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Large Scale Quantitative Vulnerability Analysis for Regional Flood Hazard

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Synopsis

The paper attempts to present a methodology for characterizing vulnerability to large-scale flood hazards. Firstly the conceptual framework for analyzing vulnerability to flood hazards is put forth. Then according to biophysical vulnerability analysis and social vulnerability assessment, it presents a methodology for quantifying holistic vulnerability to flood hazards, which is focusing on scenario analysis of a flood event occurred in 2003. The utility of this approach in an assessment of vulnerability is illustrated in the Huaihe River Basin, China. Finally, the evaluation of holistic vulnerability is discussed. This study helps illustrate the zones necessary to decrease vulnerability to flood hazards and strengthen their resilience while living with increasing floods.

Keywords: vulnerability, flood hazard, spatial analysis, GIS

1. Introduction

Floods are known as frequent and most devastating events worldwide. In Asia continent, many countries are much affected by flood disasters, which are extremely vulnerable to flood hazards (WWAP, 2006). Particularly in view of ongoing global warming and increasing frequency of extreme weather events, only technical solutions, such as enhancing prevention standard and analyzing hazard itself, are not adequate to ensure human security in the long run. The ability to measure vulnerability is increasingly being seen as a key step towards effective risk reduction and the promotion of a culture of disaster resilience (Kasperson et al., 2005; Birkmann, 2006). The identification of regional vulnerability to flood hazard and the components contributing to vulnerability is crucial for emergency preparedness, immediate response, mitigation planning, and recovery from flood disasters. Thus the need for a spatially oriented vulnerability analysis is highlighted, such as the identification, assessment and ranking of vulnerability to flood hazards. Large-scale flooding due to heavy rainfall and drainage congestion has been regularly experienced in the Huaihe River basin, China. Taking the Huaihe River basin as case study, this research intends to develop a quantitative methodology for analyzing large-scale vulnerability to regional flood hazard.

Despite different prevailing approaches have been developed for analyzing vulnerability, there are still many differences in understanding vulnerability to natural hazards. As previous literature illustrated, in general there are three remarkable perspectives on measuring vulnerability. The first identifies vulnerability by the potential exposure to a certain hazard. Studies based on this perspective focus on the distributions of hazardous conditions and the processes influencing on livelihood and infrastructure.

The second perspective on vulnerability views it as human-environmental process. Studies pay much more attention on potential coping ability in society, including the ability to withstand the damaging effect of hazard and the ability to recover from the damage (Blaikie et al., 1994; Clark et al., 1998). This perspective highlights social characteristics of vulnerability to natural hazards. All the approaches aim to measure vulnerability through selected comparative indicators in a quantitative way in order to be able to compare different areas or communities (Birkmann, 2007), but not to actually predict consequences. Indicators are used as proxies for diverse situations at any scale (e.g., household, system, state) (Cutter et al., 2000; Wu et al., 2002; Vogel and O'Brien 2004; Chakraborty et al., 2005). Most researches demonstrate that some demographic and housing characteristics, e.g., age, gender, race, income, and building quality are influential in amplifying or reducing social vulnerability to hazards (Cutter et al., 2003).

Cutter et al. (2000) introduce the third promising perspective for quantifying vulnerability, in which vulnerability relies on not only biophysical conditions, but also social adaptation capacity within a specific geographic domain. Both social and biophysical components interpenetrate and shape holistic vulnerability to natural hazards. This conceptual understanding scientifically reflects its multi-facet feature of vulnerability. However, the solution to integrate different aspects of vulnerability has still not been well put forth and put into practice.

This research follows the third perspective of vulnerability. To measure holistic vulnerability to flood hazards, internal socio-economic properties that make study area vulnerable as well as external biophysical conditions are taken into consideration (Zheng et al., 2008 and 2009).

In the followings, after describing study site, firstly the conceptual framework for analyzing vulnerability to flood hazards is briefly introduced. In the section of methodology, biophysical and social vulnerability to flood hazards are analyzed respectively based on some previous studies (Zheng et al., 2008 and 2009), in which scenario analysis of typical flood event in 2003 and spatial multicriteria analysis have been performed. Then the integration of biophysical and social vulnerability is discussed as well as some evaluation is provided. Finally some concluding remarks are summarized.

2. Descriptions of Study Area

The Huaihe River basin (HRB) is situated in eastern China. Geographically it is located between the latitude 31°N-36°N and longitude 112°E -121°E, covering an area of 270,000km2, which is administrated by Jiangsu, Shandong, Anhui and Henan provinces (Fig.1) (Zheng et al., 2008). The elevation ranges from 100m to 200m across the hills in the western HRB, from 50m to 100m in the southern HRB and about 100 m in the northeastern HRB. In the plain area, there are complex water systems, where the elevation ranges from 2m to 50m around the Huaihe River (Fujiyoshi and Yihui, 2006).

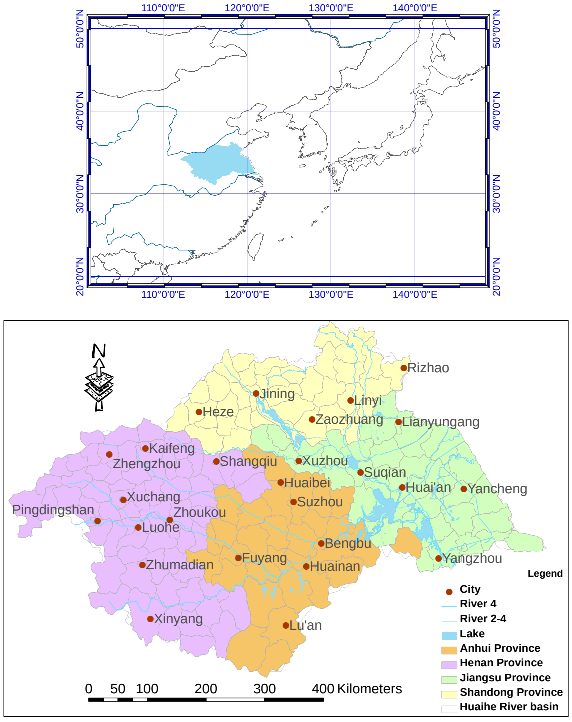

Fig. 1 Location of the Huaihe River basin (The blue area at the upper figure shows its location in China.).

Climatologically, it lies in the warm semi-humid monsoon region. Precipitation mainly occurs in the period from mid-May to mid-October. Because of anomalies of the Meiyu front during the rainy season, which is influenced by the South Asian monsoon and the unique topography, the basin has been well known for its frequent disasters.

In general, the floods occurred from the mountains of the upper reach of the Huaihe River quickly flow into the middle reach. However in the middle reach, the flood flow runs very slowly due to slight gradient. Therefore flood disaster is easily resulted while rainy season. Since the 20th century, the relatively severe floods occurred in 1954, 1991, 1998, 2003 and 2007. According to records, since 1900 disastrous flood has happened once every 5 years. As for the tributaries of the Huaihe River, flood disaster occurs once in every 2 or 3 years in average (Yearbook of the Huaihe River basin, 1999; Ning, 2003).

Furthermore, the HRB is populous with the population density of 623 capita per km2 in 2003, at the same the total population reached 168 million, accounting for 13% of the nation's population. And there is 17% of the country's cultivated land (Rao, 2004). Therefore it is of great socio-economic importance.

In 2003, the Huaihe River basin was hit by severe heavy rainfall. The rise of water level in rivers, lakes and reservoirs caused a severe flood and waterlogging disaster. This flood event was the most hazardous flood occurred in the HRB since 1954. The flood caused severe disasters in Henan, Anhui and Jiangsu provinces. There were 27.3 million residents affected by flood. 770,000 houses collapsed and 3.847 million farmers were blocked by flood disaster. The direct economic losses reached CNY 2.86 billion (US$350 million) (Yearbook of the Huaihe River basin, 2004). Therefore this typical flood event is taken as basic scenario to analyze vulnerability to flood hazards in the Huaihe River basin, China.

3. Methodology

3.1 Conceptual framework for analyzing vulnerability

Vulnerability is a concept that evolved out of social science and was introduced as a response to the purely hazard-oriented perception of disaster risk in the 1970s. In vulnerability literature, although there are different views on vulnerability from different experts and examples of methods for vulnerability analysis developed by institutions and researchers, vulnerability is often viewed as an intrinsic characteristic of a system or element (McCarthy et al., 2001; UNDP, 2004; Birkmann, 2006).

The definition from IPCC is that the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity. UN/ISDR (2004) defines that the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards.

In general, vulnerability is both a biophysical risk and a social response within a specific geographic domain. Allowing for theoretical requirements and contextual characteristics in study area as well as data availability, the conceptual framework is put forth (Table 1). Because county level is an appropriate scale to supply information for central or local government in determination of policy and strategies, this research is to take county as minimum assessment unit in the followings.

3.2 Biophysical vulnerability

In the Huaihe River basin, biographical vulnerability to flood hazard has been identified by analyzing time-series MODIS satellite imagery composite data with respect to typical flood event occurred in 2003 (Zheng et al., 2008). To characterize relative vulnerability among the assessment units, the percentage of flooded area in assessment unit is taken to represent biophysical vulnerability. Meanwhile normalization of biophysical vulnerability index is conducted to make its range from 0 to 1 (Fig.2).

In Fig.2, the units depicted by larger purple dot are identified vulnerable to flood threats within biophysical context. It is found that Anhui Province is much more vulnerable to flood hazard regarding biophysical conditions, and the most biophysically vulnerable area concentrates around the middle reach of the Huaihe River, China. Suppose that statistical distribution of biophysical vulnerability index among the entire domain is evaluated, the number of biophysical vulnerability indices larger than 0.5 only accounts for around 5%.

Table 1 Conceptual framework for analyzing vulnerability in the Huaihe River basin, China

	Component	Determinant	Indicator
Vulnerability	Biophysical vulnerability	Flooded area	Percentage of flooded area
	Social vulnerability	Exposure	Population density (C_1); Land use (C_2)
		Susceptibility	GDP per capita (C_3); Dependents and inequality (C_4); Income of farmer (C_5); Income of employment (C_6)
		Resilience	Social expenditure (C_7); Household savings (C_8); Hospital beds per 10k people (C_9); Institutional preparedness (C_{10})

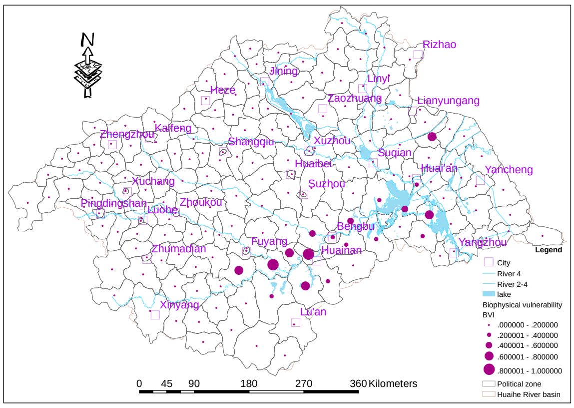

Fig. 2 Distribution of biophysical vulnerability to flood hazard in the HRB, China (2003).

The result indicates that the ratio of the most relatively vulnerable area within biophysical context is not high. However it is necessary to mention that it should be paid more attention on studying vulnerability and providing strategies for vulnerability reduction because the total of area affected by flooding is still very large.

3.3 Social vulnerability index

Social vulnerability is not directly observable phenomenon and there are some difficulties in quantification. Many researches have paid much more attention on the theoretical and conceptual aspects of social vulnerability (Turner et al., 2003; Adger, 2006; Eakin and Luers, 2006), yet relatively few have presented methods to assess it empirically. One of the most common approaches for characterizing social vulnerability is the use of a range of proxy indicators (Cutter et al., 2003; Adger et al., 2004; Birkmann 2006; Burton and Cutter, 2008). In essence, social vulnerability can be interpreted as inherent inequality with respect to natural hazards.

On the basis of conceptual framework for analyzing vulnerability to flood hazards, a quantitative methodology to characterize social vulnerability to flood hazard has been developed, which employs spatial multicriteria analysis approach (MCA) based on entropy weight determining and scenario analysis of the flood event occurred in 2003 (Zheng et al., 2009). The general scheme has been designed, in particular how to quantify the proxy indicators and to aggregate them has been studied. Herein a brief description is given as follows.

For dealing with quantitative measure of social vulnerability, the method used in MCA is an additive model, in which social vulnerability index is calculated based on a set of indicators illustrated in Table 1(Equation (1)).

$$SVI(i) = \sum_{j=1}^{n} w_j \times c_{ij} \tag{1}$$

where $SVI(i)$ is social vulnerability index of the unit i. n denotes the total number of indicators, w_j is the relative weight of the indicator c_j ($j = 1, \cdots, 10$). c_{ij} stands for the data normalized from the original census data. The weights have been determined by entropy-based approach, which are non-negative and sum up to 1 (Fig.3).

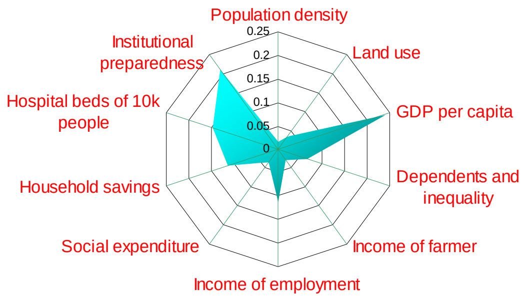

Fig. 3 Schematic diagram of indicator weight determined by entropy approach.

Social vulnerability to large-scale flood hazard has been assessed by spatial multicriteria analysis through employing demographic and socio-economic data (Zheng et al., 2009). In addition, the normalization of social vulnerability indices is conducted (Fig.4). The result indicates that many more counties are relatively vulnerable to flood hazard within social context and the whole basin is relatively vulnerable while merely considering socio-economic conditions. The spatial variability of social vulnerability at the county level across the Huaihe River basin suggests a variation in the capacities of different county or city to cope with flood disasters. It illustrates the zones necessary to reduce social vulnerability and strengthen its coping capacities while living with increasing floods, such as allocation of preparedness resources and providing additional help in the aftermath of disaster.

Noticeably the rationale for indicator selection is to cover three primary determinants of social vulnerability, i.e., exposure, susceptibility and resilience while considering data availability. On the other hand the number of proxy indicators should be kept minimal and simple for applicability. In previous research, especially in developed countries, there are large amount of data sets related to socio-economic aspects, thus many more indicators were selected to interpret social vulnerability. For a more comprehensive analysis it might be desirable to extend this indicator set while data are available and sufficient.

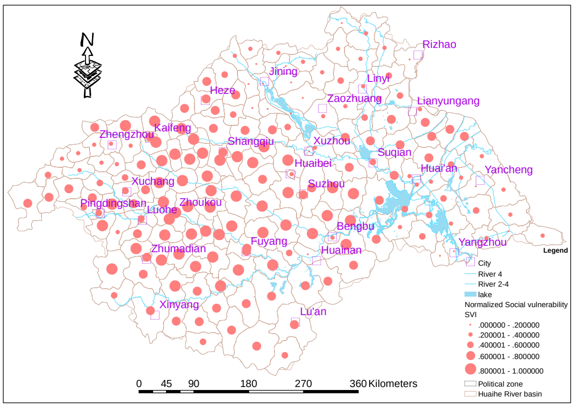

Fig. 4 Distribution of social vulnerability to flood hazard in the HRB, China (2003).

3.4 Integration of biophysical and social vulnerability indices

According to the evaluation of biophysical and social vulnerability, both aspects of vulnerability are characterized. It indicates that the spatial distribution of biophysical vulnerability and social vulnerability is different, which improves our understanding on vulnerability to natural hazards. Although mapping spatial variability of biophysical vulnerability or social vulnerability is significant, it does not adequately reflect the essences of all components contributing to vulnerability regarding flood hazard at one specific assessment domain. The integration of biophysical vulnerability with its social context (i.e., social vulnerability) is critical because humans are often not considered vulnerable in the absence of a certain degree of exposure to physical threats. In previous researches, although some thinking about integrated method has been proposed, generally only framework has been put forth. In other words, social vulnerability and biophysical vulnerability are always discussed separately. In this study, based on the conceptualization of Cutter et al. (2003) and the framework proposed in Section 3.1, the methodology for integrating biophysical and social vulnerability indices with regard to flood hazard is provided, in which biophysical vulnerability and social vulnerability are merged by ArcGIS within the consideration of their relative importance.

For aggregating biophysical vulnerability and social vulnerability, a simple additive model is adopted here again while little research has ever contributed on the integration (Adger et al., 2004; Birkmann, 2006). A common tactic for combining information is to weight each component inversely to its variance (Piegorsch and Bailer, 2005). To obtain their relative importance of two indices, inverse-variance weighting approach is adopted, which is described as follows.

Suppose that these estimators have different variances, the inverse-variance weight is defined as Equation (2).

$$P_k = \frac{1}{VAR(\xi_k)} \quad (2)$$

where k stands for the classification of vulnerability indices ($k = 1,2$), P_k is the weight of the k-th index, ξ is the value of vulnerability index, and $VAR(\xi)$ denotes the variance of ξ.

Then, integration of biophysical vulnerability and social vulnerability $\bar{\xi}_k$ can be conducted by Equation (3).

$$\bar{\xi}_k = \frac{\sum P_k \xi_k}{\sum P_k} \quad (3)$$

Finally, to convert the indices into the range from 0 to 1, linear normalization is performed.

The calculated result shows that the weight of biophysical vulnerability is much higher than that from social vulnerability (Table 2). Despite this method is based on the underlying mathematical attribute of vulnerability indices, this approach is effective for determining vulnerability since vulnerability assessment is to find potential inequality or relative difference regarding to flood hazard among the assessment units. Therefore this result is going to be used in the calculation of integrating vulnerability to flood hazard within biophysical and social contexts.

Table 2 Characteristics of vulnerability indices

Item	Variance	Max	Min
Biophysical Vulnerability	0.00042083	0.1273	0.0000
Social Vulnerability	0.02020527	0.71	0.19
Integrated (Before normalization)	49.4867	315.419	9.403

4. Results and Discussion

Based on Equation (3), the integrated vulnerability indices are computed, which also can be named as holistic vulnerability indices. The result shows that some counties such as Hongze, Huaiyuan, Wuhe, Fengtai, Shouxian, Guannan, Jinhu, Funan, Yingshang, and Huainan, etc. are significantly vulnerable to flooding in study area while some of them have the highest levels of both social vulnerability and biophysical vulnerability. The pattern appears to represent a combination of biophysical conditions and socio-economic factors (Fig.5).

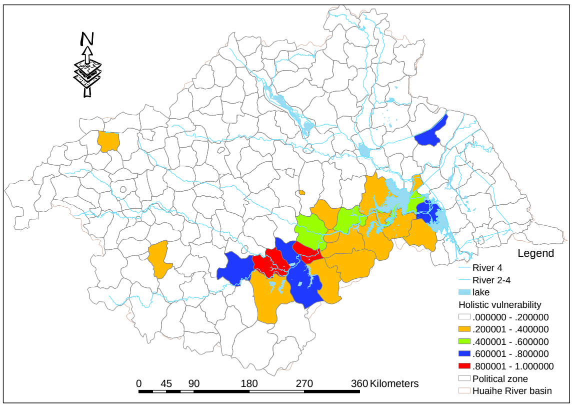

Fig. 5 Distribution of integrated vulnerability to flood hazard in the HRB, China (2003).

It is acceptable that vulnerability concentrates around the main trunk of the Huaihe River as well as nearby Lake Hongze. It is also found that the areas with high holistic vulnerability have higher level of social vulnerability. Even though Jiangsu Province has better economic development level, the integrated vulnerability indices from Hongze and Jinhu counties in Jiangsu are also relatively larger. The integrated vulnerability index not only can be used to identify the vulnerable area with regard to flood hazard, but also it is much significance of improving understanding on vulnerability theory.

Meanwhile it is necessary to note that the three kinds of vulnerability indices (i.e., biophysical, social and holistic indices) are very useful to decision-maker and manager, which reflect that vulnerability is multi-facet and multi-dimensional. Definitely the index proposed is uncertainty due to perceptive, model and parameter as well as proxy indicators. Furthermore the vulnerability is dynamic with the changes of study context and time. This research on assessing vulnerability will improve the understanding vulnerability to hazards as well as it will make the theory profound to some extent. It is helpful to make deeper understand the essence of vulnerability.

According to conceptualization on vulnerability, vulnerability is related to physical context (hazard itself) and socio-economic system (coping capacity and adaptation capability), as well as to some extent, the integrated vulnerability should have some relationship with losses induced by flood hazard. To check this perception and evaluate the performance of assessment model, the flood occurred in Jiangsu Province is taken as study case. If analyzing loss per capita with integrated vulnerability index (CoVI), the result indicates that loss per capita is higher while integrated vulnerability index is lower, even though there is no definite function correlation (Fig.6). It also proves that socio-economic development level has much effect on vulnerability to natural hazards. While vulnerability is lower, maybe risk is higher since economic development level is different.

To exclude the effect from socio-economic development level as possible, the division of Loss per capita and GDP per capita (Loss/GDP) is taken as analysis factor (Fig.7). The result from linear regression analysis indicates that there is acceptable linear function relationship between Loss/GDP and CoVI while eliminating two removed data points. It is significant to find the relationship of the integration of SVI and BVI with flood losses after integrating the two indices.

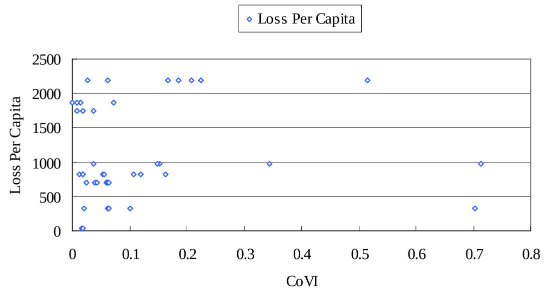

Fig. 6 Loss per capita and CoVI in Jiangsu Province, China 2003 (Unit for Loss: CNY).

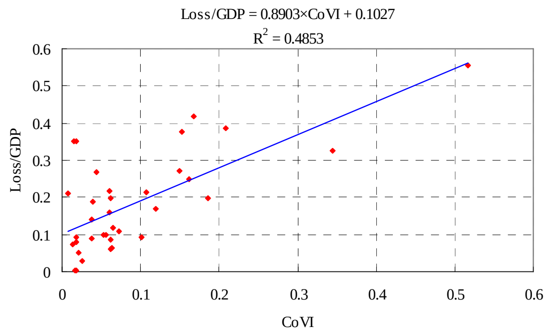

Fig. 7 Relationship between Loss/GDP and CoVI in Jiangsu Province, China (2003).

5. Summary and Conclusions

This study presents a methodology for quantitatively analyzing vulnerability to flood hazards in the Huaihe River basin, China. After putting forth conceptual framework, the results about biophysical vulnerability and social vulnerability in study area are provided according to past research works. Then it presents a methodology to integrate biophysical vulnerability and social vulnerability. The method itself is based on the mathematical attribute of vulnerability indices. Taking inverse-variance of vulnerability indices as the relative importance, holistic vulnerability to flood hazards in the Huaihe River basin is solved. Finally, the relationship between holistic vulnerability and flood loss is discussed, which indicates the proposed method is feasible and also is helpful to improve understanding on inherent characteristics of vulnerability.

In conclusion, the geographic variability in biophysical, social, and holistic vulnerability indices at the county level across the Huaihe River basin in 2003 suggests a variation in physical conditions and the capacities of different county or city to cope with flood disasters. It indicates that the proposed method is applicable to large-scale flood hazard context. In terms of quantitative information of vulnerability, the vulnerable areas are able to be identified. This study helps illustrate the zones necessary to decrease vulnerability and enhance their resilience while living with increasing floods, especially to supply for priority policies aiming at basin emergency management and hazard mitigation.

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References

Adger, N.W., Brook, N., Bentham, G., Agnew, M., Eriksen, S. (2004): New indicators of vulnerability and adaptative capacity, No.7. Tyndall Center Technical Report.

Birkmann, J. (2006): Measuring vulnerability to natural hazards: Towards disaster resilient societies, United Nations University.

Birkmann, J. (2007): Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications. Environmental Hazards 7, pp. 20-31.

Blaikie, P., Cannon, T., Davis, I. and Wisner, B. (1994): At risk: Natural hazards, People’s vulnerability, and Disasters, 1st edn, London: Routledge.

Burton, C. and Cutter, S.L. (2008). Levee failures and social vulnerability in the Sacramento-San Joaquin Delta area, California. Natural hazards review 9(3), pp. 136-149.

Chakraborty, J., Tobin, G.A. and Montz, B.E. (2005): Population Evacuation: Assessing spatial variability in geophysical risk and social vulnerability to natural hazards. Natural hazards review 6(1), pp. 23-33.

Clark, G.E., Moser, S.C., Ratick, S.J., Dow, K., Meyer, W.B., Emani, S., Jin, W., Kasperson, J.X., Kasperson, R.E. and Schwarz, H.E. (1998): Assessing the vulnerability of coastal communities to extreme storms: the case of Revere, MA, USA. Mitigation and Adaptation Strategies for Global Change 3: 59-82.

Cutter, S.L., Mitchell, J.T. and Scott, M.S. (2000): Revealing the Vulnerability of People and Places: A Case Study of Georgetown County, South Carolina. Annals of the AAG 90 (4), pp. 713-737.

Cutter, S.L., Boruff, B.J. and Shirley, W.L. (2003): Social vulnerability to environmental hazards. Social Science Quarterly 84(2), pp. 242-261.

Eakin, H. and Luers, A.L. (2006): Assessing the vulnerability of social environmental systems. Annual Review of Environment and Resources 31, pp. 365-394.

Fujiyoshi, Y. and Yihui, D. (2006): Final Report of GAME/HUBEX-GEWEX Asian Monsoon Experiment/ Huaihe River Basin Experiment, pp. 497-514.

IPCC. (2001). Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change (R.T. Watson and the Core Writing Team, eds.). Cambridge University Press, Cambridge, United Kingdom, and New York, USA.

Kasperson, J., Kasperson, R., Turner, B.L., Hsieh, W. and Schiller, A. (2005): Vulnerability to global environmental change. In Kasperson eds, The social contours of risk. Volume II: Risk analysis, corporations & the globalization of risk, London: Earthscan, pp. 245-285.

McCarthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J. and White, K.S. (Editors). (2001): Climate Change 2001: Impacts, Adaptation and Vulnerability, Report of the Intergovernmental Panel on Climate Change, Cambridge University Press, Cambridge, UK.

Ning, Y. (2003): Manual for Water Harnessing in

the Huaihe River basin,China. Science Press, China (in Chinese).
Piegorsch, W.W. and Bailer, A.J. (2005): Analyzing Environmental Data. Chichester, John Wiley & Sons.
Rao, Y.G. (2004): Statistic Bureau of Anhui Province. Anhui Statistical Yearbook. China Statistics Press (in Chinese).
Turner, B.L., Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A., Schiller, A. (2003): A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Science USA 100, pp. 8074-8079.
United Nations Development Programme (UNDP). (2004): A global report-reducing disaster risk, a challenge for development, UNDP-Bureau for Crisis Prevention and Recovery (BCPR), New York.
Vogel, C. and O'Brien, K. (2004): Vulnerability and global environmental change: rhetoric and reality. AVISO-Information Bulletin on Global Environmental Change and Human Security 13.
WWAP. (2006): UN World Water Development Report, World Water Assessment Programme-WWAP, Paris.
Wu, S.Y., Yarnal, B. and Fisher, A. (2002): Vulnerability of coastal communities to sea-level rise: a case study of Cape May County, New Jersey, USA. Climate Research 22(4), pp. 255-270.
Yearbook of the Huaihe River basin, China (1999). Huaihe River Commission, Ministry of Water Resources, China (in Chinese).
Yearbook of the Huaihe River basin, China (2004). Huaihe River Commission, Ministry of Water Resources, China (in Chinese).
Zheng, N., Takara, K., Tachikawa, Y. and Kozan, O. (2008): Analysis of vulnerability to flood hazard based on land use and population distribution in the Huaihe River Basin, China. Annuals of Disaster Prevention Research Institution, Kyoto University 51B, pp. 83-91.
Zheng, N., Takara, K., Yamashiki, Y. and Tachikawa, Y. (2009): Assessing vulnerability to regional flood hazard through spatial multi-criteria analysis in the Huaihe River Basin, China. Annual Journal of Hydraulic Engineering, JSCE 53, pp. 127-132.

地域洪水に対する定量的な大規模脆弱性評価解析

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要　旨

本論文は，巨大スケールの洪水災害に対する脆弱性特徴づける手法を述べたものである。まず脆弱性を解析するための概念的枠組みを構築する。次に生物物理学的な脆弱性解析と社会的な脆弱性評価を考慮して，洪水災害に対する包括的な脆弱性を定量化する手法を述べ，2003年に発生した洪水事象のシナリオ解析に焦点を当てている。ここで確立された脆弱性評価のアプローチの有用性が中国・淮河流域において例証されている。最後に，包括的な脆弱性評価について議論している。本研究は，洪水災害に対する脆弱性を減少させるべき地域が明らかにし，またこのような増大する洪水の危険地域に居住する住民の回復能力を高める事に貢献するものである。

キーワード：脆弱性，洪水災害，空間的解析，地理情報システム