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Urbanization and Environmental Challenges in Asia/Pacific, Middle East and Africa—Ranking of Worldwide Centers of Commerce

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Urbanization and Environmental Challenges in Asia/Pacific, Middle East and Africa—

Ranking of Worldwide Centers of Commerce

In 2007 MasterCard Worldwide launched its inaugural "Worldwide Centers of Commerce Index." The report, ranked leading global cities along six dimensions, collectively providing a first-ever assessment of how such cities contribute to global commerce.[1] Across Asia/Pacific, Middle East and Africa, there are 21 cities ranked among the top 50 of the world's centers of commerce. The launch of the Worldwide Centers of Commerce Index also took place in the context of a year signifying another important milestone. According to the United Nations Population Fund, a historical turning point was reached in 2006 with urban population exceeding rural population, making 2007 the first year in which humanity existed as an "urban species."

With urbanization and urban living comes a new challenge, that of protecting and improving the urban environment. Nowhere is this more acute and pressing than across the Asia/Pacific, Middle East and Africa region. This report summarizes findings from a groundbreaking research study that assesses the vulnerability of the 21 centers of commerce to key environmental factors (air pollution, water pollution, etc.) that affect the quality of life in the cities and the risks to health and safety from such factors. This assessment ranks these centers of commerce according to their different environmental vulnerabilities.[2]

The assessment process is based on consideration of three dimensions: (i) environmental indicators that are largely under governmental control; (ii) environmental indicators affected by climate change and not (at least not directly) under governmental control; and (iii) indicators of unpredictable environmental risks.[3]

Dimension 1

Indicators included in this dimension are those considered to be under government control; and they include conditions of water potability, water availability, sewage system, waste removal, air quality, and infectious diseases. Their weighting in the calculation of the rankings is shown in Table 1.[4]

Based on the weighting of these indicators, rankings of the 21 centers of commerce in the Asia/Pacific, Middle East and Africa region are summarized in Table 2.

Those cities that rank lowest in environmental quality suffer from very high levels of air pollution (especially vehicular emissions), absent or ineffective waste removal and coverage (solid wastes and sewage network) and high instances of infectious diseases. Severe limitations to water availability and potability are marked in New Delhi and Mumbai, with Jakarta and Beijing subject to significantly impaired potability. Beirut suffers from degraded environmental services due to political disturbance.[5]

Dimension 2

Indicators included in this dimension are not considered to be under government control (at least not directly); and are subject to potential impact from climate change. These include rise of sea level, water scarcity due to drought, severe storms, and fires.

The weighting of these indicators is summarized in Table 3.

Based on the weighting of these indicators, the rankings of the 21 centers of commerce in the Asia/Pacific, Middle East and Africa region are summarized in Table 4.

The impact of climate change is likely to be especially marked in Bangkok, Jakarta, Shanghai and Sydney due to flooding from a rise in sea level; they may be less marked in Singapore, Tokyo and Melbourne where adaptive strategies may be easier to implement. Drought is predicted to be significant in the Middle East countries

Table 1
Weights of Indicators in Dimension 1

Indicator	Weight
Water Potability	12%
Water Availability	12%
Sewage System	12%
Waste Removal	16%
Air Quality	32%
Infectious Diseases	16%

Table 2
Rankings in Dimension 1

Rank	Centers of Commerce	Normalized Score (1=Best)
1	Melbourne	1.0
2	Singapore	1.7
3	Tokyo	1.7
4	Sydney	1.8
5	Dubai	2.2
6	Johannesburg	2.7
7	Tel Aviv	3.6
8	Seoul	3.8
9	Kuala Lumpur	4.6
10	Riyadh	5.2
11	Hong Kong	5.3
12	Bangkok	5.3
13	Shanghai	6.0
14	Chengdu	6.7
15	Shenzhen	6.9
16	Cairo	7.1
17	Beijing	7.4
18	Jakarta	7.8
19	Beirut	8.2
20	New Delhi	9.7
21	Mumbai	10.0

Table 3
Weights of Indicators in Dimension 2

Indicator	Weight
Sea Level Rising	70%
Water Scarcity	20%
Severe Storms	5%
Fires	5%

Table 4
Rankings in Dimension 2

Rank	Centers of Commerce	Normalized Score (1=Low Risk)
1	Kuala Lumpur	1.0
2	Chengdu	1.3
3	New Delhi	1.6
4	Johannesburg	1.9
5	Beijing	1.9
6	Tel Aviv	2.2
7	Beirut	2.2
8	Seoul	2.4
9	Riyadh	3.1
10	Mumbai	3.2
11	Cairo	4.4
12	Hong Kong	4.8
13	Shenzhen	4.8
14	Dubai	5.0
15	Tokyo	5.4
16	Singapore	5.4
17	Melbourne	6.2
18	Shanghai	6.2
19	Jakarta	6.7
20	Sydney	8.4
21	Bangkok	10.0

Table 5
Weights of Indicators in Dimension 3

Indicator	Weight
Earthquakes	75%
Typhoons/Hurricanes	20%
Volcanic Eruptions	5%

Table 6
Rankings in Dimension 3

Rank	Centers of Commerce	Normalized Score (1=Low Risk)
1	Melbourne	1.0
2	Johannesburg	1.0
3	Sydney	1.0
4	Tel Aviv	1.0
5	Riyadh	1.0
6	Bangkok	1.0
7	Beirut	1.0
8	Shanghai	1.2
9	Singapore	1.3
10	Dubai	1.4
11	Kuala Lumpur	1.4
12	Cairo	1.4
13	New Delhi	1.4
14	Mumbai	1.4
15	Seoul	1.6
16	Beijing	2.9
17	Hong Kong	2.9
18	Shenzhen	2.9
19	Chengdu	3.3
20	Jakarta	3.4
21	Tokyo	10.0

with offset strategies being variously adopted according to financial strength. Increased incidences and severity of typhoons are predicted for Hong Kong and Shenzhen and to a lesser degree Tokyo. The details of the data supporting these rankings are shown in Appendix C.

Dimension 3

Indicators in this dimension are those considered to be highly unpredictable (hence exogenous), but all have immediate impact on the environment of the centers of commerce nonetheless should they occur. They are earthquakes, typhoons, hurricanes, and volcanic eruptions.

The weighting of these indicators is summarized in Table 5.

Based on the weighting of these indicators, the rankings of the 21 centers of commerce in the Asia/Pacific, Middle East and Africa region are summarized in Table 6.

Unpredictable risks are pronounced in the case of Tokyo and to a degree in Jakarta and the cities in China. Tokyo is in close proximity to volcanic activity, subject to severe earthquakes and lies in the path of frequent typhoons. The remaining cities are relatively free of these events either singly or in combination. Preparation measures receive significant attention and have been put in place to minimize the effect of these events in Tokyo and Hong Kong.

Further details of the above weighting and rankings appear in Appendix C.

Combined Ranking

Combining the three dimensions provides the final results. Weighting for the combined dimensions is based on the perception that the most important dimension by far is the quality of the day-to-day environment (Dimension 1), since that is the daily experience of the city resident or visitor and its indicators have the most significant impact on health and welfare. Next in importance is the dimension of risks from climate change since the trends are to some extent predictable and known to be getting

Table 7
Weights of the Dimensions

Indicator	Weight
Dimension 1	70%
Dimension 2	20%
Dimension 3	10%
	100%

Table 8
Rankings Based on Combined Dimensions

Rank	Centers of Commerce	Normalized Score (1=Best)
1	Melbourne	2.03
2	Johannesburg	2.37
3	Singapore	2.40
4	Dubai	2.70
5	Sydney	3.02
6	Tel Aviv	3.08
7	Tokyo	3.27
8	Seoul	3.29
9	Kuala Lumpur	3.54
10	Riyadh	4.35
11	Hong Kong	4.93
12	Chengdu	5.25
13	Shanghai	5.54
14	Bangkok	5.79
15	Beijing	5.82
16	Cairo	5.95
17	Shenzhen	6.07
18	Beirut	6.29
19	Jakarta	7.10
20	New Delhi	7.24
21	Mumbai	7.78

more severe. The least important dimension is element of unpredictable risk. Thus, the following overall weighting is used in this study:

The rankings of the 21 centers of commerce based on the above weighting of the combined dimensions are shown in Table 8.

Compared to the rankings based on only Dimension 1, the major upward movements are for Johannesburg (up from 6 to 2), and Beijing (up from 17 to 15), due to their lack of external risks. A major decline is seen for Tokyo (3 to 7) due to extreme external risks, and to a lesser extent Bangkok (12 to 14) and Shenzhen (15 to 17). Table 9 shows two cities at extreme ends of environmental quality with a breakdown of variables used to determine the overall rankings, with brief commentaries on each variable.

Urbanization and Urban Environmental Management

Impact on the population from the environmental factors noted above may vary depending on the city's demography, economic base, level and distribution of income, and its morphology. These factors strongly influence the effectiveness of its urban management. Implications of these aspects include:

• **Demography and Urban Growth.** Cities with a large population put a greater strain on the natural resource base and their goods and services than smaller ones, and require larger and more sophisticated infrastructure. Cities which are growing rapidly are much more difficult to manage than those with low growth rates (as in a direct comparison of Mumbai with Melbourne). This should be taken into account in the assessment of the effectiveness of urban management. Large and/or rapidly-growing cities where environmental indicators are also good or improving suggest better environmental management, as witnessed in the case of Singapore.

• **City Wealth and Income Levels.** Cities with higher GDP levels and a higher income popula-

Table 9
Highest and Lowest Ranking Centers of Commerce

Environmental Factors	Highest Score	Lowest Score
	Melbourne, Australia	**Mumbai, India**
Environmental Quality Indicators		
Infectious Diseases	Rare Incidents of Infectious Diseases	Frequent Outbreaks of Endemic Diseases
Water Potability	Tap Water Drinkable	Tap Water Only Drinkable After Boiling/Filtering
Water Availability	Reliable Supply	Intermittent Supply
Sewage Systems	100% Coverage, Reliable Service	Partial Coverage and Frequent Malfunctions
Waste Removal	Comprehensive Collection and Disposal	Inadequate Collection, Resulting in Waste Accumulation
Traffic Congestion	Moderate Congestion During Peak Hours	Chronic Delays and Congestion
Air Quality	Good Air Quality as a Result of Pollution Control	Poor Air Quality from Traffic and Industry
Climate Change		
Sea Level Rise	Not Applicable	Significant Impact Predicted
Typhoons	Not Applicable	No Significant Incidence Predicted
Drought	Significant Sporadic Drought Predicted	Small Increase Predicted
Regional Fires	Small Additional Risk	No Significant Incidence Predicted
Disruptive Monsoons	Not Applicable	Significant Increase Predicted
Exogenous Risks		
Earthquakes	No Incidence	Not Predicted
Volcanoes	No Incidence	No Incidence
Typhoons	No Incidence	Rare

tion are better equipped to manage environmental quality than those with lower GDP and lower incomes. First, the population has more disposable income to protect themselves against some problems (such as contaminated water). Second, depending on its quality of fiscal and financial management, the city has more financial resources to provide environmental infrastructure to protect the residents. And third, richer cities are more likely to have a better educated and professional staff to manage the urban area. This is apparent in the very different Dimension 1 rankings of first- and third-world cities. Cities in 'emerging' economies, such as Johannesburg, Seoul and Kuala Lumpur, also do well.

• **Economic Base.** The economy of the city also has a significant influence on its environmental quality. Heavy industries consume more resources and cause more pollution than light industry, with cities based on modern services and knowledge causing the least impact. For example, an analysis of pollutant sources in Cairo reveals 30% of atmospheric pollution comes from open burning, 32% from vehicular emissions and 27% from industry. Over time, many cities change their economic base and much of the reduction in pollution in developed countries is due to the transfer of industry to developing countries in Asia. For example, Mumbai has large chemical and manufacturing plants which are heavy pollutants, as do Jakarta and Bangkok but to a lesser extent.

• **Disproportionate Environmental Impact on the Poor or Socially Marginalized.** Poor residents in many cities are more vulnerable to environmental threats than the rest of the population. They generally live in risk-prone areas such as low-lying land, close to watercourses, or on steep slopes. The infrastructure services of developing countries are often deficient and the poor live in slum or squatter areas, leading to high levels of disease that is exacerbated by poor nutrition. From the perspective of economic and commercial competitiveness, a city which has a significant proportion of poor population living in these conditions will suffer the following: i) a low income workforce which is prone to sickness and time away from work, ii) danger of contagious diseases spreading to the

rest of the city, iii) probably a higher crime rate, and iv) an unfavorable image of the city and resulting difficulty in attracting managers and inward investment. This is evident in the high levels of infectious diseases in cities such as New Delhi, Mumbai and Jakarta.

• **Morphology.** The location, elevation and natural features of a city have a significant effect on its environmental quality and risks. Over a third of the world's urban areas are located at or near sea level and thus vulnerable to sea level rise, and in some areas, typhoons and hurricanes. Some cities may be subject to temperature inversions (such as Seoul, Tokyo, New Delhi and Beijing), which affect air quality. Those located on river plains (Bangkok) or gorges are vulnerable to flooding, and those in dry areas, to increasing temperatures, fire (Sydney and Melbourne), and heat-induced illnesses, brought on by global warming. Indicators based on recent mapping of predicted global changes are used to assess the vulnerability of the cities to some of these factors.

An analysis of the environmental rankings indicates that the higher-income cities have been able to provide commensurate improvements in environmental quality (such as Singapore, Tokyo, Melbourne and Sydney). However, a proviso is needed: history indicates a sequence of changes in environmental impacts depending on the level of development of the city. Poorer cities at a lower level of development usually suffer from a lack of basic infrastructure services such as clean drinking water and sanitation. As they industrialize and income levels increase, basic services are usually improved, but new environmental problems emerge, such as traffic congestion, air pollution and toxic wastes (such as is now the case in most large Chinese cities).

Within this context the effectiveness of urban environmental management depends on a variety of factors, including i) priority given to the urban environment in overall national policy and funding, ii) the degree of political autonomy and stability at the city level, iii) the extent of fiscal and spending powers of local government and budgetary allocations from central government, iv) effectiveness of citizen pressure groups, v) establishment of skilled and influential environmental managers, and vi) leadership and vision, which is needed to establish and implement appropriate policies and programs. Most of these qualities are more apparent in developed-country cities, and cities such as Kuala Lumpur, and especially Singapore, are notable in their effective environmental management.

The determination of effective environmental management requires an assessment of the scope and effectiveness of alternative environmental policies, establishing and enforcing regulatory measures, application of economic instruments and incentives, investment in environmental infrastructure, voluntary initiatives, and education. Quantitative measures and comparisons for these factors have never been successful. On the other hand, qualitative descriptions, such as those contained in city studies by the United Nations Development Program (UNDP), the Asian Development Bank (ADB), the World Bank, and academic institutions are perhaps the most useful and revealing.

The effects of climate change and unpredictable exogenous risks present cities with serious challenges. Some cities have adopted preventive strategies and ameliorative actions to offset the effects of environmental impact from these sources. Examples include volcano and earthquake warning systems and building and planning codes (Tokyo is especially notable in these matters), flood prevention structures, and strict enforcement of environmental quality standards. Generally, these are being implemented in wealthier, developed countries, leaving those in developing countries, which have not undertaken them, far more vulnerable. A further possible impact resulting from climate change, which has not been estimated in this study, is the effect which widespread starvation, resulting in internal and international urban migration would have on the abilities of cities to

cope with such a disaster. Cities in the study which may be particularly vulnerable to these impacts are those in heavily-populated countries such as China, India and Indonesia.

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Appendix A: Research Methodology, Environmental Dimensions and Indicators

The research methodology deployed was designed to:

A. Identify key environmental factors emerging from urbanization (air, water pollution, etc.) and those occasional unpredictable environment events (volcanoes, earthquakes, etc.) which affect urban areas, and establish the links between these factors and their impact on human health, safety, city efficiency and the quality of life of the city residents;

B. Identify the factors which lend themselves to some level of human control that can be exercised over these factors;

C. Identify the urbanization and urban management influences which play a role in mitigating/exacerbating adverse environmental impact;

D. Select indicators and units of measurement for the environmental factors that relate to the impact on residents. The indicators should be i. simple yet robust, ii. capture the most important effects, and iii. be available and broadly comparable for all the cities under study;

E. Obtain the data sets for each city. (This step was one of the most difficult in view of the lack/variability/inconsistency of environmental

data at the city level. Interpretation and informed judgment were applied by the consultants in the assessment of studies, reports and professional knowledge of colleagues interviewed; Time series data was available for only the two dimensions, but not for the 'green indicators' dimension (see below);

F. Prepare a quantitative analysis for each city for key dimensions of environmental risks, including, where possible and appropriate, impact on a per-capita and city-wide basis;

G. Form a weighting system among the environmental factors, based on explicit assumptions;

H. Prepare city rankings within each environmental dimension for key groups of environmental factors;

I. Form a weighting across the environmental dimensions, based on explicit assumptions;

J. Form a consolidated city ranking; and,

K. Prepare a short descriptive summary of the approach for each city that would incorporate both the quantitative analysis and the qualitative assessment.

Dimensions

Three sets of environmental dimensions were identified along with associated indicators:

• **Dimension 1.** Environmental indicators which are largely under government control. These are environmental indicators that have a negative impact on health, quality of life and efficiency of operating in the city but are, for the most part, under the control of local governments. In almost all countries, national governments have generally decentralized responsibility for these matters to local governments, but national governments nevertheless influence the policy, institutional and financial environment in which local governments must manage these matters. The indicators include: water potability, water availability, sewage system coverage, waste removal, air quality, and presence of infectious diseases.

• **Dimension 2.** Environmental indicators affected by climate change. These indicators refer to risk factors caused or exacerbated by increase in global warming. The indicators include permanent flooding caused by rising sea level (exacerbated in some cases by subsidence due to ground water extraction), water scarcity (due to droughts), more intense and frequent storms (typhoons/hurricanes), and fire in the peri-urban areas. Dealing with the root causes of the increased risks would require concerted international action, but some ameliorative and preventative actions can be taken at the city and national levels.

• **Dimension 3.** Indicators of unpredictable environmental risks. These risks are beyond the control of governments, but pose serious periodic or future risks to the city. These are earthquakes, typhoons/hurricanes, and volcanoes.

Appendix B discusses in more detail a set of indicators, primarily physical, that would be most useful in assessing these risks and their impact on human health, quality of life and efficiency of operating in the city. An intensive effort was made to obtain city-level data, via books, journals and reports, both hardcopy and from the Internet and discussions with colleagues. However, while substantial data on the environment are available at the country level there is paucity at the city level. For the Dimension 1 factors, physical indicators of environmental quality at city level, apart from air pollution, are very patchy, and only partially available. Mercer Inc. did have a consistent database of information for all of the selected 21 cities.

Accordingly, the Mercer results for 2006 have been used for Dimension 1 indicators. Where possible, the scoring of indicators was adjusted against available physical data.

A. Data for the Dimension 2 and 3 indicators are available in a spatially mapped form within countries. This allowed the data to be interpreted for the locations of the study cities.

B. Data for Dimensions 2 and 3 are also available on a time series basis, which has enabled an assessment of future impact. Data from the

International Panel on Climate Change (IPCC reports in the case of Dimension 2) and risk (from historic events in the case of Dimension 3). No time series data were found for Dimension 1. This hampered efforts to assess trends in environmental quality and city management.

C. The resultant list of indicators used in this study is described in Appendix B. It should be noted that the indicators chosen relate to the degradation of natural resources (such as water and air quality), and not to social or economic factors. Thus, indicators such as violence or traffic congestion are not included. In some cases this may yield an unexpected city ranking.

Indicators

For each environmental factor there are many potential indicators of environmental quality, but the most commonly used indicators which characterize the chief health and safety risks to humans and to environmental integrity have been selected for discussion. Safe levels as defined by the World Health Organization (WHO) will generally be used. Differential impacts on the poor are noted. Time series data would be desirable to indicate trends in improvement or deterioration. Modifications were made where the indicators suggested are unavailable for all the cities on a consistent basis.

Dimension 1 Indicators

Air Quality

Airborne particulates, especially very fine ones (PM10) from diesel fumes, oil-fired power plants and copper smelters and to a lesser extent those from coal smoke and road dust (TSP) penetrate the small pores in the lungs and exacerbate bronchitis and asthma, affecting children and the elderly the most severely. Concentrations of ground level ozone from car exhausts also restrict breathing. The resulting breathing difficulties raise stress levels, resulting in higher rates of heart disease and stroke. Nitrous oxides (NOX) from industry and petroleum engine vehicles interact with ultraviolet light to cause ground-level ozone which reduces oxygen intake, resulting in similar afflictions. Sulphur dioxide (SOX) from industrial processes interacts in the upper atmosphere to produce acid rain which stunts growth of plants (including cereals and trees) and reduces fish populations, both of which reduce food availability. Acid rain also erodes buildings (especially stone and iron work), increasing maintenance costs and damaging historic structures. All these pollutants also stimulate eye irritations and diseases. Measures of these indicators are often recorded in concentrations at ‘hotspots' and city averages and expressed as the number of days per year recorded over safe limits. Air pollution affects the whole population, but sometimes with additional impact on the poor who may live in more polluted locations, and suffer indoor air pollution from cooking and heating with open fires.

Water Quality

River and coastal waters are often laced with a cocktail of pollutants including bacteriological, viral and toxic elements originating from human, municipal and industrial wastes, and in some situations, from road and agricultural runoff. Water bodies with high levels of BOD cause eutrophication and foul odors that reduce the city's attractiveness and decrease their capability for recreation. Polluted water not only increases water treatment costs, it can mean that water used for irrigation may be toxic to plants and farmers, seafood safety may be jeopardized, and people in contact or drinking untreated water can rapidly become ill. In addition to diarrhea and dysentery, hepatitis A, shistosomiasis (mainly in sub-Saharan Africa), and trachoma can be contracted from contact with unclean water. As there are too many pollutants to monitor for potential sicknesses, key indicators of biological oxygen demand (BOD) and fecal coliform count (FC) can provide broad indicators of the overall health of rivers and coastal waters. Where possible, heavy metals loading should be included, since they become concentrated in fish and seafood, posing the danger of neurological diseases and cancers. While all the urban population is at some risk from polluted

surface water, it is the poor who are the most affected since they often have no choice but to live near these water bodies where open land is often available.

Drinking Water Quality

Clean drinking water, whether from a piped municipal supply, a well or a vendor is the most essential environmental health requirement. Worldwide, the majority of childhood sicknesses and deaths, mainly from diarrhea and dysentery, are caused by poor water and sanitation. In some countries toxic chemicals may be naturally present (such as arsenic in Bangladesh) and fluoride in China (also caused by over-fluoridation), and inadequate steps taken to purify the water. Economic costs, especially time lost from work, are significant, especially among low-income groups. While the key epidemiological indicator is FC, the most useful indicator is the percentage of the urban population without access to clean drinking water.

Human Waste Disposal

Human wastes give rise to the same diseases as impure drinking water, which is often contaminated with human wastes. In addition, helminths and parasites are concentrated in feces, giving rise to shistomasiasis, and debilitating intestinal, liver and blood diseases. Again, the most useful indicator is the percentage of the urban population without access to sanitation.

Solid and Hazardous Wastes

Uncollected wastes are sources of vector diseases such as malaria, dengue, plague, eye and skin diseases transmitted by insects and rats. They also clog drains and cause local flooding. Industrial and hospital wastes are often not separated properly and are mixed with municipal wastes, spreading risk of infections from toxins and infectious diseases, including cancers, neurological diseases, hepatitis and HIV. The situation is compounded where disposal methods are inadequate. Open dumps are still the dominant form of disposal in many developing countries, and waste pickers at the dumps are at great risk of contracting disease, and of transmitting them to others. Leachate from dumps drains into watercourses and underground aquifers, further poisoning water supplies since toxic chemicals escape detection in standard water quality testing in many countries. Solid waste dumps and landfills emit methane, a potent greenhouse gas.[6] In view of the many types of pollutants, the best indicators are: 1. percentage of municipal waste uncollected, 2. percentage of hazardous wastes uncollected, and 3. percentage of municipal and hazardous wastes in uncontrolled dumps.

While all the urban population in many developing countries is at some risk from polluted drinking water and inadequate waste management, the poor are by far the most affected since they can not afford to buy bottled drinking water or the fuel to boil water, which are often the practices of the upper and middle income groups. The poor also live in the most unsanitary settlements, often close to pollution sources such as waste dumps, food markets and heavy industries. Of the 1.8 million people worldwide who die each year from diarrheal diseases (90% of them children, most under 5), 88% is attributed to unsafe water supply, inadequate sanitation and hygiene.[7] For the water and wastes factors, the incidence of disease will be included if data is available, and if it can be separated from other sources.

Energy Consumption

Cities are by far the main consumers of energy, either within the urban area, or from distant power stations. This consumption puts pressure on increasingly limited supplies of fossil fuels. Depending on the availability of data, estimates will be made from the relevant indicators, by source, namely barrels of oil consumed/year, tons of coal consumed/year, and from renewable sources, barrels of oil equivalent/year. If possible, these various measures will be consolidated into a common measure such as billion joules/year.

Lack of Open Space, Tree Cover

Rapid population growth in developing countries' cities together with the lack of effective planning and public investment has left many cities with little open space or recreational facilities. The result is a significant reduction in quality of life for all residents and a less attractive location for business managers. Lack of tree cover increases the urban 'heat bubble,' and rising global temperatures will exacerbate the situation, leading to an increasing number of deaths from heat in tropical cities. Trees also retain soil, and depending on the quality of catchment management, deforestation in urban and surrounding areas which are mountainous often leads to landslides and floods. Squatter settlements are often located on steep slopes and in flood plains, and the poor usually suffer disproportionately. City growth also consumes open land which may be important for water resource stability, including watersheds and aquifer recharge areas. Appropriate indicators are the area of non-road public space per capita, and percentage of city area under tree crown cover.

Local, Temporary Flooding

Increased area of hard surface in cities combined with inadequate and clogged drainage systems often lead to severe localized flooding. The impact is felt in property damage and disruption of business and transport, affecting most of the population in low-lying areas. An appropriate indicator would be the percentage of the city and days per year under water.

Dimension 2 Indicators

A certain level of impact on key environmental factors is inevitable due to climate change, according to the Intergovernmental Panel on Climate Change (IPCC). www.ipcc.ch. Scenarios of projections of sea level rise, frequency of storms and increases in temperature have already been made by the IPCC, and these have been applied to the cities under study through the year 2050. The IPCC estimates a range of global warming increases between 2000 - 2050 by between 2° C and 4.9° C, depending on the adoption and effectiveness of a range of policy measures. This study adopts a level of 3.5° C by 2050 as a basis for impact assessment.

Sea Level Rise

Small rises in sea level can probably be contained by most coastal cities through building dykes and increased planting of natural barriers such as mangroves. Any significant increase, however, will cause cities to suffer permanent flooding and destruction of property, and significant areas may have to be abandoned. Sea level rise of 20 cm by 2030 projected by the IPCC will be exacerbated in those cities where ground subsidence due to groundwater extraction is also occurring (in Bangkok, for example, at 3 cm/year). All segments of the population are likely to be affected, although the better-off will have more resources to undertake and recover from relocation. The indicator chosen is the percentage of city area covered to depth of 30cm by 2030.

Severe Storms

IPCC models predict increasing frequency of severe storms such as typhoons and hurricanes. Cities in regions affected by these events will suffer from deeper floods and property destruction and loss of life from high winds. Indicator chosen is number of days per year with winds over 150 kph.

As observed in the case of hurricane Katrina, the poor are likely to suffer more than the average from these events.

Droughts

Increasingly severe droughts are likely in tropical and warm, temperate regions. Those cities and hinterlands whose water supplies depend on rivers originating in mountain glaciers are likely to be especially affected, due to glacial melting from global warming. All segments of the population will be affected, but rises in the price of water will disproportionally affect the poor. Relevant indicators are projected declines in rainfall in mm/year, and reductions in river flow cubic-meters per second.

Heat and Fire

Increasing temperatures, exacerbated in urban areas by the 'urban bubble' effect, are likely to cause additional deaths from heat exhaustion, especially among the old and those without access to air conditioning. Wildfires in the peri-urban areas and surrounding regions will increase in frequency and severity, reducing the moderating influence of tree cover, and allow more erosion. Relevant indicators are increase in number of days over 38° C, and the percentage of increase in area burned by wildfires in the surrounding region.

Dimension 3 Indicators

Risks identified under the indicators in Dimension 3 are not susceptible to human intervention, and can only be addressed through better monitoring, prediction, and avoidance measures such as evacuation of population at risk, relocating settlements, and improvements in building technology.

Tsunami

Coastal cities around the Pacific and Indian oceans are at risk. Preventative measures can include early warning, raised building and 'secure island' construction. Relocation is only feasible for small settlements. There is currently no science to predict sub-oceanic earthquakes and landslides, so the only relevant indicator is a projection of past event frequency, taken as average frequency of major events over past 100 years.

Earthquakes

Earthquakes are extremely destructive. Locations subject to earthquakes are well-known, and there are small improvements in the prediction science. Preventative measures include early warning, and most important, implementation of earthquake-resistant construction. Again, the relevant indicator is projection of past event frequency, taken as average frequency of event over force 6.5 within 300 km of city during 20th century.

Volcanic Eruptions

Locations subject to volcanic eruptions are also well-known, and prediction science has recently improved. Preventative measures include early warning of expected major events and rapid evacuation. Measures to restrict urbanization in areas subject to lava and lahar flows are critical.

Indicator is a projection of past event frequency, taken as the average frequency of event of major lava or lahar flows or dust emissions during past 100 years.

Based on the above considerations, the following schema for environmental factors, indicators, unit measures and time changes is proposed:

The indicators selected were modified to take account of available data. Appendix B discusses the changes made for application in the report.

Environmental Factors
Potential Controlled by National and City Authorities

Environmental Factor	Proposed Indicators		Time Change	Data Sources (1)
	Indicator	Units		
Air Quality	Particulates PM10 or TSP SOX NOX Air Quality Days Policy/Operations	Days per Year Over 45 ug/m3 PM10 Days per Year Over 220 ug/m3 Days per Year 300 ug/m3 Number of 'Severe' Days per Year e.g. Ban 2-stroke Engines, Relocate Industry	Past 5 Years Ditto Ditto Ditto	Standards for PM10, SOX, NOX from UK Environmental Agency or World Health Organization
Greenhouse Gases	City CO2 Production Methane Production City Energy Consumption	Number of Tons per Year Number of Tons per Year Number of Mwh, Number of Tons Oil per Year	Past 5 Years Ditto Ditto	For Contribution to National Total
Water Quality	BOD, COD, Heavy Metals, Coliforms	BOD >6 Mg per Liter in Main River FC >1000 Colony/100ml in River	Past 5 Years Ditto	
Drinking Water Quality	Fecal Coliform Count Access to Clean Water	FC <1 Colony/100ml Percentage of Population Without Access	Past 5 Years Ditto	
Human Waste Disposal	Exposure to Fecal Waste	Percentage of Population Without Sanitation	Past 5 Years	
Solid and Hazardous Waste Management	Health Risks Collection Ratios Disposal Management Policy/Operations	Instances of Disease Percentage of Solid Wastes Uncollected Percentage of Hazardous\Wastes Uncollected Percentage of Landfills Uncontrolled Sanitary Landfills, Human Waste Disposal Plant	Past 5 Years Ditto Ditto Ditto Ditto	
Traffic Congestion	Average Speed in City Journey to Work	Km/hr Average Number of Minutes	Past 5 Years Ditto	
Traffic Accidents	Fatalities	Number of Fatalities per Year per 1000	Ditto	
Energy Consumption	Oil Coal Renewables	Barrels Equivalent/Year Tons/Year Barrels Equivalent/Year	Past 5 Years Ditto Ditto	
Open Space Trees	Area of Non-Road Public or Community Space TreeCover	Square Meters per Capita Percentage of City Area in Tree Crown Cover	Past 5 Years Ditto	
Catchment Condition Temporary Flooding	Management Quality Extent of Flooding	Ranked 1 to 5 Percentage of City, Days per Year Under Flood	Past 5 Years Ditto	

Environmental Factors
Potential Mitigation By Global Action

Environmental Factor	Proposed Indicators		Time Change	Data Sources (1)
	Indicator	Units		
Permanent Flood	Extent of Flooding Population Migration	50cm Depth Over Percentage of City Area Number Permanently Displaced	By 2050	From Climate Models
Severe Storms	Winds Over 150 km/hr	Number of Days per Year	By 2050	From Climate Models
Water Availability	Projected Rainfall in Region Projected Reduction River Flow	Percentage Decline in mm per year Percentage Decline (or Cumecs/Second per Year)	By 2050 Ditto	From Climate Models
Temperature Rise	Projected Temperatures Wildfires	Increase in Number of Days Over 100°C Percentage Increase in Area Burned	By 2050 Ditto	From Climate Models

Environmental Factors
Not Susceptible to Human Action

Environmental Factor	Proposed Indicators		Time Change	Data Sources (1)
	Indicator	Units		
Tsunami	Historic Exposure	Number of Events During 20th Century		Improve Prediction, Evacuation
Earthquakes	Historic Exposure	Number Over Force 6.5 in 20th Century		Improve Prediction, Evacuation
Volcanic Eruptions	Historic Exposure	Number of Events During 20th Century		Improve Prediction, Evacuation

Environmental Factors
Urbanization and Urban Management Influences

Environmental Factor	Proposed Indicators		Time Change	Data Sources (1)
	Indicator	Units		
Demography	City Population City Growth Rate	Number of Persons, Number of Households Percentage per Year Population Growth	Current Past 5 Years	
Poverty	LDC Cities DC and Post-Comm. Cities	Percentage of population in informal settlements	Past 5 Years Ditto	For Contribution to National Total
Income Levels	Personal Income City (or Country) GDP	Per Capita Household Income	Past 5 Years Ditto	
Economic Base	GDP Shares	Heavy Industry Light Industry Commercial Services	Past 5 Years Ditto Ditto	
Urban	Qualitative Assessment Based on Studies and Experience as discussed in Dimension 1			

Appendix B Environmental Indicators: Selection, Rating, and Weighting

The rationale for using certain indicators in determining environmental quality and risks as they affect human health and safety are outlined.

These were the ideal indicators, selected at the beginning of the study. Subsequently, limitations in the availability of data meant that some of these indicators had to be reduced and/or simplified in order to select ones which covered all the cities and could provide comparability. The following discusses i) the selection of indicators, ii) the methods used to determine the rating of individual indicators, and iii) the weights used among indicators in each environmental dimension.

Dimension 1: Environmental Factors Under Government Control

Selection of Indicators

Due to the patchiness and inconsistent availability of data on physical measurements of environmental factors, this study has relied on

the data from city surveys undertaken by Mercer Co. in 2006. The Mercer data covers over 60 cities and is the only data set which provides comparisons between all the 21 cities of the Study. The following indicators from the list in Appendix C were dropped due to the reasons noted:

• **Water Quality:** There was no data available at the city level on ambient water quality. The more important indicator for human health is drinking water potability, which is included.

• **Energy Consumption:** This was dropped since, while it indicates impact on natural resources, it does not have a direct effect on human health.

• **Vehicular Traffic:** This is a man-made factor affecting city efficiency and not an environmental factor per se. Its effect on human health is subsumed under 'air quality'. It has therefore been omitted from the overall environmental rankings, but is discussed as part of the discussion on city management.

• **Lack of Open Space/Tree Cover:** Data was not available on this factor.

• **Local/Temporary Flooding:** Data was not available for this indicator. It was also considered to be an issue more of city efficiency than of human health.

Two indicators were added which were not included in Appendix C: First is water availability— an important indicator for health, especially for the poorer segments of the population. Second, infectious diseases, a useful indicator related to overall public and private hygiene and a measure, to some extent, of poverty.

Ratings

The following indicators were therefore included in Dimension 1. The descriptions of each indicator are as follows:

• **Water Potability:** This is based on the potability of tap water from a piped supply:

1 = Tap water is safe to drink without further treatment

4 = Tap water is drinkable only after boiling

6 = Tap water should be boiled and filtered, however it is still recommended to drink bottled water

10 = Tap water not safe to drink at all.

• **Water Availability:** This refers to the access to drinking water:

1 = Piped water is available throughout the whole metropolitan area

5 = Piped water is available over 70% of the metropolitan area

10 = Piped water available only in limited central city areas.

• **Sewage System:** This refers to coverage of a piped sewer system:

1 = Sewer system operational throughout the metropolitan area

5 = Sewer system serves only in central city and upper-income residential areas

10 = Sewer system serves only central city commercial area

• **Waste Removal:** This refers to removal of solid wastes from public space. It does not indicate the safety of waste disposal, nor the extent of removal and treatment of hazardous wastes:

1 = Waste is regularly removed and the whole of the metropolitan area is clean

5 = Waste removal is effective in the central city and upper and middle income residential areas, but is sporadic or non-existent in the rest of the city

10 = Waste removal is limited to central city and upper income residential areas where it is nevertheless sporadic.

• **Air Quality:** This refers to the perceived quality of the air in central and inner parts of the city. It refers to a combination of visual perception (smog), smell, and breathability. While it does not refer to the concentrations of specific pollutants, a separate analysis of air quality from other studies indicates a similar ranking of cities, after making some adjustments:

1 = Excellent visibility, little smell and no lung congestion

2 = Hazy visibility for much of the day, occasional smell and lung congestion

10 = Very bad visibility, continuous smell, frequent difficulty in breathing

• **Infectious Diseases:** This refers to the perceived prevalence of diseases originating mainly from poor public and personal hygiene:

1 = Very low

5 = Moderate

10 = High

Weighting

The following weightings among the indicators were based on professional judgment. Air quality has been accorded a much higher rating than the others, since the other ratings are closely related to pathogens in water and wastes.

Weights of Indicators in Dimension 1

Source	Indicators	Weighting
Mercer	Water Potability	12%
Mercer	Water Availability	12%
Mercer	Sewage Systems	12%
Mercer	Waste Removal	16%
Mercer	Air Quality	32%
Mercer	Infectious Diseases	16%
		100%

Dimension 2: Environmental Risks Affected by Climate Change

Selection of Indicators

Three of the four indicators listed in Appendix C were selected. However, heat was dropped, since its main effect is to produce drought (which is included in Appendix C), plus a higher incidence of fires (which is now included).

Ratings

A scoring scale of 1 (least risk) to 10 (most risk) was developed for these indicators. The following show the ratings and sources for the indicators selected:

• **Permanent Flooding:** This will arise from a combination of sea level rise with subsidence in urban areas due to over-extraction of groundwater (severe problem in Bangkok, and to some extent in Jakarta). Severe storms (classified under a separate indicator) will further exacerbate the situation. To calculate the risk, it was assumed that a 20cm rise in sea level by the year 2030 would occur (based on IPCC reports and commentaries on them by climate scientists).

Elevations of cities at potential risk were identified, and projections on subsidence (from city and newspaper reports[8]) added to the sea level rise projections. The cities were then ranked on this basis. Some modifications were made to the ratings, depending on the likelihood of the city to take effective mitigating actions, and on the variability of elevation in different parts of the city.

• **Typhoons/Hurricanes:** The Sharaku website[9] provided global information on severe storms. The number of severe storms hitting our cities over the past 10 years was identified, and for those in monsoon areas an additional 0.5 of a hurricane added (to account for severity). Fractional values were added for those severe storms which did not directly hit the city, but came within 60km. Also, if several storms came close to the city within 1 or 2 years, but were not fully-fledged hurricanes, a fractional value was added. Severe storms are projected to get stronger as world temperatures rise.

• **Water Scarcity:** Estimates of future water scarcity were derived from drought estimates due to global warming from IPCC and applied to the cities falling within the zones of different drought intensities. Those cities far inland will have greater problems of dealing with drought than those beside the sea, which can obtain

water for domestic and industrial purposes from de-salination plants, albeit at a much higher cost.

• **Fire:** Severe drought greatly exacerbates the hazards from fire, particularly for those cities whose suburbs are surrounded by forest and scrubland. Australian cities have been among the worst affected, and will continue to face risk. Maps showing increased temperature rise (from IPCC) with vegetation cover (Google Earth) were combined to indicate risk from fire.

Action to reduce the impact of climate change can be taken, but must be mainly at the national and international levels in order to be effective. Action taken now will, however, help to reduce the even-more-dire effects expected after mid-century. Some of the currently projected impact can be mitigated or delayed to some extent by human action, for example, sea wall defenses for inundation, building storm-resistant buildings, de-salinization plants, but these will all be costly and will not be adequate for all cities.

Weighting

Judgments were made on the relative importance of the specific indicators affected by climate change. Sea level rise combined with subsidence were considered the most certain and permanent impact, and thus given a high weighting. Water scarcity was considered the next most severe and permanent effect. Severe storms and fires, while having severe impacts, last only a short time and are events from which the city can recover.

Weights of Indicators in Dimension 2

Source	Indicators	Weighting
IPCC	Sea Level Rise/Subsidence (by 2030)	70%
IPCC	Water Scarcity (Drought)	20%
Sharaku	Severe Storms (Typhoons/Hurricanes)	5%
IPCC	Fires	5%
		100%

Dimension 3: Unpredictable Environmental Risks

Selection of Indicators

The three indicators discussed in Appendix C were retained as the most common unpredictable environmental events. More drastic events, such as asteroid and comet impacts were not assessed, since they are completely unpredictable in location and severity and are much less frequent.

Ratings

A scoring scale of 1 (least risk) to 10 (most risk) was developed for these indicators. The following show the ratings and sources for the indicators selected:

• **Earthquakes:** 20th century earthquakes of at least 6.5 Richter within 300 km. of the city were mapped from USGS data.

• **Volcanoes:** Based on Google Earth maps, volcanoes active since the year 1500 were mapped and found to have a possible effect on only two cities (Tokyo and Jakarta).

• **Severe Storms:** Typhoons and hurricanes were included in climate-related impact. They are included again here since they are part of normal, yet unpredictable events. The same basis was used as for the climate dimension.

Weighting

Earthquakes are very much more destructive than the other events, and have been accorded most of the weighting. The next-most-destructive impact comes from severe storms which are

Weights of Indicators in Dimension 3

Source	Indicators	Weighting
USGS	Earthquakes (in 20th Century)	75%
Sharaku	Typhoons/Hurricanes (Past Incidences)	20%
Google	Volcanoes (Active Since 1500)	5%
		100%

frequent events in at-risk areas. Volcanic eruptions affect only two of our cities. The last event was 300 years ago when Tokyo was covered in ash, but was not severely damaged.

Combined Ranking

Finally, an overall assessment of environmental quality and risk has been made. This is very much based on opinion and should be used cautiously. Much depends on the purpose and importance of the various factors as perceived by the user of the information, and should be changed according to different users' needs.

Weighting for the combined dimensions is based on the perception that Dimension 1 is the most important dimension by far— the environmental factors under government control, since these factors affect the daily experience of the city visitor or resident. Next in importance is the dimension of risks from climate change since these events are to some extent predictable and known to be getting more severe. The least important dimension is element of unpredictable risk. The following is suggested:

Combined Weighting

Indicators	Weighting
Indicators Under Government Control	70%
Indicators Affected by Climate Change	20%
Indicators of Unpredictable Risks	10%
	100%

Appendix C

Dimension 1
Rankings Based on Environmental Indicators Under Government Control

Rank	Centers of Commerce	Normalized Score (1=Best)	Weighted Average	Water Availability	Waste Removal	Sewage	Water Potability	Infectious Diseases	Air Pollution
1	Melbourne	1.0	9.2	10	9	10	10	10	8
2	Singapore	1.7	8.7	10	10	10	10	8	7
3	Tokyo	1.7	8.7	10	10	10	10	10	6
4	Sydney	1.8	8.6	10	9	9	9	10	7
5	Dubai	2.2	8.3	9	9	9	7	8	8
6	Johannesburg	2.7	7.9	9	8	9	10	7	7
7	Tel Aviv	3.6	7.3	9	7	8	8	8	6
8	Seoul	3.8	7.2	9	9	8	7	8	5
9	Kuala Lumpur	4.6	6.6	7	8	7	8	7	5
10	Riyadh	5.2	6.2	8	7	8	2	6	6
11	Hong Kong	5.3	6.1	10	7	7	8	7	3
12	Bangkok	5.3	6.1	6	6	6	4	4	8
13	Shanghai	6.0	5.6	8	7	7	4	8	3
14	Chengdu	6.7	5.1	8	5	6	2	7	4
15	Shenzhen	6.9	4.9	8	6	6	2	7	3
16	Cairo	7.1	4.8	8	5	5	5	6	3
17	Beijing	7.4	4.6	8	6	6	2	7	2
18	Jakarta	7.8	4.3	7	6	6	2	4	3
19	Beirut	8.2	4.0	3	4	4	2	6	4
20	New Delhi	9.7	2.9	2	4	5	3	3	2
21	Mumbai	10.0	2.7	4	4	3	1	3	2

Dimension 2
Rankings Based on Indicators Affected by Climate Change

Rank	Centers of Commerce	Normalized Score (1=Best)	Weighted Average	Permanent Flooding (Elevation + Subsidence)	Drought	Typhoons Index	Fires	Typhoons
1	Kuala Lumpur	1.0	1.2	1.0	2	1.0	1	0.00
2	Chengdu	1.3	1.4	1.0	3	1.0	1	0.00
3	New Delhi	1.6	1.6	1.0	4	1.0	1	0.00
4	Johannesburg	1.9	1.8	1.0	5	1.0	1	0.00
5	Beijing	1.9	1.8	1.0	5	1.0	1	0.00
6	Tel Aviv	2.2	2.0	1.0	6	1.0	1	0.00
7	Beirut	2.2	2.0	1.0	6	1.0	1	0.00
8	Seoul	2.4	2.2	2.0	3	2.0	1	0.83
9	Riyadh	3.1	2.6	1.0	9	1.0	1	0.00
10	Mumbai	3.2	2.7	2.5	4	1.3	1	0.25
11	Cairo	4.4	3.5	4.0	3	1.0	1	0.00
12	Hong Kong	4.8	3.8	4.0	2	10	1	7.5
13	Shenzhen	4.8	3.8	4.0	2	10	1	7.5
14	Dubai	5.0	3.9	4.0	5	1.0	1	0.00
15	Tokyo	5.4	4.2	5.0	1	8.5	1	6.25
16	Singapore	5.4	4.2	5.5	1	2.2	1	1.00
17	Melbourne	6.2	4.7	4.5	6	1.0	6	0.00
18	Shanghai	6.2	4.8	6.0	2	2.0	1	0.83
19	Jakarta	6.7	5.1	6.5	2	1.0	1	0.00
20	Sydney	8.4	6.2	6.5	6	1.0	8	0.00
21	Bangkok	10.0	7.3	10.0	1	1.0	1	0.00

Dimension 3
Rankings Based on Unpredictable Environmental Risks

Rank	Centers of Commerce	Normalized Score (1=Best)	Weighted Average (1=Best)	Earthquakes Index	Volcanoes Index	Typhoons Index	Earthquakes in 20th Century	Volcanoes Active Since 1500	Typhoons
1	Melbourne	1.0	1.00	1.0	1.0	1.0	0	0	0.00
2	Johannesburg	1.0	1.00	1.0	1.0	1.0	0	0	0.00
3	Sydney	1.0	1.00	1.0	1.0	1.0	0	0	0.00
4	Tel Aviv	1.0	1.00	1.0	1.0	1.0	0	0	0.00
5	Riyadh	1.0	1.00	1.0	1.0	1.0	0	0	0.00
6	Bangkok	1.0	1.00	1.0	1.0	1.0	0	0	0.00
7	Beirut	1.0	1.00	1.0	1.0	1.0	0	0	0.00
8	Shanghai	1.2	1.20	1.0	1.0	2.0	0	0	0.83
9	Singapore	1.3	1.24	1.0	1.0	2.2	0	0	1.00
10	Dubai	1.4	1.36	1.5	1.0	1.0	1	0	0.00
11	Kuala Lumpur	1.4	1.36	1.5	1.0	1.0	1	0	0.00
12	Cairo	1.4	1.36	1.5	1.0	1.0	1	0	0.00
13	New Delhi	1.4	1.36	1.5	1.0	1.0	1	0	0.00
14	Mumbai	1.4	1.42	1.5	1.0	1.3	1	0	0.25
15	Seoul	1.6	1.56	1.5	1.0	2.0	1	0	0.83
16	Beijing	2.9	2.78	3.4	1.0	1.0	5	0	0.00
17	Hong Kong	2.9	2.80	1.0	1.0	10.0	0	0	7.5
18	Shenzhen	2.9	2.80	1.0	1.0	10.0	0	0	7.5
19	Chengdu	3.3	3.13	3.8	1.0	1.0	6	0	0.00
20	Jakarta	3.4	3.23	3.4	10	1.0	5	2	0.00
21	Tokyo	10.0	9.48	10.0	5.5	8.5	19	1	6.25

1.See Worldwide Centers of Commerce Index, 2Q, 2007, MasterCard Worldwide; and The Dynamics of Global Cities and Global commerce, 2Q, 2007, MasterCard Worldwide.

2. The research was carried out by the Centennial Group, under the direction of Dr. Anthony Pelligrini, who is Director of the Urban and Infrastructure Policy and Finance Practice at Centennial.

3. See Appendix A for details of the research methodology, the specifications of the dimensions, indicators; and data limitations.

4. See Appendix B for details on the determination of the weights and structure of the indicators.

5. Details of indicators in this dimension are shown in Appendix C.

6. Equivalent to four times the effect of CO_2 by weight.

7. World Health Organization 2004

8. For example, Bangkok is presently subsiding at 3 cm per year, and the lowest-lying parts of the city are already permanently under water.

9. http://sharaku.eorc.jaxa.jp/cgi-bin/adeos2/typhoon

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