D R A F T

APPENDIX

FOR

Indicator Issues and Proposed Framework for a Disaster Preparedness Index (DPi)

Index Breakout	SOURCE
INDEX ONE:	**Urban Earthquake Disaster Risk Index (Davidson)**
INDEX TWO:	**Environmental Vulnerability Index (EVI) – South Pacific Applied Geoscience Commission**
INDEX THREE:	**Disaster Risk Index (DRI)- United Nations**
INDEX FOUR:	**Hurricane Disaster Risk (Davidson and Lambert)**
INDEX FIVE:	**Indicators of Disaster Risk and Risk Management (Cardona)**
INDEX SIX:	**Measuring Improvements in the Disaster Resilience of Communities (Chang and Shinozuka)**
INDEX SEVEN:	**Social Flood Vulnerability Index (Tapsell, Penning-Rowsell, Tunstall, Wilson)**
INDEX EIGHT	**Social Vulnerability to Environmental Hazards (SoVI) (Cutter, Boruff, Shirley)**
INDEX NINE	**Natural Hazard Index for Megacities (Munich Re)**

INDEX ONE

Urban Earthquake Disaster Risk Index (Davidson)

Formula

$EDRI = w_H H + W_E E + W_V V + W_C C + W_R R$

$H = W_{H1}X'_{H1} + W_{H2}X'_{H2} + W_{H3}X'_{H3} + W_{H4}X'_{H4} + W_{H5}X'_{H5} + W_{H6}X'_{H6} + W_{H7}X'_{H7}$
$E = W_{E1}X'_{E1} + W_{E2}X'_{E2} + W_{E3}X'_{E3} + W_{E4}X'_{E4} + W_{E5}X'_{E5} + W_{E6}X'_{E6}$
$V = W_{V1}X'_{V1} + W_{V2}X'_{V2} + W_{V3}X'_{V3} + W_{V4}X'_{V4} + W_{V5}X'_{V5} + W_{V6}X'_{V6}$
$C = W_{C1}X'_{C1} + W_{C2}X'_{C2} + W_{C3}X'_{C3}$
$R = W_{R1}X'_{R1} + W_{R2}X'_{R2} + W_{R3}X'_{R3} + W_{R4}X'_{R4} + W_{R5}X'_{R5} + W_{R6}X'_{R6} + W_{R7}X'_{R7} + W_{R8}X'_{R8} + W_{R9}X'_{R9}$

H = Hazard, E = Exposure, V= Vulnerability, C = Context, and R = Emergency Response and Recovery

Items Measured

1. Hazard
2. Exposure
3. Vulnerability
4. External Context
5. Emergency Response & Recovery Capability

Methodology

Aggregated composite index
Linear combination
Scaling technique of mean minus two standard deviations used.
3 alternatives for determining weighting 1) regression 2) principal component analysis 3) subjective assessments through questionnaires to professionals in the field of earthquake research. Weights were normalized so that sums would equal 1.
Conceptual basis for indicator selection done without regard to data availability
Sensitivity analysis to determine robustness of results

Variables

1) Hazard***: Ground Shaking*** weight 0.7

- A. Bedrock ground shaking (sub weight 0.85)
  - I. exp(MMI w/50year return period) (sub weight 0.5)
  - II. exp(MMI w/500year return period) (sub weight 0.5)
- B. Soft Soil (sub weight 0.15)

2) Hazard***: Collateral Hazards*** weight 0.3

- A. Liquefaction (sub weight 0.33)
- B. Fire following earthquake (sub weight 0.33)
  - I. %buildings wood (sub weight 0.5)
  - II. Population density (sub weight 0.5)
- C. Tsunami potential (sub weight 0.33)

3) Exposure***: Population Exposure*** weight 0.4

4) Exposure***: Physical Infrastructure Exposure*** weight 0.4

- A. Population (sub weight 0.35)
- B. Per capita GDP (sub weight 0.15)
- C. Number of housing Units (sub weight 0.35)
- D. Urbanized land area (sub weight 0.15)

5) Exposure***: Economic Exposure*** weight 0.2

6) Vulnerability ***Population Vulnerability*** weight 0.4

7) Vulnerability ***Physical Infrastructure Vulnerability*** weight 0.4

- A. seismic code (sub weight 0.2)
- B. city wealth (sub weight 0.3)
- C. city age (sub weight 0.2)
- D. population density (sub weight 0.2)
- E. city development speed (sub weight 0.1)

8) External Context: ***Economic External context*** weight 0.8

9) External Context: ***Political External context*** weight 0.2

- A. political country external context (sub weight 0.5)
- B. political world external context (sub weight 0.5)

10) Emergency Response & Recovery Capability: ***Planning*** weight 0.33

11) Emergency Response & Recovery Capability: ***Resources*** weight 0.33

- A. financial resource (sub weight 0.5)
  - I. per capita GDP (sub weight 0.8)
  - II. avg annual per cap GDP growth (sub weight 0.2)
- B. equipment & facilities (sub weight 0.25)
  - I. housing vacancy rate (sub weight 0.5)
  - II. number of hospitals (sub weight 0.5)
- C. trained manpower (sub weight 0.25)
  - I. number of physicians

12) Emergency Response & Recovery Capability: ***Mobility*** and Access weight 0.33

A. extreme weather	(sub weight 0.33)
B. population density	(sub weight 0.33)
C. city layout indicator	(sub weight 0.33)

Scope

Index measures: Earthquakes
Scale (or level of Geography): Cities

Application

Table 8.1. Sample analysis results for Figures 8.1. and 8.2

Factor	Indicators included	Factor components	Boston	Istanbul	Jakarta	Lima	Manila	Mexico City	San Francisco	Santiago	St. Louis	Tokyo
Hazard	xh1	short-term seismicity	28	41	21	88	49	21	46	32	29	49
	xh2	long-term seismicity	44	53	14	75	30	12	48	27	58	44
	xh3	soft soil	63	38	28	51	26	82	41	25	20	32
	xh1-xh3	Ground shaking	40	46	19	77	37	27	46	29	40	45
	xh4	liquefaction	54	21	71	43	72	19	33	18	38	37
	xh5	tsunami	20	43	43	65	43	20	65	20	20	65
	xh6-xh7	fire following	38	46	38	28	55	31	39	46	37	48
	xh4-xh7	Collateral hazards	38	37	51	45	57	23	46	28	32	50
		HAZARD	40	43	29	68	43	26	46	29	37	46
Exposure	xe1-xe4	Physical Infrastructure	40	31	32	31	32	45	43	28	34	89
	xe5	Population	32	31	37	34	37	54	33	29	26	93
	xe6	Economy	66	26	25	24	24	27	65	26	57	66
		EXPOSURE	42	30	33	31	32	45	44	28	35	86
Vulner-ability	xv1-xv5	Physical Infrastructure	37	42	50	48	54	43	25	46	37	24
	xv6	Population	70	28	19	24	29	32	56	44	75	28
		VULERABILITY	39	41	49	46	53	42	26	46	39	24
External Context	xc1	Economic	38	33	33	32	33	36	39	33	33	97
	xc2-xc3	Political	26	26	47	44	44	46	26	44	25	76
		EXTERNAL CONTEXT	35	32	36	35	35	38	36	35	32	93
Emerg. Resp. & Recovery	xr1	Planning	34	34	68	34	68	34	17	68	34	17
	xr2-xr3	financial resources	20	51	43	59	57	54	23	52	27	18
	xr4-xr5	equipment & facility resources	56	60	56	33	74	68	70	76	48	-4
	xr6	trained manpower resources	10	39	66	41	67	38	16	60	25	42
	xr2-xr6	Resources	27	47	46	44	60	50	33	57	29	14
	xr7-xr9	Mobility and access	39	55	41	31	49	34	39	39	41	38
		EMERG. RESP. & RECOV.	33	45	51	36	59	39	30	54	35	23
		EDRI	39	38	39	45	44	38	37	37	36	54

INDEX TWO

Environmental Vulnerability Index (EVI) – South Pacific Applied Geoscience Commission

Formula

$$\text{EVI} = \frac{REI + IRI + EDI}{3}$$

Where
EVI = Environmental vulnerability index
REI = Risk exposure sub index
IRI = Intrinsic resiliency sub index
EDI = Environmental degradation sub index

Items Measured

1. The ***level of risks*** which act on the environment. The intensity of risks events which may affect the environment. Observed over the past 5-10 years. Risk Exposure Sub Index. (REI)
2. ***Intrinsic vulnerability*** or resilience of the environment to risks, forming the intrinsic Resilience sub-index (IRI).Refers to characteristics of country which would tend to make it less/more able to cope with natural and anthropogenic hazards.
3. ***Extrinsic Vulnerability*** or resilience as a result of external forces acting on the environment, forming the Environmental Degradation sub-index(EDI). Describes ecological integrity or level of degradation of ecosystems.

Methodology

Average aggregated composite index
Linear effect model used for assigning scores to indicators. Scores ranged from 0 and 7. Each sub-index was an aggregated average of the scores for the indicators.
Weighting subjectively assigned. Six of the 57 indicators assigned weight of 5, while the rest were assigned weights of 1.
Indicators selected based on the data availability
Indicator selected because applicable over the entire region, habitat and climate types, unbiased, easy to understand, and applicable over different scales.

Variables

Sub-index REI

1. Deviation in avg. sea temperatures during moderate or greater El Nino – weight 1
2. Number of months over last 5 years during which rainfall is more than 20% above 30 yr average for that month (flood risk) – weight 1
3. Number of months over last 5 years during which rainfall is more than 20% below 30yr average for that month (drought) – weight 1
4. No. category 1-5 cyclones (<994 hPa central pressure) / decade / 10,000 sq km (last decade only)- weight 1
5. Mean number of days per yr (last 5 yrs) in which the maximum temperature was >5^{o}C above the mean monthly maximum (calculated over last 30 years) – weight 1
6. Mean number of days per yr (last 5 years) in which the minimum temperature was >5^{o}C below the mean monthly minimum (calculated over last 30 years) – weight 1
7. No. severe storms and tornadoes/10,000 sq. km / decade (last 10 years) – weight 1
8. Number of earthquakes over the last 50 yrs/ 10,000 sq km land areas with intensity of > 6.0 Richter – weight 1
9. No. tsunamis with runup 2m+ last 50 years /10,000 sqkm coastal area – weight 1
10. No. volcanoes with potential for eruptions / 10,000 sq km land area – weight 1
11. % of land area burned by forest fires per yr (worst year of last 5 years)–weight 1
12. % of agricultural land under subsistence / organic agricultural – weight 1
13. Tons pesticides produced,imported/10,000 sqkm area (avg last 5 yrs) – weight 1
14. Tons of N,P,K fertilizers produced or imported / 10,000 sq km of land area / year (average last 5 years) – weight 1
15. Rate of deforestation of primary forest (% of remaining forest lost per ear) (average of last 5 years) – weight 5
16. % of ag. land which is mechanized, monoculture and or commercial – weight 1
17. # of commercial inshore fishing vessels / 10,000 sq km coast area /year(average of last 5 years) – weight 1
18. # of commercial offshore fishing vessels / area of EEX / year (average of last 5 years) – weight 1
19. Destructive fishing methods used? (dynamite, etc) – weight 1
20. No. of patrols run (boat or plane) /10,000 sqkm of EEZ (avg last 5 yrs) – weight 1
21. Fisheries observer programs – weight 1
22. % of marine zone set aside as reserves -weight 1
23. Environmental Legislation – weight 1
24. % of development projects accomp. by Environmental Impact Assess.– weight 1
25. % of terrestrial zone set aside as reserves – weight 1
26. Ton coral extracted/year/10,000 sqkm coast zone (avg of last 5 years) – weight 1
27. Kilotons of sand/gravel extracted/year/10,000 sqkm coastal area (avg last 5 yrs)
28. Kilotonnes of all mining material (ore + tailings) extracted / 10,000 sq km land area / year (avg of last 5 years)
29. Total tonnage of imported toxic or hazardous wastes / 10,000 sq km land area / year (average last 10 years) – weight 1
30. Millions of liters of hydrocarbons used / 10,000 sq km land area / year (average over last 5 years) – weight 1
31. # of Nuclear facilities / 10,000 sq km land area – weight 1
32. # shipping ports maintain, produce ships/10,000 km area coastal zone – weight 1

33. Electricity consumption kilowatt hours / capita/ year – weight 1
34. Number of cars / 1,000 persons – weight 1
35. % toxic wastes disposed by high temp incineration (avg last 5 yrs) – weight 1
36. % of population with at least secondary sewage treatment – weight 1
37. Annual population growth rate (over last 5 years) – weight 1
38. Total human population density per sq km land area – weight 1
39. Standing stock of tourists / 100 sq km land area (standing stock = # of tourist x average # of days stay/365)(average for last 5 years) – weight 1

Sub index - IRI

40. Total land area sq km – weight 5
41. Ratio of length of shoreline: total land area (fragmentation) – weight 1
42. # of endemic species per 10,000 sq km land area – weight 1
43. % of land area < 20m above sea level – weight 1
44. % of coastal land area composed of unconsolidated sediments – weight 1

Sub index - EDI

45. has nuclear testing occurred – weight 1
46. % of land desertified since 1950- weight 1
47. % of degraded coral reed area – weight 1
48. % of primary/ old growth forest or vegetation remaining – weight 5
49. % of fisheries stocks over fished – weight 1
50. % of land under agriculture including plantation / forestry (now) – weight 1
51. # of mariculture farms / 10,000 sq km coastal area – weight 1
52. % of original mangrove / salt marsh area remaining – weight 5
53. # of harmful algal blooms including ciguatera, red tides, etc over the last 5 years / 10,000 sq km coastal area – weight 1
54. % of total land area affected by mining / quarrying – weight 1
55. # of species which have become extinct this century / 10,000 sq km land and (coastal area *0.5) – weight 1
56. # threatened, endangered species/10,000 sqkm land (coastal area *0.5) – weight 1
57. # introduced terrestrial species/10,000 sqkm land (over last 100 years) – weight 1

Scope

Index Measures: Environmental vulnerability through 53 various environmental indicators

Scale: Suitable for international comparisons and able to differentiate among countries, applicable at different spatial scales (regional, country, and island)

Application

ISO	COUNTRY	EVI	DATA%	STATUS
AD	Andorra	257	42	At risk
AE	United Arab Emirates	293	90	Vulnerable
AF	Afghanistan	289	76	Vulnerable
AG	Antigua & Barbuda	307	56	Vulnerable
AI	Anguilla	312	52	Vulnerable
AL	Albania	330	94	Highly vulnerable
AM	Armenia	247	72	At risk
AN	Netherlands Antilles	323	60	Highly vulnerable
AO	Angola	225	96	At risk
AQ	Antarctica	235	40	At risk
AR	Argentina	287	94	Vulnerable
AS	American Samoa	436	50	Extremely vulnerable
AT	Austria	369	84	Extremely vulnerable
AU	Australia	238	96	At risk
AW	Aruba	291	46	Vulnerable
AZ	Azerbaijan	354	74	Highly vulnerable
BA	Bosnia & Herzegovina	306	70	Vulnerable
BB	Barbados	403	70	Extremely vulnerable
BD	Bangladesh	340	94	Highly vulnerable
BE	Belgium	387	94	Extremely vulnerable
BF	Burkina Faso	229	82	At risk
BG	Bulgaria	323	96	Highly vulnerable
BH	Bahrain	326	62	Highly vulnerable
BI	Burundi	288	80	Vulnerable
BJ	Benin	278	92	Vulnerable
BM	Bermuda	373	52	Extremely vulnerable
BN	Brunei Darussalam	313	62	Vulnerable
BO	Bolivia	250	84	At risk
BR	Brazil	281	94	Vulnerable
BS	Bahama	248	62	At risk
BT	Bhutan	253	68	At risk
BV	Bouvet Island	271	42	Vulnerable
BW	Botswana	181	84	Resilient
BY	Belarus	239	72	At risk
BZ	Belize	258	90	At risk

INDEX THREE

Disaster Risk Index (DRI)- United Nations

Formula

Equation 1: Risk

$$R = H^* Pop^* Vul$$

Where
R = risk (# of people killed)
H = the hazard which depends on the frequency and strength of a given hazard
Pop = is the population living in a given exposed area
Vul = vulnerability and depends on the socio-political economical context of this population

Equation 2: Risk Evaluation using Physical Exposure

$$R = PhExp^* Vul$$

Where
PhExp is the physical exposure, i.e. the frequency and severity multiplied by exposed population

Equation 3: Estimation of the Total Risk

$$Risk_{Tot} = Risk_{Flood} + Risk_{Earthquake} + Risk_{Volcano} + Risk_{Cyclone} + \ldots Risk_n)^b$$

Equation 4 Computation of Physical Exposure

$$PhExp_{nat} = F_i * Pop_i$$

Where
$PhExp_{nat}$ = the physical exposure at national level
F_i = annual frequency of a specific magnitude event in one spatial unit
Popi = total population living in the spatial unit

Equation 5 Physical Exposure Calculation without Frequency

$$\mathbf{PhExp} = \frac{\mathbf{Pop_i}}{\mathbf{Y_n}}$$

Where
Popi = total population living gin particular buffer, the radius of which from epicenter varies according to the magnitude
Yn = the length of time in years
PhExp = total physical exposure of a county in other words the sum all physical exposure in this country

Equation 6 Computation of current physical Exposure

$$PhExp_i = \frac{Pop_i}{Pop_{1995}} * PhExp_{1995}$$

Where
PhExpi = physical exposure of the current year
Popi = population of the country at the current year
Pop1995 = population of the country in 1995
PhExp1995 = physical exposure computed with population as in 1995

Equation 7 Probability to Annual Frequency for Cyclones

$$E(x) = -\ln (1-P(x \geq 1))$$

Where
E(x) = statistical expectation, i.e. the average # of events per year
P(x) is the probability of occurrence

Equation 8 Estimated of Killed

$$K = C * (PhExp)^{} * V_1^{a1} * V_2^{a2} \ldots * V_p^{ap}$$

Where
K = # of persons killed by a certain type of hazard
C = multiplicative constant
PhExp = physical exposure: population living in exposed areas multiplied by the frequency of occurrence of hazard
Vi = socio-economic parameters
i = exponent of Vi, which can be negative for ratio

Equation 9 Logarithm Properties

$$Ln(k) = \ln (C) + (PhExp) + {}_1\ln(V_1) + {}_2\ln(V_2) + \ldots {}_p\ln(V_p)$$

Equation 10 Transformation for Variable Ranging Between 0 and 1

$$V_i' = \frac{V_i}{(1 - V_i)}$$

Where
Vi' is the transformed variable (ranging from -∞ to +∞)
Vi is the socio-economic variable (ranging from 0 to 1)

Equation 11 Multiple Logarithmic Regression Model For Earthquakes

$$ln(K) = 1.26ln(PhExp) + 12.27 \bullet U_g - 16.22$$

Where
K is the number of killed from earthquakes
PhExp is the physical exposure to earthquakes
Ug is the rate of urban growth (rates do not request transformation as it is already a cumulative value)

Equation 12 Multiple Logarithmic Regression Model For Tropical Cyclone

$$ln(K) = 0.63ln(PhExp) + 0.66ln(Pal) - 2.03ln(HDI) - 15.86$$

Where
K is the number of killed from cyclones
PhExp is the physical exposure to cyclones
Pal is the transformed value of percentage of arable land
HDI is the transformed value of the Human Development Index

Equation 13 Multiple Logarithmic Regression Model For Flood

$$ln(K) = 0.78ln(PhExp) + 0.45ln(GDP_{cap}) - 0.15ln(D) - 5.22$$

Where
K is the number of killed from floods
PhExp is the physical exposure to floods
GDPcap is the normalised Gross Domestic Product per capita (purchasing power parity)
D is the local population density (i.e. the population affected divided by the area affected)

Equation 14 Multiple Logarithmic Regression Model For Drought

$$ln(K) = 1.26ln(PhExp3\_50) - 7.58ln(WAT_{TOT}) + 14.4$$

Where
K is the number of killed from droughts
PhExp3_50 is the number of people exposed per year to droughts. A drought is defined as a period of at least three months less or equal to
50 percent of the average precipitation level (IRI, CIESIN/IFPRI/WRI)
WATTOT is the percentage of population with access to improved water supply (WHO/UNICEF)

**Equation 15 Computation of Multiple Risk By Summing Calculated Deaths-
As Modelled for Risk for Cyclone, Flood, Earthquake And Drought**

$$K_{cyclones}\,(PhExp^{0.63\ cyclones} \cdot Pal^{0.66} \cdot HDI^{-2.03} \cdot e^{-15.86}) + K_{floods}\,(PhExp^{0.78\ floods} \cdot GDP^{-0.45\ cap} \cdot D^{-0.15} \cdot e^{-5.22}) + K_{earthquakes}\,(PhExp^{1.26\ earthquakes} \cdot U^{12.27\ g} \cdot e^{-16.27}) + K_{droughts}\,(PhExp3\_50^{1.26} \cdot WAT^{-7.58\ TOT} \cdot e^{14.4})$$

Where
e is the Euler constant (=2.718…)
PhExp is the physical exposure of selected hazard
HDI is the Human Development Index
GDPcap is the Gross Domestic Product per capita at purchasing power parity
D is the local density (density of population in the flooded area)
Ug is the Urban growth (computed over three-year period)
WATTOT is the access to safe drinking water

Items Measured

Measures Risk of Death in Disaster through 3 components

- Physical Exposure
- Vulnerability
- Risk

Methodology

Mortality-calibrated index

Enables the calculation of average risk of death per country in large and medium scale disasters associated with earthquakes, tropical cyclones and floods based on data from 1980-2000.

Calculation of Physical Exposure

Identity the areas exposed to each of the four hazard types (earth quakes, tropical cyclones, floods, and droughts) and the population living in these areas to arrive at a calculation of physical exposure. Average # of People exposed to hazard each year. Varies by number of people as well as frequency of hazard events.

Calculation of relative vulnerability

Dividing the number of people actually killed by the number exposed.

Variables

Risk

1. # of Killed
2. Killed / Population
3. Killed / Population Exposed

Vulnerability

1. Economic: GPD per inhabitant at purchasing power parity
2. Economic: Human Poverty Index (HPI)
3. Economic: Total debt service (% of the exports of goods and services)
4. Economic: Unemployment, total(% of labor force)
5. Economic Activity: Arable land (in thousands of hectares)
6. Economic Activity: % of arable land and permanent crops
7. Economic Activity: % of urban population
8. Economic Activity: % of agricultures dependency for GDP
9. Economic Activity: % of labor force in agricultural sector
10. Quality of Environment: Forests and woodland (in % of land area)
11. Quality of Environment: Human-induced soil degradation(GLASOD)
12. Demography: Population growth
13. Demography: Urban Growth
14. Demography: Population Density
15. Demography: Age dependency Ratio
16. Health and Sanitation: % of people with access to improved water supply
17. Health and Sanitation: # of physicians per 1,000 inhabitants
18. Health and Sanitation: Number of hospital beds
19. Health and Sanitation: Life expectancy at birth for both sexes
20. Health and Sanitation: Under five year olds mortality rate
21. Early warning capacity: # of radios per 1,000 inhabitants
22. Education: illiteracy rate
23. Development: Human Development Index (HDI)

Scope

Index Measures: Hurricanes (Cyclones), Floods, Earth quake, drought.
Scale: International Comparisons of countries.

Application

TABLE 3 DISASTER RISK FOR EARTHQUAKES, 1980 - 2000

	Average number of events per year*	Number of people killed per year	Average number of people killed per million inhabitants	Average physical exposure per year	Physical exposure in percentage of population	Relative Vulnerability	Percentage of Urban growth (as average for 3-year period)
Country Name	Event per year	Killed per Year	Killed per million	People per year	%	Killed per million exposed	%
Armenia	0.05	1 190.48	343.96	155 560	4.49	7 652.82	0.03
Iran (Islamic Republic of)	1.43	2 250.81	38.68	2 094 097	3.60	1 074.84	0.15
Yemen	0.10	72.29	6.90	95 423	0.91	757.53	0.24
Turkey	0.76	949.86	15.58	2 745 757	4.50	345.94	0.15
Afghanistan	0.81	399.95	2480	1 749 097	0.11	228.1	0.13
India	0.67	576.52	0.73	2 730 309	0.35	211.16	0.09
Italy	0.52	225.71	3.98	1 288 265	2.27	175.21	0.00
Russian Federation	0.29	95.29	0.65	658 876	0.45	144.62	0.03
Algeria	0.38	137.19	5.79	1 252 109	5.28	109.57	0.14
Mexico	0.76	427.24	5.05	4 145 529	4.90	103.06	0.08
Nepal	0.10	38.52	2.42	512 716	3.22	75.14	0.19
Georgia	0.14	13.29	2.44	286 210	5.25	46.42	0.04
El Salvador	0.10	53.33	11.23	1 272 919	26.81	41.90	0.07
Pakistan	0.62	30.95	0.30	793 845	0.77	38.99	0.14
Egypt	0.10	27.19	0.45	834 006	1.38	32.60	0.08
Colombia	0.48	85.05	2.34	2 663 322	7.33	31.93	0.09
Bolivia	0.14	5.95	0.86	186 491	2.69	31.92	0.13
Australia	0.14	1.10	0.07	40 727	0.25	26.89	0.04
China	2.10	92.24	0.08	3 493 705	0.30	26.40	0.13
South Africa	0.14	1.62	0.05	82 467	0.25	19.63	0.08
Ecuador	0.43	28.33	2.75	1 542 854	14.97	18.36	0.12
Panama	0.05	1.43	0.58	95 128	3.89	15.02	0.08
Kyrgyzstan	0.10	2.76	0.62	227 769	5.10	12.13	0.04

INDEX FOUR

Hurricane Disaster Risk (Davidson and Lambert)

Formula

$HDRI = (H^{WH})(E^{WE})(V^{WV})[0.1(1-a)R + a]$

$H = (H_{Wind})[0.1(1 - b)H_{Coll} + b]$

$H_{Wind} = W_{H1}X_{H1}\, W_{H2}X_{H2} + W_{H3}X_{H3}$

$H_{Coll} = W_{H4}X_{H4} + w_{H5}X_{H5}$

$E = W_{E1}X_{E1} + W_{E2}X_{E2} + W_{E3}X_{E3} + W_{E4}X_{E4} + W_{E5}X_{E5} + W_{E6}X_{E6} + W_{E7}X_{E7}$

$V = Wv_1Xv_1 + Wv_2Xv_2 + Wv_3Xv_3 + Wv_4Xv_4 + Wv_5Xv_5 + Wv_6Xv_6$

$R = W_{R1}X_{R1} + W_{R2}X_{R2} + W_{R3}X_{R3} + W_{R4}X_{R4} + W_{R5}X_{R5} + W_{R6}X_{R6} + W_{R7}X_{R7} + W_{R8}X_{R8} + W_{R9}X_{R9}$

Units were scaled and into unit less scores by the following

$$C_{ij} = \frac{X'_{ij} - \min poss_i}{\max poss_i - \min poss_i} * 10$$

Items Measured

1. Hazard
2. Exposure
3. Vulnerability
4. Emergency Response & Recovery

Methodology

Two variations of HDRI – the economic HDRI and the Life HDRi

-Developed in 3 stages. 1) identify factors – meteorological, engineering, economic, and social - that contribute to economic and life loss 2) Measurable scalar indicators were chosen to represent each factor identified. 3) Mathematical index was developed to combine the indicators into two composite index values.

Variables

1. Hazard - wind:XH1 mean return of hurricanes Cat 1-2
2. Hazard -wind :XH2 mean return period of hurricanes Cat 3-4
3. Hazard - wind:XH3 mean return period of hurricanes Cat 5
4. Hazard – Storm Surge: XH4 % area below 50-year Stillwater elevation
5. Hazard – Rainfall: XH5 average forward speed of hurricanes [knots]
6. Exposure – Population: XE1 resident population
7. Exposure – Population: XE2 average daily # of tourist, June-Nov
8. Exposure – Building: XE3 # of housing units
9. Exposure – Building:XE4 Median home value [dollars]
10. Exposure – Economic: XE5 income from agriculture [$1000's]
11. Exposure – Economic: XE6 number of business units
12. Exposure – Lifeline: XE7 value of power lines [dollars]
13. Vulnerability – Population: XV1 % of population aged 0-4 or 65+
14. Vulnerability – Population: XV2 % of population (aged16-64) w/mobility limitation
15. Vulnerability – Population:XV3 public educator indicator
16. Vulnerability – Building: XV4 Avg BCEGS grade
17. Vulnerability – Building: XV5 % of homes that are mobile homes
18. Vulnerability – Economic: XV6 % of business with less than 20 employees
19. ERRC – Connectivity: XR1 % county land area detached from mainland
20. ERRC – Evacuation & Shelter: XR2 # of shelters available
21. ERRC – Evacuation & Shelter: XR3 evacuation clearance time [hours]
22. ERRC – Evacuation & Shelter:XR4 % of population expected to evacuate
23. ERRC – Mobility: XR6 Population density [people per square km]
24. ERRC – Mobility:XR7 City layout (road in grid=0, otherwise=1)
25. ERRC – Resources:XR8 # of hospital beds per 100,000 people
26. ERRC – Resrouces:XR9 # of physicians per 100,000 people
27. ERRC – Resources: XR10 Per capita state gross product [constant 1990 US$]

Scope

Index Measures: Hurricanes
Scale: U.S. Counties

Application

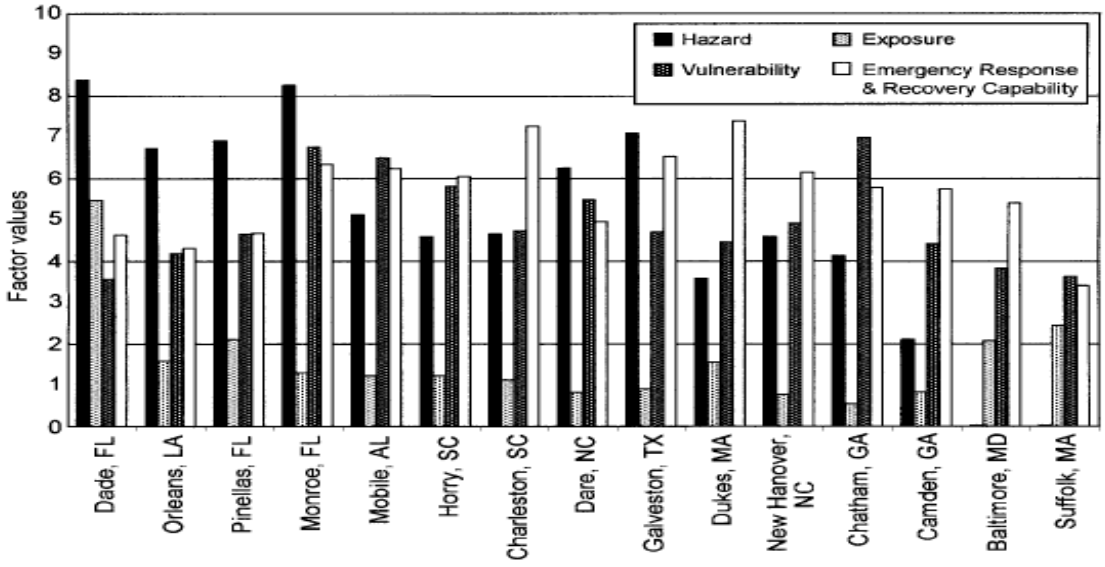


FIG. 4. Factor Economic HDRI Sample Analysis Results

INDEX FIVE

Indicators of Disaster Risk and Risk Management (Cardona)

Formula

1) DDI = $\frac{MCELOSS}{Economic\ \text{Re}siliance}$

Where
DDI = Disaster Deficit Index
MCE Loss = Maximum Considered Event

2) LDI = $LDI_{Deaths} + LDI_{Affected} + LDI_{Losses}$

Where
LDI = Local Disaster Index
The LDI_{deaths} = the number of deaths in the community
$LDI_{affected}$ = the number of affected people
LDI_{losses} = the losses in each municipality

3) PVI = $\left[PVI_{Exposure} + PVI_{Fragility} + PVI_{\text{Re}siliance}\right] / 3$

Where
PVI = Prevalent Vulnerability Index

4) RMI = $\left[RMI_{RI} + RMI_{RR} + RMI_{DM} + RMI_{FP}\right] / 4$

Where
RMI = Risk Management Index
RI = Risk Identification
RR = Risk Reduction
DM = Disaster Management
FP = Financial and Protection Indicators

Items Measured

1. Exposure
2. Fragility
3. Lack of Resilience
4. Risk Management
    - Risk Reduction
    - Disaster Management
    - Government and Financial Protection Indicators

Methodology
Additive Index
Risk management index was determined by experts from Directorate of Emergency Prevention in Columbia
Risk management officials established the weights applied – subjective process
Measures risk and vulnerability through relative indicators at the national level.
Indicators are transparent and easy to up date
Permits monitoring over time
Indices are proxies for measuring risk

Variables
PVI Exposure: ES1 Population Growth Avg Annual Rate
PVI Exposure: ES2 Urban Growth Avg Annual Rate (%)
PVI Exposure: ES3 Population Density (People / 5 KM^2)
PVI Exposure: ES4 Poverty, Population living on less that US $1 day PPP
PVI Exposure: ES5 Capital Stock in Million US Dollar Per 1000 Square KM
PVI Exposure: ES6 Imports and Exports of Goods and Services as % of GDP
PVI Exposure: ES7 Gross Domestic Fixed Investment as % of GDP
PVI Exposure: ES8 Arable Land and Permanent Crops as % of land area.

PVI Fragility: SF1 Human Poverty Index, HPI-1
PVI Fragility: SF2 Dependants as a proportion of the working age population
PVI Fragility: SF3 Inequality as measured by the Gini coefficient
PVI Fragility: SF4 Unemployment as a total % of labor force
PVI Fragility: SF5 Annual Increase in food prices%
PVI Fragility: SF6 Share of agriculture in total GDP growth (annual %)
PVI Fragility: SF7 Debt service Burden as % of GDP
PVI Fragility: SF8 Soil degradation resulting from human activities (GLASOD)

PVI (Lack of) Resilience: LR1 Human Development Index, HDI [Inverse]
PVI (Lack of) Resilience: LR2 Gender Related Development Index, GDI [Inverse]
PVI (Lack of) Resilience: LR3 Social Expenditures on Pensions, Health, and Education as % of GDP [Inverse]
PVI (Lack of) Resilience: LR4 Governance Index (Kauffman) [Inverse]
PVI (Lack of) Resilience: LR5 Infrastructure and Housing Insurance as % of GDP [Inverse]
PVI (Lack of) Resilience: LR6 Television Sets per 1000 people [inverse]
PVI (Lack of) Resilience: LR7 Hospital Beds per 1000 people [inverse]
PVI (Lack of) Resilience: LR8 Environmental Sustainability Index, ESI [Inverse]

PVI Risk Management: RI1 Systematic Indicator of disaster and losses
PVI Risk Management: RI2 Hazard monitoring and forecasting
PVI Risk Management: RI3 Hazard evaluation and mapping
PVI Risk Management: RI4 Vulnerability and risk assessment
PVI Risk Management: RI5 Public Information and community participation
PVI Risk Management: RI6 Risk management training and education

Risk Reduction: RR1Extend to which risk is taken into account in urban planning and land use
Risk Reduction: RR2 Management of river basins and environmental protection
Risk Reduction: RR3 implementation of control and protection techniques before hazard event
Risk Reduction: RR4 Relocation of people living in disaster prone areas and the improvements to housing in those areas
Risk Reduction: RR5 Updating and enforcement of safety standards and construction codes
Risk Reduction: RR6 Reinforcement and retrofitting of public and private assists

Disaster Mgmt: DM1 Organization and coordination of emergency operations
Disaster Mgmt: DM2 Emergency response planning and implementation of warning systems
Disaster Mgmt: DM3 supply of tools, equipment and infrastructure
Disaster Mgmt: DM4 simulation, updating and testing of inter-institutional response capability
Disaster Mgmt: DM5 community preparedness and training
Disaster Mgmt: DM6 rehabilitation and reconstruction planning

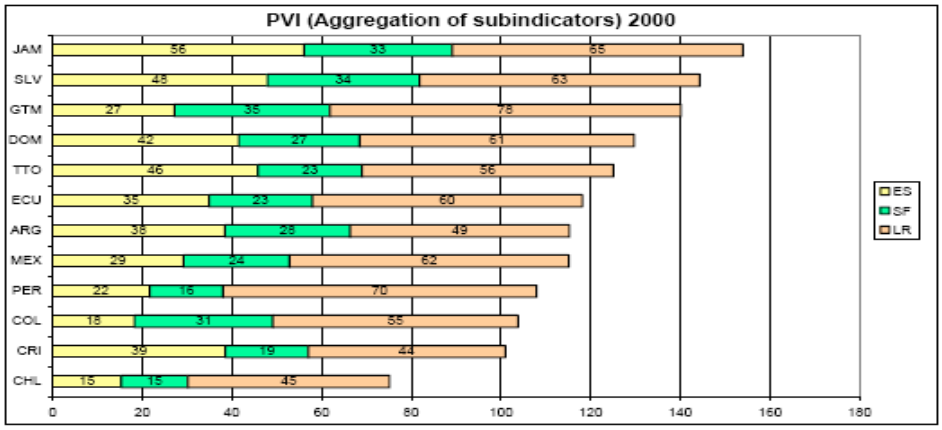
Govt& Financial Protection: FP1decentrlized organizational unit's inter-institutional and multi-sector coordination
Govt& Financial Protection: FP2 availability of resource for institutional strengthening
Govt& Financial Protection: FP3 budget allocation and mobilization
Govt& Financial Protection: FP4 existence of social safety nets and funds
Govt& Financial Protection: FP5 Insurance coverage and loss transfer strategies for public assets
Govt& Financial Protection: FP6 housing and private sector insurance and reinsurance coverage

Scope

Index Measures: Risk from any natural disasters
Scale: National and Sub national level

Application

Figure 12. Aggregate PVI



INDEX SIX

Measuring Improvements in the Disaster Resilience of Communities (Chang and Shinozuka)

Formula

Defined as the probability that the system of interest will meet pre-defined performance standards A in a scenario seismic event of magnitude I, or Pr(A|i) :

$$\Pr = (A \mid I) = \Pr\left[r_0 < r^* \;\&\; t_1 < t^*\right]$$

Where

$r^* = rosbustness$

$t^* = rapidity$

$r_0 = initial \quad loss$

t_i = time to full recovery

A broad system of resilience of resilience can be defined as Z_A in reference to the entire range of possible earthquake events:

$$Z_A = \sum_i \Pr(A \mid i) \Pr(i)$$

Items Measured

1) Technical Performance
2) Organizational Performance
3) Social
4) Economic

Methodology

Robustness measures indicate the initial post-earthquake conditions while rapidity measures consider the repair and restoration Framework.

Loss of water service could mean a population displacement

Resilience is defined by comparing loss of system performance to pre-defined performance standards of robustness and rapidity. Resilience refers to capacity for dealing with potential future events.

For both technical and organizational performance, robustness measures indicate the initial post earth quake conditions while rapidity measures the repair and restoration time frame

Social/ economic measures are defined at the level of the community as a whole

Loss estimation model with 200 Monte Carlo simulations run for each 3 retrofit cases and 2 earth quake scenarios

Variables

Technical (water system): the number of major pumping stations lost in an earthquake. Network physical condition.

Technical(water system): the percentage of pipes broken in an earthquake

Organizational(water system): % of population losing water service, not only does this measure the extent of physical damage, but also network flow conditions. Water Service.

Social (community): Populations displaced form their homes, forced to seek emergency shelter. Population living at home.

Economic (community): Loss of Gross Regional Product, GRP due to disaster and should consider water outage to business along with other sources of economic disruption. Economic activity.

Scope

Index Measure: resilience to earth quake disasters
Scale: city level

INDEX SEVEN

Vulnerability to flooding: health and social dimensions
(Tapsell, Penning-Rowsell, Tunstall, Wilson)

Social Flood Vulnerability Index

Formula

0.25(financial deprivation) + health problems + single parents + the elderly

Items Measured

1. Health Problems
2. Financial deprivation
3. Elderly
4. Single Parents

Methodology

Composite additive index based on three social characteristics and 4 financial-deprivation indicators.

To identify financially deprived the Townsend index was used and focuses on deprivation outcomes such as unemployment. Townsend used because it focuses on deprivation outcomes such as unemployment (rather than targeting predefined social groups. In order to prevent undue bias in the SFVI towards financial deprivation then four Townsend indicators were summed and multiplied by .25)

Interviews used to determine the most influential variables (age and financial status of the affected populations were the most commonly important variables, followed by the prior health status of the population.

In order to prevent bias towards financial deprivation the four Townsend indicators were summed and multiplied by .25 before being added to the other variables.

Crude percentages were transformed by the method that produced the minimum skewness and kurtosis within their distributions. The data was than standardized as Z-scores and then summed.

SFVI categorized into a limited number of bands (five) where category (1) represents low vulnerability and category (3) average vulnerability and category (5) high vulnerability

Variables

1. **Unemployment**: unemployed residents aged 16 and over as a percentage of all economically active residents aged over 16
2. **overcrowding**: households with more than one person per room as a % of all households
3. **none-car ownership**: households with no car as a % of all households
4. **non-home ownership**: households not owning their own home as a percentage of all households

5. **the long term sick:** residents suffering from limiting long-term illness as a percentage of all residents
6. **single parents**: lone parents as a proportion of all residents
7. **the elderly:** residents aged 75 and over as percentage of all residents.

Scale

Index Measures: Vulnerability to flooding
Scale: small geographical areas (census tracts) because flood plains are often narrow and short.

INDEX EIGHT

Social Vulnerability to Environmental Hazards – Cutter, Boruff, Shirley

Social Vulnerability Index (SoVI)

Formula

SoVI = Personal wealth + Age + Density of the Built Environment + Single Sector economic + Housing Stock and tenancy + Race (African American + Hispanic + Native American + Asian) + Occupation + Infrastructure Dependence.

Items Measured

Vulnerability through 11 factors: 1) Personal Wealth 2) Age 3) Density of the built Environment 4)Single Sector Economic Dependence 5) Housing Stock and Tenancy 6)Race 7)Ethnicity 8)Occupation 9) Infrastructure Dependence

Methodology

Composite additive index

No assumptions made on the relative importance made of each variable, no weighting used. All factors have equal importance.

Scaling used to make positive values indicate higher vulnerability and negative values decrease vulnerability

Analysis conducted at the county level for all 3,141 in 1990

Factor analysis (Principal component analysis) was used to determine most relevant factors of vulnerability and to reduce the 250 variables to a smaller set. Study ended up selecting 42 independent variables after the factors analysis that reduced to 11 factors and explained 76.4% of overall variation.

Variables

1. Median Age
2. Per capita income
3. Median dollar value of owner-occupied housing
4. Median rent
5. Number of physicians per 100,000 population
6. Vote cast for president (percent voting for leading party)
7. Birth rate per 1000 population
8. Net international Migration
9. Land in farms as percent of total land
10. % African American
11. % Native American
12. % Asian
13. % Hispanic
14. % of Population under the age of 5
15. % of Population over the age of 65
16. % of civilian labor force unemployed
17. Average number people per household

18. % of households earning more the $75,000 per year
19. % living in poverty
20. % renter occupied housing units
21. % rural farm population
22. General local government debt to revenue ratio
23. % of homes that are mobile
24. % of population over the age of 25 with no high school diploma
25. Number of housing units per square mile
26. Number of housing permits per new residential construction per square mile
27. Number of manufacturing establishments per square mile
28. Earnings in all industries per square mile
29. Number of Commercial establishments per square mile
30. Value of all property and farm products sold per square mile
31. % of population participating in the labor force
32. % of females participating in the civilian labor force
33. % employed in primary extractive industries
34. % employed in transportation, communications and other public utilities
35. Percent employed in service occupations
36. Per capita residents in nursing homes
37. Per capita number of community hospitals
38. % population change
39. % of Urban Population
40. % females
41. % female-headed households, no spouse present
42. Per capita social security recipients

Scope

Index Measures: Vulnerability to environmental hazards
Scale: county level

INDEX NINE

Natural Hazard Index for Megacities– Munich Re Group
Annual Review: Natural Catastrophes 2002

Formula

Total Risk = Hazard * Vulnerability * Exposed Values

Items Measured

1. Hazards 2. Vulnerability 3) Exposed Values

Methodology

Index is intended to measure material loss potential

Takes absolute approach, by using absolute quantities for objectifying weighting of individual components.

Considers all hazards at once

Multiplicative index

Subcomponents were standardized

Total Hazard exposure was calculated by adding the values for the average annual loss from that hazard and weighting it at 80% and adding that value to the highest value for the probable maximum loss and weighting that at 20%.

Variables

- Earthquake – change in vibration intensity
- Earthquake – Liquefaction (softening of subsoil)
- Earthquake – Tsunami
- Earthquake – Fire following earthquake
- Windstorm –Tropical storms
- Windstorm – Extratropical storms
- Windstorm –Local storms (tornadoes, hail storms)
- Flood – River
- Flood – Flash Flood
- Flood – Storm surge
- Vulnerability – specific to building class
- Vulnerability – standards of preparedness/safeguards (building regulations, town and country planning in respect to specific hazards, flood protection).
- Vulnerability – General quality of construction
- Vulnerability - building density
- Exposed values – Average vale of household for residential buildings
- Exposed values – Gross domestic product for commercial buildings
- Exposed values – Global economic significance

Scope

Index Measures: Vulnerability and Exposure to Earthquakes, Windstorms and Floods
Scale: City

Application

Megacity*	Population* (millions)	Total risk index	Risk index components		
			Hazard	Vulnerability	Exposed values
Tokyo-Yokohama	34.9	710	10.0	7.1	10.0
San Francisco Bay	7.3	167	6.7	8.3	3.0
Los Angeles	16.8	100	2.7	8.2	4.5
Osaka-Kobe-Kyoto	18.0	92	3.6	5.0	5.0
Miami	4.1	45	2.7	7.7	2.2
New York	21.6	42	0.9	5.5	8.3
Hong Kong-Pearl River Delta	14.0	41	2.8	6.6	2.2
Manila-Quezon	14.2	31	4.8	9.5	0.7
London	12.1	30	0.9	7.1	4.8
Paris	11.0	25	0.8	6.6	4.6
Chicago	9.4	20	0.8	5.6	4.4
Mexico City	25.8	19	1.8	8.9	1.2
Washington-Baltimore	7.9	16	0.6	5.4	4.4
Beijing	13.2	15	2.7	8.1	0.7
Seoul	21.2	15	0.9	7.2	2.2
Ruhr area	9.6	14	0.9	5.8	2.8
Shanghai	14.2	13	1.1	7.0	1.7
Amsterdam-Rotterdam (Randstad)	8.0	12	0.9	5.6	2.3
Moscow	13.2	11	0.7	8.7	1.8