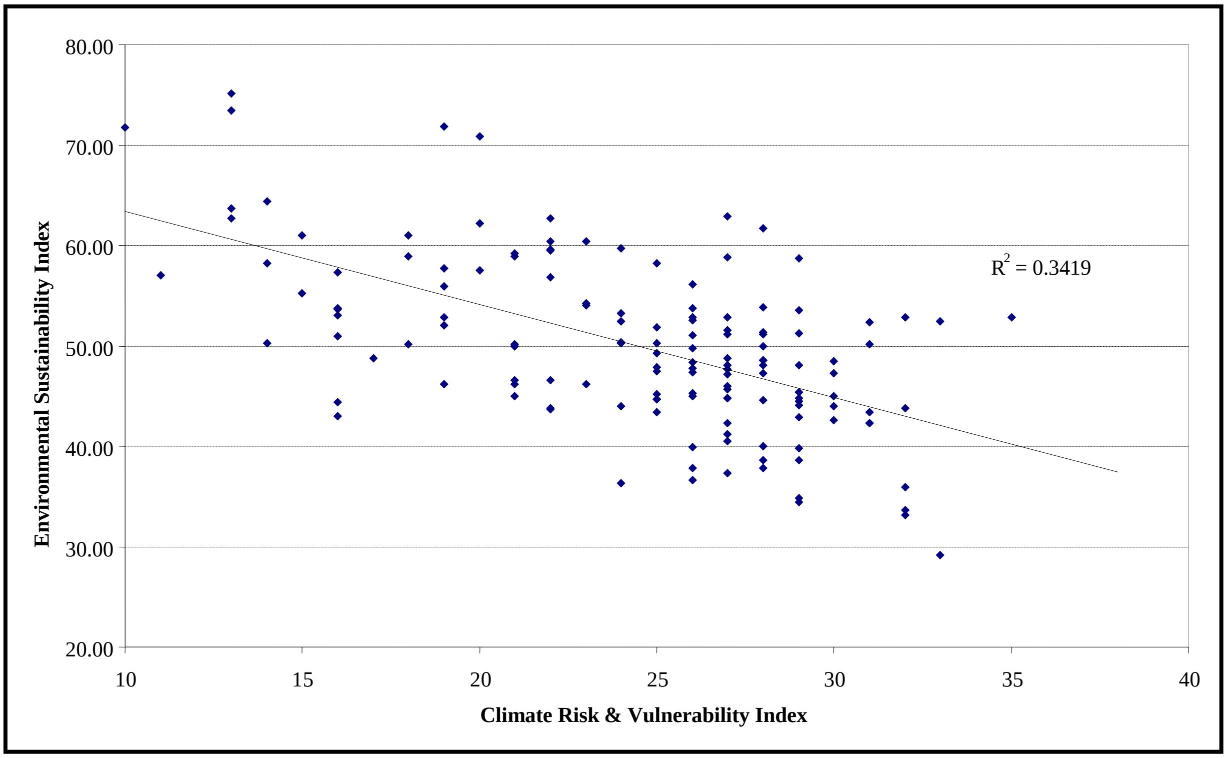

Figure 3. Linear regression analysis between the climate risk and vulnerability index and the 2005 environmental sustainability index. $R^2 = 0.3419$.

CONCLUSIONS AND IMPLICATIONS

The comparison of the disparate climate vulnerability and Environmental Sustainability indices reveals underlying issues related to global national indices, classification, mapping and the environment. One issue is related to non-OECD countries with high ESI values but not classified as low in the CVI. In the ESI, non-OECD countries are ranked high when they have significant natural resources. While GDP is implicit in the ESI, the CVI attributes more significant weight directly to GDP as 1/8 of the sum (Figure 4). The correlation coefficient of 0.4046 is consistent with the correlations of GDP to death, homeless and impacted demonstrated by Roberts and Parks 2007. Other factors used in the CVI are likely related to GDP or a country's engagement in OCED, thus explaining the prevalence of OECD countries in the CVI or lack thereof non-OECD countries in the lowest climate vulnerability class. Economic development dampens vulnerability (Toya and Skidmore, 2007). GIS allows for an accessible way to use modern quantitative methods and interactive maps to engage and construct open dialogues (Klinkenberg, 2007) to analyze the relationship between socioeconomic conditions, natural resources and vulnerability to climate-related risk and synergize critical and quantitative geographies (Kwan and Schwanen, 2009).

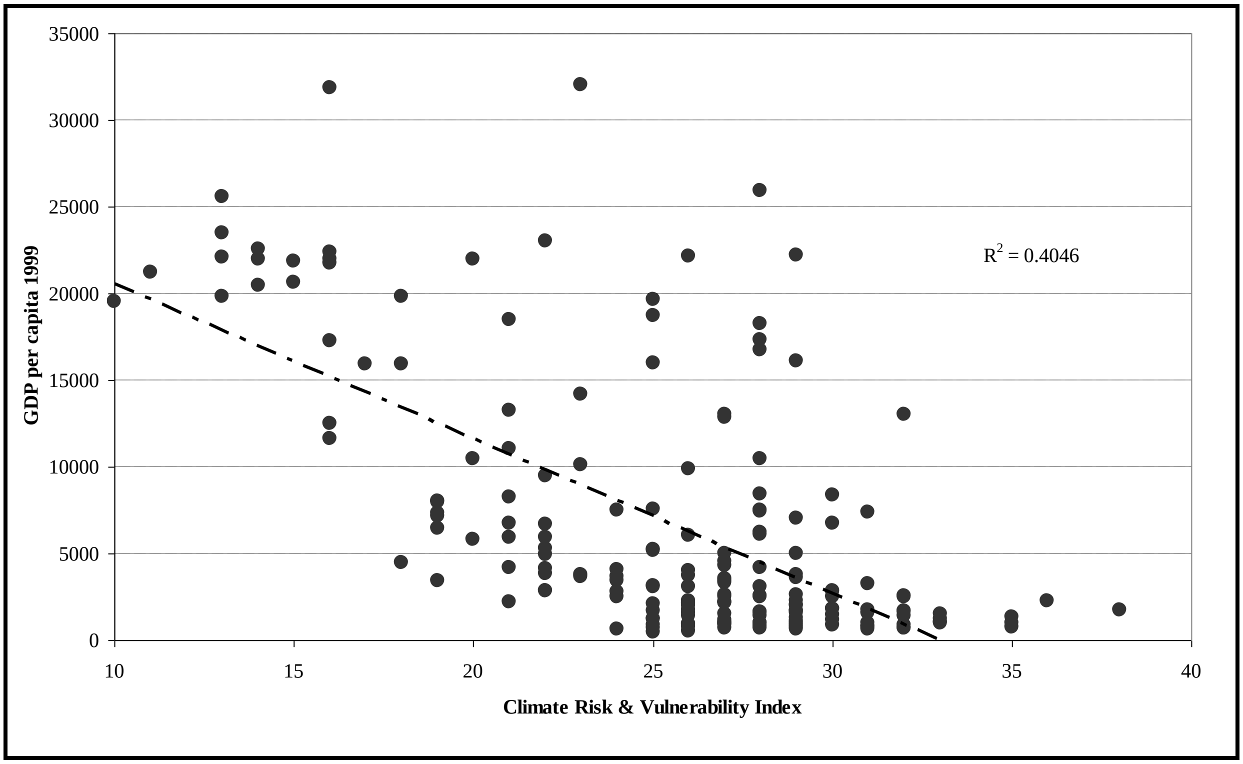

Figure 4. Linear regression analysis of GDP to the climate risk and vulnerability index. R^2=0.4046.

A second issue is related to the global geographic and spatial distribution of hazard based on national political boundaries. Equatorial regions are less vulnerable to natural disasters (Kahn, 2005). The United States is located in the mid latitudes and has the highest average total count per year of 17.9565. Neither total population nor population density adequately account for such a high count. Other studies have projected that all countries will be more vulnerable in the future to climate change (Yohe et al., 2006b). This research supports projections indicating risk and vulnerability in wealthy mid-latitude countries, the global north, are as considerable as the rich geographic literature on the vulnerabilities of the global south has purported. This geographic connection can be extended to relate OECD countries with low climate vulnerabilities, moderate ESI and relatively high probabilities of natural disasters such as the United States. Overall, the United States experiences the highest number of natural disasters with a disproportional death toll, supporting the low rank for climate vulnerability. The environmental sustainability index value and rank (moderate) for the United States should raise concerns about domestic and foreign policy in developed countries to confront global warming and greenhouse gas emission scenarios. On local scales, places with high biophysical risk may have low social vulnerability and vice versa, resulting in moderate to low hazards. Places with moderate biophysical risk and moderate to high social vulnerability are often more susceptible to hazards (Cutter et al., 2000). It has been further argued that national scale indices of vulnerability should not be used as policy tools due to the aggregation of data in an attempt to quantify and simplify complex problems (Barnett et al., 2008). However, there is a need for improvement in understanding climate change initiatives and implementation at the national scale, such as carbon taxation and greenhouse gas emissions trading in the context of market environmentalism, and national policy styles in developed nations (Bailey, 2007).

GIS can be used effectively to evaluate global national data and provide data driven insight into global issues of climate and climate-related risk and vulnerability and disaster and address the challenge of understanding natural and social interactions using geographic investigation to convince decision makers (White, 1991). Beyond data collection and spatial representation, GIS can reveal patterns and relationships between vulnerable places and vulnerable populations (Cutter et al., 2000). This research examines global climate risk and vulnerability at a national scale and while others have argued that analyses at this scale should not be used to comparatively as a means to assess the actual performance of a country (Barnett et al., 2008), GIS provides a platform for creating mental models of specific issues. It is important to recognize that within country vulnerability is also a critical issue and vulnerability is not a generic condition to be broadly applied (Barnett et al., 2008) Future work should consider alternate boundary units such as dasymetric mapping (Chen et al., 2004) and use national level indices of vulnerability with discretion (Boruff and Cutter, 2007). Education, informed decision making and policy construction in the new millennium requires less fragmentation and a systems approach no matter what the cultural context (Lee and Williams, 2006). GIS facilitates the ability to compare data classified in maps using a statistically and contextual rich approach (Foody, 2007) to define classes and provide common legends for thematic maps. The use of GIS as tool and as science in this research provides a less fragmented view of complex environmental issues related to sustainability and geography.

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