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Institute for Environment and Human Security

Munich Re Foundation

From Knowledge to Action

From Social Vulnerability to Resilience: Measuring Progress toward Disaster Risk Reduction

Edited by

Susan L. Cutter and Cosmin Corendea

SOURCE

'**S**tudies **O**f the **U**niversity: **R**esearch, **C**ounsel, **E**ducation' - Publication Series of UNU-EHS

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Dr. Susan Cutter is a Carolina Distinguished Professor of Geography at the University of South Carolina where she directs the Hazards and Vulnerability Research Institute and served as the Munich Re Foundation Chair on Social Vulnerability (2009 – 2012). She received her B.A. from California State University, Hayward and her M.A. and Ph.D. (1976) from the University of Chicago. Her primary research interests are in the area of disaster vulnerability/resilience science – what makes people and the places where they live vulnerable to extreme events and how vulnerability and resilience are measured, monitored and assessed. She has authored and edited 12 books, and more than 100 peer-reviewed articles and book chapters.

Dr. Cutter has also led post-event field studies of the role of geographic information technologies in rescue and relief operations in (September 11th World Trade Center attack) and studies of evacuation behaviour from Three Mile Island (1979), Hurricane Floyd (1999) and the Graniteville, SC train derailment and chlorine spill (2005). Most recently (2006) she led a Hurricane Katrina post-event field team to examine the geographic extent of storm surge inundation along the Mississippi and Alabama coastline and its relationship to the social vulnerability of communities. She has provided expert testimony to Congress on hazards and vulnerability and was a member of the US Army Corps of Engineers- the Interagency Performance Evaluation Task Force (IPET) team evaluating the social impacts of the New Orleans and Southeast Louisiana Hurricane Protection System in response to Hurricane Katrina. She has authored a Trends and Outlook report for the US Army Corps of Engineers on Natural and Human-Induced Disasters and other Factors Affecting Future Emergency Response and Hazard Management. Dr. Cutter serves on many national advisory boards and committees including the National Research Council (NRC), the American Association for the Advancement of Science (AAAS), the National Science Foundation (NSF), the Natural Hazards Center and the National Institute of Standards and Technology (NIST). She also serves on the international Integrated Research on Disaster Risk Science Committee supported by the International Social Science Council (ISSC), International Council for Science (ICSU) and The United Nations Office for Disaster Risk Reduction (UNISDR). Dr. Cutter serves as co-executive editor of Environment Magazine and is an associate editor of Weather, Climate, and Society Journal. She was coordinating lead author of Chapter Five of the IPCC Special Report on "Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation", and chaired the US National Research Council Committee that authored the recent 'Disaster Resilience: A National Imperative' report. She is an elected Fellow of the American Association for the Advancement of Science (AAAS) (1999), past President of the Association of American Geographers (2000) and past President of the Consortium of Social Science Associations (COSSA) (2008). In 2006, Dr. Cutter was the recipient of the Decade of Behavior Research Award given by a multidisciplinary consortium of more than 50 national and international scientific organizations in the social and behavioural sciences, and in 2011 she received the Lifetime Achievement Award from the Association of American Geographers, its highest honor.

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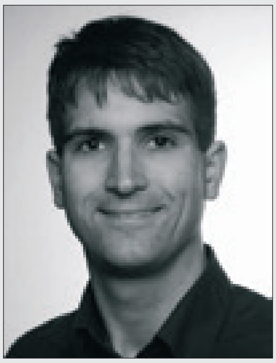

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The research line of **Professor Sabine Henry** (Geography, University of Namur, Belgium) is the interaction between environment and migration at the household or individual-level. In West Africa, she provided one of the rare empirical evidences now available on the effects of drought on migration. In Ecuador, she focuses on the environmental benefits of the international migration for the home country, and in the Philippines, she tries to provide an in-depth understanding of the links between migration, vulnerability, land use and water management. Sabine Henry was a member of the Steering committee of the Population and Environment Research Network (2008–2011) and more recently, in recognition of her expertise and work, she became a member of the scientific panel on the Impact of Internal Migration in Developing Countries of the International Union for the Scientific Study of Population.

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Michael Hagenlocher is a multi- and interdisciplinary researcher with a broad interest in socio-economic, health and development-related issues. Michael is currently working as a researcher, lecturer and consultant at the University of Salzburg's Department of Geoinformatics (Z_GIS), Austria, where he is also associated to the Doctoral College GISscience (Geographic Information Science) which is funded by the Austrian Science Fund (FWF). He is co-author and lecturer of over 10 GIS key qualification courses and teaches a masters course in advanced remote sensing at the University of Tübingen's Department of Geosciences, Germany. His PhD research models risk and vulnerability to high impact water-related vector-borne diseases (VBDs) in eastern Africa and Latin America and a particular focus of his work is on the spatial assessment of the vulnerability of exposed population groups to malaria and dengue fever on different scales. Before taking on his current teaching position he completed an M.A. in geography, sociology and geoinformatics at Tübingen and Stuttgart University, Germany. Through his involvement in several European (FP7, EC ECHO, DIPECHO) and UN-funded (UNDP, UNEP) projects and consultancies, Michael has gained profound experience in using methods from GIScience (GIS, remote sensing, spatial composite indicators, etc.) for spatial vulnerability assessments concerning natural hazards and VBDs in Africa, Europe and Latin America.

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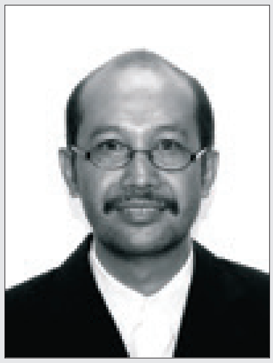

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Hamonangan Ritonga is a statistician in the field of social and economics, and works for Badan Pusat Statistik (BPS-Statistics) Indonesia. Currently, he is the Chairman of Institute of Statistics, an undergraduate programme in statistics at BPS-Statistics Indonesia in Jakarta, Indonesia. Previously, he held various management positions within BPS-Statistics Indonesia, such as Director of Social Welfare Statistics, Director of Social Resilience Statistics and Director of Methodological Development for Censuses and Surveys. He received his PhD degree in human development with a minor in statistics from Iowa State University, Ames, USA, a master degree in economics from University of Illinois, Urbana, USA, a diploma in economics from Economics Institute, Boulder, USA, and a bachelor degree in Statistics from Academy of Statistics, Jakarta, Indonesia. His expertise is in poverty and labour force statistics.

Acknowledgements

The partnership with the Munich Re Foundation (MRF) made the MRF Chair on Social Vulnerability and the annual Summer Academy possible. For the seventh year running the Foundation's generous funding of the Summer Academy allowed forums to be created where the discussion of environmental change and social vulnerability could take place, where professional skills could be demonstrated and where professional networks could be expanded and strengthened.

We are grateful to Mr. Thomas Loster, Chairman of the Munich Re Foundation for his vision and leadership in bringing together young scientists and experienced scholars and practitioners to expand the frontier of applied science. And we appreciate the collaboration of the Munich Re Foundation in preparing and executing the Summer Academy. Our thanks go to Mr. Christian Barthelt, who strongly supported organizational and logistical arrangements for the Academy.

Our gratitude extends to Professor Susan L. Cutter, who chaired the 2012 Summer Academy 'From Social Vulnerability to Resilience: Measuring Progress toward Disaster Risk Reduction', as well as Professors Mohamed Hamza and Michelle Leighton, the two other MRF Chairs on Social Vulnerability, who helped participants to accomplish one of the main outcomes of the Academy: demonstrating the importance of providing evidence-based support for managing disaster risk by addressing some of the methodological challenges in measuring social vulnerability and resilience. We also thank Dr. Melanie Gall (Department of Geography and Anthropology Louisiana State University), Dr. Stefan Kienberger (University of Salzburg, Centre for Geoinformatics), Dr. Joern Birkmann (UNU-EHS) and Ms. Angelika Wirtz (Munich Re Insurance Company) for their special contributing roles during the academy.

We are deeply grateful to Dr. Koko Warner and Dr. Tamer Afifi for their support in planning and running the 2012 Summer Academy, as well as all our colleagues at UNU-EHS, in particular Ms. Kristina Yuzva whose tremendous effort and commitment made the organizational preparations for the academy possible. Futher we are grateful to Ms. Katharina Brach and Ms. Andrea Wendeler for their valuable work in publishing this SOURCE.

Finally, we would like to thank all the participants, Chairs, experts and facilitators who took part and contributed to this tremendously successful project – the Munich Re Foundation Chair on Social Vulnerability – over the last seven years.

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Outcomes of the 7th UNU-EHS Summer Academy of the Munich Re Foundation Chair on Social Vulnerability

1 – 7 July 2012, Hohenkammer, Germany

Foreword

The Intergovernmental Panel on Climate Change (IPCC, 2007) defines vulnerability as "the degree to which a system is susceptible to and unable to cope with adverse effects of climate change". In comparison, scholars perceive resilience as being the positive "capacity of a system to maintain its basic functions and structures in a time of shocks and perturbations" (Oliver-Smith, 2009). In all climate change scenarios, however, vulnerability and resilience play a significant central role, both scientists and practitioners offering insights into various methodologies for exploring and measuring the dynamics of the (in) adaptive capacity of human beings to climatic stressors.

The 2012 Summer Academy 'From Social Vulnerability to Resilience: Measuring Progress toward Disaster Risk Reduction' demonstrated the importance of providing evidence-based support for managing disaster risk. It achieved this by focusing on the hazards of places and providing a comprehensive examination of a number of empirically based approaches for measuring hazard exposure, losses and social vulnerability. At the close of a series of seven very successful summer academies under the Munich Re Foundation Chair on Social Vulnerability, participants' skills were deepened and their professional networks enriched and strengthened.

Designed and conducted by Professor Susan L. Cutter and supported by Professors Mohamed Hamza and Michelle Leighton, the Academy proved once again the capacity of the United Nations University Institute for Environment and Human Security (UNU-EHS) and the Munich Re Foundation (MRF) to bring together scholars, experts, practitioners and magnificent PhD students to contribute to the field of social vulnerability with significant pieces of policy relevant research and concrete proposals for effective and durable solutions.

This SOURCE edition as a product of the seventh Summer Academy comprises seven scientific papers from participants originating from different countries and working in various disciplines debating issues associated with social vulnerability and resilience.

On the occasion of the last SOURCE publication of the MRF Chair on Social Vulnerability, I am honoured to express our gratitude to MRF for their tremendous support and partnership through the past seven years, contributing to this series of publications which will serve as a point of departure for further academic research and rewarding discussions.

Professor Jakob Rhyner
Director, UNU-EHS

Foreword

The Summer Academy 2012 not only marked the end of a seven-year success story but it was particularly special for me and my colleagues at the Munich Re Foundation. Under the heading "Strengthening societies – from social vulnerability to resilience" it brought together two topic areas that have always occupied us: vulnerability and resilience. Both of which play a very important role in disaster prevention and when adapting to climate change.

When the Munich Re Foundation began its work in 2005, the Chair on Social Vulnerability project with UNU-EHS, from which the Academy's directors were chosen, was one of its first milestones. In order to share the project results with young academics from all over the world and integrate their experience into the research, we joined forces with UNU-EHS in creating the Summer Academies in Hohenkammer Castle. Over the last seven years, the Summer Academy project has contributed to the education of more than 150 young researchers from 45 countries. The perspectives of the Academy also changed during this time: initially, the focus was on modelling the vulnerability of individuals and societies, whereas today the strengthening of society is becoming ever more central.

Resilience describes the ability of an individual or a society to prepare for an existing or potential future negative event. This includes planning ways to deal with the event, how its adverse effects can be mitigated and what options there will be for recovering from it. The potential to swiftly and lastingly adapt to new parameters is also a part of resilience research. The more quickly, flexibly and comprehensively an individual, group or society is able to cope with, for example, the impacts of climate change, the more resilient it is.

As the last holder of the Chair, Professor Susan L. Cutter hosted the seventh Summer Academy. She brought together aspects of disaster prevention, cultural features of resilience and modern research methods, some of which were IT-based. For example, in many academic disciplines it is becoming increasingly important to use geographic information systems (GIS) and this was shown in some of the Academy workshops.

At the end of the week it was evident that resilience research is a broad field that demands interdisciplinary understanding and the involvement of the local population in decision-making processes is becoming increasingly important. Only after considering these parameters in relation to each other and forming an overall picture of the risk can suitable steps be initiated towards a more resilient society.

Detailed discussion and analysis of these issues is presented in this edition of SOURCE.

I hope you enjoy it.

Thomas Loster
Chairman, MRF

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Abbreviations and acronyms

AIC	Akaike Information Criterion
ANSD	Agence Nationale de la Statistique et de la Démographie (Statistical and Demographical National Agency, Senegal)
AVHRR	Advanced Very high Resolution Radiometer
BIC	Bayesian Information Criterion
BMI	German Federal Ministry of the Interior (Bundesministerium des Innern)
BMJ	German Federal Ministry of Justice (Bundesministerium der Justiz)
BMVBS	German Federal Ministry of Transport, Building and Urban Development (Bundesministerium für Verkehr, Bau und Stadtentwicklung)
BNPB	National Disaster Management Agency (Indonesian: BNPB)
BPS	Badan Pusat Statistik (Indonesian: BPS) or BPS-Statistics Indonesia
CCA	Climate Change Adaptation
CD	Census District
CER	Emiliano-Romagnolo Canal
CI	Critical infrastructure
CILSS	Permanent Inter-State Committee for Drought Control in the Sahel
CIP	Critical Infrastructure Protection
CLC	Corinne Land Cover
CRED	Centre for Research on the Epidemiology of Disasters
CRFH	Coastal River Flood Hazard
CRU	Climatic Research Unit, University of East Anglia, UK
CSE	Centre de Suivi Ecologique (research center in Senegal)
DEM	Digital Elevation Model
DEMDEN	Population density
Depdagri	Department of Internal Affairs (Indonesian: Depdagri)
DFO	Dartmouth Flood Observatory, University of Colorado, USA
DIW	German Institute for Economic Research (Deutsches Institut für Wirtschaftsforschung)
DRM	Disaster Risk Management
EC	European Commission
ECI	European Critical Infrastructure
ECOWAS	Economic Commission of West African States
EM	Expectation Maximization
EM-DAT	International Disaster Database (CRED)

EU	European Union
F_M_INC	Ratio female/male mean monthly income
GADM	Global Administrative Areas
GIS	Geographic Information System
GITEWS	German-Indonesia Tsunami Early Warning System
HDI	Human Development Index
HFA	Hyogo Framework for Action 2005–2015
HLTHCOV	Estimated population coverage by basic health teams
HOP model	Hazard-of-places model
HOP	Hazard of place
IBGE	Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics)
ICT	Information and communication technology
INPE	Instituto Nacional de Pesquisas Espaciais (National Institute of Spatial Research)
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche et de Développement (research center in France)
ISTAT	Italian National Institute of Statistics
ITS	Institut Teknologi Sepuluh Nopember
ITZ	Intertropical Convergence Zone
LUBW	Baden-Württemberg State Office for Environment (Landesanstalt für Umwelt, Messungen und Naturschutz Baden-Württemberg)
MAUP	Modifiable Area Unit Problem
Max	Maximum
MEDAGE	Median Age
MEDIN	Mean income of population age 10 and older
Min	Minimum
MML	Minimum Message Length
NDVI	Normalized Difference Vegetation Index
NEDA	National Economic Development Authority
NESDIS	NOAA Satellite and Information Service
OCHA	Office for the Coordination of Humanitarian Affairs
PAI	Hydrological Management Plan
Pardo	Term used to describe population with multiracial background. Pardo is one of the five classifications of the Brazilian Census's Color or Race (White, Black, Asian, Pardo and Indian)

PCA	Principal Component Analysis
PERCAP	Average household per capita income
PNLP	Programme National de Lutte contre le Paludisme (National Program against Malaria)
PNUD	Programa das Nações Unidas para o Desenvolvimento (United Nations Programme for Development)
POPGROW	Population growth 2000–2010
PSGC	Philippine Standard Geographic Codes
QACCOM	Percentage of population employed in Accommodation and feeding activities
QAGEDEP	Percentage of population under age 14 and over age 60
QAGRI	Percentage of population employed in agriculture, fishing, forestry production, livestock and aquaculture
QASIAN	Percentage of Asian population
QAUTO	Percentage of households with automobile (not including motorcycle)
QBLACK	Percentage of Black population
QBORNST	Percentage of population born in other states
QCOM	Percentage of population employed in Information and communication
QED12LES	Percentage of population that completed middle school or with high school incomplete
QEMPL	Percentage of employed population
QEXPOV	Percentage of population living in households earning less than R$70,00 per month (Extreme Poverty)
QEXTRACT	Percentage of population employed in Extractive industry
QFEMALE	Percentage of female population
QFEMEPL	Percentage of females in the employed population
QFHH	Percentage of female-headed households with children (no spouse present)
QFORBORN	Percentage of foreign-born population
QHHS	Percentage of population employed in human health and social work activities
QILLIT	Percentage of illiterate population age 15 and older
QINDIAN	Percentage of Indian population
QLOWQUAL	Percentage of households with low quality external walls
QMORFAM	Percentage of families living in households with more than one family
QNEWRES	Percentage of residents immigrating in the past year
QNOGARB	Percentage of households with no garbage collection services
QNOMS	Percentage of population with no education or middle school incomplete
QNOSEWER	Percentage of households without any kind of sewer infrastructure

QNOTLEG	Percentage of population with no legal work registration, self-employed or subsistence
QNOWATER	Percentage of households with no water supply infrastructure or well
QPARDO	Percentage of Pardo population
QPERBED	Percentage of households with three or more people per bedroom
QPPUNIT	Average number of people per household
QPUBAD	Percentage of population employed in Public administration, Defense and Social Security
QRENTER	Percentage of population living in rented households
QSERVICE	Percentage of registered jobs in Services
QSHH	Percentage of single-headed households
QSPCNED	Percentage of population with special needs
QTRAN	Percentage of population employed in Transformation industry
QURBAN	Percentage of urban population
RBM	Roll Back Malaria
RUMA	Rapid Urban Malaria Appraisal
SoVI	Social Vulnerability Index
SPOT 5	Système Pour l'Observation de la Terre i. e. "System for Earth Observation"
SREX	Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation
SSBENPC	Number of benefits granted by social service per year per capita
St.Dev	Standard deviation
STAR	The Center for Satellite Applications and Research
TS	Tropical Storm
UFSC CEPED	Universidade Federal de Santa Catarina, Centro Universitário de Estudos e Pesquisas sobre Desastres (Federal University of Santa Catarina, University Center of Studies and Reseach on Disasters)
UMBW	Baden-Württemberg State Ministry of the Environment, Climate Protection and the Energy Sector (Ministerium für Umwelt, Klima und Energiewirtschaft Baden-Württemberg)
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNEP-PCDMB	UNEP Post-Conflict and Disaster Management Branch
UNISDR	United Nations Office for Disaster Risk Reduction
UNISDR	United Nations international Strategy for Disaster Reduction
UNU	United Nations University

VHI	Vegetation Health Index
VRS	Organisation of the Greater Region Stuttgart (Verband Region Stuttgart)
VVS	Transit and Tariff Association Stuttgart (Verkehrs- und Tarifverbund Stuttgart)
WFD	Water Framework Directive
WMO	World Meteorological Organization
Z_GIS	Department of Geoinformatics, University of Salzburg, Austria

Introduction

Over the last decade, the scientific research community has developed exemplary conceptualizations of social vulnerability to hazards and disasters ranging from root causes, to underlying drivers, to differential impacts (Cutter, 1996; Turner et al., 2003; Wisner et al., 2004; Adger, 2006; Birkmann, 2006a; Eakin and Luers, 2006; Wisner et al., 2011; Cardona et al., 2012). Vulnerability, broadly defined, is the potential for loss. Most often, it includes elements of exposure (people, places, infrastructure at risk from a hazard), and sensitivity (the degree to which the people, places, or infrastructure are harmed), and coping (the skills, resources, and opportunities of people and places to survive, absorb the impacts, and manage the adverse outcomes). For some researchers, coping equates to resilience, while for others, vulnerability and resilience are separate and distinct concepts, interrelated but not the obverse of one another (Cutter et al., 2008; Turner, 2010). Resilience refers to the capacities of people, places and infrastructure to not only cope with hazards, but also the longer term processes that enable the social system to adjust to and learn from hazard events and adapt to future ones. There are many debates in the literature on the concepts themselves (Miller et al., 2010), but these simplified definitions capture the essence of vulnerability and resilience. These broad definitions provide sufficient latitude for governmental agencies to develop and implement policies and practices that suit their specific mandates and in this way, move from theory to practice (U.S. National Research Council, 2012).

Vulnerability and resilience science seek to explain the complex interactions between social, natural and engineered systems, and the capacity of these systems to respond to and recover from adverse events. Vulnerability science helps us explain why the same hazard event can produce different consequences across natural and human landscapes. It also helps us to understand how and why a singular event (a category 1 or 2 hurricane, for example) can quickly turn into a major disaster such as Hurricane Katrina in 2005 (Laska and Morrow, 2006) or the recent Superstorm Sandy in 2012. Resilience science enables us to understand the integrated nature of building and enhancing capacity for people, communities, and infrastructure to not only plan and prepare for, absorb, respond to, and recover from hazards and other threats, but also to enhance existing abilities to more successfully adapt to actual or potential hazards (and other threats), likely changes in social and environmental systems, and unanticipated surprises.

While our conceptual understanding of vulnerability and resilience has improved during the past two decades, one of the missing links in our understanding is how to measure social vulnerability and resilience. In particular, robust indicators and benchmarks need to be developed as a means for assessing achievement and monitoring progress towards disaster risk reduction; for example the goals and actions outlined in the Hyogo Framework (UN/ISDR, 2008). However, the development of metrics and indicators focused on social vulnerability assessment has lagged behind the theoretical and conceptual research in the field (Cutter et al., 2003, 2008; Birkmann, 2007). There are many different approaches to measurement – some are qualitative in orientation and others are more empirically-based; some are applicable to the geographic scale of community or places, others are only available at national levels; some are specific to individual threats, while others take an all hazards perspective. The development of resilience indicators is still in its infancy. Infrastructure and economic resilience metrics are more advanced, both looking at individual infrastructure behaviour in response to a particular threat source such as an earthquake (SPUR, 2008) or the economic behaviour in response to an actual event (Rose et al., 2009). Few focus on communities and the interrelationships among all the systems within them developing resilience metrics (National Research Council, 2012). There are some promising developments at integrated risk assessments that include vulnerability and resilience, but presently these are country-level comparisons (IDB, 2007; Peduzzi et al., 2009; Alliance Development Works, 2012). In order to understand and monitor our progress towards achieving the goal of disaster risk reduction (including the reduction in exposure and social vulnerability) and creating resilient communities, we

need adequate and comparable measures social vulnerability and we need to begin to develop measures of disaster resilience.

The 2012 Academy

The 2012 Summer Academy addressed some of the methodological challenges in measuring social vulnerability and resilience. Nineteen students, with academic backgrounds ranging from engineering to the social sciences (geography, urban studies, regional planning) to statistics and the computational sciences participated in the programme. Each student brought a unique set of disciplinary skills as well as inter-and multi-disciplinary perspectives. Prior to the beginning of the Summer Academy, students were asked to prepare a background paper on a prototype empirically-based hazard vulnerability assessment for a study area of their choice, and to include a literature review on the place-based integrated research on hazard exposure, social vulnerability and resilience at it related to their study area. The papers were also asked to include an overview of the availability of hazard exposure, hazard loss and socio-demographic data for their study area.

Learning objectives

The learning objectives for the Summer Academy were 1) to introduce students to the differing methodological and empirically-based approaches to hazard vulnerability assessment currently in use; 2) to have students interact with some of the primary developers of vulnerability assessment metrics to better understand their strengths and weaknesses; 3) to have students become conversant in the use of geographic information systems (GIS) and its application to social vulnerability assessment and resilience; 4) to assist students in developing a prototype hazard vulnerability assessment for their home region/country; and 5) to provide mentorship opportunities for students on their dissertation research and publications and careers, and give them experience in crafting an interdisciplinary research proposal as part of their professional development.

Content and approach

Through a series of content lectures on existing approaches and metrics for vulnerability assessments and hazard loss estimation, students were first exposed to the range of methodologies and indicators (see Table 1). The topics covered included: a history and overview of hazards and vulnerability research (Cutter), vulnerability frameworks (Birkmann), natural hazard loss data (Wirtz) and transitions from vulnerability to resilience in the research community (Cutter). The implementation of social vulnerability indicators was illustrated using a regional approach that focused on Mozambique (Kienberger), Viet Nam (Birkmann) and the United States (Gall and Cutter). Given that most of the instructors were the primary developers of such indicators, students were afforded a unique opportunity to learn first-hand of the strengths and weaknesses of these metrics and methods through an extended roundtable discussion. Students were also provided tutorials on GIS and their use in social vulnerability assessments.

The individual papers, lectures and tutorials set the stage for students (in self-selected groups) to embark on the preparation of a multi-authored, multi-disciplinary research proposal for potential funding in order to gain some practical experience in proposal writing. Using the prepared papers as background, supplemented with the materials at the Summer Academy, the students self-organized into four research teams to write a proposal for conducting an empirically-based vulnerability assessment for a selected study site. They created research proposals and then presented them to an expert panel who evaluated their oral presentation and written document using standards from national science funding agencies and organizations. The evaluating questions included: What research questions would the assessment address? What methodological approach would you use to conduct your assessment? What is the intrinsic merit of the proposal (contributions to advancing science or the development of new knowledge or techniques)? What are the broader impacts of the proposed research? The purpose of the exercise was to provide practical advice on proposal writing and review as part of the professional development of the students.

Name	Affiliation	Topic
Content specialists		
Susan Cutter	University of South Carolina, Dean of 2012 Summer Academy	Social Vulnerability Index (SoVI)
Joern Birkmann	United Nations University	WorldRiskIndex
Stefan Kienberger	University of Salzberg	Integrated assessments
Angelika Wirtz	MunichRe	Loss estimation models
Melanie Gall	Louisiana State University and former Summer Academy student	GIS and GIS-based integrated assessments
Mo Hamza	MRF Chair	Facilitator, Proposal Review Panel
Michelle Leighton	MRF Chair	Facilitator, Proposal Review Panel
Koko Warner	United Nations University	Climate change adaptation
Thomas Loster	Munich Re Foundation	Munich: the city

Table 1: Content specialists participating in the 2012 Summer Academy. Source: Editors.

Learning outcomes

The first two learning objectives (background on empirically-based approaches to vulnerability; and strengths and weaknesses of existing methods) were achieved through content lectures and panel discussions. Exposure to and improvement in GIS was accomplished through a hands-on practicum on GIS basics as well as through an interactive demonstration of the construction of the Social Vulnerability Index. Mentoring occurred throughout the Summer Academy and afterwards with the MRF Chairs as well as the content specialists. This included the feedback on the group research proposals, one-on-one conversation with each student on their individual papers, career paths and professional development conducted by the content specialists. Written feedback on all 19 papers was provided approximately six weeks after the conclusion of the Summer Academy.

The final objective, the development of a prototype hazard vulnerability assessment that included both social and environmental dimensions, was achieved in the preliminary papers that students submitted to the Summer Academy. A sampling of those papers, revised after participating in the Summer Academy, is represented in the chapters that follow.

Findings

A number of significant findings regarding the utilization of metrics for vulnerability assessment and resilience were found based on the work of the Summer Academy. These are briefly described below.

Existing conceptualizations of vulnerability are incomplete

A one-size-fits-all vulnerability framework does not exist, so it is important to look at each context and choose the best model that fits into the overall project research design. Most of the vulnerability frameworks are static representations, largely due to the availability of core data limita-

tions in methods. The use of scenario techniques in such models could improve the dynamic representation of change, and provide opportunities for advancing the science of vulnerability.

Second, while the existing models profess to be integrated, including information about infrastructure, physical systems and social systems, some of these elements are represented more strongly in the models than others. Specific strengths and weaknesses of the existing models were identified. For example, the socio-ecological framework (Turner et al., 2003) was conceptually sound, but its implementation becomes problematic. The relationship between scales (place, region and global) and the interaction between variables outlined in the schema were unclear, so defining specific metrics would be difficult in an integrated assessment using this approach. In contrast, the Pressure and Release Model (PAR) (Wisner et al., 2004) has a level of abstraction that precludes distinguishing one driving factor from another, especially in defining proxies for measurement. Finally, the BBC Framework (Birkmann, 2006b) and the Hazards of Place Model (Cutter, 1996) have both been tested empirically. Yet, there are concerns about cross-scale dynamics (at which scale do the models work best), the balancing of the different components (is one more significant than the other and thus should be weighted somehow), and how the model can be used for multiple hazards, not just a single hazard approach.

Data for constructing vulnerability and resilience metrics are lacking or are at the wrong scale

In many countries, basic foundational data for constructing hazard vulnerability assessments are not available at all, or not available at a scale that is useful for analytical purposes (e.g., subnational administrative units). The lack of data was not a simple developing versus developed world division. For example, some of the best socio-economic data for constructing social vulnerability indices were in Indonesia and Philippines (see Siagan et al., and Ignacio and Henry papers in this volume). Cross country or sub-country analyses are especially problematic because of data availability at different resolutions (individuals, households, places), different enumeration units (districts, city, region or entire nation), and representing different time periods.

Challenges remain for translating vulnerability and resilience metrics into practice

Conducting hazard vulnerability assessments necessitates an interdisciplinary approach where social science and natural science models are integrated, and the results are communicated effectively to policymakers. Natural science models predominate as there is relatively little experience in the social sciences with integrative modelling, although that is rapidly changing with the increased focus on climate change adaptation. The output of social science models could be used as inputs into the natural science modelling efforts to achieve the integration of physical and human systems. At present, this is only being done at a very rudimentary level, and the full coupling of these models remains a challenge.

Participatory research approaches are good for understanding the qualitative dimensions of vulnerability from the social science perspective, but they lack quantification, which means these efforts are not integrated into any of the hazard exposure modelling efforts. The challenge is to how to create robust vulnerability and resilience metrics (qualitative and quantitative) that advance our understanding of vulnerabilities, but are at the same time robust enough to be incorporated into some of the larger national and regional integrated disaster risk modelling.

There is a subtle difference between policy relevant research on one hand and research to inform policy on the other. For example, one may claim that every research project is policy relevant even when policy has neither heard about it, nor paid attention paying attention to it. However, a research project may be policy relevant, but not end up influencing policymaking at all. Therefore informing policymakers requires a bit of activism from the researcher's side. The researcher needs to build the trust and always ask the question: What is it that you as a policymaker need from me as a researcher or scientist? By asking this question and producing corresponding research to answer it, the researcher can start moving the knowledge (science) to action (policy). This requires that researchers have more engagement with various stakeholders and decision makers. The challenge is then to improve both the construction and dissemination of vulnerability metrics in ways that are

mutually understandable and beneficial for the researcher and the decision makers.

The path forward

The seven papers included in this volume address various aspects of integrating social, environmental and infrastructure elements in understanding vulnerability and resilience. They represent new and innovative approaches to vulnerability and resilience metrics, with an eye towards informing policy. Atzl and Keller offer in their paper a conceptual framework on infrastructure vulnerability utilizing a systems perspective. They examine the connectivity between the social environment, natural environment and critical infrastructure, where the social environment regulates the critical infrastructure and the critical infrastructure maintains the social environment. This new conceptualization provides a mechanism for understanding and empirically testing the connectivity of infrastructure in building resilience in communities. Hummell provides an overview of the availability of research and data on hazard exposure and vulnerability in Brazil. She found that no consistent methodologies or subnational databases were available for conducting place-based or spatial assessments of integrated hazards. However, even with data limitations, Hummell demonstrated the ability to replicate the Social Vulnerability Index (SoVI) in this data-constrained environment using Paraná (one of the states of Brazil) as a test case. In a different context, Carrera et al. examined the integration of social vulnerability and flood risk exposure in the Po River Basin as a methodological proof of concept for compliance with EU Flood Risk Management Directive 2007/60/EC. In this example, the science to practical application is abundantly clear. In another flood example, Ignacio and Henry illustrated the intersection of social and biophysical vulnerability to riverine flash flooding in the Philippines. They were able to spatially delineate high risk zones (based on social vulnerability and biophysical exposure) and produce maps. Further, they were able to validate the mapping products based on the flooding associated with Tropical Storm Washi.

Two illustrations of advanced spatial modelling of hazards were both carried out in Africa. Hagenlocher used four climate-related variables (seasonal rainfall, temperature patterns, drought occurrences and major flood events) in the Sahel region to identify and delineate hotspots of cumulative climate change impacts. Utilizing a spatial composite/meta-indicator method, the individual "layers" of impacts are integrated and then aggregated through regionalization techniques, which themselves are independent of administrative boundaries. This concept is significant as physical parameters such as droughts or temperature patterns do not fit neatly into political or administrative boundaries. Borderon also took an innovative approach to exposure assessment examining the problem of urban malaria in Dakar. Utilizing proxies for malaria exposure based on breeding areas (sites with water and dense vegetation) and distance, potential exposure zones were mapped. A social vulnerability measure was then created and through bi-variate mapping the relationship between social vulnerability and exposure was highlighted on the map.

Finally, a methodological contribution on social vulnerability index construction was provided by Siagian et al. who used a model based clustering method with minimum message length (MML) criterion. The result was the identification of clusters of social vulnerability in Indonesia.

Each of these papers represents unique contributions to the advancement of vulnerability metrics and integrated hazard assessments. As a group, they demonstrate the value and significance of interdisciplinary research and the exciting opportunities it affords for the next generation of vulnerability scholars and those who utilize their work.

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A systemic approach for the analysis of infrastructure-specific social vulnerability

Andreas Atzl and Sina Keller

Abstract

Hurricane Sandy, that hit the US east coast at the end of October 2012, has provided practical proof of the vulnerability of society for infrastructure failures due to natural hazards. This paper addresses this issue by introducing a new systemic framework for the analysis of critical infrastructure and its linkages to the social and natural environment. The paper reviews existing concepts of social vulnerability and classifies their indicators. It illustrates that empirical studies measure either latent social vulnerability or hazard-specific social vulnerability. However, regulation and planning institutions are in need of indicators for infrastructure-specific social vulnerability. The authors approach infrastructure-specific vulnerability by the combination of existing concepts of infrastructure criticality and social vulnerability. The conceptualisation of infrastructure-related vulnerability allows planners to benchmark and assess the availability of critical infrastructure against the actual needs of society. The approach is one component of the larger systemic framework for infrastructure vulnerability assessment which is developed by the authors for application in the Stuttgart region.

Keywords: infrastructure, criticality, social vulnerability, regulation, Germany

Introduction

Six weeks after hurricane Sandy, that hit the US east coast end of October 2012, New York's mayor Mike Bloomberg claimed that it is "clear that new steps are needed to safeguard key elements of our infrastructure – in electrical power, transportation, telecommunications, hospitals, and other areas – from disruptions during hurricanes, heat waves, or other extreme weather events" (The Office of the Mayor of the City of New York, 2012). Hurricane Sandy is only one recent example of how the impact of extreme weather events on critical infrastructure can disturb and interrupt social and economic life even in industrialized countries. In 2005, the simultaneous appearance of freezing point temperatures, strong precipitation and stormy winds in northern Germany resulted in a blackout lasting several days and affecting about 250,000 people (Reichenbach et al., 2008). In its 2012 special report on extreme events, the Intergovernmental Panel on Climate Change (IPCC) states that "weather- and climate-related extremes are expected to produce large impacts on infrastructure" (IPCC, 2012: 248). The IPCC argues that urban centres, depending on "lengthy infrastructure networks" (IPCC, 2012: 249), are particularly threatened by the increase of climate-related extreme events.

Infrastructure in urban agglomerations

The Stuttgart region in the state of Baden-Württemberg in south-west Germany is one of the most densely populated urban agglomerations in Europe (VRS, 2013). A study conducted on behalf of the German Federal Ministry of Transport, Building and Urban Development has identified an increased susceptibility of the Stuttgart region towards climate change impacts (Gruehn et al., 2010). The study underlines population density and critical infrastructure as major factors leading to increased susceptibility of the region towards climate change (Gruehn et al., 2010). The German Institute for Economic Research (DIW Berlin) estimates the costs that will be caused by damages related to climate change in the state of Baden-Württemberg between 2008 and 2050 to be about 130 Billion euro (UMBW and LUBW, 2012).

These studies show that there is a connection between climate-related extreme events, critical infrastructure and the resultant impacts on population and society. However, an in-depth scientific analysis of linkages between these factors is still missing. This paper presents elements of a new vulnerability and risk analysis framework seeking to fill this research gap. Following a holistic approach, infrastructure is considered as a system connecting the natural and the social en-

vironment.[1] Thus, the purpose of this paper is to illustrate the gap between critical infrastructure research and other areas of vulnerability research and to present a methodological frame combining the concepts of criticality and social vulnerability in order to allow the integration of the dimension of social vulnerability into the analysis of critical infrastructure vulnerability towards climate change.

Critical infrastructure protection and the trichotomy of vulnerability concepts

In the course of the past 10 years, critical infrastructure protection has evolved into an important issue on scientific and political agendas. One major trigger for this increase in importance has been the fight against terrorism.[2] Others include an increasing societal dependency on information and communication technologies (ICT) (Atzl et al., 2012) and, as mentioned before, raising awareness on environmental and climate change risks (IPCC, 2012).

In 2005, the European Commission published the Green Paper on a European Programme for Critical Infrastructure Protection (EC, 2005). Three years later, in December 2008, the European Council adopted the Directive 2008/114/EC on the identification and designation of European critical infrastructures and the assessment of the need to improve their protection (EC, 2008). According to the Directive, critical infrastructure includes "an asset, system or part thereof […] which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions" (EC, 2008: § 2(a)).

In 2009, the German Federal Ministry of the Interior launched the German National Strategy for the Protection of Critical Infrastructure (BMI, 2009). In coherence with earlier national German concepts and with the EU directive, the strategy emphasises the growing linkages between social vulnerability and critical infrastructure as a consequence of an increasing relevance of critical infrastructure for the functionality of all areas of life. Yet, neither the European directive nor the German strategy paper specifies the exact ways in which society and critical infrastructure are connected.

Along with the raising awareness of the interlacing between society and critical infrastructure systems, a number of concepts to define and operationalise the state of 'vulnerability' have emerged. Cutter and others (2003) stated that while there are a recognizable number of vulnerability assessments on "biophysical vulnerability and the vulnerability of the built environment" (Cutter et al., 2003: 243), much less is known on the social dimension of vulnerability. Since then, researchers have come up with new frameworks and a number of studies have attempted to assess social and human vulnerability (for some examples, see Gall, 2007; Tate, 2011; Carreño et al., 2007; Birkmann et al., 2011; Kienberger, 2012).

Hence, the trichotomy of vulnerability concepts, namely concepts on the vulnerability of the natural environment, the built environment, and the social environment has remained. The hazard-of-place model (HOP model) introduced by Cutter (1996) illustrates the ideas leading to this trichotomy of vulnerability concepts). Being aware of the interconnectedness of different types of vulnerability, Cutter attempted to combine biophysical and social vulnerability through a place-centred concept.

From this perspective, the vulnerability of a specific place is the result of two contexts filtering the potential impact of a hazard (Cutter, 1996), 1) the geographic context leading to biophysical vulnerability; and 2) the social fabric leading to social vulnerability (Cutter et al., 2003).

Interestingly, Cutter et al. (2003) list the built environment as part of social vulnerability. In the 1996 publication however, the built environment was seen as a part of the geographic context or as a pre-existing condition: "A subset of [biophysical vulnerability] studies examines the distribution of structural losses and vulnerability reduction in the built environment associated with natural disasters events" (Cutter, 1996: 532). This obvi-

1 The two authors' contributions to this paper are based on their different scientific backgrounds in social and organisational science (A. Atzl) and mathematics and natural science (S. Keller).

2 For instance, the preface of the European Directive on critical infrastructures (2008/114/EC) states that the Directive is a contribution to "enhance European prevention of, preparedness for and response to terrorist attacks involving critical infrastructures" (EC, 2008, preface).

ous contradiction illustrates the difficulty to assign infrastructure either to geographic context or to the social fabric. As a consequence, Borden and others (2007) created a Built Environment Vulnerability Index and combined it with the Social Vulnerability Index and a Hazard Vulnerability Index to assess the vulnerability of U.S. cities. Although the integration of three different indices into the assessment of place vulnerability is a step forward, the linkages between these indices are not addressed yet. An example for such a linkage would be the degree to which the vulnerability of a certain infrastructure improves or worsens social vulnerability in a specific place or of a specific group.

Other studies tried to approach vulnerability with holistic and systemic frameworks focusing on the dependencies between environmental and social systems and their vulnerabilities (see Turner et al., 2003, Carreño et al., 2007, and Birkmann, 2006). However, although these studies implicitly include critical infrastructures in their framework[3], none of them explicitly recognizes critical infrastructure as a distinct system describing the relationship between natural and social systems.

On the other hand, a number of authors have tried to define and operationalize the vulnerability of critical infrastructure. For some examples see Kröger (2008), Utne et al., (2008); Lenz (2009); Chang, McDaniels and Beaubien (2009); Damm, Fekete and Bogardi (2010); Rübbelke and Vögele (2011); and Krings (2011). Yet few of them (among the mentioned studies only Chang and others, 2009; Damm and others, 2010; and Krings, 2011) contextualize their work with concepts of social or environmental vulnerability. Lenz (2009) underlines the fact that existing concepts of social vulnerability are ineligible to be applied to critical infrastructure. The reason is that indicators and methodology for their measurement are based on different scientific paradigms and are therefore difficult to integrate (Becker and Keil, 2006).

3 For instance, Carreño et al. (2007: 146) use damages of water, gas and road infrastructure to operationalize their vulnerability dimension ‘physical risk’.

I. Concepts of infrastructure and criticality

Characteristics of critical infrastructure

This section discusses definitions of the term ‘critical infrastructure' and explains the understanding of critical infrastructure that forms the basis of the introduced framework. Depending on the respective authors’ scientific, disciplinary and geographic context, definitions of critical infrastructure may vary. Table 1 provides an overview of three exemplary definitions of critical infrastructure. While their terminology differs, the definitions of critical infrastructure share two characteristics: they are networks, assets, systems, or individual structures (infrastructures) that 1) maintain essential societal functions; and 2) their failure and/or disruption can cause significant societal harm (criticality).

Lenz (2009) lists further definitions of critical infrastructure from government institutions of six countries in Europe, North America and Australia. Both characteristics can also be found in these national definitions.

Infrastructure levels and sectors

To operationalize infrastructure, two dimensions can be applied: its sector (horizontal dimension) and its level of scaling (vertical dimension). Level of scaling refers to infrastructure sectors, infrastructure systems and infrastructure components as introduced below. The EU classifies infrastructure on the basis of its affiliation with a sector. In Annex 2, the EU Green Paper on critical infrastructure lists eleven sectors as key constituents of critical infrastructure, including technical infrastructure like water and energy supply facilities, provision with food, goods and financial services as well as civil administration and “public and legal order & safety” (EC, 2005: 24). The EU directive (EC, 2008) sets political priorities at the identification of critical infrastructure in the energy and transport sectors. In further steps, the EU member states are then requested to review other sectors as to their potential criticality

Definition	Characteristics	Source
"Critical infrastructures are technological networks, such as energy supply, transport services, water supply, oil and gas supply, banking and finance, and ICT (information and communication technology) systems [1,2]. These systems are important to maintain essential functions of society, and infrastructure failures can cause serious harm to population, economy, and national security."	• Technological networks; • Maintenance of essential functions; • Failure can cause harm.	Utne, Hokstad and Vatn, 2011, p. 671
"'Critical infrastructure' means an asset, system or part thereof located in Member States which is essential for the maintenance of vital societal functions, health, safety, security, economic or social well-being of people, and the disruption or destruction of which would have a significant impact in a Member State as a result of the failure to maintain those functions."	• Asset, system or part thereof; • Maintenance of vital functions; • Disruption has significant impact.	EC, 2008, § 2(a)
"Critical infrastructures (CI) are organizational and physical structures and facilities of such vital importance to a nation's society and economy that their failure or degradation would result in sustained supply shortages, significant disruption of public safety and security, or other dramatic consequences."	• Organizational and physical structures; • Vital importance to society and economy; • Failure or degradation results in dramatic consequences.	BMI, 2009, p. 4

Table 1: Definitions of critical infrastructure and their characteristics. Source: Authors.

of infrastructure, "inter alia, the information and communication technology ('ICT') sector" (EC, 2008, preface (5)).

The German CIP-Strategy classifies similar infrastructure sectors into technical basic infrastructure and socio-economic services infrastructure. Infrastructures in both classes are seen as "vital" (BMI, 2009: 7) by the CIP-Strategy. This dichotomy of technical/physical vs. social/economic infrastructure again illustrates the challenge to clearly allocate infrastructure to either the natural or the social environment.

In this context, it is important to underline that infrastructure sectors are highly interdependent (Krings, 2011, and McDaniels et al., 2007). A clear distinction between technical basic infrastructure and socio-economic services infrastructure is not always possible. As an example, emergency and rescue services or public administration are infrastructure dimensions which are also inherent in the power supply and transportation sectors. Similarly, many types of infrastructure such as finance and media services highly depend on information and communications technology, which are infrastructure sectors on their part. The complexity of interdependencies between infrastructure sectors demands to scale down the analysis on specific infrastructures and their components.

Lenz (2009) proposes a multi-level approach to analyse critical infrastructure based on three different levels of scaling. The first level of scaling refers to the infrastructure sectors as described in the previous paragraphs.

The second level of scaling refers to the infrastructure itself. Each sector comprises a number of different infrastructure assets that can be analysed separately. For instance, the transport sector can be subdivided into road infrastructure, rail infrastructure, aviation infrastructure and water transport infrastructure (Lenz, 2009; EC, 2005). These sub-levels of a given infrastructure sector are highly interconnected within and across sectors, too. However, as in many other countries, the administrative structures governing infrastructure planning and operation in Germany are strongly sector-specific (Einig, 2011), turning the integrated regulation of infrastructures within and across sector borders a challenge (Moss, 2011).

The third level of scaling is the level of infrastructure components. For the example of rail infrastructure, this includes train stations, rail roads, maintenance factories and transfer sites. Transfer sites are a good example of infrastructure components that are part of two or more infrastructure systems, as they could either belong to rail transport infrastructure or to water transport infrastructure or both.

Recently, Susanne Krings (2011) has applied this multi-level approach in a project assessing the vulnerability of critical infrastructure towards floods in Dresden, Germany. This project developed guidelines for the assessment of critical infrastructure vulnerability on a local level, consequently focusing on the infrastructure and infrastructure component level to operationalize critical infrastructure (Krings, 2011). The sectoral level, though, was used in an earlier step to limit the infrastructure assets and facilities that would be included in the assessment (Krings, 2011).

A structural model of critical infrastructure and its environments

As mentioned in section A, the assessment of vulnerability has so far been limited to specific environments (natural, social, built environment). Figure 1 shows the structural model developed in the paper aimed at bridging the gap between different types of vulnerability. The model does so by identifying processes and reciprocities between and within three systems, namely 1) the critical infrastructure; 2) the natural environment; and 3) the social environment.

The system critical infrastructure

The system critical infrastructure includes technical and organizational multi-level structures which are crucial for the maintenance of functions in their social environment, as defined below. Rinaldi et al. (2001: 12) define critical infrastructure from a systemic perspective as "a network of independent, […] man-made systems and processes that function collaboratively and synergistically." Interaction, feedback mechanisms and cascade effects from one infrastructure to another, especially in case of failure, create a complex topology of infrastructure (Rinaldi et al., 2001) with reciprocal dynamics and

changes. Linkages between infrastructures can be of physical, virtual, logical or geographical nature (Rinaldi et al., 2001; Utne et al., 2011). Change in one infrastructure can affect others directly or indirectly (Wang et al., 2012).

The natural environment and its linkages to critical infrastructure

In addition to dynamics within the system, linkages exist between critical infrastructure and its natural environment. Following the chorology concept by Hettner (1927), the natural environment of critical infrastructure is a system of components like topography (land relief), climatology, geomorphology, soil and vegetation (Jackowiak, 2007). Examples for measurable factors of this system include temperature, precipitation, root zone and water-holding capacity (Becht and Damm, 2004; Neuhäuser et al., 2012; Auld and MacIver, 2007). These and other factors are relevant for both, the analysis of climate change impacts on the natural system as well as on infrastructure systems (Hamilton et al., 2012). All components of the natural environment are characterized by reciprocal dynamics and change over time and space (Jackowiak, 2007).

In one direction, infrastructure systems are linked to their natural environment by the environment's conditions. These conditions create the frame for the use, transformation and movement of components from natural environment such as water, energy and space by infrastructure. As a consequence, the management of infrastructure systems is affected by climate change and other dynamics of the natural environment that may cause hazards and other events (Hamilton et al., 2012; Eusgeld et al., 2011; Auld and MacIver, 2007). In the second direction, infrastructure also affects the natural environment in various ways that are not deepened here due to the paper's focus on the link between infrastructure and its social environment. The same applies to direct linkages between the natural and social environments, although these linkages will not be discussed in this paper. For instance, these linkages are reflected in hazard-specific concepts of social vulnerability (see below) or in concepts of ecosystem services.

The social environment of critical infrastructure

Coming from an actor-centred perspective (Schimank, 2007), the social environment is generally characterized by actors and their characteristics and interactions. These interactions create social patterns and institutions such as spatial mobility, age distribution of a population or the societal discourses and administrative settings that frame the planning and operation of technical infrastructure. Social actors, patterns and institutions are named social units in the following. The challenge is to identify those social units particularly relevant for the linkages between critical infrastructure and its social environment.

The two linkages between critical infrastructure and its social environment are regulation and maintenance. Infrastructure planners and operators are part of the social environment and regulate critical infrastructure. Conversely, critical infrastructure maintains functions of its social environment, depending on the infrastructure's degree of criticality. Both relationships will be specified in the following.

Social criticality: linking critical infrastructure and its social environment

As mentioned, there are two one-way influences between critical infrastructure and the social environment: maintenance and regulation. While the focus of this paper is on maintenance, a few words on regulation are necessary for a better understanding. The concept of regulation summarizes all formal and informal measures used by infrastructure planners and operators to ensure that critical infrastructure maintains societal functions (for a more detailed explanation of regulation see Hummel and Kluge, 2006). Regulation and spatial planning in general are normative processes (Moss, 2011). Thus, the objectives and general principles of spatial planning are the result of political and societal processes and discourses (Fürst, 2011). Currently, the general principles for spatial planning in Germany are 1) growth and innovation, 2) security of services for the public, and 3) conservation of resources and design of the cultural landscape (BMVBS, 2006: 12 ff.). These national principles are completed by further objectives and principles defined on

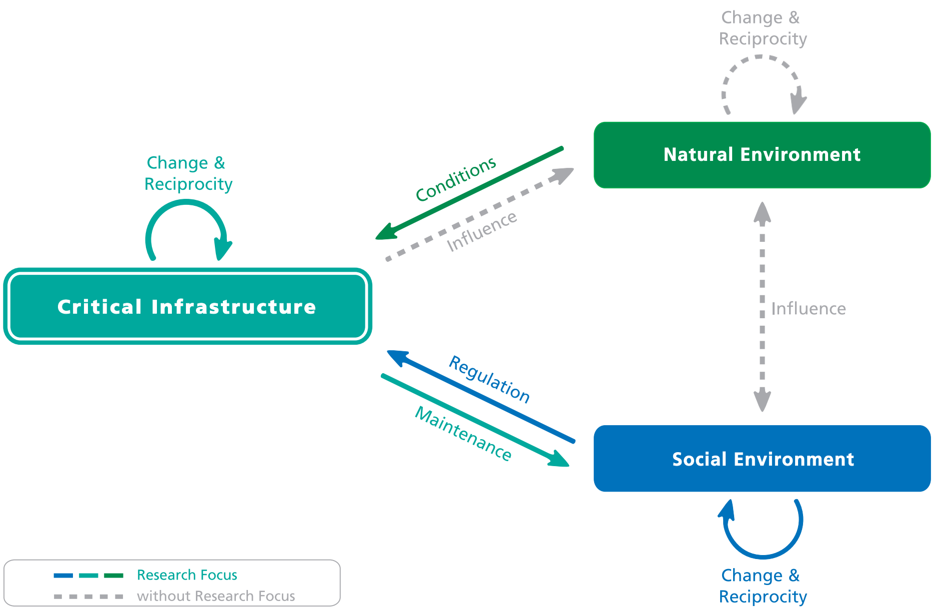

Figure 1: Structural model of critical infrastructures and their natural and social environment. Source: own draft.

state, regional and local levels. While the first two principles are related to the social environment, the last is related to the natural environment (BMVBS, 2006).

The normative character of regulation in spatial planning applies accordingly to the regulation of (critical) infrastructure (Becker and Jahn, 2006). Infrastructure counts among the instruments applied by spatial planning institutions (and other administrative bodies) to achieve their objectives and general principles (Benzel and others, 2011). Depending on the function it maintains, a given infrastructure element can be more or less decisive for the functionality of its social and natural environment. Additionally, an infrastructure can maintain the functionality of other critical infrastructure. The authors conceptualize this 'relevance' of an infrastructure as its criticality (Lenz, 2009; BMI, 2009).

While criticality also includes the influence on the natural environment, the scope of this paper is limited to the link between critical infrastructure and its social environment. The concept to operationalize this link is the social criticality of infrastructure.

The measurement of criticality

Although the term criticality has encountered increasing recognition in infrastructure-related strategies and documents during the last decade, little research has been conducted on the actual measurement of criticality.

The EU Directive on critical infrastructure demands the member states to identify European critical infrastructures according to the "significance of the impact" (EC, 2008, §2(b)) of their failure. To evaluate the significance of impact, member states should use sector-specific criteria taking "into account the characteristics of individual ECI [European Critical Infrastructure] sectors" (EC, 2008, §2(b)). In addition to sector-specific criteria, the directive defines three cross-cutting criteria for the identification of critical infrastructure. The casualty criterion is "rated to the potential number of fatalities or injuries" (EC, 2008, §3.2(a)). In contrast to this very specific criterion, the two other criteria are not operationalized by the EU Directive. The economic effects criterion is supposed to be assessed by economic losses including environmental effects (EC, 2008, §3.2(b)). Finally, the public effects criterion is supposed to be assessed by "the impact on public

confidence, physical suffering and disruption of daily life, including the loss of essential services" (EC, 2008, §3.2 (c)).

This unspecific definition of criteria has resulted in an inconsistent implementation of the EU Directive by the member states. In Germany, information is limited to the responsibilities and general dimensions of assessments of infrastructure criticality, though does not include information on the actual criteria and indicators applied. Based on propositions from the grid operators, the criticality of the power grid infrastructure is defined every two years by the German Federal Network Agency (BMJ, 2005). Yet, criteria and methodology for this assessment are classified information. For other sectors like transport, infrastructure operators are responsible for the definition and selection of criticality assessment indicators. A guideline recommends the selection of indicators from a number of dimensions, including economic and environmental effects and impacts on regulative norms but leaves the decision to the operators (BMI, 2011, §16). Consequently, assessments of infrastructure criticality are neither transparent nor comparable, even within identical sectors and member states. Above, private infrastructure operators are free to assess their own infrastructure without external control (Birkmann, 2011).

Independent from the EU Directive, Fekete (2010) has developed a more coherent approach to measure the criticality of infrastructure in a project conducted by the German Federal Office of Civil Protection and Disaster Assistance. Fekete (2011) distinguishes three dimensions of criticality: 1) critical proportion; 2) critical time; and 3) critical quality. These dimensions allow the definition of specific infrastructure settings with a certain level of infrastructure availability in quantity, time and quality. The idea is that the environments of infrastructure are able to cope with certain levels of infrastructure interruption. The dimensions of infrastructure criticality define thresholds above which this coping capacity is exceeded. The Fekete approach to criticality fits well with this paper's understanding of social vulnerability as it is introduced in the following paragraph.

II. Dimensions, levels and indicators of social vulnerability

Social vulnerability as a normative concept

As mentioned above, individuals, households, social groups, institutions or societies (social units) are more or less able to cope with events like the interruption of infrastructure depending on their specific situation. These specific situations are analysed by concepts of social vulnerability. Social vulnerability is defined in this paper as the degree to which a social unit is unable to cope with an external event. Coping is defined as the ability of a social unit to remain in or return to a normatively acceptable state after an external impact. Basically, the idea is close to what Luhmann (1997) calls the structural coupling of systems. Societal and political discourses lead to the norms that decide which situations of social units acceptable for a society are and which are not. As noted previously, spatial planning and infrastructure planning define their objectives, programmes and plans according to these norms. While spatial planning contributes to the normative orientation of what is acceptable and what is not, the concept of social vulnerability allows the identification and measurement of dimensions and factors of the social environment that are related to these norms.

Selection of reviewed frameworks

Studies on social vulnerability are often embedded into frameworks including other concepts such as biophysical vulnerability, risk, resilience and coping capacity. Cutter (2003) and Birkmann (2006) provide an overview on existing vulnerability frameworks.

With the following review of existing frameworks for social vulnerability, the authors identify dimensions of social vulnerability that are currently used in the measurement of social vulnerability. The frameworks chosen had to fulfil two criteria. They should: 1) include a systemic relationship between at least social and environmental systems; and 2) have been operationalized for and applied to an industrialized country.[4]

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4 Since this paper's framework is developed for the model region of Stuttgart in Germany, the indicators of social vulnerability need to be applicable to an industrialized country's context.

The first criterion ensures that the chosen concepts of social vulnerability are at least to some extent compatible with this paper's systemic framework. The second criterion guarantees that the chosen concepts of social vulnerability have proven to be applicable in the empirical assessment of social vulnerability under the conditions of an industrialized country. This would qualify them to be suitable to contribute to the development of measurable indicators for the assessment of infrastructure criticality.

Based on these criteria, three vulnerability frameworks have been chosen to collect indicators of social vulnerability:

1. The hazard-of-places model (Cutter et al., 2003);

2. Cardona's model for a holistic approach (Carreño et al., 2007); and

3. The BBC Framework (Birkmann et al., 2011).

The Hazard-of-Place model (HOP-model) was developed by Cutter in 1996 and since that time has mainly been applied to the United States. The social component has been expanded to quantitatively measure social vulnerability through the use of a Social Vulnerability Index (SoVI) (Cutter and others, 2003). The HOP-model operationalises social vulnerability according to population characteristics such as the socio-economic situation, demography and the availability of public services (Cutter et al., 2003).

Cardona's model for a holistic approach was originally developed in 2001 (Cardona, 2001). The work of this paper, however, refers to a revised version of Cardona's model that has been employed to rate the extent of social vulnerability to seismic activities in Bogota and Barcelona (Carreño et al., 2007). The approach follows a systemic model using fuzzy mathematics. According to this model, social vulnerability is conceptualized as a function of the physical damage and as an impact factor "obtained from contextual conditions, such as the socio-economic fragility and the lack of resilience, that aggravate initial physical loss scenario" (Carreño et al., 2007: 139).[5] Here, social vulnerability indicators are thus gathered from the impact factor.

The BBC-Framework (Birkmann, 2006) has been composed from other frameworks, including the aforementioned model by Cardona et al. (2007). The BBC-Framework's objective is to provide a holistic, dynamic model integrating the factors of vulnerability assessment and sustainable development (Birkmann, 2006). The BBC-Framework has recently been applied in an integrated flood vulnerability research project in Dresden and Cologne, Germany. In addition to evaluating critical infrastructure (Krings, 2011), the project also analysed social vulnerability towards flood events (Birkmann et al., 2011).

Dimensions of social vulnerability

A review of the three vulnerability frameworks chosen allows the classification of all of their social vulnerability indicators. Table 2 lists these indicators in the three columns on the right and their classifications in the three columns on the left. The indicators are classified according to three aspects: 1) the dimension of social vulnerability they can be attributed to; 2) the extent of specificity to a hazard; and 3) their scaling either on the individual and household level or on the institutional level.

External factors of social vulnerability

External factors are integrated into the concepts of social vulnerability in different ways. The HOP-model considers biophysical vulnerability as an additional factor which, combined with social vulnerability, creates the vulnerability of places (Cutter et al., 2003). Later, the conceptualization of external impacts was expanded through the recognition of the vulnerability of the built environment (Borden et al., 2007). In contrast to this, the BBC-Framework (Birkmann et al., 2011) considers the dimension of exposure to be inherent in social vulnerability. Cardona's model integrates both the infrastructure-related and the impact-related dimension by its concept of physical damage filtered through an impact factor (Carreño et al., 2007).

For this paper, the exposition of social units to an infrastructure failure is a part of the concept of infrastructure criticality, and thus of the link between infrastructure and the social environment (see Figure 1). The more social units depend on

5 This definition of the impact factor shows that the concept is similar to this paper's concept of criticality.

Level	Specificity	Dimension of social vulnerability	Indicators used by frameworks		
			SoVI-index	Cardona's model	BBC-framework
external			*Biophysical vulnerability*	*Physical damage*	*Exposure*
Individual level	*Latent*	*Wealth/socio-economic situation*	Socio-economic status/ Social dependence	Social disparity index	
			Residential property/Renters	Slums-squatter neighborhoods	
			Commercial and industrial development	Development level	
			Occupation/Employment loss		
			Education		
		Demography	Population growth	Mortality rate	
			Age/Gender/Race and ethnicity		
			Special needs populations		
			Family structure		
				Delinquency rate	
	Hazard-specific	*Individual preparedness*			Information on flood endangerment
					Potential/actual insurance coverage
					Flood experience/sensitivity
					Flood protection measures of private households
Institutional level	*Latent*	*Public services availability*	Rural/urban	Population density	
			Infrastructure and lifelines		
				Public space	
			Medical services	Hospital beds/Health human resources	
				Rescue and firemen manpower	Possibility/time to evacuate
				Preparedness emergency planning.	

Table 2: Classification of social vulnerability indicators. Source: authors' own compilation based on Cutter et al. (2003); Carreño et al. (2007) and Birkmann et al. (2011).

infrastructure, the more exposed they are to its failure and the higher is the infrastructure's criticality. Therefore, external impacts like exposure are not part of social vulnerability as used in this paper.

Individual level indicators for social vulnerability

Social vulnerability indicators on the individual level can be distinguished by latent and hazard-specific dimensions. Although data on these dimensions is not always available on the individual or household level, it can still be aggregated or predicted information characterising their (average) situation.

The term latent goes back to Robert King Merton's conception of latent functions that are "unintended and unrecognized consequences" (Merton, 1968: 117) of social action. From this paper's action theory approach, social institutions and structures are lasting or repeating social actions (Schimank, 2007). This paper therefore defines latent social vulnerability as vulnerability that is 1) unintended (or even unrecognized) and 2) inherent to social actions and structures. Similar to Amartya Sen's understanding of poverty (Sen, 2001), latent social vulnerability is a social unit's deprivation of the capability to cope with external events in general.

As a consequence, latent dimensions of social vulnerability are measured by socio-structural indicators like wealth, the socio-economic situation of households or individuals as well as demographic patterns. Indicators in these dimensions are used by the hazards-of-places model (Cutter et al., 2003) and Cardona's model (Carreño et al., 2007). Most demography variables are included in Cutter's SoVI-Index which employs these variables in a highly differentiated way. In contrast, latent demography variables only play a minor role in the applications of the other two frameworks, particularly in the BBC-model (Birkmann et al., 2011).

In contrast to the choice of latent social vulnerability indicators, the BBC-model-based project processed demographic data into hazard-specific indices. For instance, information on age was collected in order to create an index on evacuation time and possibility (a combined indicator of individual and institutional aspects). By this approach, the BBC-model is able to assess the hazard-specific preparedness of social units.

For the analysis of linkages between infrastructure and the social environment, the hazard is less important than its actual impact on infrastructure availability. Therefore, hazard-specificity is part of the linkage between the natural environment and critical infrastructure (see Figure 1). In contrast to other frameworks, the authors show how to approach infrastructure-specific social vulnerability that may contribute to the critically assessment of specific infrastructures. This does not replace the need for latent or hazard-specific analysis. Moreover, infrastructure-specific social vulnerability completes existing perspectives of latent and hazard-specific vulnerability by another dimension.

Institutional level indicators for social vulnerability

Similar to the individual dimensions, social vulnerability indicators on the institutional level can be distinguished by latent and hazard-specific. The latent availability of public services is a broad dimension. It summarizes indicators that range from the general spatial situation (rural/urban) to the availability of specific infrastructure components (hospital beds). In addition to these, hazard-specific indicators can be summarized as the dimension of institutional preparedness, again including infrastructure-related aspects like the availability of firemen.

Both dimensions on the institutional level are best reflected in Cardona's model. While SoVI recognizes mainly dimensions of latent social vulnerability on the individual level, the project based on the BBC-Model has its focus on hazard-specific vulnerability on the individual level.

III. Linking critical infrastructure and its social environment

Critical summary of links between infrastructure and social vulnerability in reviewed frameworks

The review has illustrated that existing frameworks use data on the availability of infrastructure for the assessment of social vulnerability, particularly on the institutional level. Critical in-

frastructure maintains the social functions of emergency response, for example in the direct use of infrastructure components (hospital beds or number of firemen). In addition to counting infrastructure components, existing frameworks use indirect infrastructure measures. Examples are population density or the geographic setting in an urban or rural area which, in addition with further information about a region, indicate the latent density and availability of infrastructure. A high infrastructure density has two consequences for social vulnerability towards infrastructure. On the one hand, the failure of one infrastructure may be compensated by another infrastructure (redundancy). On the other hand, an increased availability of infrastructure may cause people to rely on and trust in these infrastructures. As a consequence, individual levels of self-protection or preparedness may decrease (Atzl et al., 2012). For this paper, redundancy and infrastructure availability are not only a part of social vulnerability they include technical as well as environmental and social aspects that need to be integrated by the systemic approach introduced earlier.

A systemic approach to link critical infrastructure with its social environment

Dimensions of social vulnerability were classified in the last section by the individual and institutional level. Regarding the linkage between social vulnerability and critical infrastructure, there is one major difference between these two levels. Social units on the individual level, like people or households, are mainly connected to critical infrastructure by the maintenance of societal functions (see Figure 1), such as facilitating emergency response. In comparison, actors on the institutional level have another function in that they are involved in the regulation and operation of critical infrastructure.[6] This is reflected by the fact that existing frameworks use infrastructure variables in their measurement of social vulnerability. However, this paper analytically distinguishes technical components of critical infrastructure from governance components situated on the institutional level of the infrastructure's social environment. Both infrastructure and its social environment are linked by plans, programmes and operational structures, summarized as regulation and based on norms coming from the social environment.

From a practical point of view, the norms and objectives of regulation reflect the needs of the population (and of the natural environment). The challenge for regulation is that norms are very abstract reflections of these needs. Regulation requires the measurement of these needs to benchmark them with existing infrastructure. The review earlier in this paper introduced indicators and dimensions that allow the more specific measurement of needs. The authors understand social vulnerability as a concept that measures the needs of social actors, groups or other social units. The more vulnerable a social unit, the more it needs (or depends on) external support. Coping capacity and preparedness on the other hand are concepts that can reduce this need for external support.

As a consequence, infrastructure availability is a response to these needs. Where infrastructure availability and societal needs match, infrastructure is able to maintain societal functions. Where there is a mismatch between them, societal functions are either restricted (infrastructure-specific vulnerability) or the social environment is able to compensate this lack of external support (coping capacity).

As argued above, the latent and hazard-specific social vulnerability indicators of existing frameworks are not infrastructure-specific enough for this matching between needs of the social environment and specific infrastructure. The concept of criticality that has been introduced allows this matching. On the one hand, criticality is always specific to an infrastructure, an infrastructure sector or an infrastructure component. On the other hand, it can be used to measure the specific thresholds of infrastructure availability that are needed by specific social units. An example should illustrate how this matching works.

About 30 per cent of the people transported by the public transport system of Stuttgart is via commuter traffic (VVS, 2011). This group is of a high relevance for regulation in an economically productive region like Stuttgart. It is reasonable

6 It is important to notice that the role of households and individuals is changing. The energy transformation in Germany is currently leading to a more decentralized system of energy production with households becoming energy producers. The result is an increasing complexity of actors involved in infrastructure regulation (Mautz, 2012).

to analyse the public transport-specific vulnerability of commuters in Stuttgart. Therefore, existing data on the need of commuters for public transport could be used. Such indicators on the individual level are travel distance, number of public transport lines and different types of public transport (e.g., train, tram or bus), availability of alternative transport means (e.g., car or bike), option of home-office days and others. Combined with latent socio-economic information, as they are used in concepts of latent social vulnerability (e.g., income, age, education social status), this information can be used to classify typical commuter groups. The more detailed the information, the better it can be matched with the actual infrastructure systems. This approach allows the definition of specific levels of public transport-criticality (in quantity, time and quality) for each group of commuters. That way, regulating institutions are able to decide on infrastructure priorities according to the infrastructure-specific vulnerability of different groups. The example can be expanded to the institutional level or to other sectors, allowing spatial and infrastructure planners to benchmark existing and assess planned infrastructure against the infrastructure-specific needs and vulnerabilities in the social environment.

IV. Conclusion

One purpose of this paper was to illustrate the gap between critical infrastructure research and other areas of vulnerability research. The review of existing concepts of social vulnerability in this paper has shown that existing indicators measure either a latent social vulnerability or a hazard-specific social vulnerability. Although some frameworks recognize the relevance of critical infrastructure by measuring infrastructure-related indicators, they do not allow the systematic assessment or benchmarking critical infrastructure.

To address this gap, the authors presented a new framework for vulnerability and risk analysis. Approaching social vulnerability from a system theoretical point of view, the framework gives an overview on the linkages between critical infrastructure and its social environment: regulation and maintenance of societal functions. The paper illustrated that besides latent and hazard-specific social vulnerability, indicators for infrastructure-specific social vulnerability are needed for regulation. The paper also conceptualized infrastructure-specific social vulnerability through the concept of infrastructure criticality. The example of public-transport-specific vulnerability of commuters in the Stuttgart region illustrates the analytic potential that is provided by this new framework. Next, the authors aim to provide additional proof of their concept by operationalizing further infrastructure-specific indicators and applying them in their analysis of critical infrastructure vulnerability towards climate change in the Stuttgart region.

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Hazards, social vulnerability and resilience in Brazil: An assessment of data availability and related research

Beatriz L. Hummell

Abstract

This paper presents an assessment of hazards, social vulnerability, resilience research and spatial data availability in Brazil. It analyses how research in this country has been conducted in order to understand social vulnerability, hazard exposure and resilience. It also examines possible indicators for use in measuring social vulnerability and hazard exposure. A Social Vulnerability Index (SoVI) replication study was conducted for the State of Paraná enabling the construction of a relative measure of social vulnerability at the city level, which illustrates how different populations can be affected by disasters. The paper shows the availability of research that discusses disasters, risk and vulnerability in Brazil, which has gaps in covering the entire territory and making integrated place-based assessments. In addition, there are no consistent methodologies or frameworks available to assess vulnerability for the entire country. The SoVI replication study, however, demonstrated that a tool for assessing social vulnerability in Brazil using existing data is possible. SoVI allows understanding which populations are more socially vulnerable as well as which aspects turn them more vulnerable. This knowledge can be used as guideline for policymakers to develop tools for helping communities better prepare for and recover from disasters, and ultimately reduce losses.

Keywords: Social Vulnerability, Resilience, Hazards, Data Availability, SoVI, Brazil.

Introduction

The increasing trend in both the occurrence of disasters as well as their impact on the economy and society, especially since the 1950's (EM-DAT, 2011; MunichRe, 2003) is empirically linked to human activity, urbanization, population growth, climate change and technology advances, among other factors (Birkmann, 2006; Wisner et al., 2004; Tobin and Montz, 1997; Hochrainer, 2006; The World Bank, 2006). Exposure and vulnerability are the main drivers of trends in disaster losses (IPCC, 2012). Urban expansion and population growth increase the number of families exposed to hazards and most growing cities are located in developing countries (The World Bank, 2010; UN, 2010).

While only 11 per cent of people exposed to natural hazards live in countries with low human development, they represent more than 53 per cent of total recorded deaths. In contrast, high-level human development countries are exposed to 15 per cent of all hazards, but account for only 1.5 per cent of deaths. Losses are expectedly higher in developed countries. In less developed regions, a lower rate of losses due to disasters "reflect a deficit of infrastructure and economic assets rather than a low impact on development" (UNDP, 2004: 13).

When considering that populations from poorer countries are relatively more easily devastated by natural disasters, some authors point out that vulnerability is concentrated in specific socio-economic classes and populations (Birkmann, 2006; Hogan et al., 2000; Kasperson et al., 2001; Coppola, 2007). The way a society reacts to and recovers from a disaster is also important and emphasizes the relevance of perceiving how hazards affect populations locally. Resilience can be defined as "a system's capacity to absorb disturbance and re-organize into a fully functioning system. It includes not only a system's capacity to return to the state (or multiple states) that existed before the disturbance, but also to advance the state through learning and adaptation" (Cutter et al., 2008: 599 f.). In developing countries, when considering that some demographic groups are more vulnerable to disasters than others, it becomes essential to understand how they are affected in order to enable preparedness and prevent losses among those populations.

This paper intends to fulfill this gap by presenting an assessment of hazards, social vulnerability and resilience data availability and place-based research in the Brazilian territory. It analyses how research in this country has been conducted in order to understand social vulnerability, hazard exposure

and resilience. This preliminary work will build a foundational understanding of how different populations in Brazil experience disaster impacts in different ways, uncovering approaches for determining actions that can be taken to help communities better prepare for adverse events.

Concurrent with the aforementioned background, the same increasing trends in disaster frequency and impacts can be observed in Brazil (Marandola Jr. and Hogan, 2006; Marcelino et al., 2006). The country has faced an accelerated urbanization process combined with economic growth and political changes, mainly in the past 20 years. This plays an important role regarding occupation patterns within cities (i.e., rapid urban expansion leads to occupation of areas unfit for development, among other facts) and the way different governments levels handle disaster response and preparedness. Although there has been an important improvement in the quality of life for a considerable amount of the population in the last decade, there is still an obvious disparity among socioeconomic classes in Brazilian cities and the way they are affected by disasters. The rapid population growth observed in the country is accompanied by an increasing number of natural disasters, which affect certain demographic groups differently. Many investments in natural disaster preparedness and mitigation have been initiated in the country, especially since 2005. Although many attempts have been made to standardize information on disasters in the country, there are still different scenarios among Brazilian States in the way they report disaster impacts.

Brazil still lacks comprehensive understanding of how its different social groups experience disaster impacts and how they can become more resilient to and prepare for disasters. The first step for understanding what has been done and what is missing on the hazards, vulnerability and resilience in the country is to assess the existing research and data availability.

I. Background

Brazil presents many socio-economic differences among its regions. An integrated approach on hazards, vulnerability and resilience would certainly demand a specific methodology that could include the diverse aspects (social, economic, etc.) found in the country. When searching for examples of Brazilian integrated hazards research, it is noticeable that there are many case studies that focus on specific aspects, such as social vulnerability or hazard exposure or risk to natural disasters (Paraná Civil Defense Secretariat, 2012; City of São Paulo, 2011; Marcelino et al., 2006; Ultramari and Hummell, 2011; Sherbinin et al., 2007; UFSC CEPED, 2012). However, there is not a national system or methodology that simultaneously examines the physical and social systems that covers the entire territory. Place-based integrated research, such as the DROP model (Cutter et al., 2008) that focuses on natural disaster resilience, for example, could not be found for the Brazilian territory. This absence notwithstanding, the most representative studies that focus on natural hazards, social vulnerability and risk, even though not entirely on an integrated approach, will be briefly discussed in the following. Table 1 presents a brief summary of this research.

While this summary does not provide an exhaustive representation of all hazards applications conducted in Brazil, these selections represent the most relevant works in the context of this research. What can be noticed is that only a few of the studies exposed in Table 1, such as the assessment of disaster recurrence (UFSC CEPED, 2012) and landslide risk mapping (Brazil, Ministry of Mines and Energy, 2011) cover the entire Brazilian territory. Also, it is important to highlight that they do not make an integrated approach (with hazard, vulnerability and resilience information), focusing instead on isolated subjects.

While studies that examine hazard exposure are useful in determining areas at risk (UFSC CEPED, 2012; Brazil, Ministry of Mines and Energy, 2011), they do not provide specific information concerning populations at risk, and vulnerability. Information on populations at risk is identified in the City of São Paulo (City of São Paulo, 2011), City of Rio de Janeiro (City of Rio de Janeiro, 2012), State of Santa Catarina (Marcelino et al., 2006) and State of Minas Gerais (Prudente and Reis, 2010). For the cities of São Paulo and Rio de Janeiro (City of São Paulo, 2011; City of Rio de Janeiro, 2012) the results identify the populations at risk of landslides. In both cases it was evident that the populations at risk are those with lower income and those living in precarious conditions, mostly because they are settled in areas unfit for development (such as slopes and riverside areas).

Disasters and hazards				
Research stream	Content summary	Coverage	Scale	References
Disaster recurrence and hazard exposure	*Disaster recurrence (1991-2010), most common disaster typologies, most affected areas and greater disasters*	*Country*	*Regions, States and Cities*	*UFSC CEPED (2012)*
Disaster occurrence mapping	*Mapping of areas affected by disasters based on Civil Defense data*	*South Region*	*City*	*INPE (2012)*

Risk				
Research stream	Content summary	Coverage	Scale	References
Landslide risk mapping	*Provides the suscepti-bility of landslides oc-currence and classifies from low to high risk*	*Country*	*City*	*Brazil, Ministry of Mines and Energy (2011)*
	Provides the susceptibility of land-slides occurrence	*City of Rio de Janeiro*	*Local*	*City of Rio de Janeiro (2012)*
Risk mapping	*Mapping of areas subject to the most common disasters in the state and areas subject to disaster risk (1980–2010)*	*State of Paraná*	*State*	*Paraná Civil Defense Secretariat (2012)*
	Identification of all areas in risk of land-slides in areas of slopes and stream margins	*City of São Paulo*	*Local*	*City of São Paulo (2011)*
Disaster risk area mapping	*Provides risk, disasters and vulnerability mapping using social and disasters data*	*State of Santa Catarina*	*City*	*Marcelino, Nunes and Kobiyama (2006)*
	Provides risk to natural disasters mapping using social and disasters data	*State of Minas Gerais*	*City*	*Prudente and Reis (2010)*

Vulnerability				
Research stream	Content summary	Coverage	Scale	References
Curitiba Vulnerability Index	*Provides an assessment of a vulnerability index, using social and disasters data*	*City of Curitiba*	*Local*	*Hummell (2009)*
Natural adversities and social vulnerabilities	*Makes an analysis of natural disasters and socioeconomic scenarios*	*Country*	*State*	*Ultramari and Hummell (2011)*
Vulnerability in Rio de Janeiro	*Analyses the vulnerability of global cities to climate hazards*	*City of Rio de Janeiro*	*Local*	*Sherbinin, Schiller and Pulsipher (2007)*

Table 1: Research on disasters, hazards, vulnerability and risk. Source: Author.

Abbreviations: UFSC CEPED, Universidade Federal de Santa Catarina, Centro Universitário de Estudos e Pesquisas sobre Desastres (Federal University of Santa Catarina, University Center of Studies and Reseach on Disasters); INPE, Instituto Nacional de Pesquisas Espaciais (National Institute of Spatial Research).

Ultramari and Hummell (2011) represent natural disasters and social vulnerabilities spatially for all Brazilian States, taking into consideration the availability of Civil Defense information and data, the number of reported Emergency and Public Calamity Situations, HDI (Human Development Index), number of disasters and people affected. Results confirm a close relation between socio-economic factors and submission to adverse phenomena, reiterating the idea of vulnerability as a social concept.

Several studies examine specific States or cities singly. Marcelino et al. (2006) propose the construction of a risk index, including hazard, vulnerability and response indices for the State of Santa Catarina, examining social and economic conditions, disaster recurrence, loss of life and people affected. It concludes that the most vulnerable populations and with worse response capacity are the ones with high rates of people with low income and elderly. Prudente and Reis (2010) use a very similar formula to calculate the same indices, with some adaptations for the State of Minas Gerais. The results concentrate on the risk index, which shows that cities with higher risk rates have higher population density, low HDI and high poverty rates.

Hummell (2009) calculates a vulnerability index for the City of Curitiba using a simpler formula, calculated by the neighbourhood quality of life synthetic index (that includes housing, health, transportation, education and security variables) and disaster frequency. The results show that, in most cases, poorer populations are more adversely affected by disasters, and that neighbourhoods with higher income averages were the least affected.

Sherbinin et al. (2007) make an integrated analysis of the natural and built environments and socio-economic conditions in order to discuss vulnerability in the city of Rio de Janeiro. They point out the main factors (such as water supply problems, extreme rainfalls, poor building conditions, poverty and social inequalities, high crime rates, sanitation and sewage issues, among others) that increase vulnerability in the city.

From this literature, it can be concluded that place-specific integrated hazards research in Brazil lacks of a uniform methodology that covers

the entire territory. There is a lack of an integrated approach that considers hazards, vulnerability and resilience. The research on vulnerability offers mostly local approaches, with place-based data, representing the characteristics of each location. However, they offer formulas to calculate risk and vulnerability with limited variables, which might not show accurate results. There is no framework that allows researchers and policymakers to assess vulnerability for the entire country.

II. Study area

This section provides a brief historical overview of the urbanization process and its contemporary manifestation in Brazil, which is important in understanding how hazards affect different regions. It also presents an introduction to the geo-political divisions of Brazilian regions and states, and its main differences in social structures. The last sub-section presents an overview of the types of hazards that affect the country.

Understanding urbanization process and socio demographic scenario in Brazil

Brazil has a large territory that presents many differences among its regions, especially concerning social, demographic and economic aspects, which reflect directly on hazards and vulnerability. While there are other obvious aspects with direct influence on hazards and vulnerability (i.e., geophysical), this study will concentrate on social aspects. In order to place the reader among this reality, a brief historical recapitulation is presented.

Two main moments influenced the current urbanization process in Brazil. First, in the mid-nineteenth century, the combination of production and political changes shaped the country's social and economic situation. Brazil's independency in 1822, alongside opening the market to international commerce and coffee production growth resulted in a significant economic increase. The wealth resulting from the coffee production and open market enabled improvements in urban areas and infrastructure (such as train railways). The coffee production was mainly concentrated in the Center-South portions of the country, bringing development to those areas, especially in the State of São Paulo. In contrast, the Northern regions that held the previous biggest production sector in the country (sugar cane) did not get as much investments. In the same period, the arrival of the Portuguese Real Family in Brazil in 1808 and the large amount of immigrants coming to the country (resulting from the abolishment of slavery in 1888) brought changes to the country's culture and urban infrastructure (i.e., parks and green areas in Rio de Janeiro) (Prado Junior, 1981; Santos, 1996; Gomes, 2007).

Second, since the 1930s, new political conditions allowed the industrialization process and the internal market to grow in ways that provided a new economic and territorial logic (Santos, 1996). New industrialization processes and rural mechanization, allied with a growing population, boosted the migration to cities resulting in their accelerated growth. Capitalist production demanded the concentration of infrastructure and manpower close to industrial production sites, which were directed to a few urban centers. This process led to the appearance of metropolitan regions that concentrate a great deal of the population, and gather the development and production of wealth mainly in the Center-South portions of the country (Carvalho, 2006).

This differentiated development process among Brazilian regions was also applied within cities. Different social and economic patterns provided different infrastructure and services systems to different populations. The growing concentration of unqualified manpower (Bottomore, 1988) in urban centres enabled low pay, poor working conditions and the expansion of informal work, which led to growing low income populations to concentrate in peripheral areas (suburbs) with no infrastructure, due to the urban centre's high land price (Giddens, 2000). The results of this process can be seen in the present day, especially in Brazilian's biggest cities and metropolitan regions. For example, São Paulo and Rio de Janeiro Metropolitan Regions, presenting large poorly urbanized settlements within cities' and peripheral areas.

Brazil is divided in five geo-political regions, and 26 States plus the Federal District, as can be seen in Figure 1.

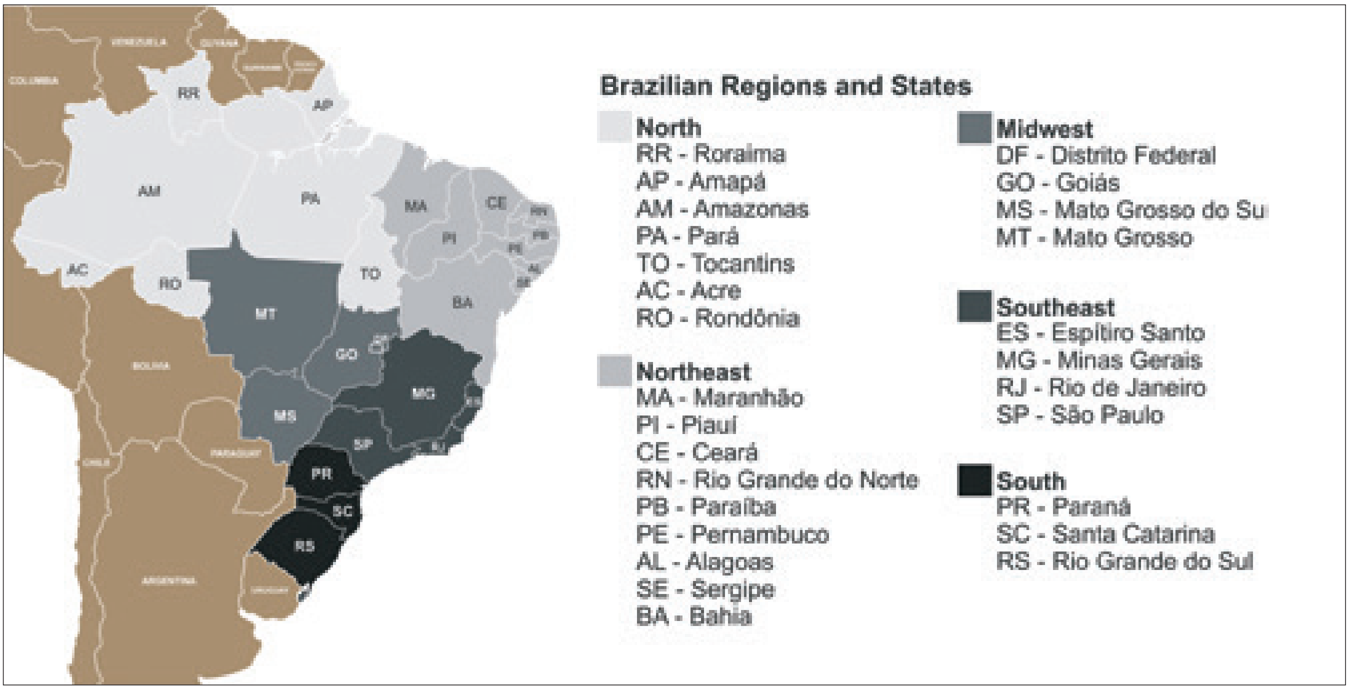

Figure 1: Brazilian regions and states. Source: Author.

As mentioned earlier, the centre and south portions of the territory were the ones that concentrated earlier development and production of wealth. Even today, as can be seen in Figure 2, these regions, specifically the South, Southeast and Midwest, are the ones that present higher HDI, as well as economic rates. The population of these areas is concentrated mainly in coastal states, which also include most of the country's biggest cities.

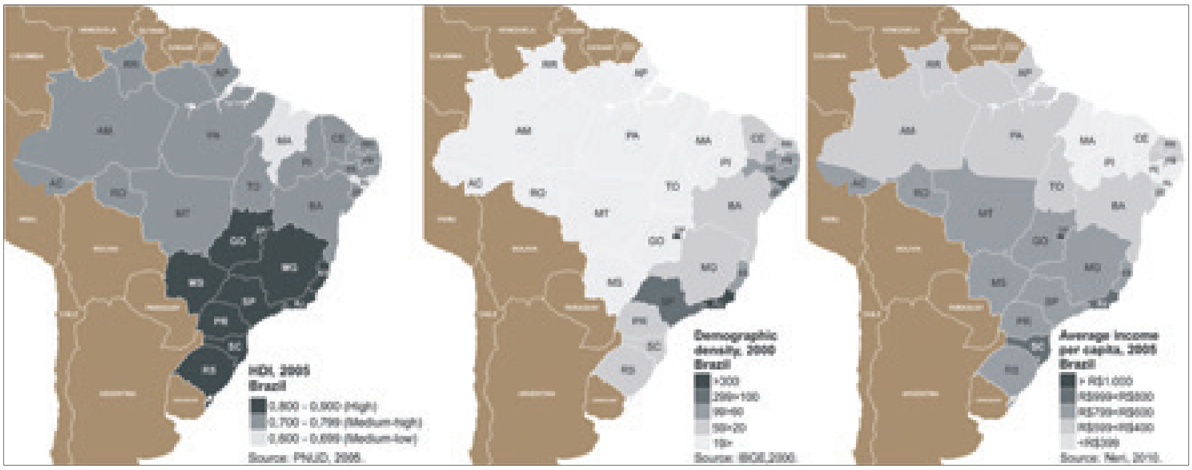

Figure 2: HDI, density and average income level in Brazilian states. Source: Author.

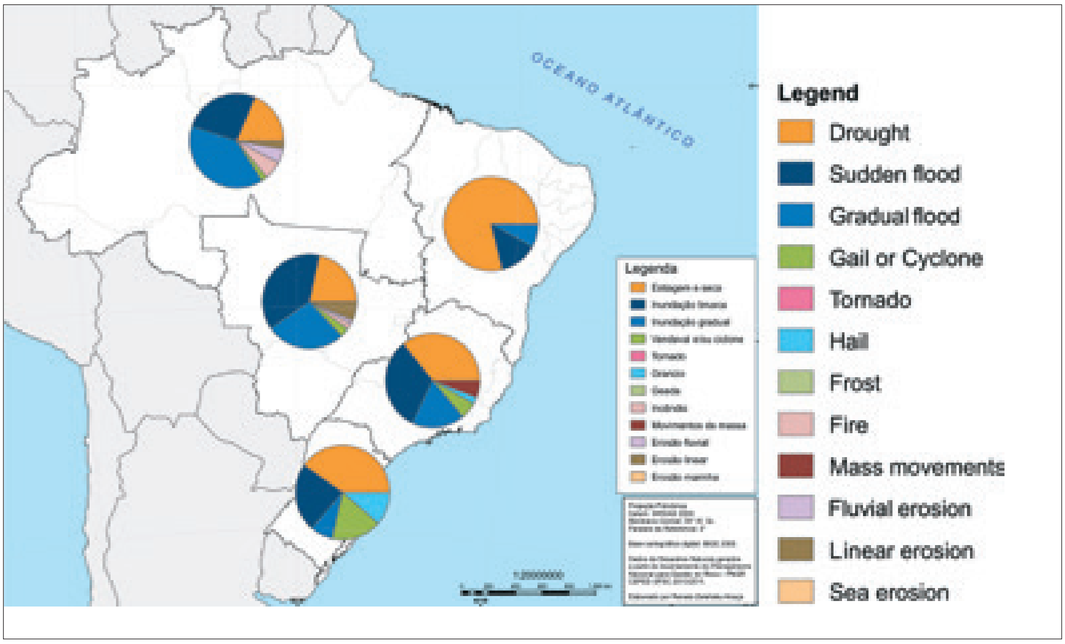

Figure 3: Distribution of natural disasters per Brazilian region. Source: UFSC CEPED (2012).

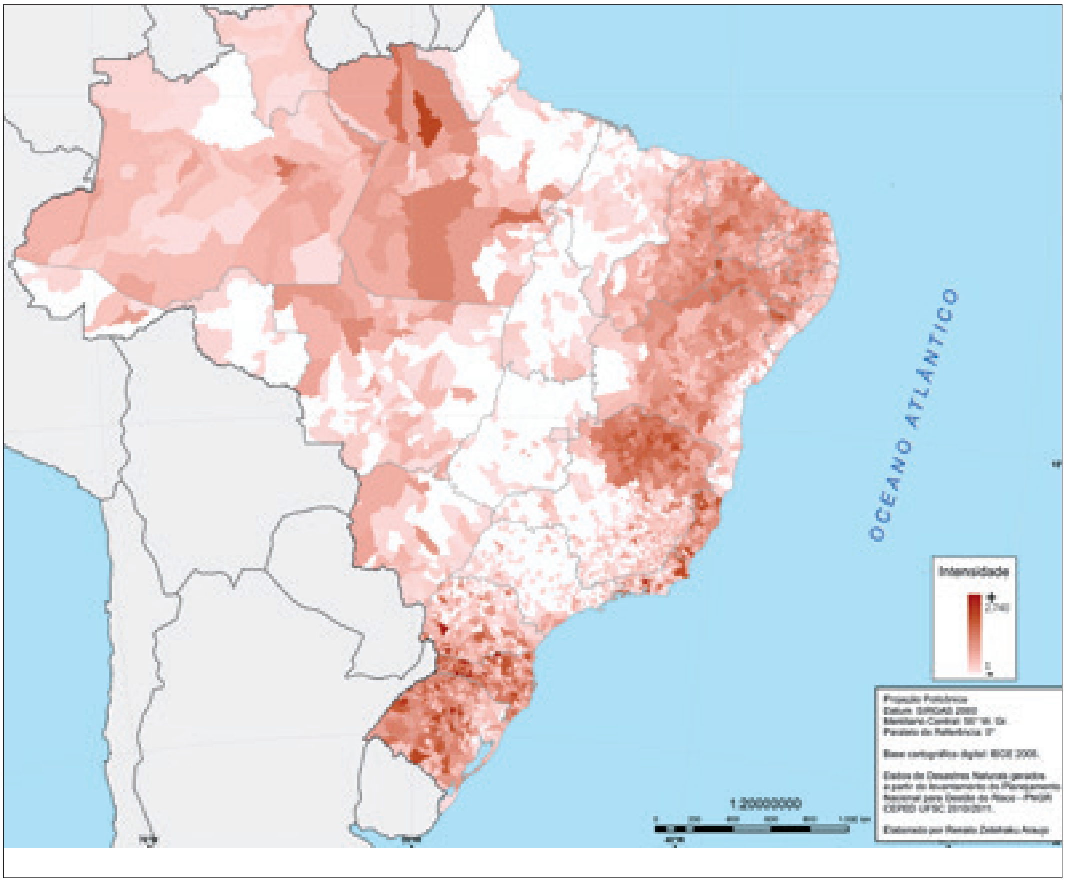

Figure 4: Intensity of natural disasters recurrence in Brazil, 1991–2010. Source: UFSC CEPED (2012). Note: The intensity refers to the sum of individual events occurring between 1991 and 2010.

Natural Disasters Profile in Brazil

The most recurrent disaster typologies in Brazil are drought (53 per cent), sudden flood (21 per cent), gradual flood (12 per cent), gale or cyclone (7 per cent), hail (4 per cent) and others (3 per cent) (UFSC CEPED, 2012). Figure 3 shows the occurrence of different disaster typologies in Brazilian regions.

Figure 4 shows the concentration of most intense recurrence of disasters in some areas, with main portions in the South, Northeast and North regions. Concerning the total number of disasters per region, the Northeast (40 per cent) and South regions (34 per cent) are the ones more affected, followed by Southeast (20 per cent). Least affected are the North and Midwest regions with 3 per cent each (UFSC CEPED, 2012).

As illustrated in this section, Brazil's regions are generally impacted by the same types of disasters (mainly drought, flood and wind-related disasters). However, different portions of the territory and populations are unevenly affected.

III. Data sources and availability at sub-national levels

The Brazilian Civil Defense System, which is responsible for attending to disasters and providing statistics concerning them, attempted multiple times to standardize and manage civil defense actions throughout the territory, with updates in 1993, 2005 and 2010. Civil Defense Institutions are organized by National, State and Regional levels.

Although there have been many efforts made to standardize information concerning disasters impacts, which would enable greater data consistency, what can be observed is a different scenario for each State. Although 59 per cent of Brazilian states Civil Defense Institutions have websites and provide data and allow research, only 18 per cent provide data on victims. Also, only two of the 27 states Civil Defense Institutions use the national Disasters, Hazards and Risk Coding (CODAR). Table 2 presents a summary of which information concerning hazards the States Civil Defense Institutions websites offer. The states of Paraná, Santa Catarina, Rio Grande do Sul, Espírito Santo and Minas Gerais have higher availability of data, highlighting a concentration of civil defense actions and preparedness in South and Southeast states.

In 2012, the Ministry of Integration has established a new national disasters database online; the National Database of Disasters Records (Brazil, Ministry of National Integration, 2012). It provides documented information of all disasters in the country. However, the system provides a limited search method, which restrains its usability for data collection. Table 3 shows a summary of hazard exposure, loss and socio-demographic data availability in Brazil.

It is possible to observe, based on the summary above, that there is a considerable amount of data on disasters and socio-economic aspects that allow an integrated research concerning hazards, vulnerability and disasters. However, considering the background discussion in Section II, there is no methodology or research that provides such information for the entire territory until this moment.

IV. Social vulnerability in Brazil

Considering key factors such as Brazil's social diversities within the country and Hyogo Framework for Action's guidelines (UN/ISDR, 2007), the measurement scheme for assessing vulnerability should be made at city level.

As an initial approach to assess social vulnerability in Brazil, a SoVI (Social Vulnerability Index) (Cutter et al., 2003) replication study was developed for the State of Paraná. It takes SoVI basic concepts and indicators in order to make an approximation to Brazil. Social vulnerability can be considered as the interaction of social and place inequalities: social characteristics that determine different group's susceptibility to harm and their ability of response (like age, income, race, gender, etc.); and community and built environment characteristics (level of urbanization, growth rates, etc.) (Cutter et al., 2003). SoVI allows making a relative measure of social vulnerability at the city level, helping to understand how different populations can be affected by disasters.

States	Registered number of victims (2000-2010)	Website (have concrete data and allow search)	Use CODAR	Data before 2000 availability	Possibility of custom search
AC	.	..	..	..	..
AL	.	..	..	..	..
AP	..	..	..	..	..
AM	..	..	..	..	..
BA	..	XX	..	..	..
CE	..	XX	..	..	..
DF	X	XX	..	..	..
ES	..	XX	..	..	..
GO	XX	..	..	..	..
MA	..	..	..	..	..
MS	..	XX	..	..	..
MT	..	..	..	..	..
MG	..	XX	..	..	..
PA	XX	X	..	..	..
PB	..	X	..	..	..
PR	..	XX	XX	XX	X
PE	XX	..	..	..	..
PI	..	..	..	..	..
RJ	..	X	..	..	..
RN	X	..	..	..	..
RS	..	XX	XX	..	X
RO	XX	XX	..	..	..
RR	..	..	..		..
SC	..	XX	..	XX	..
SP	X	XX	..	..	..
SE	..	XX	..	XX	..
TO	XX	XX	..	..	..
	..				
Total	18% available	59% available	7% use CODAR	11% available	7% allow partially

Table 2: Brazilian States Civil Defense data availability. Source: Updated from Ultramari and Hummell (2009).

Type	Spatial coverage	Time Frame	Source
Socio-economic variables (age, ethnicity, households, wealth, gender, rural/urban, among others)	Country, Regions, States, Mesoregions, Micro regions, Cities, Districts, Subdistricts, Neighbourhoods (data varies according to the scale)	2000, 2010	IBGE (2000; 2010)
Socio-economic variables (economic classes, income, labour, among others)	Country, States	1992 – 2009	Neri (2010)
HDI	Metropolitan Regions, States, Cities	1991, 2000	PNUD (2005)
Drought, sudden flood and flooding, gale or cyclone, tornado, hail, frost, forest fire, mass movement, fluvial erosion, linear erosion, sea erosion	Country, Regions, States	1991 – 2010	UFSC CEPED (2012)
Disaster frequency/occurrences	Country, Regions, States, Cities	1991 – 2010	UFSC CEPED (2012)
Human losses, people affected	Country, Regions, States	1991 – 2010	UFSC CEPED (2012)
Disaster occurrence, disaster type, people affected (killed, injured, affected), economic loss	Country, City	2000 – 2011	EM-DAT (2011)

Table 3: Data sources for Brazil. Source: Author.

Abbreviations: IBGE, Instituto Brasileiro de Geografia e Estatística (Brazilian Institute of Geography and Statistics); PNUD, Programa das Nações Unidas para o Desenvolvimento (United Nations Program for Development); UFSC CEPED, Universidade Federal de Santa Catarina, Centro Universitário de Estudos e Pesquisas sobre Desastres (Federal University of Santa Catarina, University Center of Studies and Reseach on Disasters); EM-DAT, Emergency Events Database.

This replication study considered the factors originally used for SoVI (Cutter et al., 2003) as start point to find appropriate variables for Brazil. The most generally accepted factors (age, gender, race and socio-economic status) were used. Characteristics particular to Brazil, such as the lack of infrastructure and high social inequalities within the same city, were also considered when searching for SoVI indicators.

Data was collected from the Brazilian 2010 Census (universe and sample data), Ministry of Social Assistance (2010) and Ministry of Health (2011) for all 399 cities in the State of Paraná. At first, a set of 65 variables was collected. After tests of multicollinearity among the variables, the set was reduced to 45 raw variables, used for the statistical analyses after computation and normalization. Table 4 shows the concepts and the variables used.

Concept	Name	Variable Description
Socio-economic status	QEXPOV	*Percentage of population living in households earning less than R$70,00 per month (Extreme Poverty), 2010*
	MEDIN	*Mean income of population age 10 and older, 2010*
	PERCAP	*Average household per capita income, 2010*
	QAUTO	*Percentage of households with automobile (not including motorcycle), 2010*
	QMORFAM	*Percentage of families living in households with more than one family, 2010*
	QPERBED	*Percentage of households with three or more people per bedroom, 2010*
Gender	QFEMALE	*Percentage of female population, 2010*
	QFEMEMPL	*Percentage of females in the employed population, 2010*
	F_M_INC	*Ratio female/male mean monthly income, 2010*
Race and ethnicity	QBLACK	*Percentage of Black population, 2010*
	QASIAN	*Percentage of Asian descendant population, 2010*
	QPARDO	*Percentage of Pardo[7] population, 2010*
	QINDIAN	*Percentage of Indian population, 2010*
Age	MEDAGE	*Median Age, 2010*
Employment loss; Single sector reliance	QSERVICE	*Percentage of registered jobs in Services (total), 2010*
	QAGRI	*Per cent of population employed in agriculture, fishing, forestry production, livestock and aquaculture, 2010*
	QEXTRACT	*Per cent of population employed in extractive industry, 2010*
	QTRAN	*Per cent of population employed in transformation industry, 2010*
	QACCOM	*Per cent of population employed in accommodation (lodging) and feeding activities, 2010*
	QCOM	*Per cent of population employed in information and communication, 2010*
	QPUBAD	*Per cent of population employed in public administration, defense and social security, 2010*
Rural/urban	QURBAN	*Percentage of urban population, 2010*
	DEMDEN	*Demographic density, 2010*

7 Pardo is the term used to describe population with multirracial background. Pardo is one of the five classifications of the Brazilian Census's Color or Race (White, Black, Asian, Pardo and Indian) (IBGE, 2009).

Concept	Name	Variable Description
Renters	QRENTER	*Percentage of population living in rented households, 2010*
Occupation	QEMPL	*Percentage of employed population, 2010*
	QNOTLEG	*Percentage of employed population with no legal work registration, self-employed or subsistence, 2010*
Family structure	QSHH	*Percentage of single-headed households, 2010*
	QFHH	*Percentage of female-headed households with children (no spouse present), 2010*
	QPPUNIT	*Average number of people per household, 2010*
Education	QILLIT	*Percentage of illiterate population age 15 and older , 2010*
	QNOMS	*Percentage of population with no education or middle school incomplete, 2010*
	QED12LESS	*Percentage of population that completed middle school or with high school incomplete, 2010*
Population growth	POPGROW	*Population growth 2000–2010*
Medical services & access	QHHS	*Percentage of population employed in human health sectors and social services, 2010*
	HLTHCOV	*Estimated Population coverage by basic health teams, 2011*
Social dependency (dependency ratio)	SSBENPC	*Number of benefits granted by social service per year per capita, 2010*
	QAGEDEP	*Percentage of population under age 14 and over age 60, 2010*
Special needs populations	QSPCNED	*Percentage of population with special needs, 2010*
Quality of the built environment	QNOWATER	*Percentage of households with no water supply infrastructure or well, 2010*
	QNOSEWER	*Percentage of households without any kind of sewer infrastructure, 2010*
	QNOGARB	*Percentage of households with no garbage collection services, 2010*
	QLOWQUAL	*Percentage of households with low quality external walls, 2010*
Migration	QBORNST	*Percentage of population born in other states, 2010*
	QFORBORN	*Percentage of foreign born population, 2010*
	QNEWRES	*Percentage of residents immigrating in the past year, 2010*

Table 4: Concepts and variables used for Brazilian SoVI. Source: Adapted from Cutter et al. (2003).

Factor	Name	Per cent variation explained	Dominant variable	Correlation
1	Urban employment	13.42	% population with no education or middle school incomplete	+ 0.760
2	Wealth	9.68	Median age	+ 0.910
3	Low wage labour	8.34	% population employed in Transformation industry	- 0.896
4	Lack of education	7.68	% illiterate population age 15 and older	+ 0.674
5	Race (Black and Pardo)	6.16	% Pardo population	+ 0.723
6	Female employment	5.62	% single-headed households	- 0.716
7	Immigrant population	4.20	% residents immigrating in the past year	+ 0.743
8	Race (Indian) and poverty	3.25	% Indian population	+ 0.736
9	Race (Asian)	3.15	% Asian descendant population	+ 0.718
10	Social security	2.95	Number of benefits granted by social service per year per capita	+ 0.905
11	Extractive industry employment	2.75	% population employed in extractive industry	- 0.755
12	Lacking infrastructure	2.70	% households with no water supply infrastructure or well	+ 0.727

Table 5: Factors and dominant variables. Social Vulnerability Index (SoVI).
Source: Adapted from Cutter et al. (2003).

The primary statistical procedure used to reduce the variables was principal component analysis. "The use of reductionist technique such as factor analysis allows for a robust and consistent set of variables that can be monitored over time to assess any changes in overall vulnerability" (Cutter et al., 2003: 251). Twelve factors were produced, explaining 69.9 per cent of the variance among the 399 cities, briefly described below. Table 5 shows the 12 factors and the dominant variable of each.

Urban employment

The first factor identified employment in sectors common to urban areas, such as communication and information, and feeding and accommodation activities as some of its main drivers. Other indicators, such as gender (female), single female-headed households, population density loading positively, and population with low level of education, workers in agriculture and illegal workers loading negatively, also relate to highly populated areas. Concentration of employment in a determined area could indicate that, if a natural disaster were to occur, a large number of people could loose their jobs or spend a considerable amount of time without being able to work. Having a harder time to recover from the disaster turns this population more vulnerable.

Wealth

This factor identified indicators of poverty (number of people per bedroom and number of people per household) loading negatively. It also identified median age as its main driver, pointing out an older and most likely wealthier portion of the population. It explains 13.42 per cent of the variation among cities. It is possible to say that wealthier population can recover from losses quicker, but also have more material losses. Poorer communities have fewer resources and capability of recovering from impact and loss (Cutter et al., 2003).

Low wage labour

The low wage factor was driven by extreme poverty, illegal workers and employment sectors commonly related to low wage (services and agriculture) loading positively. Employment in transformation industry loaded negatively. As mentioned earlier, poorer populations are more vulnerable to natural disasters, having less capacity of recovery turning them less resilient.

Lack of education

This factor identified indicators of low or no education (illiterate or incomplete middle school) and age dependent population loading positively. Indicators of higher degrees of education (high school incomplete) and families with cars, loaded negatively. This factor explains 7.68 per cent of the variation among cities. Uneducated individuals have access to fewer employment options and usually low standard living conditions (Cutter et al., 2003).

Race (Black and Pardo), race (Indian) and poverty, race (Asian)

"Race contributes to social vulnerability through the lack of access to resources, cultural differences, and the social, economic, and political marginalization that is often associated with racial disparities" (Cutter et al., 2003: 253). Pardo and Black populations, and illiteracy, loading positively drove the fifth factor. Also, population employed in public administration, defense and social security loaded negatively. Usually this type of employment is related to secure jobs and a fair standard of payment. Together with illiterate population, it shows some of the disparities related to race in the country.

Indian and households with low quality external walls drove the eighth factor, pointing to a race and poverty component, increasing vulnerability. There are many problems concerning the quality of constructions in Brazil, especially in poorer areas and favelas, which can put these populations at great risk especially during landslides and floods.

The Asian population is the only indicator driving the ninth factor. Usually Asians are related to fairly higher wages and good living conditions. In this sense, they would contribute to a lower vulnerability.

Female employment

This factor identified the employed population and employed females loading positively. Single-headed households loaded negatively. This factor explains 5.62 per cent of the variation among cities. Women can have a harder time, especially in the recovery period, due to dependency in employment specific sectors, lower wages and family care responsibilities (Cutter et al., 2003). A major natural disaster could result in the loss of jobs. Unemployed females would have more difficulty to recover from losses.

Immigrant population

Immigrant population, especially ones that have recently moved to a different city or country, are not used to natural disasters most likely to happen in a determined place, having a hard time reacting to and recovering from them. Population born in other states, foreign-born population and residents immigrating in the past year, all loading positively drove this factor.

Social security

Populations relying in the social security system usually are related to lower living standards or to dependency issues (age, special needs populations, unemployment, etc.). In the case of a natural disaster, those populations would have a hard time to recover from losses, once they rely on government as the main income provider. This factor identified the number of social security benefits granted per year as its main driver.

Extractive industry employment

Specific sectors, especially primary-related ones, can be severely affected and have a difficult time to recover from the impact of disasters (Cutter et al., 2003). Populations that rely on the extractive industry can face a large period of unemployment after a natural disaster. Also, in the case of dependency of an entire region or city in the extraction industry activity, major economic problems can occur in the case of a major natural disaster.

Lacking infrastructure

Brazil has many problems concerning the availability of infrastructure, which reflects directly on the population's quality of life. This fact can make populations more vulnerable to disasters, such as floods, which can greatly affect health and infrastructure in general. Households with no water infrastructure or well, and ratio of female/male income, drove the last factor.

The composite SoVI index score resulted from the addition of the 12 factor scores as independent variables to the original file of the 399 cities. Selecting an additive model shows that there was no assumption of the importance of each factor in the overall sum. All factors have an equal contribution to the vulnerability measurement for the cities. The cardinality of each factor was determined so positive values indicated higher vulnerability, and negative values lessened the overall value. In order to enable identificating the least and most vulnerable cities in the state, the SoVI scores were mapped based on the standard deviation of the mean into six categories, ranging from -1.5 (low vulnerability) to +1.5 (high vulnerability) (Cutter et al., 2003). Figure 5 illustrates SoVI in the State of Paraná.

Social vulnerability in the State of Paraná

As expected, the majority of cities in the State of Paraná present a moderate level of social vulnerability (depicted in green in Figure 5). The SoVI values range from +17.76 (high social vulnerability) to -12.89 (low social vulnerability). The mean vulnerability score is 0 and standard deviation is 3.46 for all cities. With some exceptions, the most vulnerable cities are concentrated in the Curitiba (state capital) Metropolitan Region, shore region and central portion of the state. The state capital metropolitan region offers a fair amount of education institutions, infrastructure and varied employment sectors. However, this populated region also presents greater socio-economic disparities among its population (that reflects on employment and wage rates), a larger proportion of working females and urban employment.

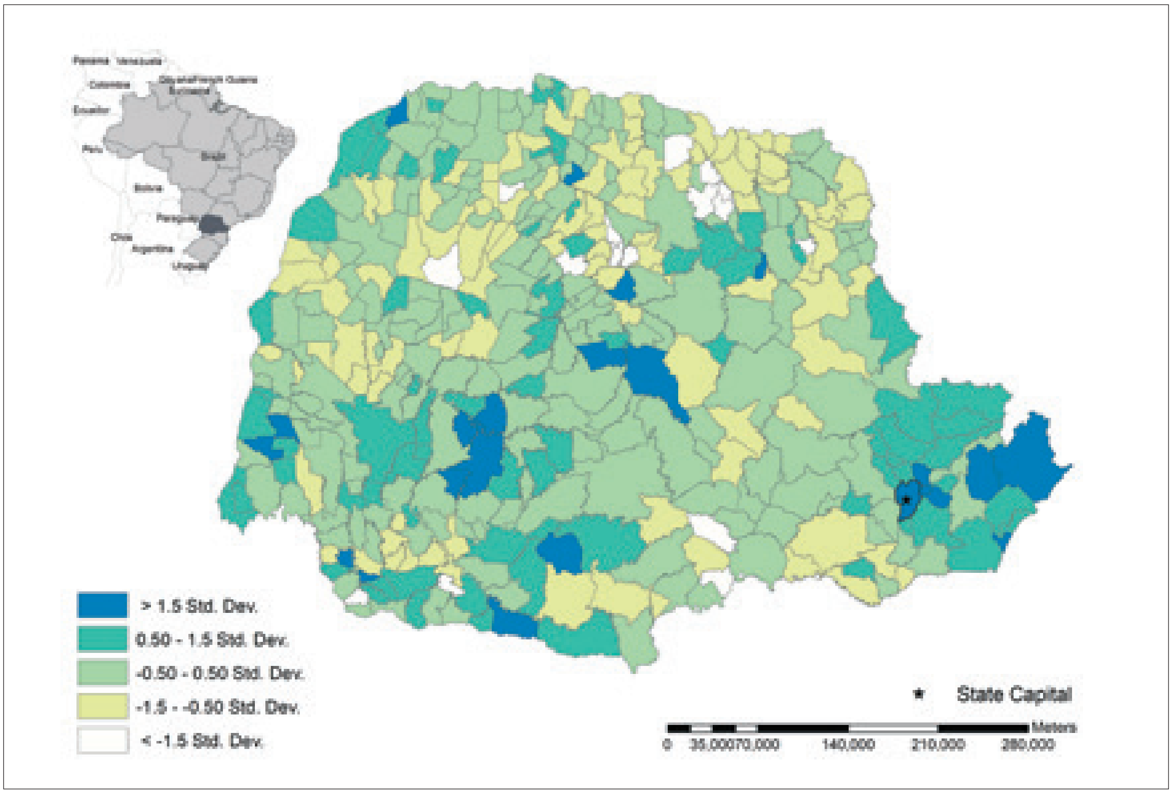

Figure 5: Comparative vulnerability of State of Paraná cities on the Social Vulnerability Index (SoVI). Source: Author.

The shore region often presents issues regarding infrastructure, employment and low wage. The shore region in the State of Paraná is characterized by having natural reserves that could justify the lack in infrastructure, since interfering with the natural environment is either limited or prohibited. There are two seaports in the region, which concentrate the main economic activity in its hosting cities. Other economic activities are mostly undeveloped. The central portion of the territory is often characterized by having Indian reserves, low wage labour and social security reliance. This region is commonly identified with low human development, low education standards and lack of infrastructure. In this region the economy relies on agriculture, lacking on industry and service activities. This region is poorly served by main roads and railroads (that represented where main cities were settled in the past), which would justify historically low levels of development.

Most of the cities with low vulnerability (in yellow) are concentrated in the north portion of the state. This region concentrates two of the state's biggest cities (Maringá and Londrina) that brought diversified economic activities and agricultural cooperatives to the region. Also, this region has a kind of soil used for soy plantations, which are very productive and profitable. The region is also known for concentrating a large proportion of Asian descendant population, mostly resulting from hosting Japanese immigrants in the 1930s.

Usability of SoVI for preparedness

SoVI can indicate which populations are more socially vulnerable as well as which aspects are the leading causes of this. Understanding what aspects turn different populations vulnerable to natural disasters enables governments to unveil approaches and prepare for actions to help communities better prepare for disasters (Cutter et al., 2003).

The next step towards and integrated approach is to compare SoVI to natural disasters information. The disaster info can be measured using recommended indicators from the Hyogo Framework for Action for measuring the reduction of disaster losses (UN/ISDR, 2008). These include the number of deaths arising from disasters, economic losses attributed to natural hazard events and number of people affected by these events. Comparing social and physical aspects of disasters enables to identify which populations are more affected by dissasters, and plan for interventions based on what aspects turns them vulnerable.

V. Discussion and conclusion

Recently, a law was published (Brazil, Lei nº12.608/2012) that stands for the creation of a National Policy (PNPDEC), National System (SINPDEC) and Council of Protection and Civil Defense (CONPDEC)[8] which has authorized the creation of a disasters monitoring and information system. It has also made important legal changes regarding disaster, vulnerability and risk prevention, mitigation, preparedness, response and recovery in different areas, such as education, urbanization and planning, among others. It is possible that this law will create new boundaries for data availability and research of disasters in Brazil.

Also, following some more recent disaster events in the last five to eight years – especially floods and landslides in 2005, 2008, 2010 and 2011 – there have been improvements in local and national Civil Defense Systems, data availability, monitoring and prevention actions and policies. The States most affected by those episodes, Rio de Janeiro, São Paulo and Santa Catarina, as well as some Northeastern States, are the ones that show more improvements.

In general, the research on disasters, risk and vulnerability available in the country has gaps with regard to covering the entire territory and making integrated place-based assessments. Also, there are no methodologies or frameworks available to assess vulnerability for the entire country. Nevertheless, the data available for enabling research in those topics provide a significant amount of information on disasters.

New legal innovations show growing political and overall concern with natural disasters in Brazil. It is possible that this brings improvements to research and data availability in the country. The recent rise of Brazil on the world's stage through hosting important international events (such as the Soccer World Cup in 2014 and the Olympics in 2016) may act as an important incentive for the country to improve research and preparedness for disasters. Special attention to constructing an integrated model to such a diversified country will be needed, as well as improvements in availability and patterned standards on disasters data.

The replication study of SoVI for the State of Paraná demonstrated that a tool for assessing social vulnerability in Brazil using existing data is possible. The same methodology can be applied for the entire country, with potential adaptations regarding data availability.

SoVI can respond to the Hyogo Framework for Action by empirically looking at hazard zones, through monitoring progress in vulnerability reduction through time (if there is availability of social data for different time-frames), and identifying the most vulnerable populations. The results offer guidelines for policymakers to develop tools for helping communities better prepare for and recover from disasters, and ultimately reduce losses.

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8 National Policy of Civil Protection and Defense (Política Nacional de Proteção e Defesa Civil – PNPDEC), National System of Civil Protection and Defense (Sistema Nacional de Proteção e Defesa Civil – SINPDEC) and National Council of Civil Protection and Defense (Conselho Nacional de Proteção e Defesa Civil – CONPDEC).

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Risk assessment to extreme hydro-meteorological events: evidence from the Po River basin, Italy

Lorenzo Carrera, Fabio Farinosi and Alexandros Maziotis

Abstract

European River Basin District Authorities are in the process of implementing the 2000/60/EC European Water Framework Directive (WFD) and the 2007/60/EC Flood Risk Management Directive for extreme hydrometeorological events. The latter Directive requires Member States to produce flood risk maps by 2013 and flood risk management plans by 2015. In the midst of such dynamic context of European water governance, it is crucial for European River Basin District Authorities to develop a flood related risk assessment methodology. This study draws on an empirical analysis of an Italian case study, the Po River basin. Hazard exposure and social vulnerability are deduced from available information on hydrological risk, and socio-demographic data. Through the aggregation of these criteria this study frames a prototype risk assessment methodology for hydrometeorologic extremes, which includes social vulnerability. The framework is aimed to support River Basin District Authorities in the development of flood risk maps, and in the consequent monitoring of progresses in risk reduction.

Keywords: risk assessment, vulnerability, natural hazards

Introduction

Climate conditions determine the natural variability of precipitations and water resources availability through time and space around the globe. In a climate change context, the "stability" of past climate cannot be taken for granted and the future is more and more uncertain. While the impact of increasing variability of climate is still unclear, there is evidence that societal exposure to hydrometeorologic extremes is growing (IPCC, 2012). Global change, growing world population, unsustainable development, and inappropriate land use threaten to induce or intensify natural hazards' exposure with disastrous consequences for the environment and societies (IPCC, 2012).

Extreme water-related hazards, like floods and wet mass movements, could be induced by several events, such as high tide, storm surge, overflow or breaks of embankments, dam failure and extreme precipitation. Globally, water-related extremes account for the greatest share of natural disasters' inflicted economic damage and death toll (Kunreuther and others, 2007).

The modern flood risk management approach acknowledges that floods cannot be stopped from occurring and places emphasis on how to reduce hardship and vulnerability of risk-prone communities. This shift is also supported by the European Union Flood Risk Management Directive (2007/EC/60). The Directive states that flood management plans need to consider the harmful potential of floods and identify tangible measures able to reduce exposure and sensitivity to floods, and improve risk governance. In light of this, this paper analyses the importance of improved understanding of vulnerability to flood events. Specifically, the paper aims to define a flood risk assessment methodology, where vulnerability is investigated and combined with hazards and exposure. This methodology could support the elaboration of the regional flood management plans, currently under development by several river basin Authorities throughout Europe. The EC Directive does not provide a specific methodology, but it requires the inclusion of social characteristics for the estimation of risk. The methodology proposed by this paper is applied to a specific case study, the Po river basin, in Northern Italy, which ordinarily suffers from the impacts of flooding from its main river, the Po, and some of its tributaries, particularly those from the Alps.

To the authors' knowledge, vulnerability has never been included in the overall estimation of risk at the Po River basin. Therefore the importance of this study is the inclusion of social vulnerability as a fundamental factor for the definition of risk, at the same level as hazard and exposure.

• EU: Flood risk maps and hazards maps by 2013, considering three scenarios with rare (500 year return period), frequent (100-200 years return period), and common (20-50 years return period), including flood extent, water depths, flow velocity, number of inhabitants, and type of economic activities at risk
• EU: Flood risk management plan by 2015
• IT: The Italian Legislative Decree 49/2010 requires that flood impacts shall be estimated using the following criteria: number of inhabitants, infrastructures and strategic structures (e.g., highways, railways, hospitals, schools, etc.), heritage and historical goods, distribution and category of economic activities, potentially polluting industrial plants and natural protected areas. Risk is defined as a conjunction of the probability of the event and potential impacts on human health, territory, environment, goods, cultural heritage and socio-economic activities

Table 1: Elements in the European Flood Directive 2007/60/EC and Italian L.D. 49/2010. Source: own draft.

I. Background

A. Legislative framework in Europe and Italy

On 23 October 2007, the European Commission adopted the Flood Directive 2007/60/EC, which addresses the assessment and management of flood risks focusing on prevention, protection and preparedness (see Table 1). The aim of the implementation of flood risk management plans is on the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity (EC, 2007). Member States therefore need to assess river basins, coastal areas that are at risk of flooding and the potential impact of floods in human life and economic activities. In order to be implemented, the European Flood Directive 2007/60/EC was subsequently introduced into the Italian Legislation through the Legislative Decree nr.49/2010 adopted on 23 February 2010. Since then, Italian river basin district Authorities, including the Po River basin District Authority, began the investigation of the vulnerability level of the territory to floods.

B. Conceptual background and experiences in measuring risk and vulnerability

The modern approach towards natural disasters has shifted away from being hazard-oriented towards a risk-based approach (Lastoria et al., 2006). Until recently, research and protection to natural hazards policy had been dominated by a technical world view, focusing on the technical and financial aspects and ignoring the impact and significance of socio-economic drivers. However, in the past decade, social and socio-economic components gained more importance as a result of a shift from flood protection to flood risk analysis (Messner and Meyer, 2005).

Three factors are defined as of great importance to set the framework of risk analysis: exposure, vulnerability and hazard. According to UNIDSR (2009) the risk to natural hazards is defined as the anticipated probability of harmful consequences or losses resulting from interactions between natural or anthropogenic hazards and vulnerable conditions with (human) exposure. The concept of risk can be represented with equation (1).

$$R = f\,(H, E, V)$$

(1) Where R denotes risk as a function of Hazard H, Exposure E and Vulnerability V.

Hazard is the probability of occurrence within a specified period of time in a given area of a potentially damaging event; hence it implies considerations of frequency and magnitude of threatening events (Lastoria et al., 2006). Exposure includes people, property, systems or other elements present in hazard zones that are thereby subject to potential losses (UNIDSR, 2009). Vulnerability refers to a propensity or susceptibility to suffer a loss and it is associated to a range of physical, social, political, economic, cultural and

institutional characteristics. For example, poorly built housing, schools, hospitals and lifeline infrastructure are characteristics of physical vulnerability (UNIDSR, 2009).

Kienberger (2012) states that vulnerability is present everywhere at any time, but its significance depends on its degree: in certain areas it may be close to zero, while in others it may have a higher degree. A comprehensive overview of the evolution of approaches to vulnerability is provided by Cutter (1996) and Adger (2006). The authors state that much of the research in the past was concerned with identifying and predicting vulnerable groups and critical regions to hazards, whereas later applications focused on combining social, physical and ecological system vulnerability to future risks. Given the wide range of approaches to vulnerability, Adger (2006) concluded that a generalized measure of vulnerability is needed, defined as social vulnerability, which should account for the human well-being, the temporal dynamic dimensions of risk (e.g., mobility of income) and the distribution of vulnerability within the system (e.g., urban versus rural environment).

There have been several studies in the past that measured, qualified and/or assessed social vulnerability using both qualitative and quantitative techniques (e.g., Adger, 2000; Cutter et al., 2003; Adger et al., 2004; Birkmann, 2006). A qualitative vulnerability assessment takes into account the participation of individuals (Moser, 2009; Wisner, 2006), whereas quantitative vulnerability assessments commonly include the selection of indicators obtained by a combination of norms (Vincent, 2004; Adger, 2006; Birkmann, 2006). Moreover, mixed assessment is possible; these represent a combination or association of qualitative and quantitative research elements in tandem which goes beyond simply collecting and analysing both kinds of data (Jean-Baptiste et al., 2011; Creswell, 2009). Kuhicke et al. (2011) provide a comprehensive overview of the strengths and weaknesses of the vulnerability assessments. However, many of the studies often lack a systematic and transparent approach (Birkmann, 2006). For example, there is still no consistent set of metrics used to assess vulnerability to environmental hazards, although there have been calls for just such an index (Cutter et al., 2003). Research findings are fragmentary and there is still no consensus on (a) the methodology to assess social vulnerability, or (b) an equation that incorporates quantitative estimates of social vulnerability into either overall vulnerability assessment or risk (Yoon, 2012; Fekete, 2012; Kuhlicke et al., 2011).

Therefore, it appears that defining and integrating the different dimensions of vulnerability for a comprehensive assessment of risk is far from simplistic. This paper will follow the approach developed initially through the Hazards of Place (HOP) model of vulnerability (Cutter, 1996). The HOP model shows how risk and mitigation interact in order to produce hazard potential, which is filtered through (1) social fabric to create social vulnerability and (2) geographic context to produce biophysical vulnerability (Cutter and Morath, 2012). In the HOP, a geographical information system was employed to set up areas of vulnerability based on twelve environmental factors such as flood plains, surge inundation zones, seismic zones and historical hazard frequency. Social vulnerability was defined based on eight socio-economic indicators such as total population and structure, differential access to resources/greater susceptibility to hazards due to physical weakness, wealth or poverty, level of physical or structural vulnerability (Cutter et al., 2000). More recent studies from Cutter (Cutter et al., 2003) developed the Social Vulnerability Index (SoVI), which is based on 250 socio-economic and environmental variables that vary according to the context where the index is applied, and it defines a comparative assessment of the relative levels of vulnerability between places (Cutter and Morath, 2012).

C. Italian experiences in measuring vulnerability

A recent study by De Marchi and others (2007) assessed the risk of destruction and social vulnerability in an Italian Alpine region which was damaged by flash floods and debris flows between 2000 and 2002. Although the area is partially outside the Po River basin, it remains a useful source of information for this study. The purpose of De Marchi's work was to promote preparedness, increase resilience and reduce vulnerability at community level. Therefore the authors explored the main strengths and weaknesses of communities exposed to flood risk, focusing on

socio-psychological, cultural, economic and organizational aspects. The main conclusions from that case study can be summarized as follows.

Increase in risk awareness such as knowledge of hydro-geological risks and their unpredictability, frequency of the events and their consequences, and information about the role of protection works were considered of great importance for reducing vulnerability to floods. The efficiency risk management agencies can encourage people to enact self-protection behaviours. Risk maps need to be constantly updated to provide with valuable information regarding the risk-prone flooded areas. Finally, the designation of an area as a risky one might lead to a decrease in property values and as a result, residents who lived there are deprived twice, they do live in an unsafe area and it is not feasible for them to sell their property. Although this vulnerability assessment is not place-based, it is an Italian experience, which clearly defines amplification and attenuation factors of vulnerability at local level.

Other studies in Italy have also measured the risk and socio-economic impact of floods without assessing social vulnerability. Rusmini (2009) employed simulated techniques to assess and improve the accuracy in calculating the water extent and depth in flood areas in the Po River basin. A flood damage assessment and lives loss estimation were also conducted. Lastoria et al (2006) reported economic losses for the flood events that occurred in the country during the years 1951–2003, calculated based on the partial or total destruction of buildings, infrastructures and engineering works, interruption of economic activities and public services. Guzzetti and Tonelli (2004) underlined that in Italy, 382 municipalities (5.9 per cent) have a 0.90 or larger probability of experiencing at least one damaging flood or landslide, and 1319 municipalities have a 0.50 or larger probability of experiencing at least one flood or landslide for a 10 years period. Finally, the Po River Basin Authority in the Po River Basin Hydrology Management Plan (PAI) provides a comprehensive and elaborated risk assessment, including potential losses for dike failures, but it does not take into consideration recent vulnerability assessment frameworks (Po River Basin Authority, 1999 and 2002).

II. Study area

A. Po River basin

With 71,000 km^2 (aproximately 24 per cent of the state territory), the Po River basin is the largest (single river) basin in Italy and the economically most important area. The basin area is home to 17 million inhabitants (aproximately 28 per cent of the state population). More than one third of country's industries producing 40 per cent of the national GDP are located in the basin area. The agricultural output accounts for 35 per cent of the national production. The agricultural sector generates an added value of about 7.7 billion €/year (aproximately 1.2 per cent of the total added value produced in the basin). The one thousand or so hydroelectric plants installed on the Po River and its tributaries generate on average 20 billion kWh/year (aproximately 48 per cent of the installed hydropower in Italy). Additional 400 thermoelectric plants generate around 76 TWh every year. The natural and artificial lakes in the basin regulate a volume of 1,858 million m^3 per year (Po River Basin Authority, 2006).

The river basin spreads over eight (out of 20) Italian regions including Valle d'Aosta, Piedmont, Lombardy (all three entirely included in the basin area), Emilia Romagna (with about a half of the area included in the basin), Autonomous province of Trento, Veneto, Liguria and Toscana (marginally included in the basin area).

The Po River basin annual average precipitation is 1,108 mm with maximum values in the Alps (over 2,000 mm per year) and minimum values in the eastern Paduan plain, (700 mm per year) (Po River Basin Authority, 2006). This amount of precipitation produces an annual water flow of 78 billion m^3, which correspond to a water flow of 2,464 m^3/s. Two third of this flow runs on the surface, that is approximately 47 billion m^3 per year, 1,470 m^3/s. The remaining 31 billion m^3 are consumed by evapotraspiration and deep percolation. Two mountain chains, Alps and Apennines, feed all rivers in the basin. River cycle characteristic depends on the source of water. Alpine rivers have water flow peak in summer due to ice melting, while Apennines' rivers have lowest peak in summer due to their dependency from precipitations, and highest peaks in spring and autumn.

Figure 1: Po River Basin and its surface hydrology. Source: own draft.

The Po River basin is water rich thus its surface water component is remarkable. The principal reticulum includes 141 major water affluents (>20km of length), while the secondary surface river network is nine times more extended than the primary river network, which lengthens in the basin for over 6,750 km (Po River Basin Authority, 2006). Artificial networks, including irrigation channels and drainages, are also highly developed throughout the basin. This complex and extended water network is the result of thousands of years of human alterations of the natural environment. Flow of water from mountain basins and natural lakes to the Po River running along the Paduan Plain is intensively interfered by artificial abstractions, rice field submersions, dripping irrigation, deviations for irrigation channels, irrigation losses and the interaction between surface water with aquifers. The surface water network also includes major artificial irrigation canals. Among them the Cavour Canal, the Emiliano-Romagnolo Canal (CER) and the Muzza Canal are of the most important in terms of water flow derived from the natural network.

Due to its long history of human development, Po River flooding events have been recorded since the year 204 B.C., when Tito Livio reported a flooding event. Since then several major floods have been recorded. Over the centuries the river flooded several areas of the plain, including major cities and town, such as Rovigo, Mantova, Ferrara, Modena, Cremona and Piacenza. The most destructive flood recorded in the recent period occurred in the year 1951, when 100,000 hectares of Polesine area (Rovigo) were flooded. It caused 84 causalities and displaced 180,000 people.

Nowadays the Po River basin is extremely anthropized. Natural river flow is regulated by hydrogeological protection structures, which contain the flow within the riverbed and reduce the ability for extreme events to impact its natural flow. Until the end of nineteenth century, the dyke protection system along the Po River Basin was not fully closed, and rivers flooded into the plains during extreme precipitation events. At present the dyke protection system along

the Po riverside is completed, with an extension of 2,292 km (Po River Basin Authority, 2006). Floods are ordinarily contained within the second level dykes, so that the surrounding plain is rarely inundated. In order to control Po River flow back effects on river tributaries, both continuous and discontinuous dykes were also constructed in the lower river courses of Po tributaries. Continuous dyke systems have also been constructed in all rivers of Emilia and lower parts of Mincio, Oglio and Adda. Smaller protection dykes exist in lower parts of Piedmont plain rivers. Some river beds have very high level of confinement along their course, among them we find: Adda, Serio, Oglio, Mella, Chiese, Toce, Dora Baltea, Dora Riparia, Bormida and Orba. Rivers in the plain have frequently higher level of anthropization than the ones in the mountains. Because of urban pressure, riverbeds are normally channelized when running in the plains. This fact increased the inability of the water network to adapt to changes in water flow, which consequently increases the vulnerability of the system to extreme events. Within the basin it is extremely rare to find rivers characterized by untouched natural conditions and limited artificial regulation.

B. Hydrological profile

The Po River Basin Authority within the Hydrological Management Plan (PAI) provides a dataset of potential hazards related to the hydrological risk. PAI analyses the hydrological risks (Po River Basin Authority, 1999), territorial hydrological characteristics and system of interventions. In order to improve the basin's security level against hydrological risk, the plan defines structural (hydraulic works) and non-structural (rules) actions for soil and water uses. The PAI aims to design a functioning framework of the basin with the clear objective of preventing the risk, therefore it:

- defines and quantifies critical exposure, actual and potential, investigating relevant causes;
- identifies required actions to deal with specific issues related to the gravity and extent of damages; and
- formulates safeguards rules that enable the effective and positive actions to protect soil and water.

The PAI considers two types of areas: territories where emergency status has been declared and those characterized by high level of risk for people, good infrastructure, cultural and environmental heritage security. The plan identifies potential hydrological risk for flood-prone areas, with three grade of inundation gravity (very high risk, high risk, medium risk), including also river buffer areas prone to rare flood risk (500 years return period), frequent flood risk (100-200 years return period) and common flood risk (20-50 years return period). The Plan also provides geo-referenced information about active, stable, and stabilized landslides. Figure 2 represents the exposed areas to hydrological risk in the Po River basin.

III. Methods and data

A. Hazard profile of the basin

In order to define the hazard profile of the basin (see Figure 3) the PAI described above has been analysed for combining the different typologies of hazard (landslides, floods, inundation) threatening the basin, in order to obtain a hazard value at municipality level. Municipalities are divided into four categories: low, medium, high and very high hazard. The most hazardous areas appear to be the mountainous regions of the basin. This could be explained by the large presence of small rivers and torrents that, in case of extreme rainfall events, are suddenly subject to flash floods with catastrophic consequences. Moreover, the mountainous regions of the basin are characterized by the presence of multiple active or stabilized landslides that constitute a serious problem in case of a consistent increase of the humidity rate of the soil. It could appear controversial that the alluvial plain created in the geological eras by the main river of the basin is characterized by a low hazard only. This is mainly due to the fact that several engineering and infrastructural interventions (dykes, embankments, levees, artificial channels, etc.) have been implemented in the last three centuries to contain floods with a return period lower than 500 years.

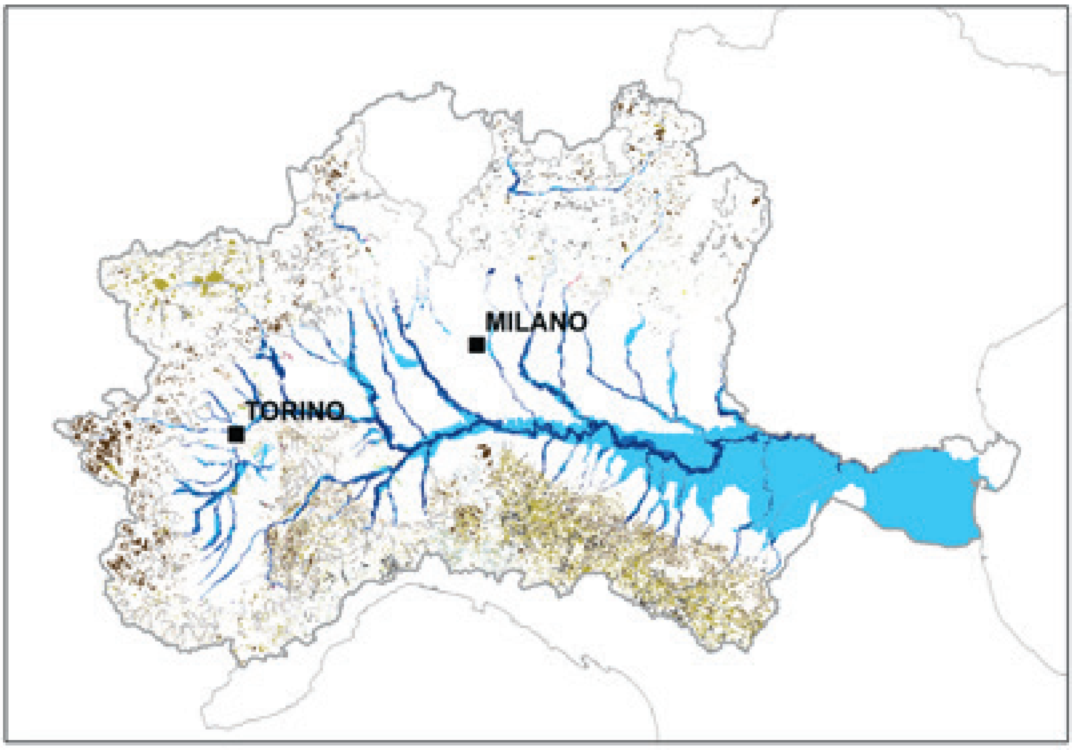

Figure 2: Hydrological Management Plan, flood and landslide prone areas of the Po river basin. Blue: flood and inundating prone areas. Brown: landslide prone areas. Source: own elaboration based on the Po River Basin Authority dataset.

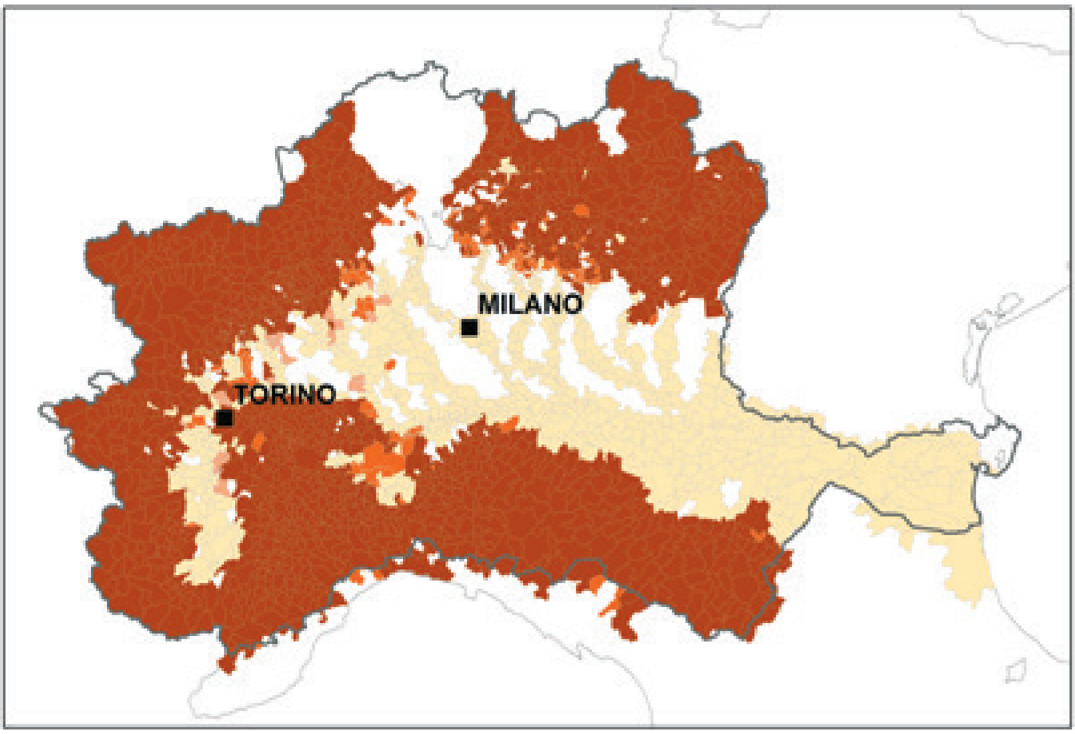

Figure 3: Hazard map of the municipalities in the Po river basin. Source: Authors' own elaboration based on Po River Basin Authority data. The map presents 4 classes of hazard: low, medium, high and very high.

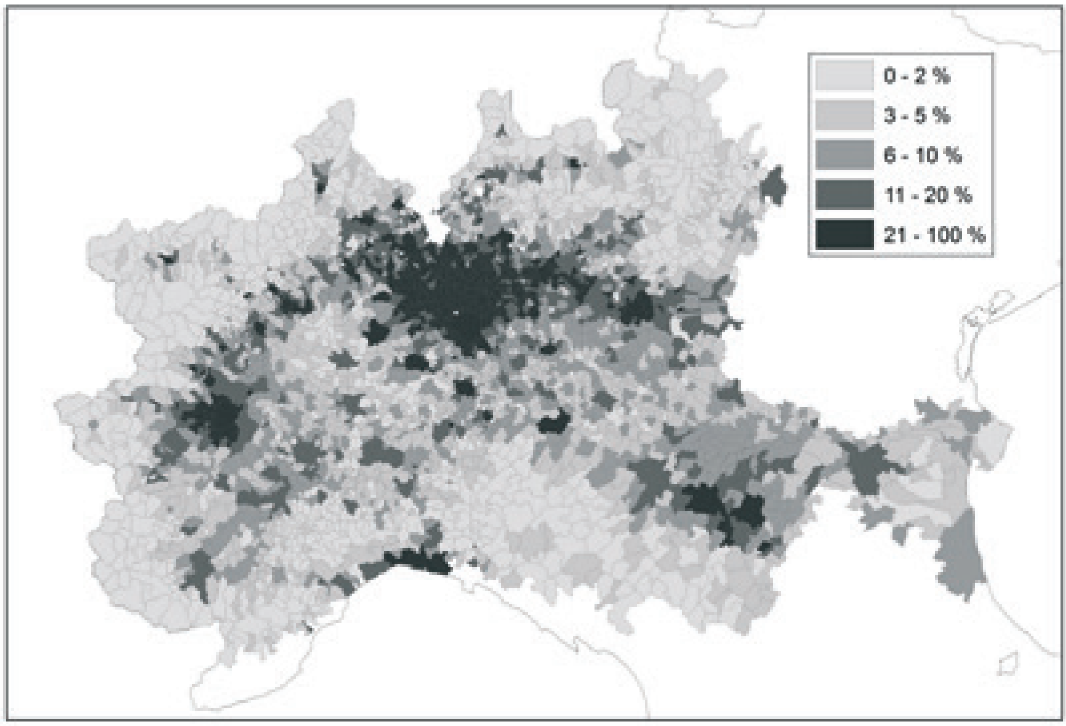

Figure 4: Exposure map of the municipalities in the Po River basin. Percentage of constructed area over the total municipality. Source: Authors' own elaboration based on CORINE Land Cover (2006).

B. Exposure profile of the basin

In order to define the exposure profile of the Po River basin, the percentage of the constructed area over the total area of the municipality, from Corine Land Cover (CLC) (ISPRA, 2006), has been chosen as a proxy of the value exposed to the hazard. The final exposure map classifies the municipalities into five categories: 0 to 2 per cent, 3 to 5 per cent, 6 to 10 per cent, 11 to 20 per cent, 21 to 100 per cent of the area used for construction. The five classes of exposure were chosen considering the 20th, 40th, 60th, 80th and 100th percentile of the calculated values of exposure in the basin. As expected, the highest values are reached in the areas where the main cities are located (see Figure 4). The highest exposure is registered in the areas of Milan (mainly), Turin, Reggio Emilia and Modena. The lowest values are registered in the mountainous areas of the basin (white areas in Figure 4).

C. Socio-demographic data

To the best of our knowledge there is not any spatially aggregated social vulnerability index available at basin level. Socio-demographic data produced by the National Institute of Statistics (ISTAT) are extensively available at national and regional scales, but less so at provincial and municipal level. Therefore, the variable selection for conducting a social vulnerability index for the study area has two considerations: (1) justification based on existing literature on its relevance to vulnerability and (2) availability of quality data from national source.

Based on these considerations the variables that were employed to capture social vulnerability are the following: population density (Cutter et al., 2003; Tapsell et al., 2005), percentage of population less than 18-years-old (King and MacGregor, 2000; Cutter et al., 2000 and 2003; Tapsell et al., 2005), percentage of population more than 65-years-old (King and MacGregor, 2000; Cutter et al., 2000 and 2003; Tapsell et al., 2005; De Marchi et al., 2007), percentage of population not reaching the basic education (De Marchi et al., 2007; Tapsell et al., 2005; Cutter et al., 2003), percentage of population reaching a high level of education (high school or more) (Tapsell et al., 2005; Cutter et al., 2003), percentage of foreigners (King and MacGregor, 2000; Cutter et al., 2003), employment rate (Tapsell

et al., 2005; Cutter et al., 2003), percentage of population commuting to work by car or train (Brunckhorst et al., 2011), percentage of population with a vehicle (Morrow 1997; Flanagal et al., 2011; Dunno, 2011). A summary of the selected criteria, and their availability, for assessing the flood risk in the basin is presented in Table 2.

D. Aggregation of social vulnerability criteria and other risk components

Vulnerability of people is measured by a social vulnerability index. Due to the restriction of data because of privacy at the individual level, municipality level data have been used. The selected indicators in the risk vulnerability index are proxies of the vulnerable social groups (Cutter et al., 2003; Tapsell et al., 2005).

Vulnerability, V, has been calculated as the equally weighted sum of normalized criteria[9].

Normalization and aggregation

The data referring to each of the indicators are different in unit and scale. This work adopts the Min-Max normalization proposed by UNDP's Human Development Index (HDI) (UNDP, 2006). This methodology allows to standardize the values of the indicators and to obtain a final result ranging between 0 and 1 (ICRISAT, 2009).[10] Criteria with decreasing effect on vulnerability level, such as education level and employment rate has been treated as (1-x).

After normalization, the indicators were aggregated to calculate the social vulnerability index, which represents the summation of equally weighted average sub-index scores (Simple Additive Weighting). The choice is motivated by the inability to concretely proof differences in the contribution of the single indicators in the overall determination of a Vulnerability Index (Cutter et al., 2010).

Aggregation of risk components

For each municipality, social vulnerability, exposure and hazards components were finally aggregated using an equally weighted sum. Thus, the risk index is defined for each municipality from very low to very high.

IV. Results

Vulnerability profile of the basin

After aggregating all the criteria, the vulnerability profile of the Po River basin was calculated, which provides a good representation of the most vulnerable areas of the basin at municipality level. The final output classifies the municipalities into four categories obtained considering the quartiles of the results. The areas characterized by the lower level of vulnerability (ranging from 0.268 to 0.393) are located in the most remote and less populated areas, such as the Alpine regions of Piedmont (west part of the basin), Lombardy (north part of the basin) and the Apennine region of Emilia Romagna (south part of the basin) where the landscape is characterized by the presence of forests, national parks and natural ecosystems. The situation is very different in Valle d'Aosta, where the level of vulnerability reaches the highest values (dark blue in Figure 5). This is explained by the fact that even if the density of the population could suggest a low level of vulnerability, its composition (e.g., age, education, presence of foreigners) leads to be classified as one of the highest vulnerable areas (ranging from 0.428 to 0.539). Other high vulnerable areas are located in the central of the basin, where the highest population density is reached.

Risk profile of the basin

The combination of hazard, exposure and vulnerability, using equation (1) with equal weights, provides the risk profile of the basin. The map classifies the municipalities into five categories: very low, low, medium, high and very high. The five classes of risk were chosen considering the 20th, 40th, 60th, 80th and 100th percentiles of the calculated values of risk in the basin (see Figure 6). The highest risk areas are located in the mountainous and in the most populated portions of the basin.

9 $V_j = \sum_{i=1}^{K} W_j X_{ij}$ with $W_i > 0$ for $1,....K$ with $W_i = \frac{1}{K}$

V_j represents the vulnerability to flood for each municipality *j*, X*ij* the set of the i indicators of vulnerability for each municipality *j*, and W*i* the weight for each indicator *i*, where i=1,…, K with K being the total number of indicators.

10 $$X_{ij} = \frac{X_{ij} - \underset{i}{Min}\{X_{ij}\}}{\underset{i}{Max}\{X_{ij}\} - \underset{i}{Min}\{X_{ij}\}}$$

Domain	Criteria	Source	Project	Time Frame	Spatial Coverage	Resolution
Hazard	Flood and land-slide prone areas	Po River Basin Dist. Aut.	PAI	1999 –2010	Po basin	n.a.
Exposure	Land cover	ISPRA	CLC	2006	Italy	100m
Vulnerability	Pop. Density	ISTAT	Census	2001	Italy	Municipality
Vulnerability	Pop <18 years	ISTAT	Census	2001	Italy	Municipality
Vulnerability	Pop>65 years	ISTAT	Census	2001	Italy	Municipality
Vulnerability	Education	ISTAT	Census	2001	Italy	Municipality
Vulnerability	Foreigners	ISTAT	Census	2001	Italy	Municipality
Vulnerability	Car/Train Commuters	ISTAT	Census	2001	Italy	Municipality
Vulnerability	Pop. with a vehicle	ACI	Census	2001	Italy	Municipality
Vulnerability	Employment rate	ISTAT	Census	2001	Italy	Municipality

Table 2: Sources of data for the Po River basin. Source: own draft.

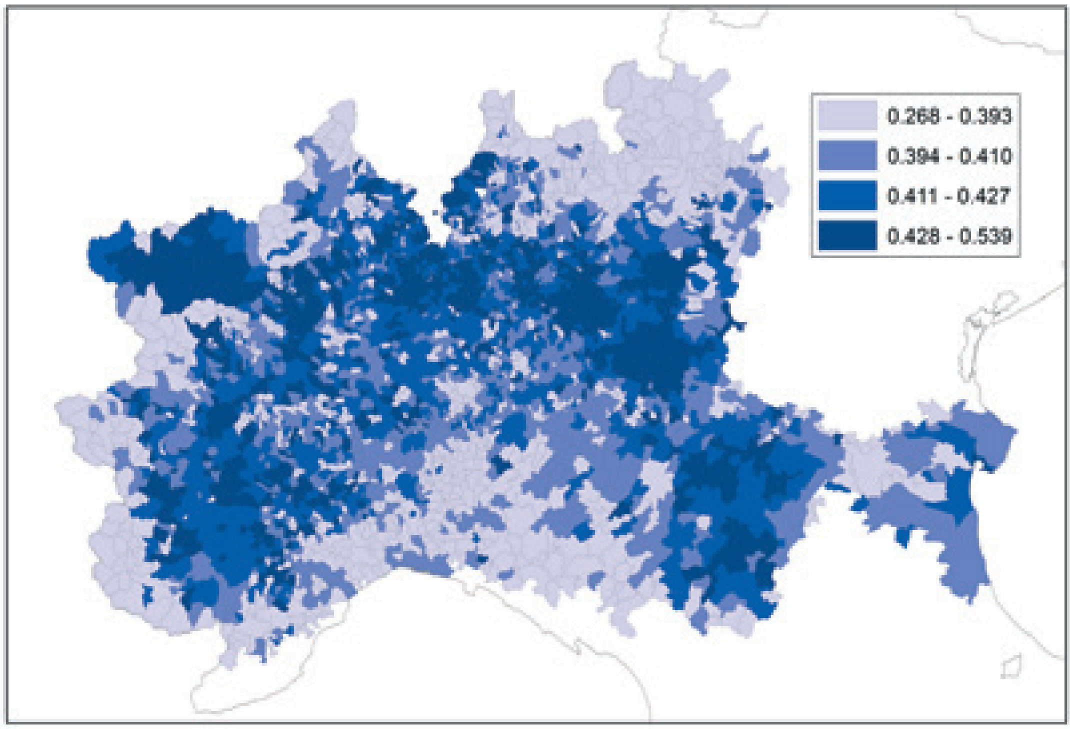

Figure 5: Vulnerability map of the municipalities in the Po River basin.
Source: Authors' own elaboration based on ISTAT and ACI Data.

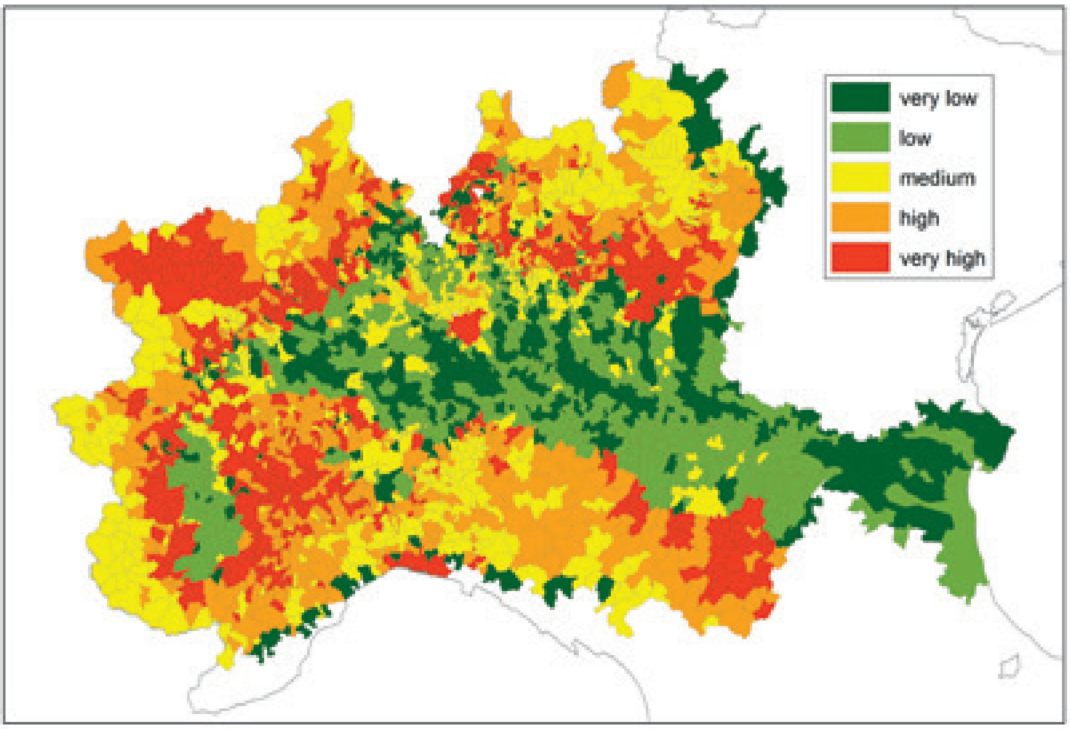

Figure 6: Risk map of the municipalities in the Po river basin. Source: Authors' own elaboration.

Almost the entire Valle d'Aosta region is characterized by the highest risk, which is consistent with the high values of hazard and vulnerability for the specific area. The same is apparent for the metropolitan areas of Milan, Turin, Parma, Reggio Emilia and Modena. On the other hand, low and very low levels of risk were registered in the plain part of the basin, mainly driven by the low hazard.

V. Conclusions

The new European policies on water management, European Water Framework Directive (WFD) and Flood Risk Management Directive, ask for better knowledge of risk, vulnerability and potential losses due to extreme hydrometeorologic events in the European basins. Several studies have been already performed in the Po River basin and Italy aiming to these objectives, however, none have included social vulnerability, which is fundamental to define the risk, as a factor. Marchi et al. (2007) did consider social vulnerability in their work, but they focused on a limited area and a specific event. Through the analysis of available information on hazard exposure and socio-demographic data of the Po River Basin District, our study draws a possible methodology for understanding the spatial distribution of risk at municipality level. It is a first effort towards the inclusion of social vulnerability in the estimation of risk to hydrometeorologic extremes within the Po River basin.

However, several factors still cause limitations to the implementation of the methodology described in this document. First is the resolution at municipality level, which could cause biases in the definition of hazard and exposure. To mitigate, further research efforts could provide downscaled risk profile to higher resolution other than municipality, including recent household data from the latest Census (2012) and from the National Register of Properties and Land. Second, socio-economic data availability is still scarce. Appropriate downscaling of aggregated information at larger scale (Labor Local Systems, Provinces, Regions, etc.) could be a source of additional information for the construction of improved dataset at municipality level, like in SoVI (Cutter et al., 2003). Third, recent efforts in updating flooding maps, within the implementation of 2007/60/EC, will possibly provide better understanding of the hazard profile of the basin. Although this study was developed on Hazards of Place (HOP) model of vulnerability (Cutter, 1996) and Social Vulner-

ability Index (SoVI) (Cutter et al., 2003), it deviates from both methodologies in terms of risk component calculation approach. The inclusion of social vulnerability is based on selected indicators, like in HOP, but do not analyse larger set of variables like in SoVI. Hazard and exposure components are deduced from hydrological maps, from River Basin District Authority, aggregated at municipality level and land cover characteristics from the Environmental Protection Institute (ISPRA).

Since both components – river basin hydrological profile and regional land cover categorization at basin level – are in the process of revision for the implementation of Italian L.D. 49/2010, we believe that the inclusion of social vulnerability in the risk estimation at municipal level provides better understating in the comparison between different geographic units within the basin. In addition to Po River basin, the methodology could be a prototype for other Italian hydrological districts, in the process of complying with EU Flood Risk Management Directive 2007/60/EC and Italian Decree L.D. 49/2010.

VI. Acknowledgments

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Assessing the vulnerability of populations at high risk to coastal river flooding in the Philippines

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Abstract

Flash floods are considered to be one of the most devastating natural hazards due to the abrupt nature of its propagation, catching susceptible populations off guard. The increasing occurrence of disasters triggered by such events, particularly in coastal river zones, emphasizes the need for preparedness and mitigation of their adverse impacts. Delineating coastal river flood hazard areas can help identify communities exposed to this risk and determining the degrees of vulnerability of these communities paves the way for prioritization and response. This research utilizes readily available biophysical and social data to respectively delineate these hazard zones and develop a social vulnerability profile of affected communities in the Philippines. A GIS was used to process and integrate the information generated and the results validated against a case study involving a flashflood event in Cagayan de Oro City triggered by Tropical Storm Washi in 2011. Notwithstanding the limitations of the spatial resolution of the available data, the model was able to accurately determine the communities that had flooded during the storm event. The social vulnerability profiles of the affected communities showed a discernible relationship between the reported number of casualties and higher levels of social vulnerability. The output of this research is a useful basis for government and assisting groups to prioritize communities exposed to coastal flood hazard that have high levels of social vulnerability for in-depth assessment of actual risks on the ground leading towards more appropriate mitigating action and resilience building.

Keywords: coastal flashflood, social vulnerability index, GIS, DEM, census, Philippines

Introduction

With the onset of climate change and its adverse effects, there has been a growing focus on disaster risk reduction and management. Climate related extremes are on the rise and with these come escalating impacts on human populations (Oliver-Smith, 2008). Areas of natural hazards, defined as threats having the potential to do harm on people and places (NRC, 2007), are increasingly being delineated as part of the Hyogo Framework for Action declaration to develop, periodically update and disseminate risk maps and related information to stakeholders (ISDR, 2005). It is in the interface between areas of natural hazards and human populations where there is great risk, here defined as the likelihood of incurring harm from a hazard event (NRC, 2007). Vulnerability is defined as the susceptibility of populations to harm from its exposure to hazards and which directly affects its ability to prepare for, respond to, and recover (Cutter et al., 2009).

Floods are considered to be the most devastating of all natural hazards, flash floods in particular are the most deadly and damaging of all types due to their sudden development (Balica, 2007). The Philippines gets more of its share of floods compared to other countries due to its location relative to the paths of typhoons and the propagation of monsoons.

This paper seeks a) to identify areas that are predisposed to coastal river flooding in the Philippines based on readily available biophysical datasets, and b) to characterize the social vulnerability of communities exposed to this particular hazard by developing a social vulnerability index based on the most recently available census data. The results of this exercise will be mapped out for the entire Philippines using a geographic information system (GIS) and validated for effectiveness using the case of Cagayan de Oro City, which suffered from a devastating flashflood episode on 16 December 2011.

I. Background

Vulnerability assessments originally focused on the biophysical or structural properties of a hazard and thus dealt with features of the natural and built landscape (Zahran et al., 2008). It

was only at the start of the 1940s that Gilbert F. White and his students developed a new event-exposure based approach to vulnerability which was termed as the risk/hazards paradigm (Cutter et al., 2009). A number of researchers at the end of the last century, however, began to question this paradigm after observing the unequal distribution of disaster effects on a population, wherein other subgroups and certain localities were affected disproportionately (Zahran et al., 2008).

O'Keefe et al. (1976) put forth the idea that the increasing global vulnerability to hazards and disasters was caused by social, political and economic pressures that magnified vulnerability and eventually the impact of the hazard by affecting how people respond to and cope with disasters. Blaikie et al. (1994) and Wisner (2003) developed the pressure and release model which ties vulnerability to "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impacts of a natural hazard (Blaikie et al., 1994). However, although strong in providing an understanding of the progression of vulnerability, the model does not incorporate the role of proximity to the threat and the ensuing interaction between the social and natural systems that produce the hazard in the first place (Cutter et al., 2009).

In 1996, Cutter developed the hazards of place model which presents the place-based interaction between hazard exposure and social vulnerability in an overall determination of the differing social burdens of hazards and how this relationship has distinct temporal and spatial dimensions. Although empirically-based and designed for geo-spatial analysis, this model does not attempt to understand the root causes of the differential vulnerabilities and the larger contexts wherein these vulnerabilities exist (Cutter et al., 2009).

Turner et al. (2003) provide a framework for vulnerability that links the local with regional and global biophysical and geopolitical dynamics in an attempt to gain a holistic understanding of the interconnectivity of the local with broader scale dynamics. This approach has its strength in qualitatively providing an understanding of cause and effect dynamics from the broad to local scales, but does not discriminate between exposure and social vulnerability and does not clearly distinguish where vulnerability begins and ends (Cutter et al., 2009).

Measuring vulnerability is increasingly regarded as an important component of effective disaster risk reduction and building resilience (Birkmann and Wisner, 2006). It is in the context of mounting disasters and environmental degradation that vulnerability measurement is seen as crucial if science is to support the transition to a more sustainable world (Kasperson et al., 2001). Vulnerability measurement is an important prerequisite to reducing disaster risk, but requires an understanding of the different vulnerabilities to hazards of natural origin, which determine risk in the first place (Birkmann, 2006). For this, the use of indicators to build indexes is a valuable tool for vulnerability metrics.

An indicator is defined by Gallopín as a sign that summarizes information relevant to a particular phenomenon (1997). In terms of vulnerability measurements, the usefulness of indicators is eventually determined by their success in achieving their objective and function, such as identifying and visualizing various vulnerability characteristics (Birkmann, 2006). This research seeks to pursue that aim by providing a means to measure vulnerability in the context of a country highly exposed to natural hazards as the Philippines.

II. Study area

The Philippines is an archipelago composed of over 7,000 islands with a total land area of 300,000 square kilometres. It ranks fourth globally in terms of the length of coastline for a country, having a total of 36,289 km (Central Intelligence Agency, 2012). This puts it at a relatively high risk for sea level rise, particularly in areas of high population density along the coast. The Philippines also lies along the typhoon belt of the Pacific through which an average of 20 tropical cyclones pass per year (PAGASA, 2012a). Rainfall variability throughout the Philippines ranges from less than a metre to over four metres per year (PAGASA, 2012b). Adding to the list, it sits along the Pacific Ring of Fire which exposes it further to volcanic and tectonic risks (Yumul et al., 2011).

According to the World Risk Report of 2012 (Alliance Development Works, 2012) the

Philippines again ranked third in terms of risk globally. This means that among countries globally, there is greater likelihood that its population will suffer loss and damage from various hazards such as floods, typhoons, earthquakes and sea level rise. With a population of 92,337,852 as of May 2010 and 41.5 per cent of the population living on less than US$2 per day (The World Bank, 2012b), poverty is widespread both in urban and rural areas, though having a higher incidence in the latter (Reyes et al., 2010). Having a population growth rate of 1.68 per cent in 2010 (The World Bank, 2012a), the number of poor is only expected to increase. The prevalence of poverty in the country indicates that socially the population is inherently vulnerable and in this context is considered to be independent to a society's exposure to hazard risk (Brooks, 2003).

There has been a growing variety of initiatives to assess natural hazard risk in the Philippines, each with its own specific objective and application. Acosta-Michlik (2005) developed a province-level national vulnerability assessment as a means to identify pilot areas for detailed vulnerability studies. The Manila Observatory (2005) presented a similar provincial scale analysis of more general hazard vulnerability maps for the country. Fano (2010) developed a flood risk index also at the provincial level based on a combination of biophysical and social indicators. Several web-based initiatives followed that mainly focused on biophysical assessment and identification of hazard risk areas (ESSC and MGB-DENR, 2012; National Institute of Geological Sciences, 2012; Department of Science and Technology, 2012).

However, as can be seen from the data presented above, there are two crucial elements that have been given inadequate consideration in the prevailing approach to managing and reducing risk in the Philippines. These are localization and the incorporation of social factors that influence vulnerability. For example, while the very coarse resolution of the provincial scale provides a wealth of information on the social conditions of the population, it does not provide enough bases for intervention on the ground. Because hazards are uniquely local in nature (Cutter et al., 2008), provincial scale data and analyses are inadequate for local level action or response.

Three of the most deadly disasters brought about by flooding in the Philippines are presented in Table 1. These disasters were triggered by typhoon events, which had dumped unprecedented amounts of rainfall into their corresponding watersheds, triggering flash floods, which affected the populations residing within the coastal floodplains of the rivers in these sites.

Period	Affected areas	Cause	Deaths	Affected	Damages
05/11/91 – 08/11/91	Ormoc City	Typhoon Thelma	5,956	647,254	US$100M
29/11/04 – 30/11/04	Infanta, Real and Gen. Nakar in Quezon	Typhoon Winnie	1,619	881,023	US$78.2M
15/12/11 – 18/12/11	Cagayan and Iligan Cities	Tropical Storm Washi	1,439	1,150,300	US$38.082M

Table 1: Summary data on the top three most devastating flood disasters in recent Philippine history. Source: CRED (2012).

These three flood events are the main drivers for this investigation, which attempts to understand the elements that contribute to the gravity of such kinds of disasters. The most recent disaster triggered by Tropical Storm (TS) Washi on Cagayan de Oro City is used as a case study.

The city of Cagayan de Oro is located in the Northern Mindanao Region and is composed of 80 barangays, the smallest political administrative division. The Cagayan River empties into the Macajalar Bay in Northern Mindanao, passing through the highly urbanized center of Cagayan de Oro City.

On 16 December 2012, TS Washi passed through Northern Mindanao, an area seldom frequented by typhoons. The storm dumped 180.9mm of rainfall in a 24-hour period, an event with a computed return probability of 75 years (RDC-X 2012). The resulting flash floods affected numerous communities along the river outlets draining to the sea. Most severely affected were Cagayan de Oro and Iligan Cities, which share a common stretch of the watershed boundary for the Cagayan and Mandulog Rivers (see Figure 1).

III. Data

A comprehensive and authoritative survey of Philippine administrative boundaries has been a challenge to put in place due to the numerous boundary conflicts among local government units at the barangay, municipal and provincial levels (PIA, 2012). In 2009 the Global Administrative Areas (GADM) initiative was established as part of a global effort to provide geographic bases for text-based locality descriptions and for mapping census data (GADM, 2009). For the first time, administrative boundary GIS data down to the barangay level for the Philippines was publicly available, mainly sourced from data provided by the National Census Bureau enumerators. As these boundaries area are not based on ground surveys, they remain indicative and highly relative in inaccessible areas such as mountain ranges and marshlands. It is however observed that the data for urban areas have an acceptable level of accuracy.

In 1977, the Philippine National Economic Development Authority (NEDA) first published the Philippine Standard Geographic Codes (PSGC), a nine character numeric coding system of classifying and coding geographic areas in the Philippines (NSCB, 2012). The PSGC continues to be updated due to changes in name, status and number of geographical sub-units. The PSGC code is divided into four major categories – region, province, municipality/city and barangay. This code hierarchically identifies and classifies all geopolitical units of the country and is used in governance-related coding, including the national census.

The National Statistics Office of the Philippines regularly conducts a census of population and housing every decade and an abbreviated census of population every five years in between (NSCB, 2010). The data used for the derivation of the SoVI for the Philippines is the 2007 census of population, originally planned for 2005 but was delayed due to budgetary constraints (Olaivar, 2007) and is the most recent publicly available census at the time of this research (see Table 2). Since the census of 1990, the PSGC code has been used as the main geographical classifier of individual census entries.

At the time of this research, the GADM dataset for the Philippines lacked the PSGC field and thus it had not been possible to readily link census data to the individual local government entities. One of the major tasks performed was the meticulous incorporation of the PSGC code to the GADM dataset so as to establish the link between census data and analysis and the local governance units. A total of 42,199 individual barangays were registered in the census dataset.

A digital elevation model (DEM) for the entire Philippines from the Shuttle Radar Topography Mission (JPL, 2009) was the main dataset processed to identify areas of exposure to coastal river flood hazard.

Code	Description
PREG	Administrative Region
PPRV	Province/Highly Urbanized City
PMUN	Municipality
PBGY	Barangay
PHSEQ	Household sequence
REL	Relationship to head
SEX	Sex
AGE	Age
BR	Birth registration
MR	Marital status
CAS	School attendance
GCA	Grade level currently attending
PPOS	Province of school
MPOS	Municipality of school
HGC	Highest grade level completed

Table 2: Data fields of the 2007 Census of Population. Source: Lipio and Esquivas (2013).

IV. Methodology

Empirical measurements of vulnerability combine a number of indicators to obtain a characteristic or parameter describing the system (Cutter et al., 2008). This research applies the Social Vulnerability Index (SoVI) methodology developed by Cutter (2003) to use census-derived indicators in a factor analytic approach to obtain statistically independent factors that are used as the basis for an index of social vulnerability.

Since the Philippine census of 2007 was an abbreviated survey of population, there was only a portion of the fields collected. Furthermore, since this was an inter-decadal census, housing-related information was not available. Table 3 shows the proxy variables extracted from the 2007 census fields based on the most common vulnerability characteristics found in the literature. It is important to note that the census data of 2007 are disaggregated for each individual, thus it was possible to construct the proxy variables and aggregated at the level of the barangay.

Using the derived proxy variables from the 2007 census of population, a factor analysis using the method of principal components (PCA) was conducted for the 41,992 barangays. PCA explores a linear combination of the proxy variables to generate axes, or principal components, which account for as much variation as possible in the original variables. The objective of PCA is to reduce the dimensionality of the original data to arrive at a smaller number of axes that can still explain a large percentage of the variability of the original input variables.

Variable	Description	Effect on Social Vulnerability
qchild	% Children (under 15)	Increases
qold	% Elderly (above 65)	Increases
qfem	% Female	Increases
avghhsz	Average HH size	Increases
qfemhdhh	% Female HH head	Increases
qfemsinhdh	% Female single HH head	Increases
qfemwrk	% Female working	Increases
medage	Median Age	Decreases
qwrkng	% Working	Decreases
qlowincwrk	% Low income work	Increases
qchldnosch	% Children not attending school	Increases
qnonhs25yr	% Less than HS	Increases

Table 3: Social vulnerability proxy variables obtained from the 2007 census data fields.
Source: Author

Abbrev: HH = household, HS = high school

The component matrix is then applied a Varimax rotation with Kaiser Normalization to aid in the interpretation of the data by separating as much as possible the components from one another. Table 4 presents the computed principal components and the percent of variance explained by each. The first three components account for 71.643 per cent of the variance and are chosen as the main components for the index.

	Total Variance explained								
Component	Initial Eigenvalues			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.455	45.46	45.46	5.455	45.46	45.46	3.267	27.227	27.227
2	1.951	16.257	61.717	1.951	16.257	61.717	2.789	23.241	50.467
3	1.191	9.926	71.643	1.191	9.926	71.643	2.541	21.176	71.643
4	0.773	6.443	78.086						
5	0.719	5.989	84.075						
6	0.629	5.239	89.314						
7	0.499	4.155	93.469						
8	0.333	2.778	96.247						
9	0.203	1.691	97.938						
10	0.113	0.942	98.88						
11	0.084	0.698	99.577						
12	0.051	0.423	100						

Extraction Method: Principal Component Analysis.

Table 4: Total variance explained by the computed principal components. Source: Author.

Table 5 shows the rotated component matrix and highlights the dominant variables in each component. Components 1, 2 and 3 can be attributed to social class, family, and work respectively.

The final step in creating the SoVI is assigning cardinality for the three different components for scaling so that positive values indicate higher levels of vulnerability, negative values decrease or lessen the overall vulnerability and when there was ambiguity the absolute value of the factors were taken (Cutter et al., 2003). In arriving at the vulnerability index for each barangay, the factor scores were then added together to arrive at the final SoVI score.

As this research deals with coastal river flood hazard, a relatively simple model was developed. A combination of two basic parametres extracted from the DEM defined primary areas of coastal river flood hazard exposure is defined as a function of elevation from the coast and slope:

$CRFH = E_{5m} + S_{2\%}$

Where *CRFH* is the coastal river flood hazard, E_{5m} is the area up to 5m elevation from the coast and $S_{2\%}$ represents the areas from the coast that have a slope gradient of 2 per cent and below, which typically defines the upper slope limit of a floodplain (Dinesh, 2009). These areas were extracted from the DEM and overlaid using the

	Component		
	1	2	3
Per cent children (under 15)	0.313	-0.407	**-0.734**
Per cent elderly (above 65)	0.091	**0.778**	0.249
Per cent female	**0.733**	-0.1	-0.029
Average HH size	-0.209	-0.458	**-0.568**
Per cent female HH head	-0.554	**0.728**	0.142
Per cent female single HH head	-0.425	**0.795**	0.016
Per cent female working	**-0.728**	0.091	0.483
Median age	-0.212	0.504	**0.716**
Per cent working	-0.171	-0.001	**0.868**
Per cent low income work	**0.858**	-0.147	-0.137
Per cent children not attending school	0.189	**-0.573**	-0.268
Per cent above 25 not finished high school	**0.847**	-0.157	-0.082

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Table 5: Rotated component matrix (dominant variables in bold). Source: Author.

intersect GIS function to locate the coastal flood hazard areas. The *CRFH* was a more logical parametre to define vulnerable zones to flash flood as compared to a mere proximity buffer from riverbanks since the *CRFH* uses river floodplains as its basis, particularly near estuarine zones.

Coastal watersheds were delineated automatically from the DEM using the basin functionality of GIS software. Two additional parametres that were considered from the DEM were the size of the watersheds (less than 180,000 hectares) and an 18 per cent slope gradient cutoff, which defines upland areas in the Philippines (Espiritu et al., 2010). Since steeper slope distributions increase the capacity in a watershed for rapid concentration of stream flow, which is one of the key features of flash floods (Marchi et al., 2010), watersheds having more than 20 per cent of their total area classified as 18 per cent slope and above were chosen as having the minimum potential for flash floods. The areal limit for considering the maximum size of the watershed capable of generating a flash flood event is based on the approximate area of the largest watershed that had experienced flashfloods in the recent years, which is the Tagoloan Watershed east of the Cagayan in Northern Mindanao in October 2006 (Crismundo, 2006). Figure 1 shows the coastal river flood hazard zones vis-à-vis the Cagayan and neighboring coastal watersheds with flash flood potential and the exposed barangays.

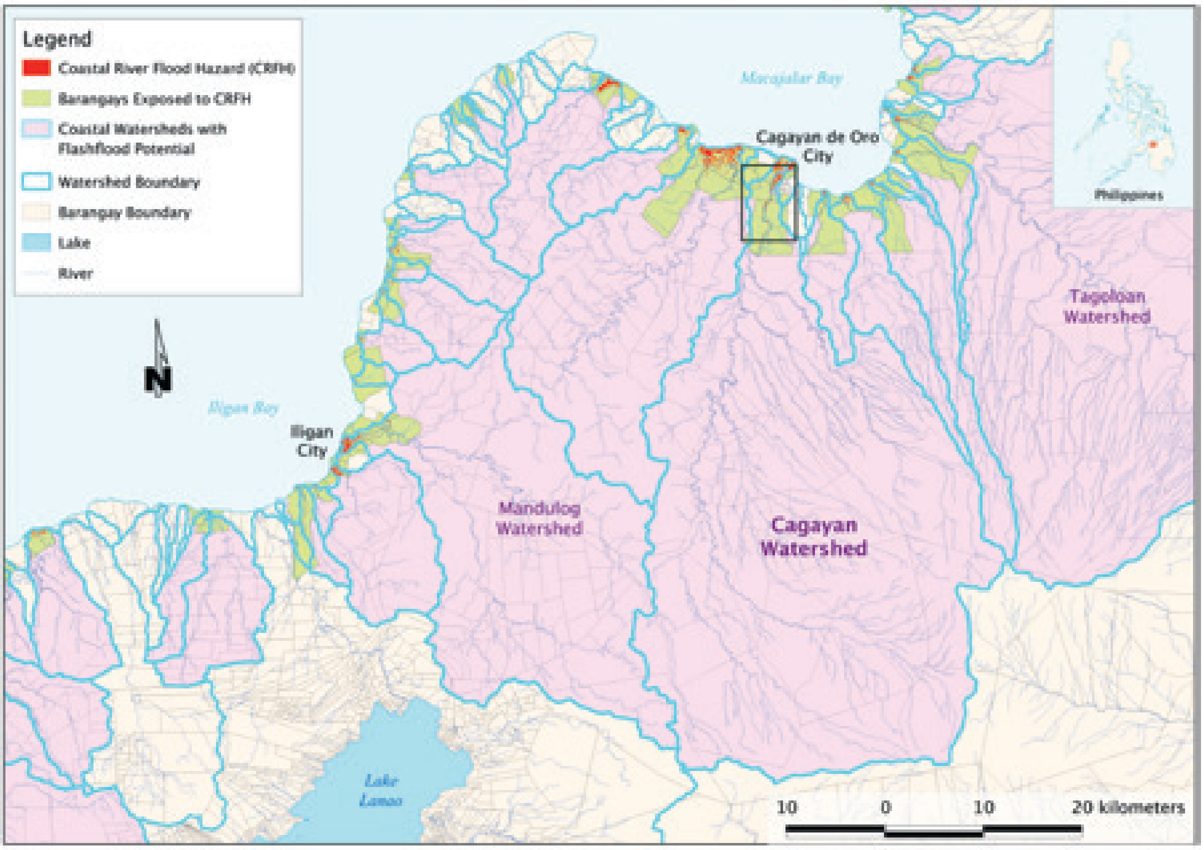

Figure 1: Coastal river flood hazard zones and affected barangays in the Cagayan Watershed area. Source: Author.

V. Results and discussion

By assigning proper PSGC codes down to the barangay level for the Philippines, it is now possible to map a number of nation-wide datasets, such as population characteristics from national census data. The resulting SoVI scores for the barangays in the Philippines from the 2007 census were linked to the GIS database and mapped using a quantile classification scheme divided into five classes ranging from very low to very high levels of vulnerability (see Figure 2).

A total of 4,521 coastal barangays out of a total of 41,992 barangays represented in the national database were identified as highly exposed to coastal river flooding. These barangays represent 10,210,740 individuals or 11.67 per cent of the total population of the Philippines. Out of this number, a total of 3,727,507 individuals are in the high and very high vulnerability category with 1,600,805 belonging to the latter, corresponding to 1,781 and 887 barangays respectively. From Figure 2, there are clusters of high to very high SoVI scores for exposed barangays in the westernmost island of Palawan as well as the northeastern portion of Luzon Island in the north and the easternmost island of Samar in the Central Philippines.

These datasets have inherent limitations to begin with in terms of resolution both for the physical and social data types, but despite these limitations the results generated have been visually accurate particularly for the social data in urban zones based on a visual assessment of barangay boundaries overlaid with very high-resolution satellite images (sub-metre pixel resolution). Improved DEM resolution would have given more accurate depiction of CRFH zones, but for the purposes of this national overview the results proved to be more than satisfactory.

To validate the efficacy of the GIS model in identifying barangay exposure to CRFH, the flood event triggered by TS Washi in the Cagayan River was taken as a case study example. Figure 3 shows a side-by-side comparison between the modeled coastal river hazard exposure zones and corresponding affected barangays and the actual flood extent (XU-ERC, 2011) resulting from TS Washi.

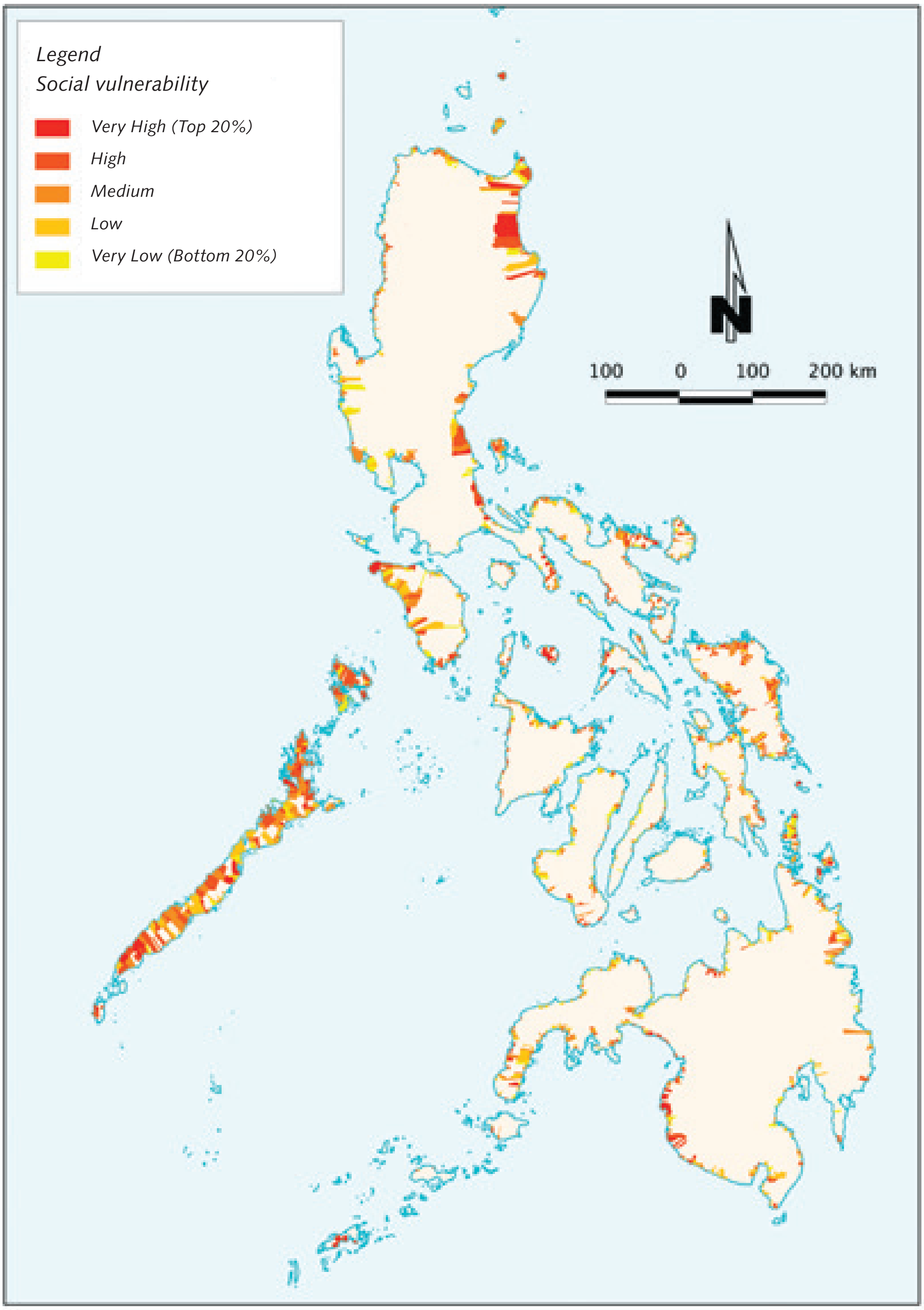

Figure 2: Social vulnerability of barangays exposed to coastal river flood hazard in the Philippines.
Source: Author.

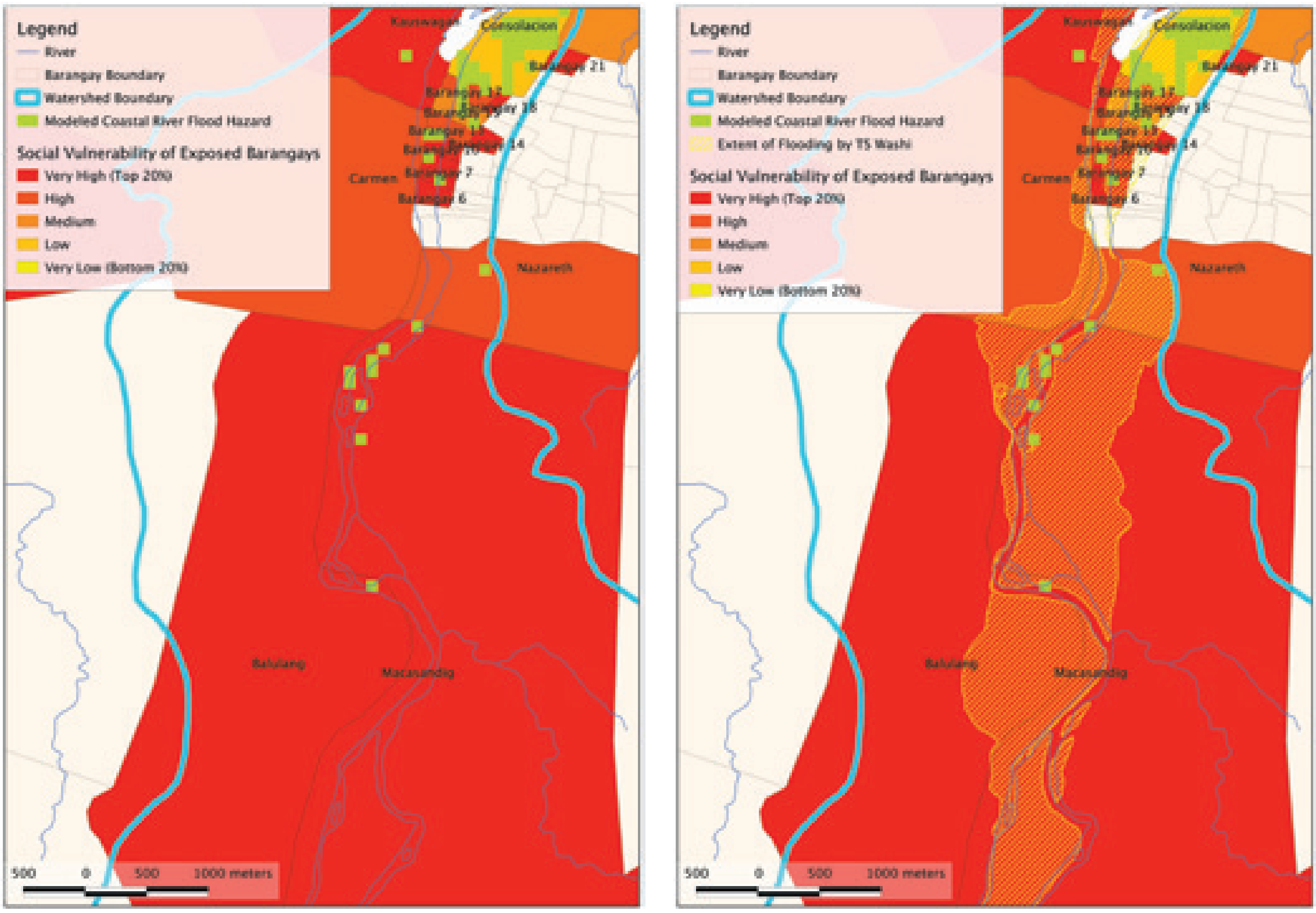

Figure 3: Side-by-side comparison of modeled versus actual flooding along the Cagayan River – left based on modeled CRFH exposure zones; right showing actual flood extent from TS Washi (XU-ERC, 2011). Source: Author.

Table 6 lists the barangays in the Cagayan Watershed that are exposed to CRFH resulting from the model. Note that 17 out of the 18 barangays that were identified through the model had actually experienced flooding during TS Washi, but with varying degrees of reported casualties, missing persons and damages. What can also be observed from the list is that the top 4 barangays in terms of confirmed deaths and missing have high to very high SoVI scores. In addition, Barangays 13 and 15 both shared portions of Isla de Oro, a natural sandbar along the Cagayan River that contained slum dwellings of thousands of inhabitants, thus contributing to the high casualty rate in these relatively small area barangays. What is worth investigating in the future is the use of even higher resolution DEMs to locally determine CRFH zones more accurately, coupled with a more accurate delineation of population concentration.

VI. Conclusions and recommendations

This research has shown that with the use of readily available biophysical and social datasets, it is possible to identify with a representative level of accuracy areas of CRFH exposure and the corresponding communities exposed to this type of hazard. The data that was generated as part of this research has made it possible to initially determine coastal communities at potential risk to flash floods throughout the Philippines. Further, the compilation of the best resolution social data available and determining degrees of social vulnerability is a major step towards prioritization and in-depth assessment of actual risks on the ground for the communities identified. From there, risk management and monitoring activities and interventions can be developed specifically in relation to flash floods in these coastal zones.

Barangay name	SoVI 2007 class	Registered deaths[†]	Missing persons[ø]	Total area (Ha)	Flooded area (Ha)	% of area flooded
Macasandig	Very high	192	279	1,346.05	375.37	27.89
Barangay 13	High	113	50	6.51	6.51	100
Balulang	Very high	83	40	726.27	180.29	24.82
Carmen	High	18	17	317.69	46.02	14.49
Barangay 15	Medium	8	6	7.93	7.65	96.5
Consolacion	Low	4	2	54.15	42.81	79.06
Kauswagan	Very high	2	0	336.4	64.88	19.29
Bonbon	Low	2	0	162.24	149.35	92.05
Barangay 18	Very high	1	0	1.83	0.59	32.39
Macabalan	Low	0	0	96.28	47.62	49.46
Nazareth	High	0	2	160.62	40.71	25.35
Barangay 6	Very high	0	0	5.31	4.87	91.81
Barangay 7	Very high	0	0	7.16	7.14	99.69
Barangay 10	Very high	0	0	4.40	4.40	100
Barangay 14	Very high	0	1	4.15	0.31	7.38
Barangay 17	High	0	0	6.45	6.45	100
Puntod	Low	0	0	105.53	8.90	8.43
Barangay 21*	Very high	-	-	-	-	-

* Did not experience flooding

† (Loquillano 2012)

ø (Cuenca 2012)

Table 6: Barangays within the Cagayan Watershed affected by TS Washi showing social vulnerability levels and degree of flooding. Source: Regional Development Council X (2012).

With the increasing availability of very high-resolution satellite images through cloud based services such as Google Maps and Bing Maps, the potential for more detailed assessments in the pre-identified barangays can now be performed, even at the housing level, as needed. This then paves the way for a more detailed and focused strategy of disaster risk management and resilience building, which can be implemented at the community level.

Further work can also be done in identifying flashflood-prone coastal watersheds that empty into regions with highly vulnerable communities. These watersheds can be prioritized for early warning instrumentation and the affected communities trained for eventual flashflood evacuation and emergency response. Local government and support organizations can be capacitated to prepare for eventual flashflood scenarios.

Finally, the existence of strong social networks in the Philippines through the church and civil society groups is a major factor in strengthening overall resilience particularly in post-disaster situations. National and local networks and hierarchies are easily tapped by civil society in post disaster rehabilitation efforts and due to their credibility, particularly among the poor, they have a positive impact in mobilizing resources and organizing relief and rehabilitation activities. Further populating the geopolitical database of the barangays will allow a comprehensive database of resources and networks that can be tapped in the event of a disaster. This information can be a focal point for a web-based initiative for disaster risk management that spans the entire country, using civil society networks as agents for updating and using the information. Where government is lacking in the Philippines, civil society is ready to fill in. What will set this apart from current efforts is the wealth of social information that can be included to give not only a presentation of biophysical processes, but more importantly the social landscape where they are taking place.

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Identifying and evaluating hotspots of climate change in the Sahel and Western Africa

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Abstract

The recently published IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX) suggests that the impacts of climate extremes and the resulting disaster risk are a function of the climate extremes and the vulnerability of exposed human and natural systems. Drawing on this concept this paper presents a modelling approach for the spatial assessment of climate change hotspots in the Sahel and Western Africa in order to provide conditioned information on the weather and climate events component of the SREX disaster risk framework. Based on time series of freely available global datasets, trends and changes of the past 24 to 36 years (depending on data availability) were analysed and mapped concerning a set of four climate-related indicators: long-term seasonal (1) rainfall and (2) temperature patterns, (3) drought occurrences and (4) major flood events. In addition to mapping these singular components of climate change, a spatial composite-/meta-indicator was developed for identifying and evaluating hotspots of cumulative climate change impact in an integrated manner. Following this approach, 19 hotspots where climatic changes have been most severe, were identified, mapped and analysed.

Keywords: climate change hotspots, disaster risk, spatial composite-/meta-indicators, geons, Sahel

Introduction

According to the Université Catholique de Louvain's Centre for Research on the Epidemiology of Disasters (CRED) widely consulted International Disaster Database (EM-DAT), statistics show that the number of disasters, the number of people affected, as well as the estimated economic losses have increased dramatically over the past decades (EM-DAT and Université Catholique de Louvain, 2012). The above mentioned statistics on disaster trends have to be scrutinized due to (i) inherent biases and inconsistencies in the EM-DAT database (see Gall et al., 2009) and (ii) the fact that the sharp increase in reported events, number of people affected and damage caused can to some degree be explained by the tremendous improvement in information and reporting technology in the past decades (Peduzzi, 2005). Despite these caveats, a general trend of increasing frequency of large-scale disasters is obvious. Moreover, there is increasing confidence that anthropogenic climate change has resulted and will further result in changes in the frequency, spatial extent, duration, timing and magnitude of extreme weather and climate events, often leading to unprecedented hazardous events (FAO, 2011; IPCC, 2012).

At the same time a series of social trends have markedly increased the world's exposure to such hazardous events in the past decades: (i) the doubling of the global population since the late 1960s (United Nations, 2011), (ii) ever increasing urbanization resulting in more than half of the world's population now living in towns and cities (United Nations, 2008) and (iii) the associated growth in built-up infrastructure. In combination with existing or even increasing vulnerabilities, as well as ongoing processes of environmental degradation and socio-economic marginalization, such change can lead to adverse impacts on coupled human and natural systems (IPCC, 2012; UN/ISDR, 2011).

In order to reduce exposure and vulnerability and to promote more resilient societies and adaptation on all levels (i.e., global to local levels), there is an urgent need for effective disaster risk management (DRM) and targeted climate change adaptation (CCA) policies, programmes and mechanisms. This need is underscored by the Hyogo Framework for Action (HFA) 2005-2015, which was adopted by 168 Member States of the United Nations during the World Disaster Reduction Conference in 2005. Among other priorities, the HFA defines the identification, assessment and monitoring of disaster risks as one of five key priority actions:

"The starting point for reducing disaster risk and for promoting a culture of disaster resilience lies in the knowledge of the hazards and the physical, social, economic and environmental vulnerabilities to disasters that most societies face, and of the ways in which hazards and vulnerabilities are changing in the short and long term, followed by action taken on the basis of that knowledge." (United Nations, 2005: 7)

Against the background outlined above, this paper lays the foundation for an integrated assessment of cumulative climate change impact on a regional (i.e., supra-national) scale using the Sahel and Western Africa as a study region. A spatially explicit modelling approach is used for the identification and a preliminary evaluation of climate change hotspots as one of three components of climate-related disaster risk.

I. The Sahel and Western Africa study region

A. Climate-related disaster risk in the Sahel and Western Africa

The countries of the Sahel and Western Africa are considered one of the most vulnerable regions to the projected impacts of climate change and related disaster risks (Parry et al., 2007; UNEP, 2011). For this reason the nine countries which compose the Permanent Inter-State Committee for Drought Control in the Sahel (CILSS), Burkina Faso, Cape Verde, Chad, the Gambia, Guinea-Bissau, Mali, Mauritania, Niger and Senegal, as well as the eight neighbouring member states of the Economic Commission of West African States (ECOWAS), Benin, Côte d'Ivoire, Ghana, Guinea, Liberia, Nigeria, Sierra Leone and Togo, were selected as case study region (see Figure 1).

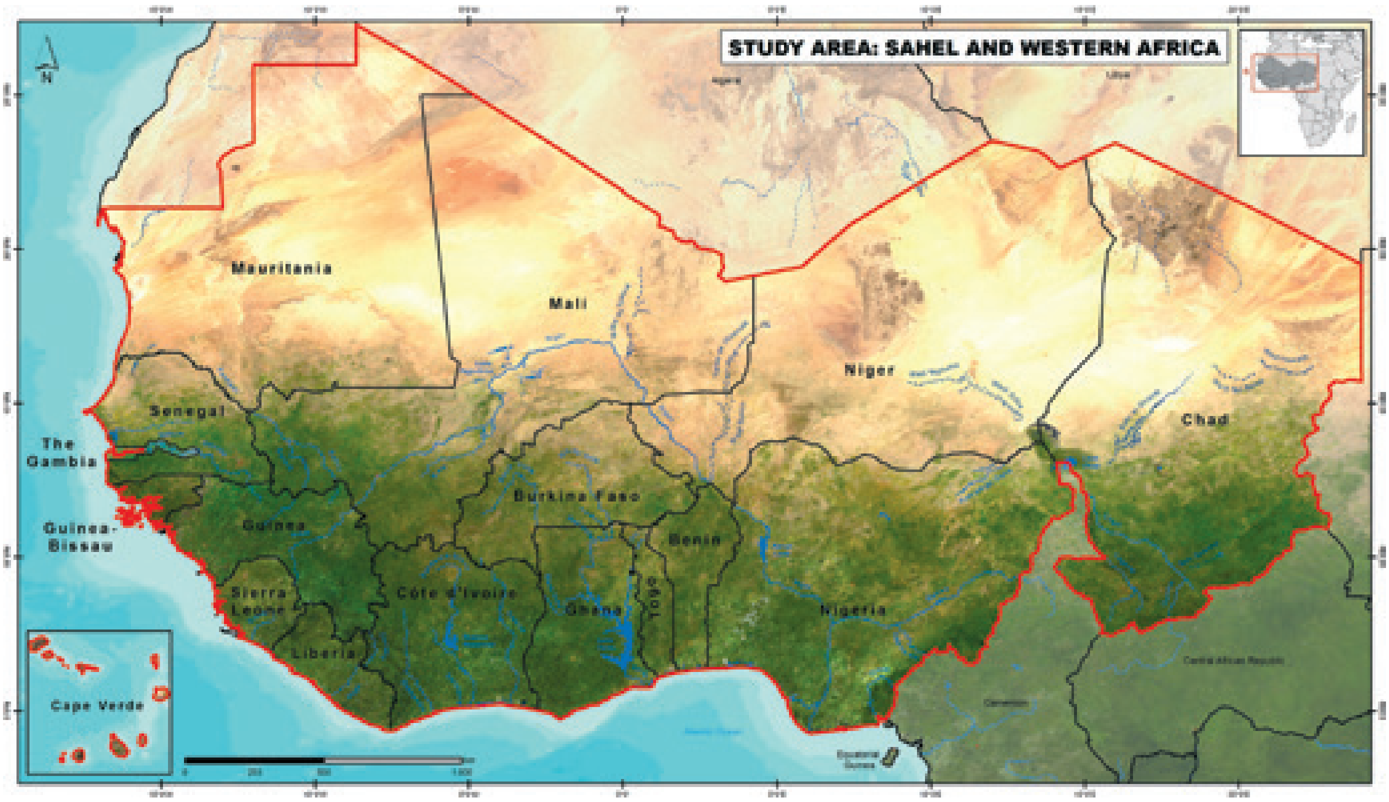


Figure 1: Base map showing the location of the study area (marked by red outlines in the map). Source: Author.

But what are the environmental, physical, social, economic, cultural or institutional factors that make the people of the Sahel so vulnerable to shocks compared to other regions? The regions particular hazard is partly the result of its extreme climate conditions (UNEP, 2011) and its strong spatio-temporal climate variability and irregular rainfall patterns (Fox and Rockström, 2003; Hulme, 2001), which can be traced back to the seasonal movements of the Intertropical Convergence Zone (ITZ) and the position of the West African Monsoon (Samimi et al., 2012). In some years, a variation in both rainfall and length of the rainy season of more than 30 per cent can be observed compared to previous years (ICRAF and UNEP, 2006). However, climate variability alone does not directly cause disaster vulnerability or risk. The combination of multiple stresses, such as rapid population growth, increasing urbanization and rural exodus, pervasive poverty, complex governance, conflicts and chronic instability, lack of investment in education and health, high sensitivity of key economic sectors to climate, fragile soils and high dependency of livelihoods on natural resources plus the resulting lack of resilience coupled with the exposure make the region and its population particularly vulnerable (ICRAF and UNEP, 2006; FAO, 2011; Parry et al., 2007; Trench et al., 2007; UNEP, 2011).

Although people and livelihoods in the Sahel and Western Africa have a long tradition in developing strategies of adaptation and mitigation in order to cope with climate variability (Adepetu and Berthe, 2007; Mortimore and Adams, 2001; Nyong et al., 2007; Trench et al., 2007), projected changes in regional climate conditions (cf. Solomon et al., 2007) and the expected increase in hazardous physical events might exceed peoples' coping capacities. Despite inherent biases in the database (Gall et al., 2009), statistics from the CRED EM-DAT database clearly show that the region is adversely affected by multiple hazards every year, such as floods and droughts, epidemics or storms (see Table 1). Moreover, the frequency and intensity of natural hazards in the region has increased over the past decades, especially in regard to cases of extreme physical events such as droughts and floods (FAO, 2011; UNEP, 2011) and is projected to further increase in the future.

These events, in combination with the above mentioned climatic, socio-economic and political conditions, result in losses of life, property and livelihoods and threaten food security, human health and sustainable development in the region. In the past four decades more than 550 hazard-related disaster incidents have led to more than 70,000 deaths (see Table 1) and affected approximately 95 million people (i.e., either injured, displaced or otherwise affected) in the Sahel and Western Africa. The impact is most severe among the poorest and most vulnerable populations, particularly among those whose livelihoods depend on agriculture (Benson and Clay, 1998; FAO, 2011; UNEP, 2011).

B. Hazard, vulnerability and risk assessments in the region

In order to get an overview of past and present hazard, vulnerability, and risk-related research in the region, a systematic literature review was carried out. In a next step the studies were compared regarding a previously specified set of guiding questions: (i) which area or region was covered by the study, (ii) what was the scale of investigation, (iii) which hazard(s) or threat(s) were taken into account, (iv) did the assessment focus on specific sectors, and if yes, on which sectors, and (v) what were the (methodological) strengths and weaknesses of the respective studies. Following these criteria, Table 2 provides an overview of the results of the literature review.

The review revealed that most research focused on the impacts of, and/or adaptation to, climate variability, climate change or climate-related extreme events. The vast majority of studies describe the impacts of drought on the agricultural sector. Despite substantive work that has already been done to analyse the root causes of vulnerability in the region, primarily making use of desk studies (cf. FAO, 2011; ICRAF and UNEP, 2006; Trench et al., 2007; UNEP, 2011), so far only singular studies have investigated the links between climate-related stressors, prevailing vulnerabilities (e.g., social, physical, environmental, economic, etc.) and resilience using spatially-explicit quantitative and/or qualitative approaches (e.g., Adepetu and Berthe, 2007; Antwi-Agyei et al., 2012; Barbier et al., 2009).

	Drought		Floods		Epidemics		Storms		Total	
	# Events	Deaths	# Events	Deaths	# Events	Deaths	# Events	Deaths	# Events	Deaths
Benin	2	0	17	179	23	1,337	1	0	43	1,516
Burkina Faso	9	0	15	127	22	16,667	0	0	46	16,794
Cape Verde	5	0	1	3	2	251	2	32	10	286
Chad	6	0	15	281	20	6,872	3	38	44	7,191
Côte d'Ivoire	1	0	6	52	13	715	0	0	20	767
Gambia, the	4	0	8	68	3	341	4	5	19	414
Ghana	3	0	15	404	16	846	0	0	34	1,250
Guinea	2	12	10	19	12	981	1	4	25	1,016
Guinea-Bissau	4	0	4	5	8	3,032	2	1	18	3,038
Liberia	1	0	5	14	11	624	2	0	19	638
Mali	7	0	19	87	16	3,406	0	0	42	3,493
Mauritania	8	0	15	45	6	185	2	5	31	235
Niger	8	0	17	149	33	9,589	1	4	59	9,742
Nigeria	1	0	39	1,014	50	20,646	4	211	94	21,871
Senegal	6	0	17	53	10	1,208	3	189	36	1,450
Sierra Leone	0	0	7	166	14	1,103	3	74	24	1,343
Togo	3	0	11	72	10	1,085	0	0	24	1,157
Total	70	12	221	2,738	269	68,888	28	563	588	72,201

Table 1: Number of selected disasters and disaster-related deaths per hazard type (1970–2012).
Source: EM-DAT and Université Catholique de Louvain (2012).

An integrated spatial assessment of climate-related disaster risk and its contributing factors (i.e., stressors, exposure, vulnerabilities) for the entire region is still missing.

II. Spatial assessment of climate change hotspots

As a first step towards a comprehensive analysis and evaluation of climate-related disaster risk in the study area, a quantitative spatial assessment of climate change hotspots was carried out. These represent areas where climatic changes (e.g., temperature and precipitation trends) and related drought and flood events have been most severe over the past decades. The assessment, which was part of a joint study conducted by the United Nations Environment Programme (UNEP) in cooperation with the International Organization for Migration (IOM), the Office for the Coordination of Humanitarian Affairs (OCHA), the United Nations University (UNU), the Permanent Interstate Committee for Drought Control in the Sahel (CILSS) and the University of Salzburg's Department of Geoinformatics (Z_GIS), aimed at providing geo-spatial information, to support climate change adaptation (CCA) planning in the region.

A. Conceptual framework

This paper draws on the disaster risk framework (see Figure 2) published by the IPCC in its SREX

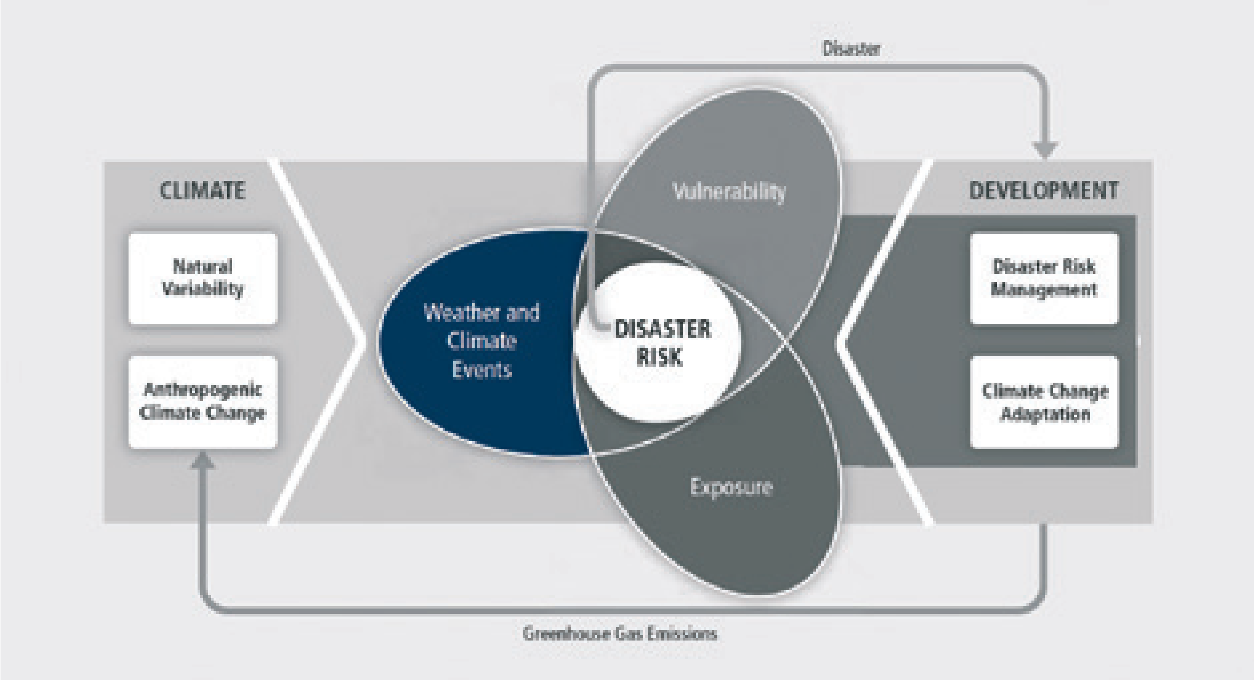


Figure 2: IPCC SREX framework. The Weather and Climate Events component which is addressed by this paper is highlighted in blue. Source: IPCC (2012).

report (IPCC, 2012). The framework acknowledges the need for a closer integration of disaster risk management and adaptation to climate change while at the same time considering the mutual interrelationships between development and disasters.

In the framework disasters are defined as severe alterations in the functioning of a system, resulting in adverse effects that require immediate emergency response to safeguard human needs (IPCC, 2012). Disaster risk is defined as the probability of such severe alterations (i.e., harmful consequences) over a specific time for a specific place due to hazardous physical natural or socio-natural events interacting with the vulnerabilities of exposed elements and which will signify the potential for severe interruption of the functioning of the system once it materializes as disaster (IPCC, 2012). Therefore, in order to understand climate-related disaster risk in the Sahel and Western Africa, it is important to consider prevailing hazards as well as existing vulnerabilities and exposure. One mechanism for doing this is the identification and assessment of areas where cumulative impacts of climate change have been most severe over the past decades.

B. Indicators and datasets

With the aim of providing information on the ‘weather and climate events’ component of the IPCC SREX framework (highlighted in dark blue in Figure 2), and thus as a first step towards the assessment of climate-related risks in the study area, a set of four climate-related indicators was selected in collaboration with domain experts of the UNEP-PCDMB (Post-Conflict and Disaster Management Branch): long-term average seasonal (1) temperature and (2) rainfall patterns, as well as frequency of extreme events such as (3) drought occurrences, and (4) major flood events over the past decades. In order to map these four singular climate-related indicators (see Table 3) time series of free, publically available global spatially disaggregated, i.e., gridded, datasets were acquired and pre-processed. Table 3 provides an overview of the datasets utilized in the study and highlights some of their properties (e.g., coverage, spatial resolution, etc.) as well as related data sources.

Study area	Scale level	Sector(s)	Threat(s)/hazard(s)	Focus	References
Regional/supra-national scale					
Sahel	Regional	Not specified	Floods	Hazard	Samimi and others, 2012
Sahel	Regional	Agriculture	Climate change, natural hazards	Vulnerability Disaster Risk Management	FAO, 2011
Sahel	Regional	Not specified	Climate change	Adaptation	Mertz and others, 2011
Sahel	Regional	Not specified	Climate change	Adaptation	UNEP, 2011
Sahel	Regional	Not specified	Drought	Vulnerability	Trench and others, 2007
Sahel	Regional	Agriculture	Climate variability, climate change	Adaptation	UNEP and ICRAF, 2006
Sahel	Regional	Water	Climate variability, climate change	Adaptation	Niasse and others, 2004
West Africa	Regional	Not specified	Climate change	Vulnerability	Joiner and others, 2012
West Africa	Regional	Not specified	Drought	Gender vulnerability	Schroeder, 1987
CILSS	Regional	Agriculture	Drought	Vulnerability	Bacci and others, 2005
National or sub-national scale					
Ghana	National	Agriculture	Drought	Vulnerability	Antwi-Agyei and others, 2012
Nigeria	National	Agriculture	Climate variability, climate change	Climate impact	Adejuwon, 2007
Niger	Sub-national	Agriculture	Climate change	Social resilience	Turner, 2010
Senegal	Sub-national	Agriculture	Climate variability climate change	Climate impact	Tschakert, 2007
Local scale					
Burkina Faso	Local	Agriculture	Climate variability	Vulnerability, adaptation	Barbier and others, 2009
Mali, Nigeria	Local	Agriculture	Drought	Vulnerability, adaptation	Adepetu and Berthe, 2007
Nigeria	Local	Agriculture	Climate change	Adaptation	Mortimore and Adams, 2001
Niger	Local	Agriculture	Drought	Vulnerability	Turner and Williams, 2002

Table 2: Overview of hazard, vulnerability and risk-related research in the study area. Source: Author.

Type	Coverage	Spatial resolution	Time frame	Source
Precipitation	Global	0.5 x 0.5 degrees	1901–2006	CRU TS 3.0
Temperature	Global	0.5 x 0.5 degrees	1901–2006	CRU TS 3.0
Vegetation health (VHI) as a proxy for drought	Global	16 x 16 km	1982–to date	NESDIS-STAR
Flood events	Global	Polygon layer	1985–to date	DFO

Table 3: Datasets and sources. Source: Author.

C. Preparatory analysis

As a first step, an observation period was defined for each of the four indicators. In line with the IPCC definition of climate as "the statistical description in terms of the mean and variability of relevant quantities over a period of time" (Solomon et al., 2007: 942), which was defined as a period of 30 years by the World Meteorological Organization (WMO), the observation period was set to the past 24 to 36 years (depending on data availability).

Due to the fact that the majority of livelihoods in the Sahel and Western Africa are highly dependent on natural resource availability, which in turn is among other factors also strongly related to rainfall, the rainy season (i.e., the months from June to August/September) was chosen as the critical season to be observed. Due to the high seasonal and inter-year climatic variability in the region, the seasonal focus for the observation of indicator 1 (precipitation), 2 (temperature) and indicator 3 (drought) was set to the months May to October. This temporal buffer was chosen in order to bracket the rainy season.

After data acquisition a subset of the datasets covering the entire target region (see Figure 1) was created. Following this step the mean temperature as well as the actual amount of precipitation was calculated for each season (May–October) for the years 1970 to 2006, for each grid cell of the datasets. Based on these values a seasonal mean temperature and precipitation trend (1970–2006) was calculated for each cell, making use of linear regression. Seasonal mean temperature/precipitation values (y) were regressed with the years (x). The output was the trend per year, reflected by the slope b of the regression line. Thus, the slope b, indicating the trend per year, was scaled up to the period of observation (1970–2006) in order to determine the overall trend in seasonal temperature/precipitation.

In order to assess the number of drought affected seasons, the Vegetation Health Index (VHI) which is based on measurements of the Advanced Very high Resolution Radiometer (AVHRR) onboard the NOAA satellite was selected as a proxy for drought. The VHI was chosen as the best available alternative due to insufficient high-quality long-term station-based precipitation data in the area under investigation. This index, which was originally developed by Kogan (1995), has been successfully applied in various regions around the globe, including Africa (Rojas et al., 2011; Unganai and Kogan, 1998), for monitoring drought conditions. Within this study, a seasonal mean VHI value was calculated based on the available weekly gridded VHI datasets (cf. Table 3). Thereby a VHI value of zero indicates extreme drought conditions, while a VHI value of 100 indicates excellent vegetation health conditions. Drawing on a critical VHI threshold (VHI values < 35 indicate severe drought conditions), which was identified from literature (cf. Rojas et al., 2011), the number of drought affected seasons was determined for the period from 1985 to 2009.

As the data which represents major flood events in the region was acquired as a polygon layer in ArcGIS Shapefile format (*.shp), a net of regular cells (fishnet) was created in ArcGIS in order to calculate the number of major flood events per grid cell for the years 1985 to 2009.

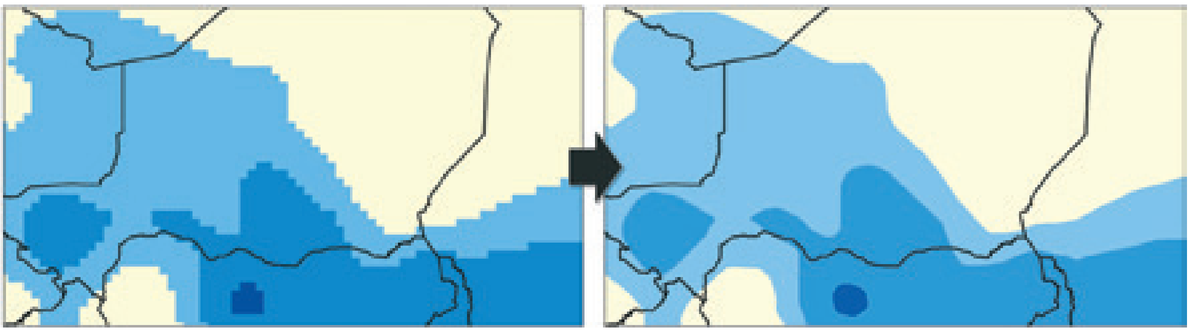


Figure 3: Original raster dataset (left) and refined/smoothed vector product showing the seasonal temperature trend in a subset of the study area. Source: Author.

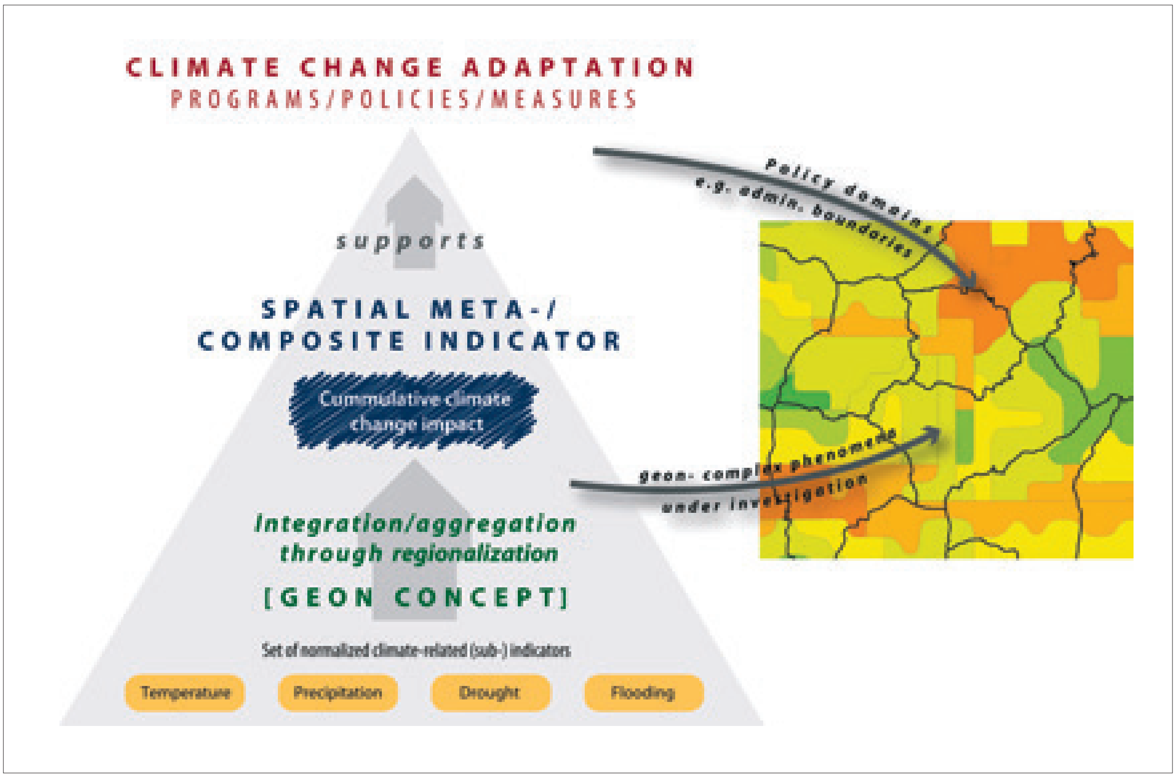


Figure 4: Schematic figure showing how to construct spatial composite-/meta-indicators based on the geon concept: different normalized (sub-) indicators (here: temperature, precipitation, drought, flooding) are aggregated by making use of regionalization techniques. Following this approach the resulting units (or geons) are independent of administrative boundaries. Source: after Lang et al. (2008), Kienberger et al. (2009), modified.

Finally, the resulting geospatial information layers were mapped and cartographically refined using common smoothing techniques such as Bezier interpolation and low-pass filters in ArcGIS to obtain a more intuitive and appealing characterization of the results (see Figure 3).

D. Modelling spatial composite-/meta-indicators

In addition to analysing and mapping singular trends in the four climate indicators, a spatial composite or meta-indicator, which aggregates/integrates the four singular sub-indicators (see Table 3), was developed for identifying and evaluat-

ing areas of cumulative climate change impact in the study area. The identification of such climate change "hotspots" illustrates which areas have been affected most by cumulative change in the four climate indicators and where adaptation programmes and policies are most needed.

Such spatial meta- or composite indicators are constructed by integrating (and weighting) data from various topics or domains and sources (e.g., earth observation-based vs. in-situ measurements) into a multi-dimensional indicator space. The aggregation of the individual sub-indicators is achieved by making use of regionalization techniques (Hagenlocher et al., 2012; Kienberger et al., 2009), which simultaneously create contiguous regions in dimensional space and in real space based on previously defined homogeneity criteria (Strobl, 2008). The resulting units, instances of geons (Lang, 2008), are homogeneous in terms of the underlying spatial phenomenon of interest. This approach, referred to as geon concept (from Greek gé = Earth and on = part, unit), was developed by Lang et al. (2008) in order to approach complex, multidimensional spatial phenomena (such as disaster risk, or vulnerability), which are of central concern in policy implementation, but due to their complexity difficult to measure or operationalize. Thus, the approach is an automated aggregation and zoning method for modelling spatial units where similar conditions apply with respect to a particular phenomenon under investigation (see Figure 4). As this approach works independent of any a-priori set of (e.g., administrative) units it thereby helps to overcome the modifiable area unit problem (MAUP) (Openshaw, 1984).

To calculate an index of cumulative climate change impact, the four singular sub-indicators (cf. Table 3) were normalized using linear min-max normalization (Nardo et al., 2005), and then regionalized/aggregated making use of a multi-resolution segmentation algorithm (Baatz and Schäpe, 2000) which is implemented in Trimble's eCognition Developer software environment. Thereby the mean values of the four integrated sub-indicators per unit (geon) were considered by calculating the vector product in a four-dimensional indicator space. In the absence of justifiable expert weights, the four indicators were given equal weight during the aggregation/regionalization process. The model output is seen as a first step towards an integrated spatial assessment of climate-related risks in the area.

III. Results and discussion

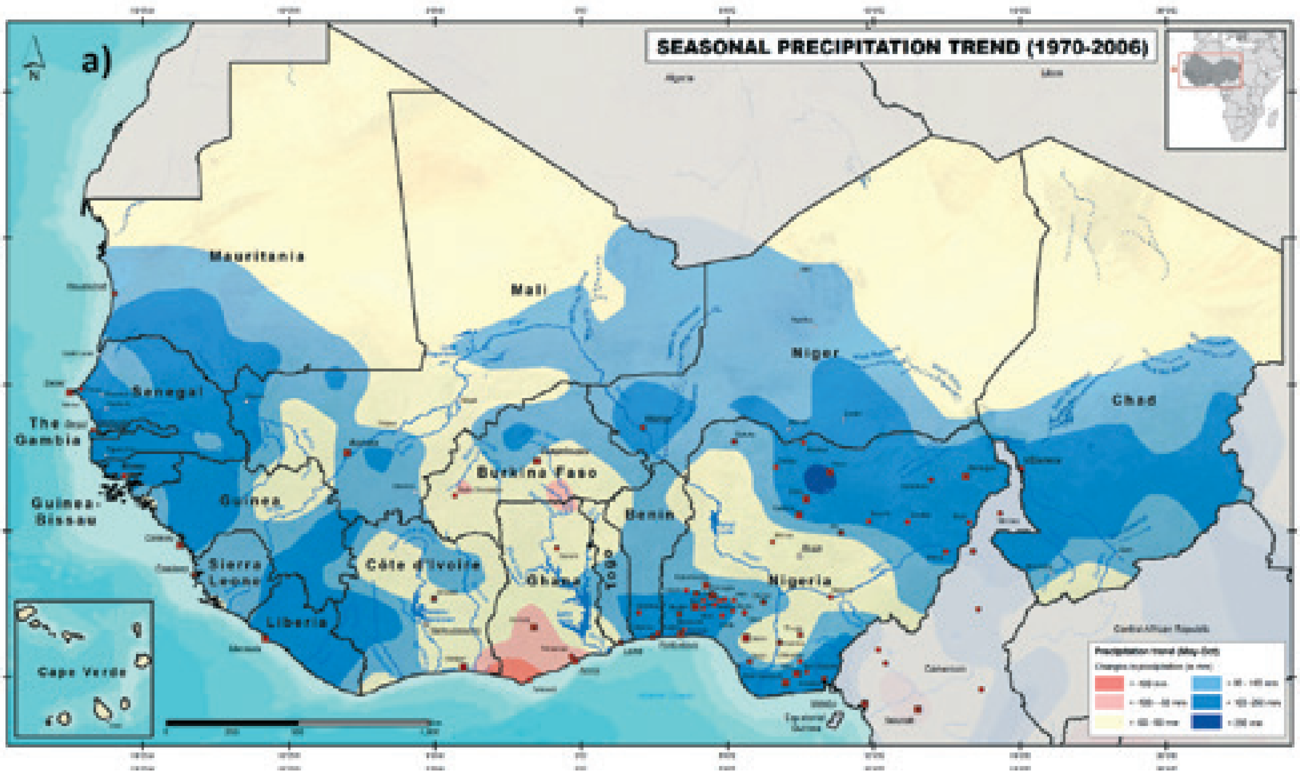
A. Historical climate trends and extreme events

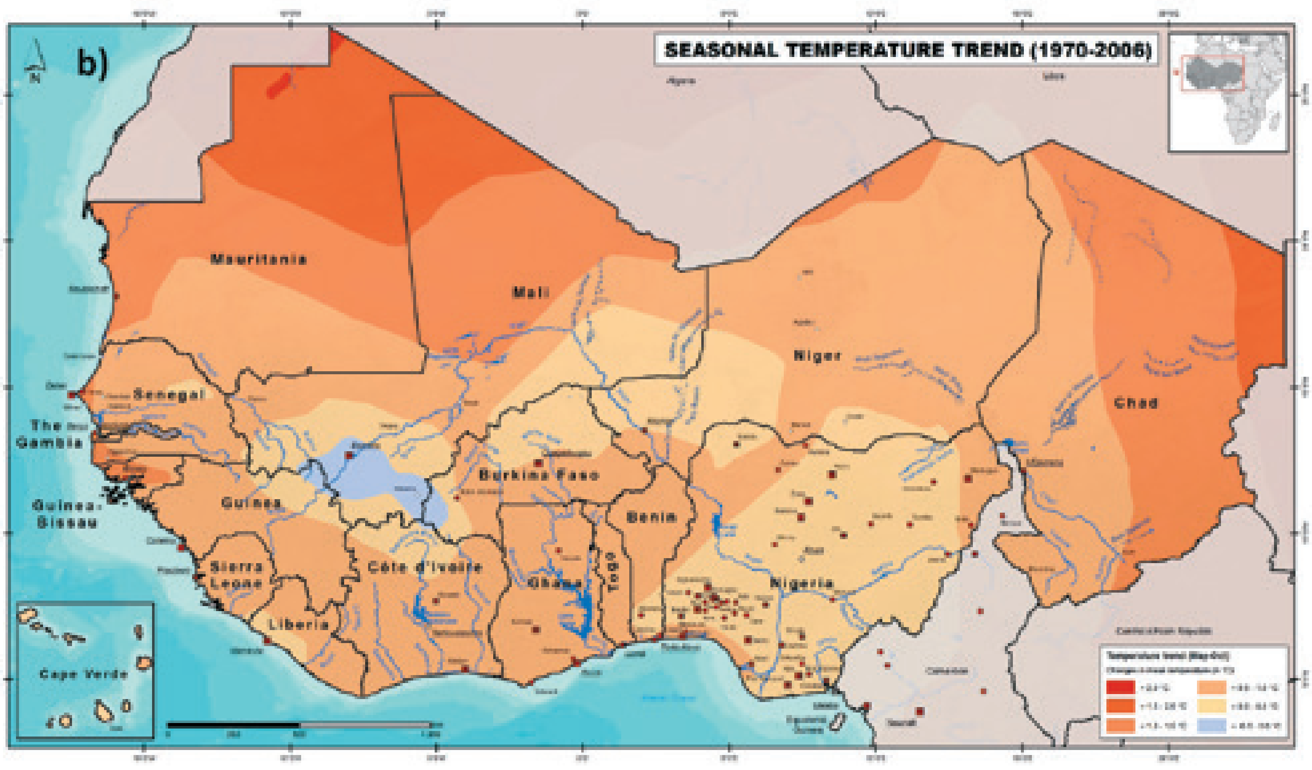
Based on the analysis of the four singular climate-related indicators and datasets Figure 5 shows the absolute long-term average changes in rainfall (1970–2006) and temperature (1970–2006), as well as the areas affected by extreme events such as droughts (1982–2009) and major flood events (1985–2009).

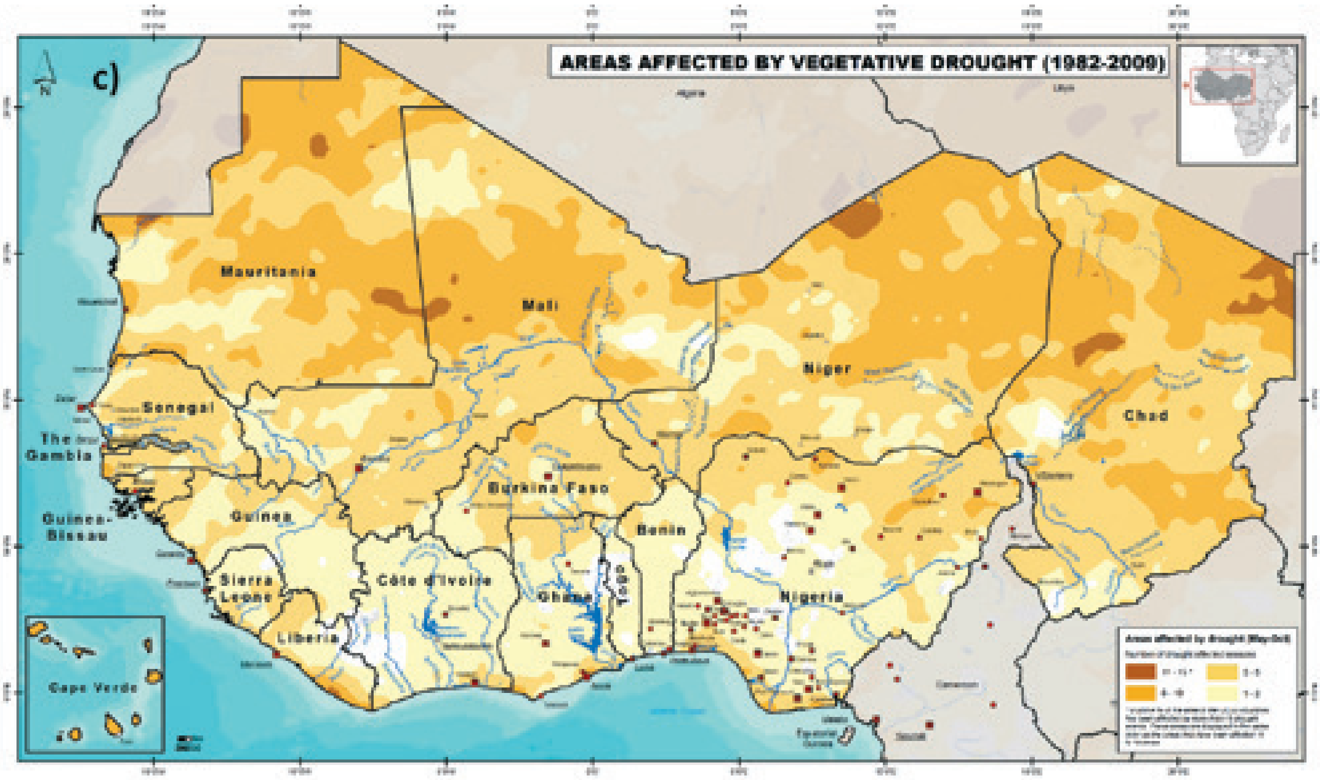
While seasonal (i.e., May–October) rainfall has increased (blue areas) or remained constant (see Figure 5a), results clearly show an overall rise in mean seasonal temperature (see Figure 5b) of approximately 1°C during the 36 years under investigation (displayed in red). A significant increase between 1.5°C and 2°C was observed in the northern part of the study area (e.g. northern Mauritania and Mali) as well as in eastern Chad (areas displayed in dark red). Concerning drought frequency, Figure 5c shows that almost every region within the study area has been affected by drought in the past decades (1982-2009), with larger areas in the northern part (northern parts of Mauritania, Mali, Niger and Chad) affected approximately every five years (areas in dark brown). Moreover, Figure 5d shows that huge areas have been affected by several major floods (displayed in blue). For example large areas of southern Burkina Faso, western Niger and northern Nigeria which have experienced up to ten floods during the period from 1985 to 2009.

B. Hotspots of climate change impact

Building on the aggregation of the four singular climate-related sub-indicators, Figure 6 shows the location and approximated size of the identified climate hotspots in the study area (displayed in red). These represent areas most affected by cumulative climate change impact over the past decades. Next to the location and approximated size of the 19 identified hotspots, the proportional influence of each of the four integrated (sub-) indicators (see Table 3) was visualized by means of a pie chart for each of the hotspots (see Figure 6).


SEASONAL PRECIPITATION TREND (1970-2006)
a)
Mauritania
Mali
Niger
Chad
Senegal
The Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Sierra Leone
Côte d'Ivoire
Ghana
Togo
Nigeria
Liberia
Cape Verde


SEASONAL TEMPERATURE TREND (1970-2006)
b)
Mauritania
Mali
Niger
Chad
Senegal
The Gambia
Guinea-Bissau
Guinea
Burkina Faso
Benin
Sierra Leone
Côte d'Ivoire
Ghana
Togo
Nigeria
Liberia
Cape Verde



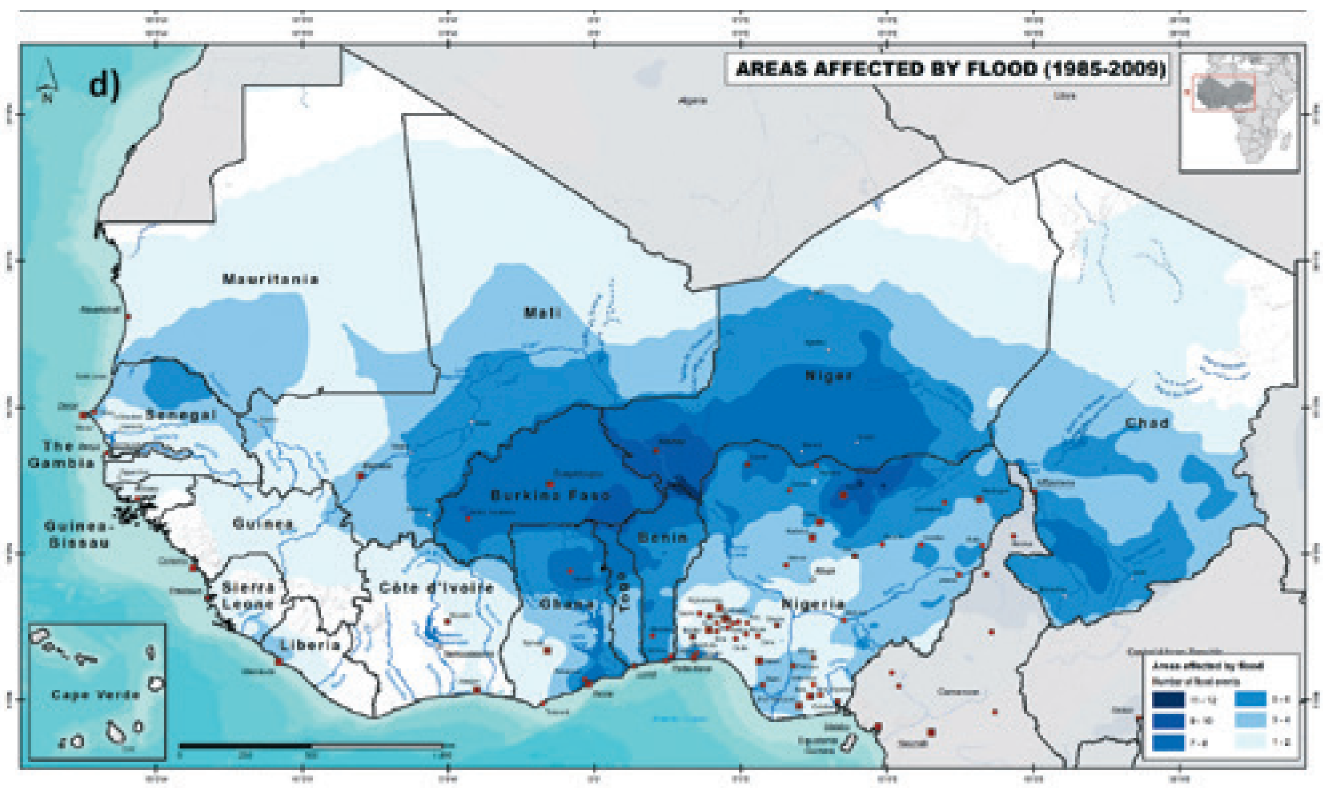


Figure 5: Seasonal (May–October) long-term (1970–2009) precipitation (a) and temperature trend (b); areas affected by drought in the season from May–October 1982 to 2009 (c); areas affected by major flood events from 1985 to 2009 (d). Source: author.

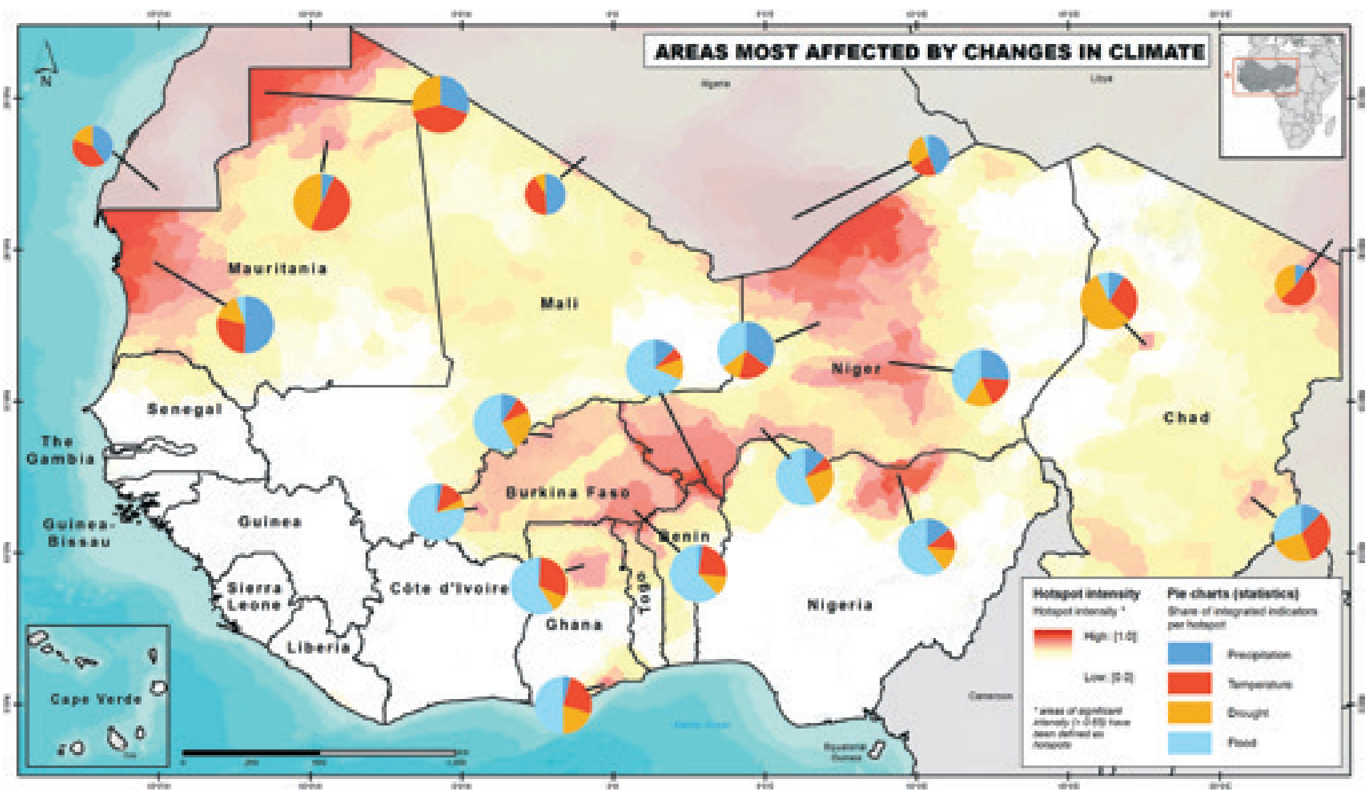


Figure 6: Hotspots of climate change in the Sahel and Western Africa. Source: own draft.

Hotspots of regional climate change were identified in three main areas: the northern and northwestern part of the study area, including Mauritania; the centre of the study area, including Niger, Burkina Faso and the northern parts of Ghana, Togo, Benin and Nigeria and Chad.

IV. Conclusions

This paper has applied the geon concept for the modelling hotspots of cumulative climate change impact based on four singular climate-related (sub-) indicators. Drawing on the recently published IPCC SREX framework and the HFA, the spatial identification and analysis of hotspots of cumulative climate change impact is seen as a crucial first step towards a comprehensive spatial assessment of climate-related risks in the Sahel and Western Africa. The presented approach enables the spatial identification and delineation of priority areas where additional, fine-scaled, follow-up studies should be conducted (e.g., within areas identified as hotspots). It also gives an indication of the type of hazard (e.g., flood, drought, etc.) that should be addressed in particular within follow up activities and targeted intervention measures.

In order to produce an integrated assessment of climate-related disaster risk in the study area, however, the missing two components of disaster risk, i.e., the (i) socio-economic vulnerability of spatially and/or temporally (ii) exposed population groups, need to be spatially identified as well. Next to this need, it also became evident during this research that the presented approach of modelling spatial composite-/meta-indicators using the geon concept still entails some methodological challenges, which require further investigation. These range from answering the question of how the delineated conceptual units (geons) of homogeneous climate change impact could be validated, to issues related to expert weighting in the process of constructing such a spatial meta- or composite indicator. For example, does it make sense to use expert weighting instead of equal weights when aggregating the individual singular indicators? And if yes, how can the influence of different weighting scenarios on the final modelling results be measured and evaluated. Moreover, when interpreting the results one has to bear in mind that several uncertainties arise when aggregating multi-source datasets due to the often varying level of quality and accuracy of the underlying datasets. These challenges in

constructing such spatial meta-/composite indicators also need to be assessed and are seen as worthwhile for future investigations.

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Why here and not there? Developing a spatial risk model for malaria in Dakar, Senegal

Marion Borderon

Abstract

This paper assesses the exposure to urban malaria by taking into account the individual and environmental vulnerabilities involved in this infection. Supported by census data and satellite imagery, the variables of interest are constructed and in some instances, proxies are used where data are unavailable. For example, the "root causes" of social vulnerability (resources and living conditions of the inhabitants) are examined as measures of vulnerability to malaria because data specific to individual behaviours are not available. The output of the analysis is a map, which combines each district of the city with a profile of exposure to the disease, highlighting the potential outbreaks. Such a tool is an asset in understanding vulnerability to malaria and its potential control. More broadly, the observations on "the poverty trap" in the Dakar urban settings question the goals of reducing social inequalities.

Keywords: Social vulnerability, GIS, urban environment, malaria transmission, risk map, Dakar

Introduction

In recent decades, urban malaria has produced huge human losses and economic damage in African cities. The fast pace of urbanization and the difficulties of malaria control in these heterogeneous and dense places have caused this emergent public health issue and Dakar has not escaped from this reality (Donnelly et al., 2005). In the Roll Back Malaria objectives this issue can be seen to be a priority, demonstrated, for example, by the Rapid Urban Malaria Appraisal (RUMA) in sub-Saharan Africa (Wang et al., 2005). To mitigate this epidemiologic risk, disaster management aims at detecting vulnerabilities and potential exposures from malaria. This study contributes to the mapping of social-ecological vulnerability on an urban scale through the development of appropriate tools and methods adapted to a data-scarce environment Indeed, the available data on the prevalence and incidence of the disease, when they exist, take only into account the people who went to a health care centre of the agglomeration and whose diagnostic test had been transcribed in the register (PNLP, 2008). The data have thus too many important biases to be used. For example, the share of self-medication concerns more than half of the population, cancelling de facto the representativeness of the data (Diallo et al., 2012). In addition, the absence of precisely geolocalized data limits their low interests. Epidemic risk is then reconstructed by two key indicators of malaria infection: the presence of the vector, Anopheles, parasite transmitter to humans, and social vulnerability, that is to say in the broad sense, the resources that the individual has to guard against the exposure to these vectors.

Vulnerability to malaria infection is thus closely correlated to the concept of social vulnerability (Bates et al., 2004). The main interest of this paper is to provide a custom-made methodology to highlight the hot spots (the areas at risk) and their spatial construction that can create “spatial poverty traps” (Jalan and Ravallion, 1997). This study, whose particular focus is on the use of GIS and remote sensing, is continuing to implement the recent methods developed by a pilot programme supported by the World Bank (Wang et al., 2009). These include hazard exposure maps and a GIS database using data gathered from various sources in order to analyse the different spatial vulnerability indicators and highlight hot spots of social exposure with high population growth and high hazard potential. This study is the first of its kind in Dakar. However, it only considers exposure and not the measuring of social vulnerabilities. Studies focus on human vulnerability and behaviour and dealt with quantitative methods are still rare (see notably Robert et al., 2003). Indeed, assessing malaria vulnerability on a large scale is a real challenge, and the encountered hurdles often reduce the study objectives, particularly as regards big agglomerations in developing countries. Indeed, in the case of malaria, assessing social vulnerability

on a large scale is a real challenge, particularly as regards big agglomerations in developing countries where socio-economical data correlated to a malaria prevalence rate are hardly available. The objective of this paper is to model the risk of malaria infection, which includes the central role of social vulnerability to the exposure rate, to the hazard. From the perspective of the Hyogo Framework, it seems essential to link the two in the same integrated approach (UNISDR, 2005).

I. Urban malaria, "a budding disaster"

A. Malaria, a global pandemic

Malaria is currently one of the leading causes of mortality and morbidity. In recent years, however, international agencies have begun to claim victory with a drastic decline of the mortality rate. Senegal has even been praised for its exemplary fight against malaria (RBM, 2010). Of course, regarding this disease, it is always important to be skeptical about the quality of data that allows one to draw such conclusions – over or under-interpretation of data is frequent (Murray et al., 2012). As well, from an epidemiological point of view, urban malaria is no longer considered to be only an imported form of malaria because the transmission also takes place in the city, which was monitored by recent entomological surveys (for the most recent studies: Salem et al., 1994; Diallo et al., 2000; Pagès et al., 2008; Machault et al., 2010; Gadiaga et al., 2011). Risk is endogenous in the city but unevenly distributed in time and space which prevents the city dwellers to acquire immunity (see notably Charmot and Mouchet, 1999). Thus, the risk of severe malaria is significantly higher in the city (notably Baudon and Spiegel, 2003). Moreover, in addition to the adaptability of the Anopheles to urban landscapes, two other factors seem to favour the spread of endogenous urban transmission (Wang et al., 2009):

- Uncontrolled urban sprawl (particularly on floodplains);
- Climatic changes (precipitations are more concentrated and stronger than in the last decades).

However, while urban malaria transmission deserves further study, there are obstacles to collecting detailed data. The urban environment is difficult to observe given that it is a “dense, heterogeneous and open environment” (Salem, 1998), and in addition, the various characteristics of populations are hard to know because the local contexts are poorly described and there is a lack of important geospatial data.

B. Urban malaria, malaria-infection, malaria-disease: the required accuracy

As mentioned, urban malaria is hyper localized in space and generates contrasts in the exposure to the disease (Machault et al., 2009). The disease distribution requires two conditions: the presence of the vector, the Anopheles and the parasite. The hazard results in a complex intersection of the vector and people, who can be reservoir host of the Plasmodies. In general, the Anopheles population is more abundant in rural areas where the breeding sites are more easily available. But paradoxically, the absence of repeated bites to the native people in their urban settings prevents the acquisition of immunity. The consequences are the increase in cases of severe malaria and the increase in the risk of outbreaks in areas that previously were relatively spared. Urban malaria, particularly in a seasonal temporality (i.e., unstable), causes significant risks of mortality and morbidity. In Dakar, studies have thus shown a correlation between the carriers of Plasmodium and the chance of having a malaria attack within a year (Diallo et al., 2012). What matters the most is to establish the presence of the vector and the people who suffer the greatest number of bites. Vulnerability to malaria-infection lies in these two conditions responsible for the circulation of the parasite.

C. Vulnerabilities: plural definitions and relativity

Vulnerability is always relative. In the case of risk of malaria infection it is defined as the result of the intersection of two vulnerabilities: an ecological vulnerability and a social vulnerability. According to Cutter (1996: 537), “Vulnerability was traditionally viewed as either a pre-existing condition or potential exposure to a risk (biophysical) or as a social condition predisposing some responds to

an environmental threat (social vulnerability)". Environmental or ecological vulnerability is the result of physical characteristics but is also socially constructed, shaped and altered by humans; the nature of a hazardous event is usually viewed as a social construct rooted in historical, cultural social and economic processes, not always as a biophysical condition (Blaikie et al., 1994; Chambers, 1989; Watts and Bohle, 1993). The interest, particularly in a malaria study, is to analyse this vulnerability process via an integrated approach without separation between a natural hazard and social responses or "capabilities" (Cutter et al., 2000). The integrative model used in this paper takes into account the social-ecological system (Bateson, 1979). Vulnerability is primarily a function of the proximity to the source of the risk or hazard in question (geographic distance). A simple mapping of the biophysical risk should result in a simplistic delineation of the likely exposure or biophysical vulnerability (Cutter, 1996). It then depends on who is exposed, and with what materials and means. In this case, the concept of capabilities (Sen, 1983) is particularly well chosen. According to one's capabilities or the community's capabilities, the degree of exposure and recovery are different.

D. "Spatial poverty traps" and accumulation of vulnerabilities

Urban areas, especially big cities with their peri-urban areas, favour the accumulation of vulnerabilities (Pelling, 2003; Lall and Deichmann, 2009). In 1997, the concept of "spatial poverty trap" was introduced (Jalan and Ravallion, 1997). The idea is that the poorest areas are characterized not only by the concentration of poor people but that these people are poor because they occupy these spaces. Many poor people are attracted by lower land prices in hazard prone locations, thereby increasing the vulnerability of the poor (Lall and Deichmann, 2009). In the suburbs of Dakar, for example, many houses were built on flood plains. Risk exposure to flooding is greater in these places. Moreover, people do not have many resources and their coping capacity is highly dependent on local or associative aid programmes. The state of poverty or its process is not of course synonymous with social vulnerability, which covers broader characteristics than just poverty. However, in the case of malaria, poverty status is the main condition of the persistence of the disease and the cause of the financial and deadly burden.[11] In addition, the effect of "traps" is interesting in this context to illustrate the vicious circle enclosing the poorest: many studies and analysis of Senegalese data indicate that the Dakar areas assembling the poorest populations are those where the environment is more susceptible to hazards (e.g., floods, epidemics, etc.) (Wang et al., 2009).

E. Study context: the vulnerability of metropolitan Dakar

The World Bank report on Dakar (2009) highlights the expansion and growth of the city, and its encroachment into high-risk lands. As the report states, "The physical vulnerability and risk in peri-urban areas are compounded by weaker institutional capacity than in traditionally urban or rural areas." (2009: 22).

With over two million inhabitants in 2002, the region of Dakar extends to the east on an area of approximately 550 square kilometres (ANSD, 2006). This space is studied through the Census Districts (CDs). Areas not covered are scattered throughout the city including areas not inhabited such as the airport, forests, parks, sand dunes or Niayes and some inter-dune depressions.

II. Materials and methods

A. The available data for the malaria exposure

One of the main issues of carrying out work in less developed countries is the difficulty in obtaining good population data. Senegal is no exception to this rule. Censuses are useful resources — the scale and quality of data are often problematic, but as aggregated data and used with a GIS they are useful (see for example Merchant et al., 2011; Guilmoto et al., 2002).

11 The typology of the living conditions is a strong marker of exposure inequalities and means of action regardless of the hazards (Wisner and others, 2004).

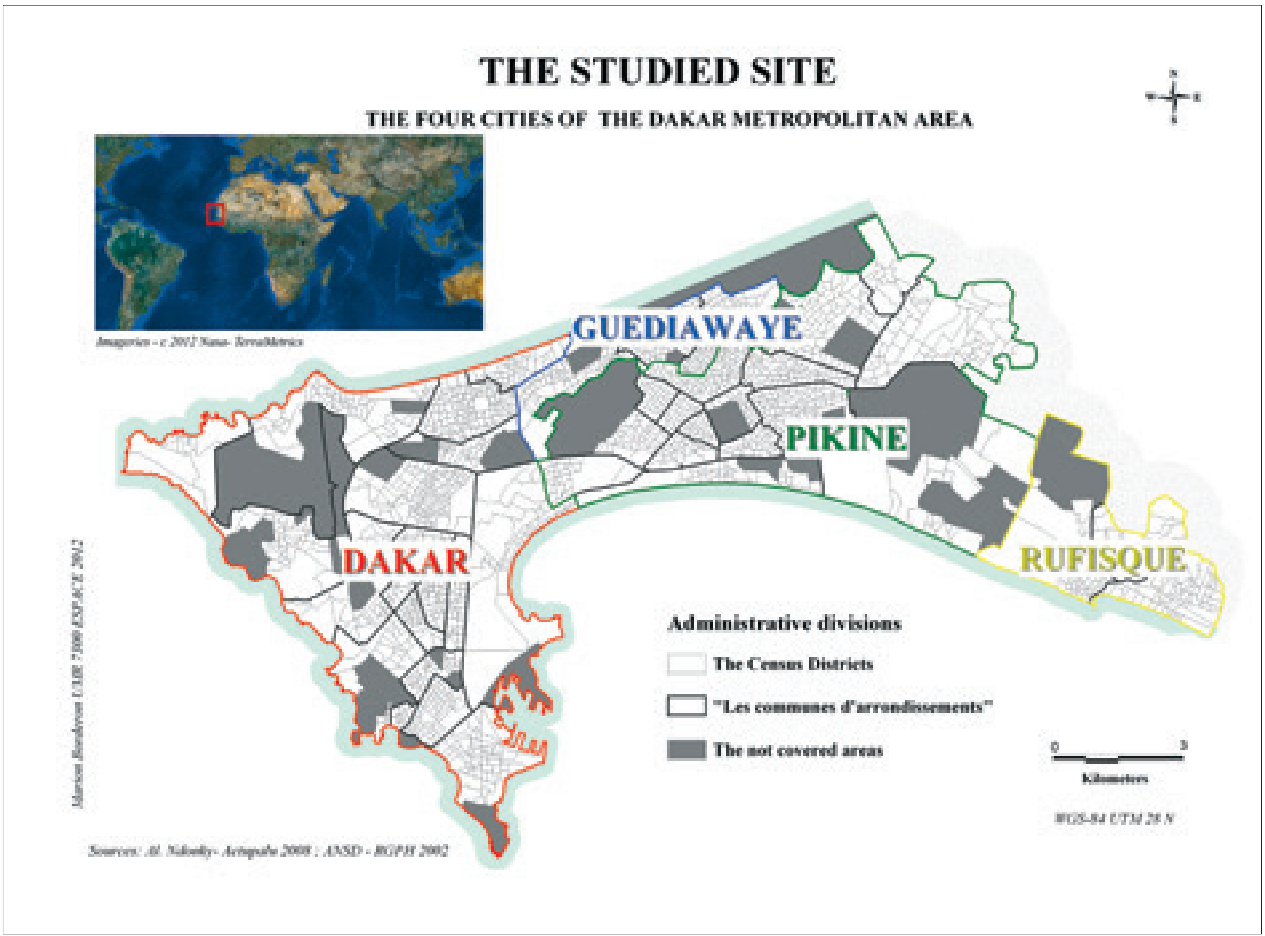

Figure 1: The situation of the studies site. Source: own draft.

Data from satellite imagery with spatial and temporal resolution is becoming more readily available. This can be helpful not only in a characterization of the landscape but also as proxy variables for the characterization of the urban environment. Although they do not directly produce socio-economic data, a number of extrapolations from their analysis can be produced (see notably Dureau et al., 1989).

Census data for Dakar is available in a digital format distributed by the National Agency of Statistics and Demography for its editions of 2002 (which has been published only in 2006). Its integration into a geographic information system was conducted by N'Donky (2011) in the context of a programme of the Institute of Resarch Development (IRD). The first processed data identified the quality of produced data and their uses in a socio-spatial analysis of the grand Dakar (Oliveau et al., 2009).

From the perspective of satellite imagery, studies are more numerous. It can be underlined here the first work on aerial photos used by Vernière (1978) and now, regarding health issues and notably the malaria study, the current work of Machault (2010).

Different kinds of data are thus available. Exposure to malaria will be modeled by environmental variables extracted from satellite imagery. Social vulnerability shall be on the other hand the subject of analyzes of census data.

The following table shows this main data available for this paper.

Type	Spatial coverage	Time frame	Source
Landcover data with 2.5 m raster size	Region of Dakar	2007 – 2008 – 2010	Satellite data from SPOT 5
Multitemporal analysis landcover	Maps on all the region of Dakar	1988 – 2008	Centre de Suivi of Ecologique (CSE)[12]
Socioeconomic variables	2000 CDS	2002	Census ANSD

Table 1: Preliminary Data sources for Dakar metropolitan area. Source: own draft.

B. Modelling the Exposure to Malaria-infection

There is an abundant literature regarding the environmental factors involved in malaria transmission. According to Beck and others (2000), the most involved variables in the link between malaria and environmental factors are: type of land use, density of green vegetation, deforestation, flooded forest, stagnant water, swamp, soil moisture and channeling of waterways (data that can be obtained by remote sensing).

What is commonly called malaria risk is the exposure index to the bite of the Anopheles. As the measurement is not available, the use of a proxy is required. This equates to determining the "pathogenecity" of landscapes (i.e., where there is a proliferation of mosquito-vector of malaria and so potential carriers of the parasite) (Lambin et al., 2010). These areas can be permanent, like niayes, market gardens, marshlands and water retention basins. But they can also be temporary, in the case of drainage channels and floodplains. This is of particular importance in the consideration of malaria risk. Indeed, malaria is a disease with a seasonal transmission in Dakar, with one of the causes being the increase of water areas during the rainy season. Estimation of the location of potential Anopheles breeding sites (i.e., the location of larval development) was carried out using remote sensing techniques. These kinds of methods are globally well-known in the case of vector-borne diseases (in the Senegalese case, see Machault et al., 2009a). A set of GIS layers was created in order to to locate these areas by extracting environmental variables from satellite images. A map of "the potential breeding sites in 2008" has been developed in a French National Research Agency (FNRA ACTU-PALU) programme.[13]

Figure 2 shows this map of potential breeding areas, i.e., sites with water and dense vegetation.

A zone based on the distance to potential breeding sites was also computed. Anopheline density is inversely proportional to the distance to larval habitats. In the literature, the flight distance of a mosquito in a dense urban environment does not exceed 600 metres (Salem et al., 1994; Machault et al., 2012). Thus, distance calculations from the layer potential breeding sites have been performed by estimating a risk zone between 0 and 600 metres, in effect creating an exposure surface for each census district. Each Census District (CD) has been informed about the percentage of its area considered within 600 metres of a potential breeding site.

12 http://svr-web.cse.sn/

13 A maximum likelihood supervised classification was carried out, followed by a post-classification smoothing, and finally a correction of the image. Indices such as NDVI were at that point in time added by a decision tree and converted into two classes: 1and 0. The pixels classified into 1 are water or dense vegetation, while the remainder is 0. These data have been integrated into the GIS software MapInfo.

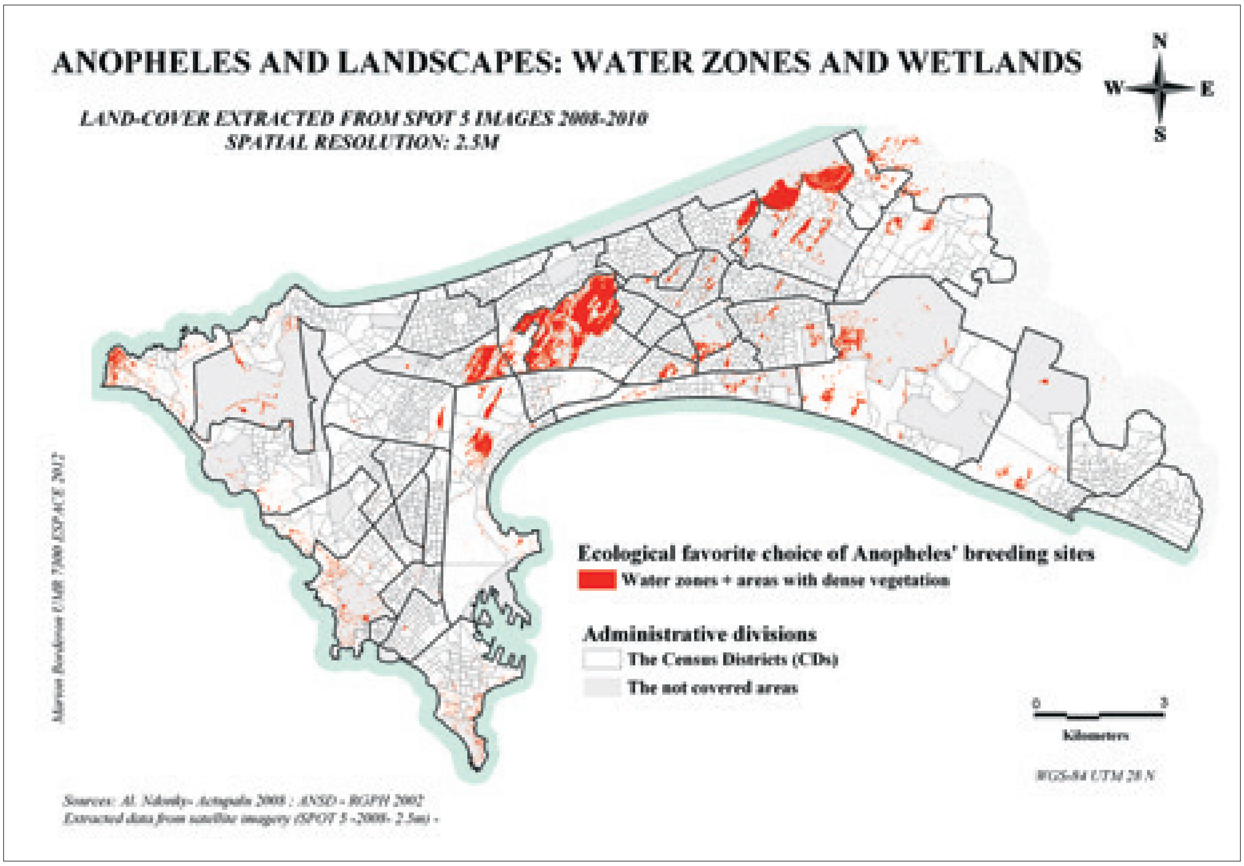

Figure 2: Map of potential breeding sites. Source: own draft.

However the risk of being bitten is also dependent on population density. The more populated the CD is, the probability of being bitten diminishes. The map was validated based on field data and work from the Centre de Suivi Ecologique (CSE) on floods.

C. Density versus risk of malaria exposure

Population density must be taken into account because of its dilution effect on bites. Density of buildings can provide further information if other precise population data are not available (Linard et al., 2010). A dasymetric map has been created using both density of buildings and population data. The principle of dasymetric mapping is to adjust the human population densities to the living space exclusively (Mennis, 2003). In Dakar, population densities are provided by CD. But CDs are not completely covered by built-up areas. Dasymetric mapping enables to recalculate the actual population density (the net density in fact) excluding areas of vegetation, water, bare soil and roads. Figure 3 shows the mapping of the urban net densities and the location of pixels with built-up areas.[14]

14 An ISODATA unsupervised classification was first performed on 4-band image with 2.5m spatial resolution. The unsupervised classification was favored to obtain a pixel to pixel classification. It gives a more "fragmented" result and therefore more conducive to identify only the buildings, regardless of their very close environment (roads, paths, courtyards, etc). It was set to generate 25 types of soil. Each pixel of the image was, therefore, affected by the algorithm to one of these classes. Following this automatic processing, the 25 classes were reassigned manually and by photo-interpretation to one of two classes: built or unbuilt (without distinction of the type of the urban environment). The output image was then a binary image: built/unbuilt. The choice of many classes at baseline (25) was used to limit confusion between the land cover types. The following calculation was applied to all pixels in the image: Net Density= (CD density x built-up area) /area of CD. It is recognized here that inaccuracies may have been introduced by not excluding systematically the non-residential buildings in the "built" class. The quality of the classification on the built / unbuilt differentiation is 88% (overall accuracy = 94%).

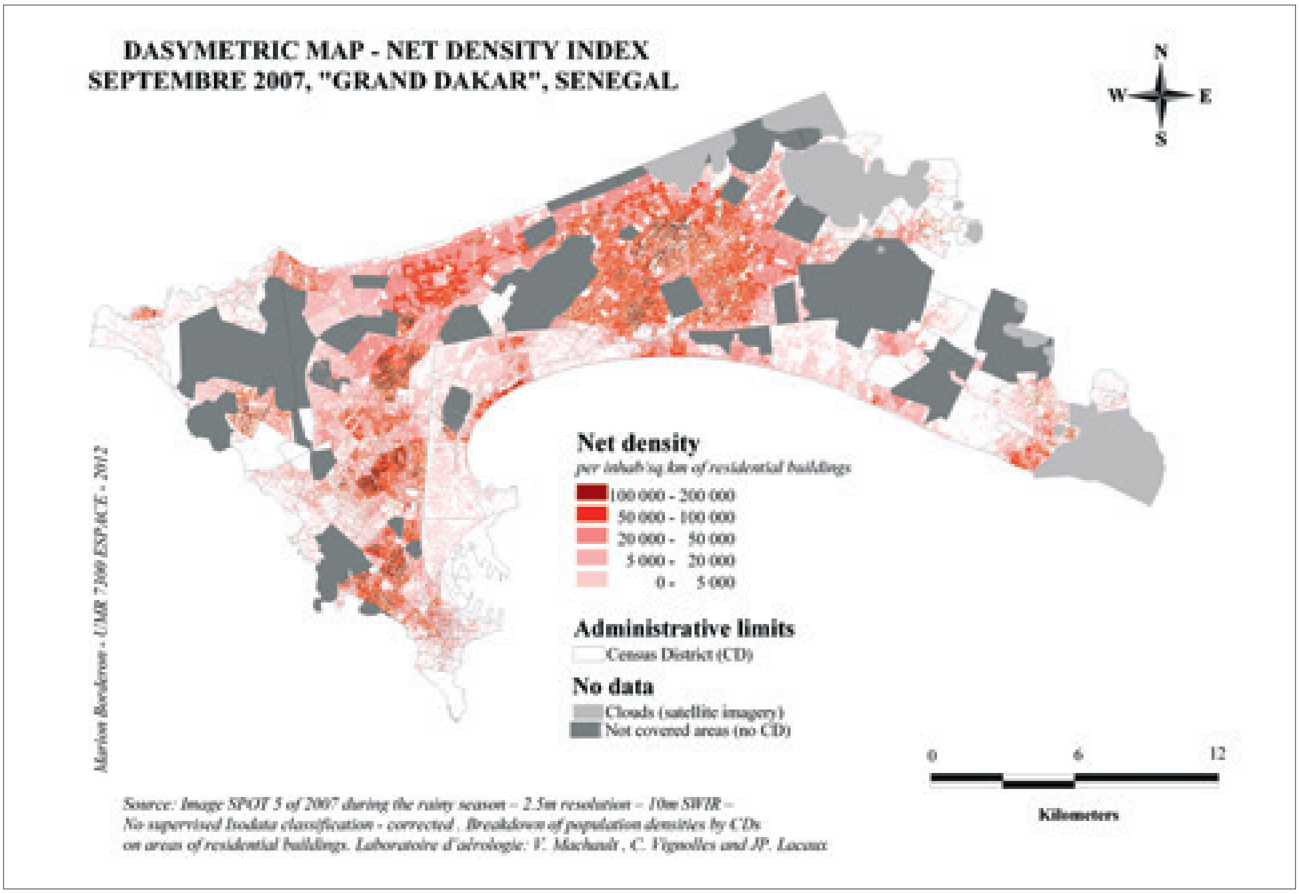

Figure 3: Net density in the agglomeration of Dakar. Source: own draft.

D. Social vulnerability: how to characterize the vulnerable groups?

Since the 1970s the concept of vulnerability has evolved from an initial characterization of social vulnerability that defined poverty solely in terms of household income (O´Keefe et al., 1976) to one that now recognizes that living conditions can provide data on vulnerability that can supplement or replace measurements of poverty by income alone. This is because in many developing countries formally declared incomes are insufficient to assess the economic situation. Therefore, an increasing use of non-monetary approaches can be seen in the literature, including the measure of poverty through the study of living conditions of inhabitants (for a Senegalese context, see Minvielle et al., 2005). Moreover, the consideration of demographic variables, the residential environment quality and the level of education must be taken into account because social vulnerability is not limited to wealth inequalities. Inspired by the creation of the Social Vulnerability Index SoVI (cf.http://webra.cas.sc.edu/hvri/products/sovi.aspx), a social vulnerability metric is implemented on the conurbation of Dakar.

E. Constructing and mapping social vulnerability in the region of Dakar

The census data includes 160 variables which are divided into five major categories and 17 subcategories. These five major groups incorporate the classical categories found in the literature to characterize the social vulnerability of households.[15]

15 They include: demographic structure of population (e.g., age, sex ratio, household size; quality of housing (e.g., housing materials, type of dwelling, number of rooms, number of people per household and concession) resources (e.g., equipment, electricity, drainage system for wastewater, garbage collection, quality latrines) education (e.g.,education level, practiced languages), and social status (e.g. activity of head of household, occupation status, marital status).

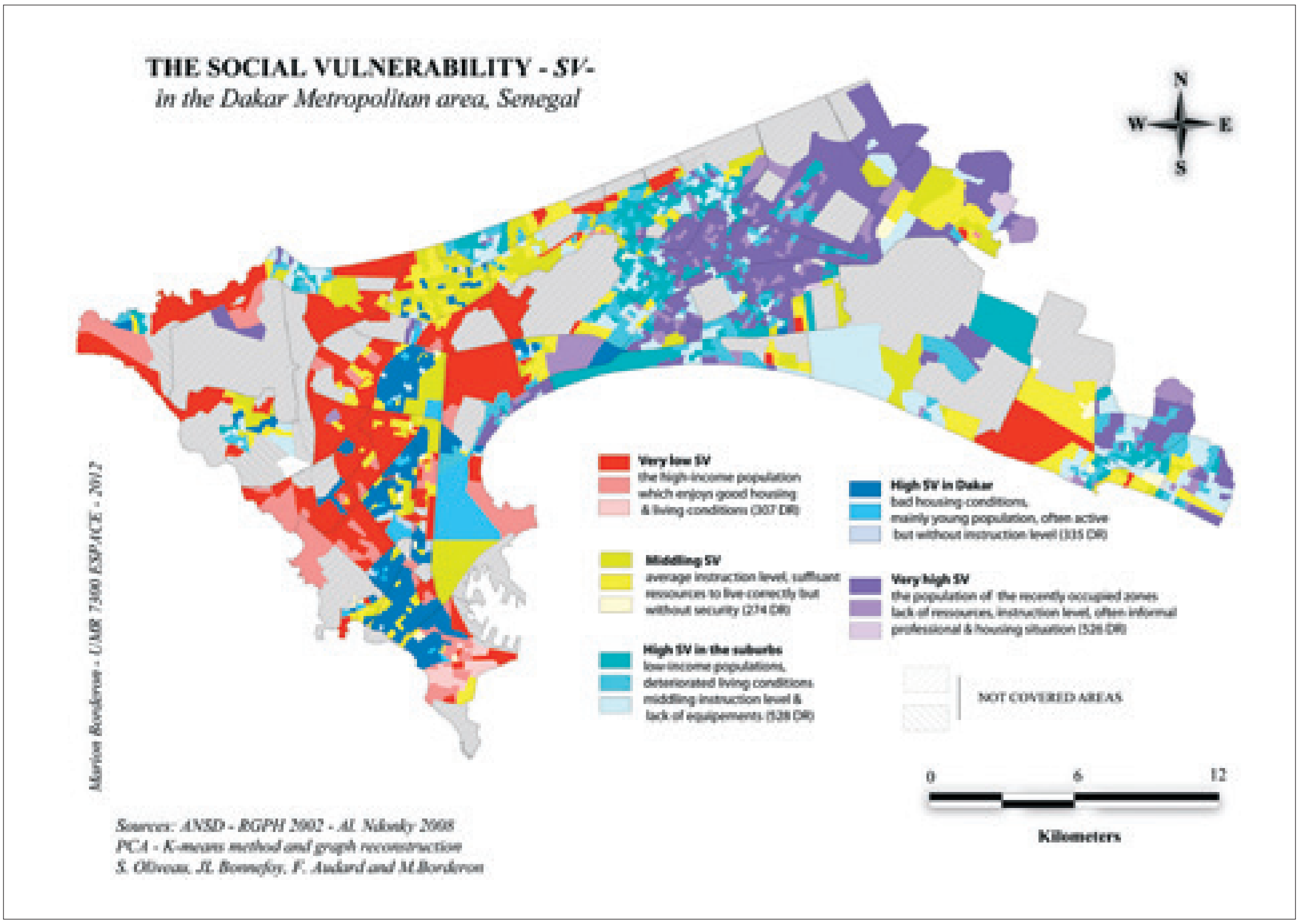

Figure 4: The clustering analysis results of the social vulnerability in Dakar. Source: own draft.

Several exploratory analyses were conducted to reduce and synthesize the information contained in the data. Principal Component Analyses (PCA) were performed on each of the 17 subcategories to allow the analysis of the reductions, through subgroups. A clustering was then carried out in order to construct a classification of individuals into classes as homogeneous and as distinct from each other as possible.[16] The clustering by k-means method allows the distance of each individual at the centre of gravity of its class to be easily obtained. These results are mapped in Figure 4; the classes are described by five different colours while the distance of the individual to its class is specified by the variation of the tint of the colour. When the individual is near the centre of gravity in its class, the colour is dark. Individuals who are clear are on the sidelines of the class.

The mapping of social vulnerability highlights the limits between Dakar and other towns. The town of Dakar, although heterogeneous, includes more CDs where the social vulnerability is low. The very low SV profiles include households that are best equipped (over-representation of air conditioning and automobiles), best integrated (higher activity rates) and live in flats which they do not own.[17] In contrast, to the east, especially in the direction of Pikine and the expansion of urbanization, the situation is much more problematic. The data structure is also interesting. For example, the patterns of social vulnerability differ between Dakar and "its suburbs", including Pikine and Guédiawaye. The precariousness is important in both cases, but does not have the same effects.

The most vulnerable (very high SV) are characterized by a strong lack of equipment. This pop-

16 The PCA and the clustering by k-means method have been performed with XLSTAT.

17 In a low city like Dakar, living in an apartment is a social marker (hyper centrality of the residence), often associated with its function: accommodation by the employer. If the property avoids partly poverty, it does not always mean a sign of wealth.

ulation is mostly young (18 to 35-years-old) and married. Basic infrastructure (water, electricity) are absent for 30 per cent of households and less than 10 per cent have garbage collection. Moreover, their education is limited to primary school level (90 per cent). They come primarily from recent migrations and they have settled where they could, in precarious conditions. For the high SV profiles, the situation is somewhat different but also historically constructed. The difference between the high SV profile in the town of Dakar and the high SV profile of census districts east of the city is primarily based on access to employment and urban amenities. In the suburbs, mainly in the old Pikine, the facilities are often outdated and the living conditions have deteriorated in recent years. The "poor zones" of the town centre more often live in precarious housing (10 per cent live in wooden huts) without facilities and the levels of education are weak.

Globally, the number of individuals per concession is high and the population rather young. Professionally, most of the people are "independent", having some small formal and informal jobs. The average category is represented with the middling social vulnerability. The educational level is not low, almost one person in two is is employed, but do not have high social status. The available resources are insufficient to protect them from hardship. Thus, the situation is not sustainable.

We can notice that in fact in the Dakar Metropolitan Area, there are three types of high social vulnerabilities (High or Very High SV, Medium SV and Low Vulnerability) and each has its own geography. Finally, these class profiles correspond to the empirical knowledge (based on fieldwork that has been done annually since 2008), to the results obtained by other work on the metropolitan Dakar (Ndonky, 2011), and to other more specific surveys on poverty (ANSD, 2007; Minvielle et al., 2005).

III. A mapping of vulnerability to malaria-infection

A. A map as an easy and legible tool

The final results are presented in a multi-variate map on the potential risk of malaria infection. The combination of the proximity to breeding sites (see Figure 2), the net density (see Figure 3) and the social vulnerability (see Figure 4) produce nine different combinations of risk. The ecological vulnerability (the proximity to the breeding sites) and the dilution effect of the bites (the net density) go in the same direction and form the individual exposure. This exposure is divided into three situations: negligible (very far from a potential breeding sites) high (close but high population density) and very high (close and low density). Social vulnerability, recalculated into three categories (the very low SV, the middling SV and the high (including the very high SV), establishes that the higher the social vulnerability is, the worse the protection against the bitese and health care will be. The map then allows us to identify sources where the circulation of the parasite could be strong and could cause an epidemic outbreak if there is no support for households by institutions or programmes to aid the most vulnerable.

In the model analysis, it is important to note four specific hotspots in the region, focused on the map. Their positions are hardly surprising and correspond to the districts that had suffered heavy flooding in 2005 and 2008 and are still under water. Resident populations are among the poorest and the habitat is largely informal in these areas. The separation of Dakar, although presenting a heterogeneous risk, and the suburbs of Pikine and Guediawaye are quite visible on the map. These comments go with the conclusion of a recent work on the two-tiered functioning of the conurbation of Dakar (Ndonky, 2011). Finally, the position of the urban fringes in the east can be highlighted as sensitive areas. The precariousness of the inhabitants and the lack of high densities accentuate the crossover between mosquitoes and humans. These areas, thus, give way to more or less vegetated plots, or even market gardening and are, therefore, attractive for Anopheles.

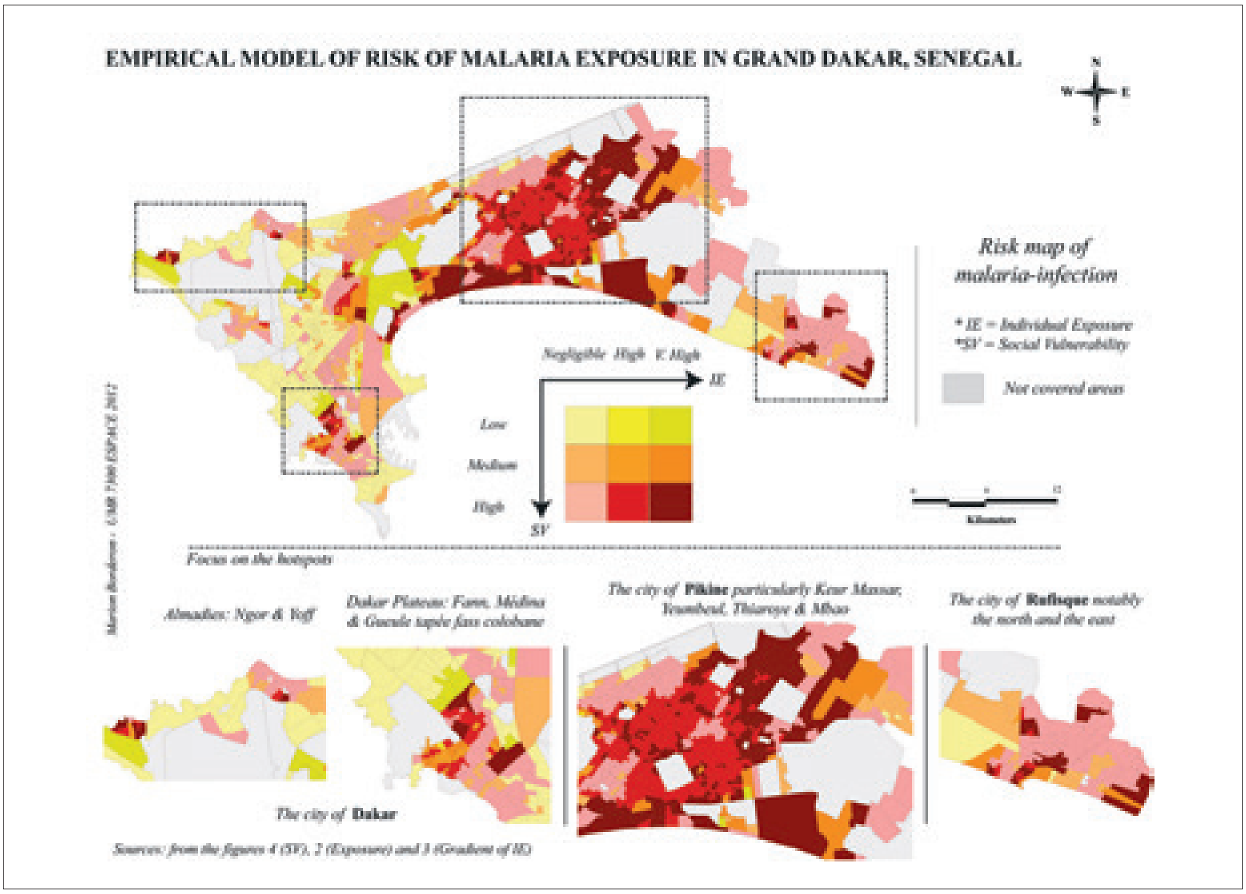

Figure 5: The potential risk of malaria-infection in Dakar. Source: own draft.

B. The choice of model components: distance between map and reality

This map is a synthesis of the factors involved in the analysis of malaria vulnerability. The initial postulates are that the hosts are bitten where they live and that the model is static and represents a general situation. This means two things: on the one hand, the effects of seasonality are not considered and, while on the other hand, mobility and nights spent outside are not counted. In addition, environmental and social vulnerabilities are monitored when they concern the place of residence. The issue in geography of: "Does it matter where I live?" has sparked debate for many years (Howe, 1986). Therefore, underlined in the map are the potential hotspots of infection that allow the maintenance of endogenous malaria and which deserve special attention during the rainy season.

Within the limits of the method, it seems important to emphasize that the action policies against malaria, which are distributed unevenly throughout the metropolitan area, were not emphasized here. In any case, it is estimated that these sensitive areas deserve to be properly characterized by specific programmes. In fact, not taking into account the degree of vulnerability and exposure of people and their territories leads to the failure of a system of risk management (Pelling, 2003).

The value of the model is to highlight the diversity and inequality of the urban landscape facing the epidemiological risk. Makers benefiting from this map will be able to check the information it contains and target vulnerable populations. The time of target programmes has come (RBM, 2002). From a general standpoint, the model suggests a localization of population at risk and the method allows the construction

of monographs on urban environments respecting the heterogeneity of these environments and thus the gradient of vulnerability that accompanies it.

A final point deserves to be raised. The choice of the mapping involves selecting thresholds for continuous variables. The problem arises here about the dilutive effect of bites. Unlike the distance to the breeding sites where we have some indications on the flight of mosquitoes and knowledge of a gradient of risk according to the distances, the bibliography does not include data or knowledge on the threshold of population density from which we can estimate that the probability of being bitten varies. The thresholds used here are thus arbitrary.

Conclusion

This custom-made methodology becomes a valuable tool for policymakers and practitioners which can be adapted to the hazard exposure. It graphically illustrates the geographic variation in malaria vulnerability. It shows where there is uneven capacity for preparedness and response and where resources might be used most effectively to reduce the pre-existing vulnerability. The final map is an efficient tool to provide information for the decision makers and to target vulnerable population and, thus, to improve resilience of the population. In addition, the advantage of the methodology is that it searches for some proxies in order to identify the characteristics of the urban settings, taking into account the heterogeneity of its landscapes. Finally, this paper concludes with the importance of such studies on vulnerability particularly in urban areas and for developing countries. Promoting studies that focus on this subject and reflecting on the concepts of risk/hazard and vulnerability is also a way to improve the strength of societies to withstand such shocks. The examples examined in this paper highlight the value of GIS and remote sensing to assess the risk of malaria infection and to provide useful information on the potential hotspots in the metropolitan Dakar.

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Social vulnerability assessment to natural hazards in Indonesia

Using model-based clustering with minimum message length

Tiodora Hadumaon Siagian, Purhadi, Suhartono and Hamonangan Ritonga

Abstract

Geographically, Indonesia is located in the region called as Pacific Ring of Fire which has made it especially prone to various natural hazards. Vulnerability assessments are considered to be effective solutions for reducing risk and losses of the impact of natural hazards. Indonesia has acknowledged the importance of recognizing social impacts of vulnerability in mitigating natural hazards through Act No. 24/2007 on disaster management. However, only little research on social vulnerability has been conducted in Indonesia. To date, there has been no institutionalized effort for social vulnerability assessment to natural hazards that covers all districts in Indonesia. Consequently, no comprehensive profile of social vulnerability is available as information for preventing larger risk and losses and reducing social vulnerability of baseline communities in Indonesia. Model-based clustering method is one of clustering methods that can be used to measure level of social vulnerability. This method is much preferred recently because it uses statistical principles and is considered to have more advantages compared to other classical clustering methods. This paper attempts to show how model-based clustering method with Minimum Message Length (MML) criterion can be used to assess social vulnerability to natural hazards. The results identified three true clusters in the social vulnerability data. These clusters can be used to identify critical districts with relative high of social vulnerability to the impacts of natural hazards. It is expected that relevant agencies both at provincial and district level can use these results and integrate them in mitigation, preparedness, response and recovery programmes of the impacts of natural hazards in Indonesia.

Keywords: social vulnerability, model-based clustering, minimum message length, Indonesia

Introduction

As a country located in the region called as Pacific Ring of Fire, Indonesia is prone to various natural hazards such as earthquakes, tsunamis, volcanic eruptions and landslides. In the last few years, Indonesia has experienced various devastating disasters, for example the Indian Ocean tsunami that hit Aceh and Nias in 2004, the earthquake causing tsunami in Southern Java in 2006, the earthquake in Padang in 2009, and the Mount Merapi volcano eruption in 2010. These disasters highlight the need for vulnerability assessments to reduce risk and the many losses of the impacts of natural hazards in Indonesia.

Many governments and numerous institutions are becoming more aware of the need for detailed and accurate assessment of vulnerability that would be suitable for developing effective solutions to reduce risk and losses from the impact of natural hazards. Still, the social aspects of vulnerability, have not sufficiently addressed as most vulnerability assessments put more emphasis on the biophysical process and built environment. In Indonesia, the importance of social aspects of vulnerability in mitigating natural hazards has been acknowledged through Act No. 24/2007 on disaster management[i]. However, only little research on social vulnerability has been conducted in Indonesia. So far, there is no institutionalized effort for a social vulnerability assessment to natural hazards that covers all districts in Indonesia. As a result, no comprehensive profile of social vulnerability is available as basis information for preventing larger risk and losses and reducing vulnerability of communities in Indonesia.

Over the past decade, many scientists use indexes as a tool to measure social vulnerability. One of the indexes to quantify social vulnerability is the Social Vulnerability Index (SoVI) proposed

by Cutter et al. (2003). However, as a composite index, SoVI has some limitations. Little is known about how to test the accuracy and validity of SoVI (Gall, 2007), it contains subjectivity in transformation, aggregation and weighting and cannot solve outlier problems. Less consensus for SoVI construction choices can also bring uncertainty into the index (Tate, 2012). Only few attempts have been done to validate this index due to several constraints such as difficulty in finding empirical evidence and difficult to estimate the index for methodological reasons (Fekete, 2009).

In addition to indexes, clustering methods can also be used to identify, categorize and classify vulnerable areas based on a combination of several indicators of vulnerability. However, classical clustering methods such as hierarchical agglomerative clustering or *K*-means clustering can lead to misleading results due to subjective judgment based on the similarity or the dissimilarity distance of the observations. Moreover, classical clustering methods lack a statistical basis and cannot solve the basic practical questions in clustering such as the true number of clusters in the data and which the best clustering method to be used. Model-based clustering can provide a principled statistical solution to these questions. In the model-based clustering approach, it is assumed that data can be modeled by a finite mixture model which consist of some components where each component follows a parametric distribution. As each component in a finite mixture model corresponds to a cluster, the problems of selecting an appropriate clustering menthod can be recast as problems of selecting the most appropriate statistical model (Fraley and Raftery, 2002; McLachlan, 2007).

This paper attempts to show how model-based clustering method with MML can be used to assess geographic variation of social vulnerability in Indonesia. Using data from the Indonesian National Statistics Office (BPS-Statistics Indonesia), the primary collector of statistical data in Indonesia, clusters of social vulnerability data have been identified and typology of social vulnerability at district level was constructed and visualized using ArcView GIS.

I. Concept of vulnerability and its assessment in Indonesia

The term of vulnerability has various definitions depending on the area of application. Vulnerability relates to the potential for damage and loss of life when a natural hazard occurs (Cutter, 1996). Wisner et al. (2004) define vulnerability as the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard while the United Nations Development Programme (UNDP) defines vulnerability as "a human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard" (UNDP 2004 cited in Birkmann 2006: 12).

In the aftermath of the devastating tsunami in Aceh and Nias in December 2004, a variety of studies that address risk and vulnerability reduction to natural hazards have been carried out in Indonesia either by Indonesian researchers or researchers from outside Indonesia. Under the German-Indonesia Tsunami Early Warning System (GITEWS) project, Post et al. (2007) carried out a risk and vulnerability assessment to tsunami and coastal hazards in order to develop indicators to measure vulnerability of coastal areas of Sumatra, Java and Bali exposed to tsunami risk. Using the decision tree technique, Post et al. (2007) formulated spatial distribution of risk and vulnerability of the coastal areas up to subdistrict level. Under the Last Mile Evacuation research project, Birkmann et al. (2008) conducted a socio-economic vulnerability assessment to tsunami in the context of early warning at household level in Padang City to give relevant information of the exposure of social groups living and conducting activities in the potentially affected areas, their access to tsunami warning alerts and potential response to the warning. Birkmann et al. (2008) found that socio-economic factors such as gender, employment sector, and economic status significantly influence the effectiveness of an early warning system and evacuation. Considering that the Bagelen sub-district in Purworejo, Central Java province is categorized as flood prone area,

Wigati (2008) conducted a study to improve the existing flood hazard map of Bogowonto River based on geomorphological factors and integrating it with social assessment from community approach. Hizbaron et al. (2011) carried out social vulnerability assessment in seismic prone areas of Bantul using Spatial Multi Criteria Evaluation.

Examining people's perception risk to natural hazards is also important in vulnerability assessment. Information of people's perception of risk behaviour, value and place in the event of an actual natural hazard impact provides valuable information for the recovery programme of the impacts of natural hazards (Dwyer et al., 2004). Considering this aspect, Lavigne et al. (2008) conducted a study examining people's behaviour in the face of volcanic hazards among Java communities living around Mount Merapi, Dieng Caldera and Sindoro twin volcanoes. Their study revealed that the Javanese people's behaviour in the face of volcanic hazards is shaped by the complex relations between risk perception, cultural beliefs and socio-economic constraints. Gaillard et al. (2008) studied ethnic groups' response to the 26 December 2004 earthquake and tsunami in Aceh and they concluded that people's behaviour has been deeply shaped by cultural, economic and political constraint. Gaillard's study has some weaknesses, however, for example, small sample size, covering only one village, and only capturing survivor's behaviour and not the victim's behaviour.

To achieve comprehensive and effective disaster risk reduction, building community resilience to natural hazards is considered to be important (Cutter et al., 2008; Djalante and Thomalla, 2010). This can be understood because vulnerability and resilience are conceptually linked. Both have several definitions. According to Cutter et al. (2008: 599), resilience is defined as "a system's capacity to absorb disturbance and re-organize into a fully functioning system", while Djalante and Thomalla (2010) discussed a number of concepts and interpretations of resilience in the context of natural hazards and concluded that resilience can be considered as both a process and an outcome.

So far, only few resilience assessments have been carried out in Indonesia. Using a Social Vulnerability Index and Place Vulnerability Index, Utami et al. (2009) studied the level of differences of disaster resilience in 55 villages affected by Mount Merapi and found that regional disaster resilience does not depend only on the distance to the sources of hazard, in this case a volcano, but it can be affected by other factors such as, the existence of resources and coping capacities of communities in the villages. The vulnerability assessments conducted in Indonesia, described in this section, cover limited areas (see Table 1). None of them extends to an entire region of Indonesia.

A systematic social vulnerability assessment needs a proper conceptual model which fits the context, target and structure of the research. Such a model of vulnerability should essentially be based upon existing data and can be updated (King and MacGregor, 2000). A conceptual model is one important step for developing and identifying systematic vulnerability indicators (Downing, 2004 in Birkmann, 2006). This paper utilizes the Hazards of Place model proposed by Cutter et al. (2003), which describes the interaction between biophysical vulnerability (exposure) and social vulnerability. The interconnection between these two components forms the overall place vulnerability, which in turn influences the initial conditions of risk-mitigation capabilities (Toscano, 2011).

II. Study area

Indonesia, an archipelago country, is located between 6°08′ North and 11°15′ South latitude and between 94°45′ and 141°05′ East longitude (BPS, 2010). It lies between the Asian and Australian continents. It is bounded by the South China Sea in the North and the Pacific Ocean in the North and East, and the Indian Ocean in the South and West. Indonesia is administratively divided into provinces and each province is divided into districts which made up of regencies (Indonesian: *Kabupaten*) and cities (Indonesian: *Kota*). Districts are divided into sub-districts (Indonesian: *Kecamatan*) and sub-districts are divided into villages (Indonesian: *Desa*).

Researcher	Vulnerability assessments	Methodology	Strengths	Weaknesses
Post and others (2007)	Risk and vulnerability assessment to tsunami and coastal hazards	Decision tree technique	Two scales of assessment, i.e., district and sub-district level	Limited coverage (Padang, Cilacap and Kuta)
Birkmann and others (2008)	Socio-economic vulnerability assessment to tsunami	Spatial analysis	Usage of vulnerability indicator framework	Limited coverage (Padang city)
Wigati (2008)	Vulnerability assessment to flood hazard	Regression and chi-square method	Determination of physical factor and social economy condition	Limited coverage (Bagelen sub-district)
Lavigne and others (2008)	Risk assessment focus on people's behaviour in the face of volcanic hazards	Analysis based on questionnaire-based surveys and interviews	Identification of factors in shaping people's behaviour	Only covered Javanese communities living around Mount Merapi, Dieng Caldera and Sindoro twin volcano
Gaillard and others (2008)	Risk assessment to earthquake and tsunami focus on ethnic groups response and their protect capacity	Questionnaire-based survey and creation of an ethnographic profile of each ethnic group	Combine quantitative and qualitative data	(i) Only covers survivors' behaviour and not behaviors of the victims (ii) Small number of respondents (iii) Only covered limited areas (Kajhu village)
Utami and others (2009)	Assessment of regional district resilience by social vulnerability index	Social vulnerability index, Analysis factor technique	Provide small area statistics data	Limited coverage (55 villages around Mount Merapi)
Hizbaron and others (2011)	Social vulnerability assessment to seismic hazard	Spatial multi criteria evaluation	Using spatial unit	(i) Contain ecological fallacies; spatially, only covered limited areas (Bantul district)

Table 1: Selected vulnerability assessments conducted in Indonesia. Source: Summarized by authors.

Disaster	Deaths	Injured	Missing
Drought	2	0	0
Earthquake	15,562	70,046	1,513
Tsunami	3,519	273	2,957
Earthquake and tsunami	167,768	3,979	6,333
Eruption	78,598	2,171	7
Flood	18,598	194,618	2,490
Landslides	1,745	1,975	142
Floods and landslides	2,203	40,356	5,356

Table 2: Fatalities for major disasters types in Indonesia, 1812–2012. Source: dibi.bnpb.go.id.

As of January 2011, there were 33 provinces, 497 districts (399 regencies and 98 cities), 6,694 subdistricts and 69,249 villages (Depdagri, 2012). Total land area of Indonesia is approximately 1.9 million km^2 and the coastline length is approximately 104,000 km (BPS, 2012). A map of Indonesia with its 33 provinces can be seen in Figure 1.

The incidence of various disasters is increasing in Indonesia in the last few years. Based on data from the past two decades, there are six dominant natural hazards in Indonesia, i.e., earthquake, tsunami, landslide/soil movement, volcanic eruption, flood and drought (BNPB, 2010). Human loss is one indicator of disaster impacts, hence Table 2 presents data of fatalities in Indonesia for several major disasters types in the period 1812–2012.

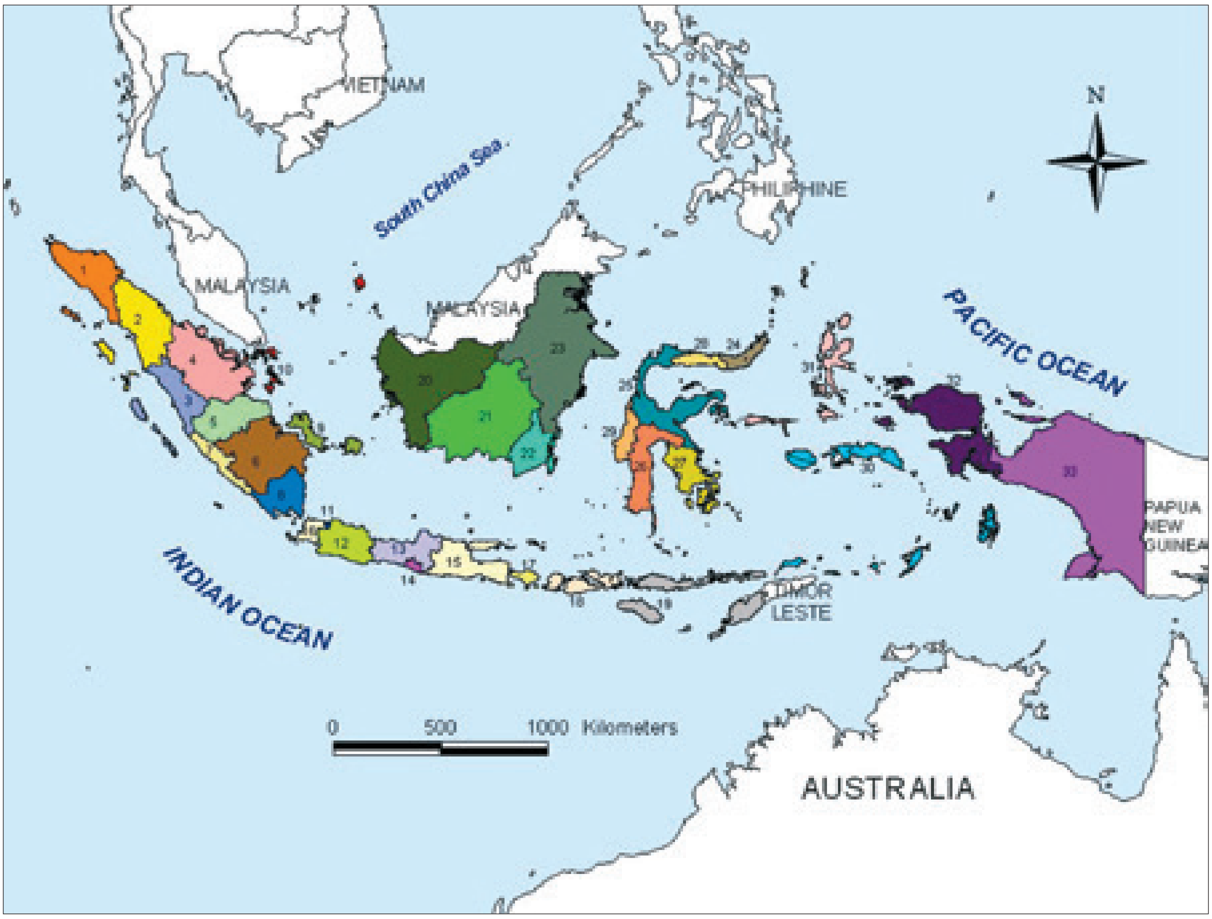
III. Data and methods

Given the inadequacies of the administrative record system in Indonesia, socio-demographic data relies on annual household surveys and the population census conducted by BPS-Statistics Indonesia. For the annual household surveys, the data can only be analysed up to district level due to the sampling size. There are 497 districts in the country that were used in this analysis.

A. Social vulnerability data

Social vulnerability influences community abilities to recover from the impact of natural hazards as social vulnerability is resulted partly by social inequalities and partly by place inequalities (Cutter et al., 2003). The factors that cause social vulnerability include personal wealth, age, density of built environment, single sector economic dependence, housing stock and tenancy, race, ethnicity, occupation, infrastructure dependence (Cutter et al., 2003), security factors (homes, public facilities, schools, colleges, hospitals, fire stations, other public infrastructure, social welfare), economic factors (wealth, income equality) and social factors (age composition, gender, family structure, occupation, employment, disability, risk perception, access to political power) (Tapsell et al., 2010).

Based on a review onf the current literature on vulnerability assessment (Cutter et al., 2003; Cutter and Emrich, 2006; Rygel et al., 2006; Birkmann 2006; Utami et al., 2009; Cutter et al., 2009; Wood et al., 2010), 13 variables were selected in the first indicator set. Other potential indicators of social vulnerability, such as medical services and 'special needs' populations, are excluded in this paper due to limited data availability at district level. Multicollinearity tests were done to avoid variables giving the same information and as a result ten variables were retained.



497 districts are spread over in the 33 provinces of Indonesia

1 Aceh

2 Sumatra Utara

3 Sumatra Barat

4 Riau

5 Jambi

6 Sumatra Selatan

7 Bengkulu

8 Lampung

9 Bangka Belitung

10 Kepulauan Riau

11 DKI Jakarta

12 Jawa Barat

13 Jawa Tengah

14 DI Yogyakarta

15 Jawa Timur

16 Banten

17 Bali

18 Nusa Tenggara Barat

19 Nusa Tenggara Timur

20 Kalimantan Barat

21 Kalimantan Tengah

22 Kalimantan Selatan

23 Kalimantan Timur

24 Sulawesi Utara

25 Sulawesi Tengah

26 Sulawesi Selatan

27 Sulawesi Tenggara

28 Gorontalo

29 Sulawesi Barat

30 Maluku

31 Maluku Utara

32 Papua Barat

33 Papua

Figure 1: The location of the study area. Source: Authors.

Selected variables	Effect on Social Vulnerability	Min	Max	Mean ($\bar{X}$)	St.Dev (s)
Percentage of children under 5 (X1)	Increases	5.53	17.17	10.05	1.8
Percentage of the elderly (X2)	Increases	0.00	13.45	4.76	2.3
Percentage of female (X3)	Increases	43.83	54.03	49.48	1.6
Percentage of female headed household (X4)	Increases	0.51	27.43	10.61	3.9
Percentage of poor people (X5)	Increases	1.67	49.58	15.51	9.4
Percentage of illiterate people (X6)	Increases	0.08	86.20	9.26	11.2
Percentage of population aged 15 and above with low education attainment (X7)	Increases	10.42	97.03	50.45	15.2
Household size (X8)	Increases	3.50	7.06	4.86	0.6
Percentage of households without electric lighting (X9)	Increases	0.00	100.00	13.49	19.1
Population growth (X10)	Increases	-2.88	18.65	1.99	2.1

Table 3: Population characteristics influencing social vulnerability and descriptive statistics. Source: Authors. Notes: St.Dev = standard deviation, Min = minimum, Max = maximum

Based on the literature on social vulnerability assessments, the effect of these selected variables on social vulnerability is determined and presented in Table 3. This table shows that all selected variables give positive effect on social vulnerability, for example, the higher the percentage of children under five the higher social vulnerability level. No values are missing in the social vulnerability data. Table 3 also presents descriptive statistics of the selected variables which will be useful for confidence intervals calculation.

B. Model-based clustering with minimum message length

In clustering methods, there are three major classes, i.e., hierarchical, partitioning and model-based method. The model-based clustering method is increasingly preferred over heuristic clustering methods due to its sound mathematical basis and the interpretability of the results (McLachlan, 2007). In the model-based clustering approach, it is assumed that the data comes from a mixture of several subpopulations represented by a mixture of underlying probability

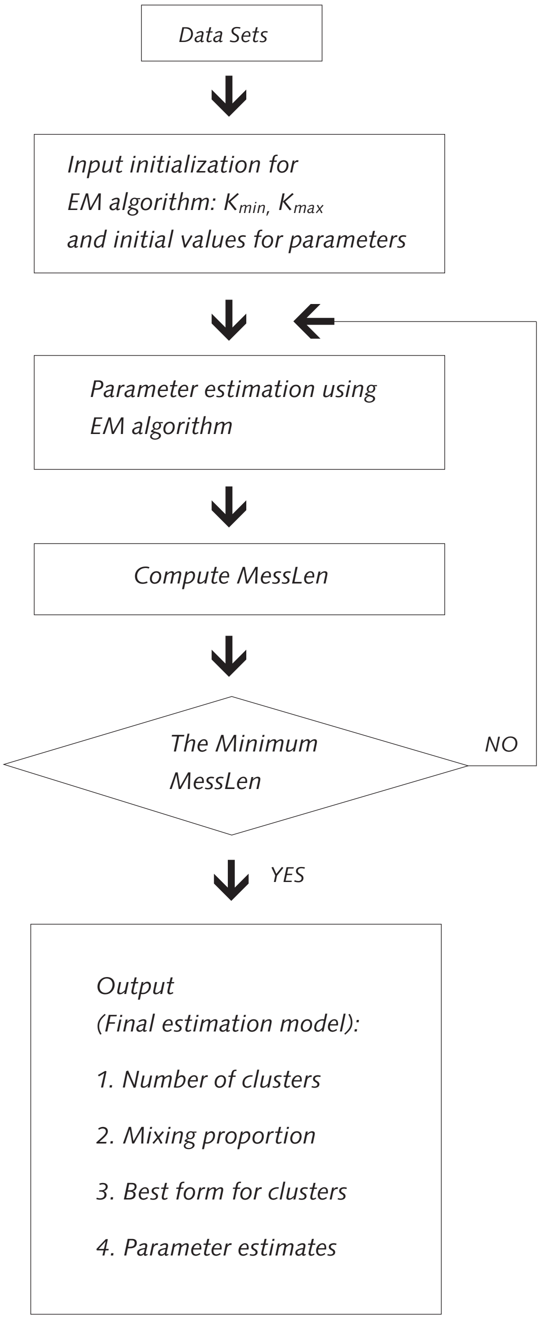


Figure 2: Procedure Algorithm of Model-Based Clustering with MML criterion. Source: Authors. (Program of the algorithm was written in MATLAB)

distributions in which each component represents a different cluster (Fraley and Raftery, 1998). This leads to a mathematical probability model for the data called a finite mixture model.[ii] In the finite mixture model framework, a separate model (distribution) applies to each cluster, and is characterized by a set of parameters.

There are two main processes in finite mixture models, i.e., parameter estimation and model selection. Generally, parameter estimation is conducted using maximum likelihood method. A best model is selected by an informational criterion, such as Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). The MML criterion is considered to outperform other criteria (Agusta and Dowe, 2002; Bouguila and Ziou, 2007). Basically, the MML principle is an invariant Bayesian point estimation and model selection technique based on the Shannon's information theory which connects computer science and statistics.

In this paper, each component of the mixture model is assumed to follow multivariate normal distribution.[iii] We employed MML criterion[iv] proposed by Figueiredo and Jain (2002) to select the best model and to determine the number of clusters. When a model is selected, the number of clusters in the mixture model is also obtained simultaneously. Basically, the MML criterion is based on inductive inference where the data are considered to form a message, which means that all information of data are encoded into binary string (the message) then they are transmitted from an imaginary sender to an imaginary receiver. The idea of the MML is to find an optimal model that minimizes the coding length of a message that consist of two parts; the first part encodes the model of data (the assertion), while the second part encodes the data based on the model stated in the assertion. The MML in mixture model was initially proposed by Wallace and Boulton (1968). The procedure for model-based clustering with MML criterion is illustrated in Figure 2.

IV. Results

The MATLAB program of the algorithm of model-based clustering with MML was applied to the social vulnerability data. To study the robustness with respect to the random initialization, the algorithm was run 100 times. The output of model-based clustering with MML algorithm comprises the following five elements: the selected number of the clusters, the mixing proportion of the clusters, the estimates of the means of the clusters, the estimates of the covariance of the clusters, the successive values of the cost function (MessLen) and the total number of iterations performed. After 38 iterations, the algorithm can identify three clusters in social vulnerability data (see Figure 3). This figure shows that the three formed clusters overlap. Since model-based clustering with other criterion, i.e., BIC criterion failed to distinguish data that tend to overlap (Siagian et al., 2011), the results show the advantage of this algorithm. The mean for the three identified clusters, variance and mixing proportion between clusters are presented in Table 4.

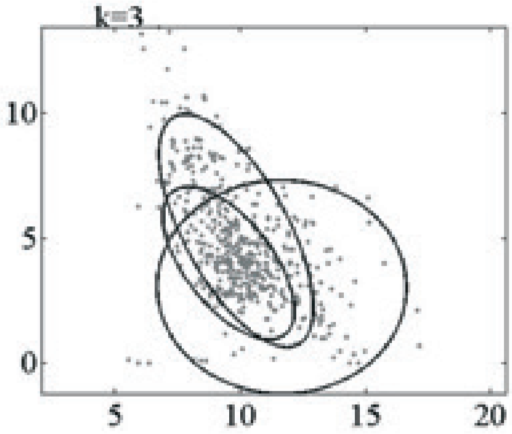


Figure 3: The best estimate of number of clusters. Source: Authors.

Variable	Mean			Variance		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
X_1	9.83	9.53	11.66	2.36	1.72	6.17
X_2	5.31	4.01	3.06	5.39	2.31	4.53
X_3	49.49	50.05	48.77	2.11	1.36	4.80
X_4	10.70	10.92	9.86	12.96	8.25	31.21
X_5	13.67	8.69	31.98	30.05	16.10	106.77
X_6	8.12	2.66	22.08	28.10	3.00	500.59
X_7	53.86	27.70	60.62	106.88	49.27	257.15
X_8	4.74	4.88	5.42	0.22	0.18	0.58
X_9	10.07	1.41	43.34	100.49	1.90	888.00
X_{10}	1.56	2.17	3.81	1.43	2.38	15.34
Mixing proportion (π_k)	0.81	0.11	0.08			

Table 4: Cluster means, variances and mixing proportion for 10 variables, 2010. Source: Authors.

Variable	Cluster 1	Cluster 2	Cluster 3
X_1	*Moderate*	*Low*	*High*
X_2	High	Moderate	Low
X_3	*Moderate*	High	Low
X_4	*Moderate*	High	Low
X_5	*Moderate*	*Low*	*High*
X_6	*Moderate*	*Low*	*High*
X_7	*Moderate*	*Low*	*High*
X_8	Low	Moderate	*High*
X_9	*Moderate*	*Low*	*High*
X_{10}	Low	Moderate	*High*

Table 5: The status of social vulnerability level based on comparison of cluster means to the 95 per cent of confidence interval, 2010. Source: Authors.

In clustering procedure, when the clusters have been formed, the next step is interpreting or labelling the formed clusters. In this paper, interpretation of the formed clusters is carried out using confidence intervals for means.[v] The results of the comparison of cluster means to the 95 per cent of confidence interval for unknown means are provided in Table 5. This table shows the interpretation result of each cluster of the status of social vulnerability level for each variable.

Finally, classification of the formed clusters by social vulnerability level was done by creating a summarization based on the results of Table 5. The classification result is presented in Table 6. The majority of districts in Indonesia are in moderate level of social vulnerability and less than 20 per cent is in high level of social vulnerability.

Cluster	Number of members	Percentage	Social vulnerability level
Cluster 1	236	47.48	Moderate
Cluster 2	173	34.81	Low
Cluster 3	88	17.71	High

Table 6: The Classification of clusters by social vulnerability level, 2010. Source: Authors.

No	Province	District	Region
1	Aceh	Pidie	Western Indonesia
2	Aceh	Aceh Utara	Western Indonesia
3	Sumatra Utara	Nias	Western Indonesia
4	Sumatra Utara	Nias Selatan	Western Indonesia
5	Jawa Timur	Sampang	Western Indonesia
6	Nusa Tenggara Barat	Lombok Timur	Eastern Indonesia
7	Nusa Tenggara Timur	Sumba Barat Daya	Eastern Indonesia
8	Nusa Tenggara Timur	Sabu Raijua	Eastern Indonesia
9	Papua	Deiyai	Eastern Indonesia
10	Papua	Intan Jaya	Eastern Indonesia

Table 7: Selected districts categorized in the high social vulnerability level and their region.
Source: Authors.

Table 7 lists selected districts and their regions categorized in the high social vulnerability level. Our results found that districts which have a long history of conflict in such as Aceh, (e.g., Pidie, Pidie Jaya, Aceh Utara) and districts struck by the tsunami in 2004, (e.g., Nias, Nias Selatan, Nias Utara and Nias Barat) are included in the high social vulnerability cluster (see Figure 4). Moreover, it was not surprising to find that Sampang in Jawa Timur Province is included in the high social vulnerability because in 2010, in Sampang, poor people constituted 32.47 per cent, while 84.50 per cent of its population had low level of education. All districts in Lombok Island and Sumba Island are included in the high social vulnerability cluster whereas 26 of 29 districts in Papua are categorized in the high social vulnerability.

Identifying which districts included in high level of social vulnerability becomes important to target for interventions. In line with this motive, spatial variation among districts in Indonesia was carried out. Determination of spatial variation in social vulnerability among districts in Indonesia is useful as it can show districts with relative high social vulnerability level to the impact of natural hazards. Hence, based on Table 5, a typology thematic map using ArcView GIS based on the derived clustering was created (see Figure 4). Of the 88 districts which classified in the high level of social vulnerability cluster, 73 (82.9 per cent) are located in the Eastern Indonesia. This finding confirmed the information that there is uneven regional development between Western Indonesia (consisting of Java, Bali, Sumatra, and Kalimantan) and Eastern Indonesia (consist of Sulawesi, Nusa Tenggara archipelago, Maluku archipelago and Papua).

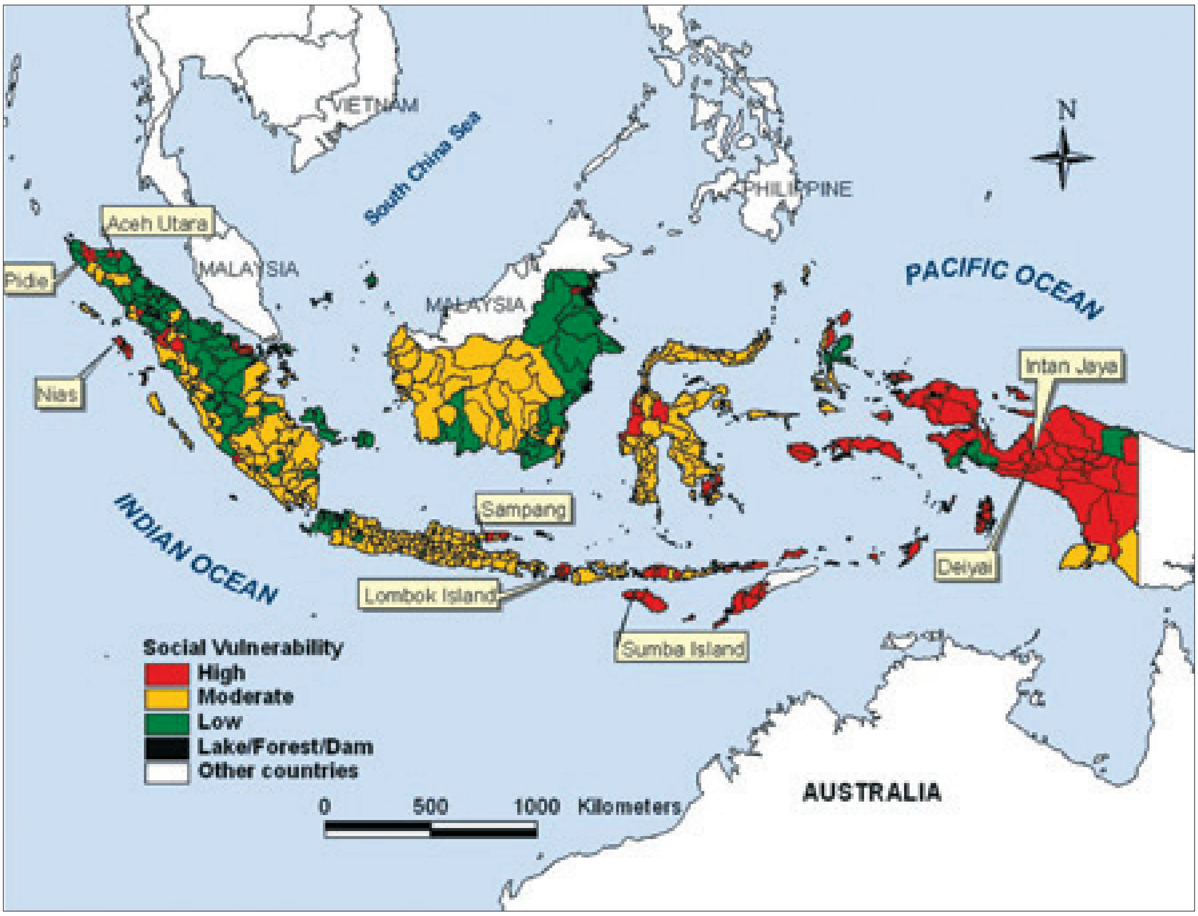


Figure 4: Map showing the clusters of social vulnerability level that each district in Indonesia belongs, 2010. Source: Authors.

V. Conclusion

In this paper, we proposed a prototype of social vulnerability assessment using model-based clustering with a MML approach which identified three true clusters of social vulnerability data in 2010. As in practice most data are assumed to follow multivariate normal distribution, we also assumed that data follow normal multivariate distribution. However, in reality not all data followed multivariate normal distribution. Data containing outliers are usually more appropriate modelled by multivariate t distribution. Thus, developing robust model-based clustering method with multivariate t distribution assumption will give better results for data contain outliers. While this will become a further challenge for assessing social vulnerability using model-based clustering approach, this paper makes a significant contribution to the advancement of methods for vulnerability assessments.

In addition to the methodological improvements, this paper also has practical applications. For example, the typology map shows that the capacity for preparedness and response is uneven between western Indonesia and eastern Indonesia. When resources are limited, this map can be used to prioritize those districts with relative high of social vulnerability level to the impact of natural hazards. By doing this, resources might be used most effectively to reduce the pre-existing vulnerability.

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Endnotes

i, ii, iii, iv, v

[i]The Act No. 24/2007 has shifted disaster management paradigm in Indonesia from a responsive orientation to preventive orientation and social aspects has been acknowledged as stated in the article 31.

[ii]Let $\boldsymbol{x}_1, \boldsymbol{x}_2, \ldots, \boldsymbol{x}_n$ denote a p-dimensional observations of size n.The probability density function of the finite mixture is

$$f(\boldsymbol{x}_i; \Psi) = \sum_{k=1}^{K} \pi_k f_k(\boldsymbol{x}_i; \boldsymbol{\theta}_k), \quad i = 1,2, \ldots, n \quad (1)$$

where K is the total number of components of the mixtures and π_k, the weight, also called the mixing proportions, are non-negative and add up to unity.

$$\pi_k \geq 0 \text{and} \quad \sum_{k=1}^{K} \pi_k = 1$$

mixing proportion is the probability that an observation belongs to cluster k. In finite mixture models framework, each component in the mixture model (1) corresponds to a cluster (McLachlan and Peel 2000; Fraley and Raftery 2002). In this paper, Bayes rule is used to allocate an observation into cluster $k$based on their posterior cluster membership probabilities

$$\tau_k(\boldsymbol{x}_i) = \frac{\pi_k f_k(\boldsymbol{x}_i)}{\sum_{k=1}^{K} f_k(\boldsymbol{x}_i)}$$

Hence, each observation is assigned to the cluster having the highest posterior probability that the observation originated from this cluster. For more detailed on model-based clustering, see the works of Fraley and Raftery (1998), McLachlan and Peel (2000) and Fraley and Raftery (2002).

[iii]Thus, the equation (1) has the form:

$$f(\boldsymbol{x}_i; \pi_k, \boldsymbol{\mu}_k, \Sigma_k) = \sum_{k=1}^{K} \pi_k f_k(\boldsymbol{x}_i; \boldsymbol{\mu}_k, \Sigma_k), \quad k = 1,2, \ldots, K; i = 1,2, \ldots, n$$

with

$$f_k(\boldsymbol{x}_i; \boldsymbol{\mu}_k, \Sigma_k) = \frac{1}{(2\pi)^{p/2} |\Sigma_k|^{1/2}} \exp\left\{-\frac{1}{2}(\boldsymbol{x}_i - \boldsymbol{\mu}_k)^T \Sigma_{\boldsymbol{k}}^{-\boldsymbol{1}} (\boldsymbol{x}_i - \boldsymbol{\mu}_k)\right\}$$

where $\boldsymbol{\mu}_k$ is mean vector and Σ_k is covariance matrix and $f_k(\boldsymbol{x}_i; \boldsymbol{\mu}_k, \Sigma_k)$is probability density function of the kth component. Therefore, the unknown parameters to be estimated are $(\pi_1, \ldots, \pi_{K-1}, \boldsymbol{\mu}_1, \ldots, \boldsymbol{\mu}_K, \Sigma_{\boldsymbol{1}}, .. \Sigma_{\boldsymbol{K}})$. These parameters are usually estimated by the maximum likelihood method using the Expectation Maximization (EM) algorithm (Dempster et al. 1977).

[iv]For the normal multivariate mixture model, the MML criterion with respect to parameter $\boldsymbol{\theta}$ is as follows,

$$MessLen = -\log h(\boldsymbol{\theta}) - \log f(\boldsymbol{x} \mid \boldsymbol{\theta}) + \frac{1}{2}\log|F(\boldsymbol{\theta})| + \frac{p}{2}\left(1 + \log\frac{1}{12}\right)(2)$$

where $h(\boldsymbol{\theta})$ is the prior probability, $f(\boldsymbol{x} \mid \boldsymbol{\theta})$ is the likelihood, $|F(\boldsymbol{\theta})|$ is the determinant of the expected Fisher information matrix, p is the dimension of $\boldsymbol{\theta}$ (Figueiredo and Jain2002). Estimation of the number of clusters is carried out by finding the minimum with regards to $\boldsymbol{\theta}$ of the equation (2).

[v]Confidence interval for unknown mean μ can be calculated using:

$$\bar{X} \pm Z_{\alpha/2}\left(\frac{s}{\sqrt{n}}\right)$$

where $\bar{X}$ is mean sample, s is standard deviation, n is sample size. We give an illustration of the calculation as follows:
For variable X_3 with $\bar{X} = 49.48$, $s = 1.6$, $n = 497$, and $\alpha = 5\%$ thus from table normal distribution $Z_{\alpha/2} = Z_{0.025} = 1.96$, an approximate 95% confidence interval for unknown mean μ is [49.37 – 49.59]. The status of social vulnerability level can be obtained by comparing means of each clusters as stated in Table 4 with this confidence interval.

	[49.37 – 49.59]	
48.77	49.49	50.05
Cluster 3 = Low	Cluster 1 = Moderate	Cluster 2 = High

As mean for cluster 3 is lower than the 95% confidence interval, it is categorized as low level, also because mean for cluster 2 is higher than the 95% confidence interval, cluster 2 is categorized as high level. Consequently cluster 1 is categorized as moderate level because its mean is still in the range of the 95% confidence interval.

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