UNIVERSITY OF SOUTHERN QUEENSLAND

SPATIAL ANALYSIS AND MODELLING OF FLOOD RISK AND CLIMATE ADAPTATION CAPACITY FOR ASSESSING URBAN COMMUNITY AND CRITICAL INFRASTRUCTURE INTERDEPENDENCY

A Dissertation submitted by

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Abstract

Flood hazards are the most common and destructive of all natural hazards in the world. A series of floods that hit the south east region of Queensland in Australia from December 2010 to January 2011 caused a massive devastation to the State, people, and its critical infrastructures. GIS-based risk mapping is considered a vital component in land use planning to reduce the adverse impacts of flooding. However, the integrated mapping of climate adaptation strategies, analysing interdependencies of critical infrastructures, and finding optimum decisions for natural disaster risk reduction in floodplain areas remain some of the challenging tasks. In this study, I examined the vulnerability of an urban community and its critical infrastructures to help alleviate these problem areas. The aim was to investigate the vulnerability and interdependency of urban community's critical infrastructures using an integrated approach of flood risk and climate adaptation capacity assessments in conjunction with newly developed spatially-explicit analytical tools.

As to the research area, I explored Brisbane City and identified the flood-affected critical infrastructures such as electricity, road and rail, sewerage, stormwater, water supply networks, and building properties. I developed a new spatially-explicit analytical approach to analyse the problem in four components: 1) transformation and standardisation of flood risk and climate adaptation capacity indicating variables using a) high resolution digital elevation modelling and urban morphological characterisation with 3D analysis, b) spatial analysis with fuzzy logic, c) geospatial autocorrelation, among others; 2) fuzzy gamma weighted overlay and topological cluster analyses using Bayesian joint conditional probability theory and self-organising neural network (SONN); 3) examination of critical infrastructure interdependency using utility network theory; and 4) analysis of optimum natural disaster risk reduction policies with Markov Decision Processes (MDP).

The flood risk metrics and climate adaptation capacity metrics revealed a geographically inverse relationship (e.g. areas with very high flood risk index occupy a low climate adaptation capacity index). Interestingly, majority of the study area (93%) exhibited negative climate adaptation capacity metrics (-22.84 to < 0) which indicate that the resources (e.g. socio-economic) are not sufficient to increase the climate resiliency of the urban community and its critical infrastructures. I utilised these sets of information in the vulnerability assessment of critical infrastructures at single system level. The January 2011 flood instigated service disruptions on the following infrastructures: 1) electricity supplies along 627km (75%) and 212km (25%) transmission lines in two separate areas; 2) road and rail services along 170km (47%) and 2.5km (38%) networks, respectively; 3) potable water supply along 246km (56%) distribution lines; and 4) stormwater and sewerage services along 33km (91%) and 32km (78%) networks, respectively.

From the critical infrastructure interdependency analysis, the failure of sewerage system due to the failure of electricity supply during the January 2011 flood exemplified the first order interdependency of critical infrastructures. The ripple effects of electricity failure down to road inaccessibility for emergency evacuation demonstrated the higher order interdependency. Moreover, an inverted pyramid

structure demonstrated that the hierarchy of climate adaptation strategies of the infrastructures was graded from long-term measures (e.g. elimination) down to short-term measures (e.g. protection).

The analysis with Markov Decision Processes (MDP) elucidated that the Australian Commonwealth government utilised the natural disaster risk reduction expenditure to focus on recovery while the State government focused on mitigation. There was a clear indication that the results of the MDP analysis for the State government established an agreement with the previous economic analysis (i.e. mitigation could reduce the cost of recovery by 50% by 2050 with benefit-cost ratio of 1.25).

The newly developed spatially-explicit analytical technique, formulated in this thesis as the *flood risk-adaptation capacity index-adaptation strategies (FRACIAS) linkage model*, integrates the flood risk and climate adaptation capacity assessments for floodplain areas. Exacerbated by the absence of critical infrastructure interdependency assessment in various geographic analyses, this study enhanced the usual compartmentalised methods of assessing the flood risk and climate adaptation capacity of flood plain areas. Using the different drivers and factors that exposed an urban community and critical interdependent infrastructures to extreme climatic event, this work developed GIS-enabled systematic analysis which established the nexus between the descriptive and prescriptive modelling to climate risk assessment.

Certification of Dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own efforts, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

Signature of Candidate | Date

ENDORSEMENT

Signature of Principal Supervisor | Date

Signature of Associate Supervisor | Date

Publications and Awards

Peer-Reviewed Conference Papers

Chapter 3

Espada, R., Apan, A. & McDougall, K., 2012. *Spatial modelling of adaptation strategies for urban built infrastructures exposed to flood hazards. In: Queensland Surveying and Spatial Conference 2012 (QSSC 2012), 13-14 Sept 2012*. Brisbane City, Surveying and Spatial Sciences Institute.

Espada, R. J., Apan, A. & McDougall, K., 2013. *Understanding the January 2011 Queensland flood: the role of geographic interdependency in flood risk assessment for urban community. In: Australia and New Zealand Disaster and Emergency Management Conference (ANZDMC) 2013, 28-30 May 2013*. Brisbane City, AST Management Pty Ltd. pp. 68-88. ISBN: 978-1-922232-04-5.

Chapters 4 to 5

Espada, R., Apan, A. & McDougall, K., 2013. *Using spatial modelling to develop flood risk and climate adaptation capacity metrics for vulnerability assessments of urban community and critical water supply infrastructure. In: 49th International Society of City and Regional Planners (ISOCARP) Congress 2013, 1-4 October 2013*. Brisbane City, International Society of City and Regional Planners (ISOCARP). ISBN: 978-94-90354-25-1.

Espada, R., Apan, A. & McDougall, K., 2013. *Using spatial modelling to develop flood risk and climate adaptation capacity metrics for assessing the vulnerability of urban community and critical electricity infrastructure. In: 20th International Congress on Modelling and Simulation (MODSIM) 2013,* Adelaide, Modelling and Simulation Society of Australia and New Zealand (MSSANZ), pp. 2304-2310. ISBN: 978-0-9872143-3-1.

Journal Papers

Chapter 5

Espada, R., Apan, A., McDougall, K, 2014. Vulnerability Assessment and Interdependency Analysis of Critical Infrastructures for Climate Adaptation and Resiliency. Manuscript submitted on 28 February 2014 to *International Journal of Disaster Resilience in the Built Environment* for publication.

Chapter 6

Espada, R., Apan, A., McDougall, K, 2014. Spatial Modelling of Natural Disaster Risk Reduction Policies with Markov Decision Processes. Manuscript accepted on 20 June 2014 in *Applied Geography* for publication.

Awards

2013 ESRI Young Scholar Award for Australia – ESRI Australia and ESRI USA

2013 Queensland Spatial Excellence Award (Highly Commended Postgraduate Student) – Surveying and Spatial Sciences Institute (SSSI) Australia

2013 ACSC Postgraduate Student Seminar Research Paper Presentation First Prize Winner – International Centre for Applied Climate Sciences, University of Southern Queensland

2012 ACSC Postgraduate Student Seminar Research Paper Presentation First Prize Winner – Australian Centre for Sustainable Catchments, University of Southern Queensland

2011 Endeavour Postgraduate Award (Australia Awards) – Australian Government Department of Education

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Abbreviations

3D	Three-Dimensional
ABS	Australian Bureau of Statistics
AC	Adaptation Capacity
AEP	Average Exceedance Probability
AER	Australian Energy Regulator
ANN	Artificial Neural Network
ARI	Annual Recurrence Interval
AOV	Assigned Ordinal Value
BCC	Brisbane City Council
BCR	Benefit-Cost Ratio
BOM	Bureau of Meteorology
BTRE	Bureau of Transport and Resources Economics
CA	Climate Adaptation
CCA	Climate Change Adaptation
CEC	Commission of the European Communities
CCIQ	Chamber of Commerce and Industries Queensland
CIS	Critical Infrastructure System
CO	Cluster and Outlier
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DBM	Digital Building Model
DCCEE	Department of Climate Change and Energy Efficiency
DCS	Department Community Safety
DEFRA	Department for Environment, Food and Rural Affairs
DEM	Digital Elevation Model
DERM	Department of Environment and Resource Management
DEWS	Department of Energy and Water Supply
DNRM	Department of Natural Resources and Mines
DOTARS	Department of Transport and Regional Services
DRR	Disaster Risk Reduction
DSM	Digital Surface Model
DTM	Digital Terrain Model
DTMR	Department of Transport and Main Roads
EHP	Environment and Heritage Protection
EMQ	Emergency Management Queensland

ENSO	El Niño/Southern Oscillation
EPA	Environmental Protection Agency
ERT	Emergency Response Time
FMV	Fuzzy Membership Values
FR	Flood Risk
FRACIAS	Flood Risk - Adaptation Capacity Index - Adaptation Strategies
FSE	Fuzzy Synthetic Evaluation
FSI	Floor Space Index
GIS	Geographic Information System
H	High Risk (Rating of flood risk model)
HH	High Values Surrounded by High Values
HL	High Values Surrounded by Low Values
IAG	Insurance Australia Group
ICC	Ipswich City Council
IDW	Inverse Distance Weight
IEO	Index for Education and Occupation
IER	Index for Economic Resources
IPCC	Intergovernmental Panel on Climate Change
IRSAD	Index of Relative Socio-Economic Advantage and Disadvantage
IRSD	Index of Relative Socio-Economic Disadvantage
KML	Keyhole Markup Language
L	Low Risk (Rating of flood risk model)
LH	Low Values Surrounded by High Values
LiDAR	Light Detection and Ranging
LL	Low Values Surrounded by Low Values
M	Moderate Risk (Rating of flood risk model)
MDP	Markov Decision Processes
NDRRA	Natural Disaster Relief and Recovery Arrangements
NFRAG	National Flood Risk Advisory Group
NS	Not Significant
PFR	Perceived Flood Risk Level
QCA	Queensland Competition Authority
QCM	Quadrat Counting Method
QFCI	Queensland Floods Commission of Inquiry
QFRS	Queensland Fire and Rescue Service
QGIS	Queensland Government Information Service
QRA	Queensland Reconstruction Authority

QUDM	Queensland Urban Drainage Manual
QUU	Queensland Urban Utilities
RDA	Rapid Damage Assessment
SEIFA	Socio-Economic Index for Areas
SEQ	South East Queensland
SOM	Self-Organising Map
SONN	Self-Organising Neural Network
SoQ	State of Queensland
TC	Tropical Cyclones
TIFF	Tagged Image File Format
UNDP	United Nations Development Programme
UNISDR	United Nations International Strategy for Disaster Reduction
UQ-CGQ	University of Queensland Centre for Government Queensland
VH	Very High Risk (Rating of flood risk model)