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# The adoption of a Climate Disaster Resilience Index in Chennai, India

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*Results derived from the Climate Disaster Resilience Index (CDRI)—consisting of five dimensions (economic, institutional, natural, physical, and social), 25 parameters, and 125 variables—reflect the abilities of people and institutions to respond to potential climate-related disasters in Chennai, India. The findings of this assessment, applied in the 10 administrative zones of the city, reveal that communities living in the northern and older parts of Chennai have lower overall resilience as compared to the flourishing areas (vis-à-vis economic growth and population) along the urban fringes. The higher resilience of communities along the urban fringes suggests that urbanisation may not necessarily lead to a deterioration of basic urban services, such as electricity, housing, and water. This indication is confirmed by a strong statistical correlation between physical resilience and population growth in Chennai. The identification of the resilience of different urban areas of Chennai has the potential to support future planning decisions on the city's scheduled expansion.*

**Keywords:** Chennai, climate-related disaster, resilience, urbanisation

## Introduction

More than one-half of the world's population has been residing in urban areas since 2007, and many of the world's fastest-growing cities are now in developing countries, predominantly in Africa and Asia (UN-Habitat, 2008). Given that urban areas are on the rise and some cities, such as Chennai in India, are expected to become megacities by 2025 (UN-Habitat, 2008), it is important to ask two key questions: (i) how can these burgeoning entities meet the basic needs of their citizens, including electricity, sanitation, and water?; and (ii) how are they going to respond if they suffer a disaster? Densely populated areas are more vulnerable in a disaster and such an incident, therefore, may have a bigger impact on urban areas than on rural villages/towns in terms of loss of human life and infrastructure (Hewitt, 1997; UNISDR, 2009). Furthermore, owing to climate change, there is a greater likelihood of more frequent and intense rainfall events, droughts, and other climate-related hazards (IPCC, 2007), putting more exposed cities at greater risk (Pelling, 2003; De Sherbinin, Schiller, and Pulsipher, 2007).

Urbanisation is occurring predominantly in cities in low- and middle-income countries (UN-Habitat, 2008)—as demonstrated by the fact that developing countries are expected to contribute eight new megacities to the pool of 29 by 2025 (UN DESA, 2010)—yet many of them are located in hazardous areas (Satterthwaite et al., 2007). Hence, while on the one hand these pressures increase the risk of disaster

 
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in these cities, on the other hand they offer an opportunity to plan for and to adapt more effectively to the impacts of climate change, since much of the projected population growth is still to happen (Satterthwaite et al., 2007). Local governments should work proactively to identify appropriate measures to make their cities more resilient to such potential events.

Chennai is an ideal example of a city with large prospects for growth (population-wise and economically), but it is also situated in a coastal area (along the Bay of Bengal) where cyclones strike occasionally. In addition, owing to its low average land elevation, it is susceptible to flooding after sporadic heavy rainfall during the post-monsoon period from October to December—most of the city lies in areas less than a couple of metres above sea-level (Revi, 2008). Dhaka in Bangladesh is another example of a fast-growing megacity with high vulnerability to climate-related disasters, as most of its urbanised areas are only around six-to-eight metres above sea-level (Alam and Rabbani, 2007); moreover, the population is expected to rise from 14.9 million in 2009 to 20.9 million by 2025 (UN DESA, 2010). Other examples of rapidly urbanising megacities susceptible to various types of climate-related disasters are Mumbai (India), Rio de Janeiro (Brazil), and Shanghai (China), all of which are also located along coastlines (De Sherbinin, Schiller, and Pulsipher, 2007).

The main aim of this paper is to understand the current resilience of cities with regard to climate-related disasters. The consequences of urbanisation are likely to increase the vulnerability of a city to a potential hazard—because of rising pressures on communities to settle in hazard-prone areas, for instance (Cross, 2001)—or generally challenge the supply of basic urban services such as water (urban drought) (Pelling, 2003). However, the principal issue is how well such a city will respond to (by absorbing and maintaining its functionality) and recover from a potential hazard or disaster (Godschalk, 2003; Vale and Campanella, 2005). This paper addresses this point through the presentation of a quantitative assessment tool—the Climate Disaster Resilience Index (CDRI)—to measure a city's resilience or its capability to withstand climate-related disasters from a community perspective. The CDRI focuses on evaluating comprehensively all sectors of a city in order to spur the process of building resilience in urban areas.

The paper is structured as follows: the first section contains a review of literature on resilience to disasters in cities; the second section defines the CDRI and its methodology in the context of Chennai; the third section presents a case study of Chennai, where a CDRI was conducted at the zone level; the fourth section conveys and analyses the results of the case study; the fifth section discusses the implications of the case study in relation to the CDRI; and the sixth section outlines some key conclusions.

## Understanding the resilience concept in the urban context

Before this study employs 'resilience' in the disaster research field and then in the development of a quantitative climate-related disaster resilience assessment, it is important to note that the term is used in various other disciplines, including economics, engineering, natural sciences, psychology, and sociology, and that it has evolved over time (Manyena, 2006; Norris et al., 2008; Pendall, Foster, and Cowell, 2010). As a result, numerous concepts and definitions from a multitude of spheres undoubtedly shape understanding of resilience (Holling, 1973; Adger, 2000; Carpenter et al., 2001, Klein, Nicholls, and Thomalla, 2003; Pelling, 2003; Vale and Campanella, 2005).

Resilience has been used interchangeably in the context of or in conjunction with 'adaptation' in the climate sector, based on the premise that all systems are adaptive in nature and in general are amenable to variability of the climate. Adaptation is thus considered to be a process of making appropriate changes to cope better with climatic uncertainties or reducing the negative effects of climate change. Understandably, the process of 'adaptation' to climate change may help in attaining resilience but it cannot be substituted by resilience (Surjan, Sharma, and Shaw, 2011).

The Resilience Alliance (2007) defines resilience as the ability to absorb disturbances, to change, and then to reorganise with the same identity (that is, to retain the same basic structures and ways of functioning). In this sense, resilience is defined in relation to the following three characteristics: the amount of change that the system can go through and still retain the same controls over function and structure; the degree to which the system is capable of self-organisation; and the ability to build and enhance the capacity to learn and to adapt. Using these characteristics, the Resilience Alliance (2007) launched an urban resilience research programme in 2007 that consists of four key elements: metabolic flow; social dynamics; governance network; and the built environment.

The Megacity Resilience Framework (UNU–EHS, 2009), among other recent studies on urban resilience, describes resilience as being opposed to vulnerability—that is, the inability to cope with risks. Furthermore, according to this framework (UNU–EHS, 2009, p. 3):

> *A (mega-) city can be regarded resilient if its inhabitants and institutions function effectively. That means that they are able to deal with unexpected disturbances and adapt to change. Furthermore, ecosystem services and their social and economic use by humans must be balanced. In this sense, the resilience of such a socio-ecological system is closely related to the concept of sustainability (economic, social and ecological).*

The Asian Cities Climate Change Resilience Network points to four elements of resilience: redundancy; flexibility; capacity to reorganise; and capacity to learn (ACCCRN, 2009). This network spans 10 cities in four countries (India, Indonesia, Thailand, and Vietnam) and has adopted a shared-learning dialogue as a process-based approach at the city level.

In a study of the resilience of a coastal community, the United States Indian Ocean Tsunami Warning System Program defines resilience according to eight elements (USIOTWSP, 2007): governance; society and economy; coastal resource management; land use and structural design; risk knowledge; warning and evacuation; emergency response; and disaster recovery. The study asserts that a community should be placed at the centre of the resilience concept and that how people adapt to change through experience and by applying lessons learned is crucial to enhancing resilience. It is vital to note, therefore, that resilience is not a stable state, but rather a dynamic concept with a cycle of its own, and that a 'generic planning and implementation cycle provides a framework for identifying the opportunities to enhance resilience' (USIOTWSP, 2007, p. 36).

The World Bank (2009) has developed a primer for climate-resilient cities, which explains the linkages between three aspects: disaster risk management; climate change; and development policy. It contends that to address climate change it needs to be viewed through the prism of the development agenda and be embedded in disaster risk management policies.

Godschalk (2003, p. 137) asserts that 'a resilient city is a sustainable network of physical systems and human communities' whereby both elements must be able to survive and function under extreme stresses (disasters). Similarly, Vale and Campanella (2005, p. 353) regard a disaster-resilient city as 'a constructed phenomenon, not just in the literal sense that cities get reconstructed brick by brick, but in a broader sense'. Accordingly, a disaster-resilient city encompasses not only physical and social aspects, but also institutional or organisational features (Klein Nicholls, and Thomalla, 2003; Norris et al., 2008).

The conceptualisations of several authors (Bruneau et al., 2003; Paton, 2003; Aalst, Cannon, and Burton, 2008; Cutter et al., 2008), examining resilience from a human perspective, suggest that the ability of communities, embedded in built environments and natural systems, to cope with a disaster is crucial to minimising damage and loss in a city. Community resilience to disasters originates in the field of social resilience, which neither is viewed in isolation from other disciplines and systems (economic, institutional, and natural) nor involves only an individual's ability to cope with shocks and stresses (Adger, 2000). Instead, social resilience is described according to the positive and negative aspects of social capital, marginalisation, and social exclusion that are observed within communities.

Twigg (2007, p. 6) characterises a disaster-resilient community as having: first, the 'capacity to absorb stress or destructive forces through resistance or adaptation'; second, the 'capacity to manage or maintain certain basic functions and structures, during a disastrous event'; and third, the 'capacity to "bounce back" after an event'. This raises the question of how to capture this 'capacity'. The Disaster Resilience of Place (DROP) model of Cutter et al. (2008) defines the resilience of a community using its ability to function well during non-crisis periods and its flexibility to respond (absorb, maintain, bounce-back) to a shock (a natural hazard leading to a disaster). Consequently, the capacity of a community is not just defined by its ability to respond to a disaster (Twigg, 2007), but also by its ability to build faculties or strengths (adaptation) before an event, suggesting that the concept of resilience must be seen as a cycle. After a community has recovered from a disaster, it will learn from its experience and generate greater capacity (inherent resilience) in order to be prepared for a future shock (Bruneau et al., 2003; Cutter et al., 2008).

Comfort (1999, p. 21) defines resilience as 'the capacity to adapt existing resources and skills to new situations and operating conditions'. This supports the notion that the term capacity, in the context of resilience to disasters, involves two phases of time. In other words, the concept of resilience is about responding to a given level of stress on the one hand, yet it also includes, on the other hand, aspects of adaptation after a shock (disaster) (Holling and Gunderson, 2002; Cutter et al., 2008; Pendall, Foster, and Cowell, 2010). Bruneau et al. (2003) further emphasise the importance of the level of strength (resilience) of a system or a community during non-emergency periods in reducing or even avoiding potential shocks (disasters). This means that, in an urban system (city), different communities embedded and interacting in economic, institutional, natural, and physical systems (environments) need to have the ability not just to respond to a disaster, but also to learn from it (adaptation), to reduce the probability of a future event, and thus to enhance their resilience.

In summary, the resilience of an urban area is a complex function of different institutional, physical, socioeconomic, and system issues. As is evident from the above discussion, several international and regional initiatives are ongoing to highlight the resilience of a city in a more integrated way. The literature review also shows that the resilience of an urban community depends on its capacity to create the ideal environment, which is most capable of minimising the probability of shocks and has the greatest ability to respond to disaster situations.

## The CDRI approach

The previous section underlined the relation between the strength of the concept of resilience and how well a community may respond to a shock, and whether it is capable of minimising the likelihood of occurrence. However, the proposed CDRI is not the only approach that seeks to enhance resilience to disasters in cities. There are also vulnerability assessments, such as those of the World Bank (2009) or the World Wildlife Fund (2009), which aim to foster the resilience of cities. They use the concept of vulnerability to measure the current condition of a city, which is slightly different to the concept of resilience. A brief discussion of the two is necessary to avoid confusion.

Among other analysts, Pelling (2003) states that vulnerability denotes exposure to risk and an inability (sensitivity) to avoid or absorb harm, whereas resilience is 'the capacity to adjust to threats and mitigate or avoid harm' (Pelling, 2003, p. 5). The concepts are interacting and hence it is difficult to separate them entirely from each other, as a less vulnerable system is likely to become more resilient to shocks and stresses (Berkes, Colding, Folke, 2003; Adger, 2006; Manyena, 2006). However, the ability of a system to respond and to recover from a disaster or to minimise the probability of a future event is not covered by the concept of vulnerability (Cutter et al., 2008). The purpose of the proposed CDRI is to understand this attribute or the strength of a city. The CDRI, described below, examines and gauges the different capabilities needed for communities, located in a city, to comprehend their resilience to climate-related disasters.

## Characteristics of the CDRI

Unlike the quantitative resilience assessment of Bruneau et al. (2003), which focuses solely on earthquakes, the CDRI is tailored to climate-related hazards, such as cyclones, droughts, floods, and heat waves, which are more likely to occur in Chennai as compared to geophysical-related hazards.

The CDRI framework has five dimensions: economic; institutional; natural; physical; and social. These are similar to the four interrelated dimensions (economic, organisational, social, and technical) that define the framework of Bruneau et al. (2003), which is geared towards describing the disaster resilience of a community embedded in a system. To clarify, the term system in relation to the CDRI represents an urban area where different communities interact within a defined geographical space (Cutter et al., 2008). In the case study of Chennai, the 10 administrative zones are considered to be 10 different communities within a system (city).

Within this space, five dimensions, 25 parameters (five in each dimension), and 125 variables (five in each parameter, 25 in each dimension) aim to cover key aspects of a community's resilience to climate-related disasters (see Table 1). Following an extensive literature review,[2] the different dimensions, parameters, and variables were carved out (as shown in Table 1) to define the resilience of communities in an urban system (city) to climate-related disasters. Based on this literature review, there is no evident reason why one dimension should have more or less parameters (or variables) than another, since all of them are fundamental elements characterising the resilience of a city to a disaster. As a result, all of the dimensions are defined by the same number of parameters and variables. The principal aspect of these indicators is that they are related to city services. To build or improve the resilience of a city, it is essential, therefore, to enhance their resilience or capacity. There are several discussions on mainstreaming disaster risk reduction, but true mainstreaming occurs when resilience is blended with the different city services. The CDRI methodology attempts to do this (see below).

As noted, various risk drivers, such as aspects of urbanisation, the decline of ecosystems, urban poverty, and unplanned growth, characterise many cities in developing countries. To alleviate them, sustainable development is required, connecting different elements of a city (Cutter et al., 2008). This explains why economic, natural, and social dimensions are part of the CDRI framework. The institutional and physical dimensions are added owing to the fact that communities are embedded in a built environment (physical dimension) and that, in the event of a disaster, local government has a crucial role to play (institutional dimension) in confronting and managing such an event (Klein, Nicholls, and Thomalla, 2003).

The selection of the physical dimension (accessibility of roads, electricity, housing and land use, sanitation and solid waste disposal, and water), for example, is based on the premise that a well-functioning or disaster-resilient city can provide key services to its residents (communities). This not only lessens the probability of a shock, but also it may enhance the capacity of communities to respond to it if they are well maintained and equipped.

This point is also particularly relevant to the social dimension where, for instance, a good social capital base among communities (Kadushin, 2004) and the level of disaster preparedness (availability of emergency materials and voluntary support in relief activities) illustrate how well people are connected and how well they may support each other in the case of a disaster (Cutter et al., 2008). Risk drivers such as urban poverty or urbanisation are reflected in various parameters, including employment, income (number of people below the poverty line), and population (number of informal settlers). Both of these risk drivers are connected to some degree, as high population growth rates are likely to increase the number of people affected by urban poverty in urban areas of India.

The economic dimension reflects the ability of people to acquire income through employment, as well as to what extent they can transfer money into savings that can be used in a time of disaster. The availability of calamity funds from local government and funding for disaster risk reduction (DRR) activities reveal whether systems are in place to finance issues related to disaster risk management before and after an event.

The institutional dimension measures the functionality of local government, including whether disaster drills are conducted and whether a disaster management plan or an early-warning system is in situ. Furthermore, it is essential to the overall functionality of the system that the local government at the zone level is able to perform during a disaster, both on its own and in communication with other stakeholders (non-governmental organisations (NGOs), private organisations, or other zones, for example). Also fundamental is the extent to which the crisis management framework is capable of responding to a potential disaster.

The natural dimension includes the fragility of the various urban ecosystems, the loss of urban green space over past decades, the existence of urban hazard maps, and efficient waste management systems. Knowing about the capacity of the environmental properties of the city is crucial to determining whether or not a potential shock can be absorbed.

The CDRI framework seeks to accommodate the context of a city, such as Chennai, where little secondary data are available at the zone or neighbourhood level, and even at the city level. As a result, engineers operating in the different zones of Chennai (total of 10), performing civic work, were selected as representatives to provide responses to the CDRI questionnaire, consisting of 125 variables based on available secondary data. Each variable offered a choice between '1' (poor/not available, or a percentage depending on the question) and '5' (best fully available, or highest percentage). In addition, the engineers weighed each variable and parameter against its importance in influencing the overall resilience score.

The CDRI tries to disentangle specific aspects of risk drivers, such as the quality of ecosystems, unplanned development, urbanisation, or urban poverty, and measures them via different factors (parameters and variables) represented in various dimensions (such as poverty). Moreover, the focus is on the ability of different systems (dimensions) to alleviate the probability of shocks and to respond effectively

**Table 1.** Dimensions, parameters, and variables (in parentheses) of the CDRI

| Dimensions | Parameters and variables |
|---|---|
| Physical | **Electricity** (access, availability, supply capacity, alternative capacity).<br>**Water** (access, availability, supply capacity, alternative capacity).<br>**Sanitation and solid waste disposal** (access to sanitation, collection of waste: treated, recycled, collection of solid waste after a disaster).<br>**Accessibility of roads** (percentage of land transportation network, paved roads, accessibility during flooding, status of interruption after intense rainfall, roadside covered drain).<br>**Housing and land use** (building code, buildings with non-permanent structure, buildings above water logging, ownership, population living in proximity to polluted industries). |
| Social | **Population** (population growth, population less than 14 and more than 64 years of age, population informal settlers, population density at day and night).<br>**Health** (population suffering waterborne/vector-borne diseases, population suffering water-borne diseases after a disaster, access to primary healthcare facilities, capacity of healthcare facilities during a disaster).<br>**Education and awareness** (literacy rate, population's awareness of disasters, availability of public awareness programmes/disaster drills, access to the internet, functionality of schools after a disaster).<br>**Social capital** (population participating in community activities/clubs, acceptance level of community leader (in ward), ability of communities to build consensus and to participate in a city's decision-making process (level of democracy), level of ethnic segregation).<br>**Community preparedness during a disaster** (preparedness (logistics, materials, and management), provision of shelter for affected people, support from non-governmental organisations (NGOs) and community-based organisations (CBOs), population evacuating voluntarily, population participating in relief works). |
| Economic | **Income** (population below poverty line, number of income sources per household, income derived in informal sector, percentage of households with reduced income owing to a disaster).<br>**Employment** (formal sector: percentage of labour unemployed, percentage of youth unemployed, percentage of women employed, percentage of employees from outside the city; percentage of child labour in zone).<br>**Household assets** (households have: television, mobile telephone, motorised vehicle, non-motorised vehicle, basic furniture).<br>**Finance and savings** (availability of credit facility to prevent disaster, accessibility to credit, accessibility to credit among the urban poor, saving practice of households, household's property insured).<br>**Budget and subsidy** (funding of disaster risk management, budget for disaster risk reduction, sufficient availability of subsidies/incentives for residents to rebuild houses, alternative livelihoods, post disaster health care). |
| Institutional | **Mainstreaming of disaster risk reduction and climate-change adaptation** (in zone's development plans, ability (manpower) and capacity (technical) to produce development plans, extent of community participation in development plan preparation process, implementation of disaster management plan).<br>**Effectiveness of zone's crisis management framework** (existence and effectiveness of an emergency team during a disaster: leadership, availability of evacuation centres, efficiency of trained emergency workers during a disaster, existence of alternative decision-making personnel).<br>**Knowledge dissemination and management** (effectiveness in learning from previous disasters, availability of disaster training programmes for emergency workers, existence of disaster awareness programmes for communities, capacity (books, leaflets, etc.) to disseminate disaster awareness programmes (disaster education), extent of community satisfaction of disaster awareness programmes). |

| Dimensions | Parameters and variables |
|---|---|
| | **Institutional collaboration with other organisations and stakeholders, during a disaster** (zone's dependency on external institutions/support, collaboration and interconnectedness with neighbouring zones, zone's cooperation (support) with central corporation department for emergency management, cooperation zone's ward officials for emergency management, zone's institutional collaboration with NGOs and private organisations).<br>**Good governance** (effectiveness of early warning systems, existence of disaster drills, promptness of zone body to disseminate emergency information during a disaster to communities and transparency of zone body in disseminating accurate emergency information, capability of zone body to lead recovery process). |
| Natural | **Intensity/severity of natural hazards** (floods, cyclones, heat waves, droughts (water scarcity), tornados).<br>**Frequency of natural hazards** (floods, cyclones, heat waves, droughts (water scarcity), tornados).<br>**Ecosystem services** (quality of city's biodiversity, soils, air, water bodies, urban salinity).<br>**Land use in natural terms** (area vulnerable to climate-related hazards, urban morphology, settlements on hazardous ground, amount of urban green space (UGS), loss of UGS).<br>**Environmental policies** (use of zone-level hazard maps in development activities, extent of environmental conservation regulations reflected in development plans, extent of implementation of environmental conservation policies, implementation of efficient waste management system, implementation of mitigation policies to reduce air pollution). |

if they occur. Finally, the CDRI assessment integrates aspects related to the Hyogo Framework for Action 2005–2015 (HFA), a key non-binding policy aimed at fostering DRR by United Nations member states at the national (UNISDR, 2005, 2007) and local (UNISDR, 2010) level. Among the five priorities of the HFA, the CDRI pertains to various tasks (underlying risk factors) formulated in priority four, which seek to strengthen economic, environmental, physical, and social aspects at different spatial scales (UNISDR, 2007, 2010). To conclude, the CDRI is an approach designed to link the concept of resilience to issues related to DRR in cities (see Matsuoka and Shaw, 2011).

## Limitations of the CDRI

First, it is apparent that one methodology cannot cover all parameters concerning the complexity of community resilience (King, 2001). Second, the questions in the CDRI are answered by city managers at the zone level and thus, may contain some subjective judgements. This limitation was addressed, however, by a long consultation process with zone-level managers and the requirement that all answers be accompanied by supplementary data. Third, better results for some parts of the CDRI questionnaire would be forthcoming—such as in the economic, physical, and social dimensions—if it was administered at the household rather than at the zone level (King and MacGregor, 2000). Finally, the frequency and the intensity of occurring natural hazards, reflected in the first two parameters of the natural dimension, are measures of exposure (vulnerability) rather than of resilience.

Nevertheless, the CDRI represents an approach for understanding the functionality and the condition of different sectors that shape the resilience of Chennai to climate-related disasters. It is also an attempt to define systematically the indicators that are expected to shape the resilience of a city and to influence its ability to respond to shocks. Rather than assessing the disaster resilience of Chennai via a qualitative approach, as done by Tanner et al. (2009), the CDRI seeks to map out resilience based on parameters and variables in a quantitative manner. Consequently, the CDRI paints a rough picture (map) of the current condition of Chennai's 10 zones and their ability to respond to potential climate-related disasters.

### Calculating the CDRI

While the CDRI questionnaire is composed of five dimensions (see Table 1), it is also defined by another five parameters, which are represented by five variables that measure a parameter in more detail. As a result, 125 variables divided evenly into 25 parameters and five dimensions define the resilience of every zone of Chennai; whereby, each variable ($x_1$, $x_2$, $x_3$, $x_4$, $x_5$) allows for five different choices between not available or poorly available (score of '1') and best (score of '5'). In addition, a weighting scheme requires that variables within a parameter, consisting of five variables, have to be ranked ($w_1$, $w_2$, $w_3$, $w_4$, $w_5$) depending on their importance (low importance ('1'), high importance ('5')) in shaping the final score of a particular parameter or dimension. This simple structured questionnaire with uniform numbers for each parameter and variable, ranging from '1' to '5', permits the transparent adoption of a weighted mean (see equation below) to calculate the CDRI scores for each variable, parameter, and dimension in a standardised and harmonised approach:

$$\frac{\sum_{i=1}^{n} w_i x_i}{\sum_{i=1}^{n} w_i} = \frac{w_1x_1 + w_2x_2 + w_3x_3 + w_4x_4 + w_5x_5}{w_1 + w_2 + w_3 + w_4 + w_5}$$

## CDRI applied at the zone level in Chennai

### Background of Chennai

Chennai or Madras was founded in 1639 by a group of British businessmen belonging to the East India Company. With the establishment of Fort St. George in the same year it became a seat of power on the Coromandel Coast (Muthiah, 2008), located in the Bay of Bengal. Over subsequent decades and centuries Madras experienced rapid urban growth (see Figure 1). This was accelerated following the development of the first piers on the shoreline of the Bay of Bengal in 1861, allowing ships to harbour and stimulating sea trade (Muthiah, 2008). The port expanded in succeeding years and contributed to the growth of Madras both in terms of its economy and its population (Muthiah, 2008). By 1901 the city spanned an area of some 70 square kilometres ($km^2$) and had approximately 540,000 inhabitants. A population growth

**Figure 1.** Historical growth of Chennai, developed areas


**Source:** authors.

rate of between five and six per cent per annum resulted in the city becoming a provincial metropolis and an administrative and commercial centre by 1941 (CMDA, 2008). Population growth and expansion of the city continued over the next decade, especially after India gained independence in 1947 and became a Republic in 1950—the population passed the one million mark in 1943. Although economic growth increased sharply until 1971, the downside of this became visible when slums began to mushroom along the canals, and the quality of drainage systems and the water supply deteriorated.

Unplanned growth was not well regulated (CMDA, 2008), a phenomenon that persists up to the current day. Nowadays, a large proportion of the population lives in slums; according to official sources, some 820,000 people (or 18.9 per cent of the total population) were living in slums in 2001 (CMDA, 2008). Per capita income in 2001 was around INR 21,738 or USD 460 (currency rate of 2010), which was two times higher than the Indian average per capita income at that time. The development of various economies, such as the automobile industry and information technology, as well as business parks, along the urban fringe is expected to accelerate the economic growth of Chennai over coming years (CMDA, 2008).

## Urbanisation and climate-related hazards

Chennai, including the wider metropolitan area, is expected to become almost a megacity by 2025 with 9.9 million inhabitants (UN DESA, 2010). However, the city, which is the core study area, excludes the outer parts of Chennai. There are large variations in population growth and density rates depending on the area (see Table 2).

**Table 2.** Demographic and land-use characteristics, Chennai zone

| Area | Size in square kilometres | Population growth per annum (%), 1971–2001 | Population density in 2001 | Key characteristics |
|---|---|---|---|---|
| Zone I | 17.3 | 2.40463 | 23699 | Urban fringe: residential and industrial area |
| Zone II | 11.52 | 0.15434 | 32638 | Old part: industrial (port), commercial, institutional, and residential area |
| Zone III | 13.51 | 1.07266 | 34048 | Old part: large urban poor areas, residential and commercial area |
| Zone IV | 19.76 | 2.72278 | 25151 | Urban fringe: residential area |
| Zone V | 26.38 | 3.08246 | 20545 | Urban fringe: fast-growing residential and commercial developments |
| Zone VI | 10.15 | 0.14961 | 33694 | Old part: institutional area, beach |
| Zone VII | 12.9 | 0.59805 | 26976 | Old part: commercial area |
| Zone VIII | 13 | 2.12478 | 35846 | Urban fringe: residential area |
| Zone IX | 23.56 | 2.65644 | 17614 | Urban fringe: residential, industrial, and institutional area, large park (green space) |
| Zone X | 27.92 | 2.25455 | 17478 | Urban fringe: fast-developing area (commercial and residential) |
| **City** | **(Total) 176** | **(Average) 1.72203** | **(Average) 26768.9** | |

**Source:** CMDA, 2008.

While the average population growth in the city is about the same as the current urban world average (1.76 per cent per annum) (UN DESA, 2010), older parts of Chennai have experienced lower growth rates (0.48 per cent per annum) as compared to areas located along the urban fringe (2.54 per cent per annum).

Apart from rapid urbanisation, challenging the supply of basic urban services, Chennai also is prone to occasional cyclones, which may strike during the post-monsoon period between October and December (Drescher et al., 2007; Revi, 2008). Heavy rainfall follows such an event, or sometimes precedes it, which leads to flooding, as in 2005 before Cyclone Fanoos and in 2008 after Cyclone Nisha, producing numerous casualties and vast damage. Although the effects of climate change, namely more frequent and more severe natural hazards (IPCC, 2007), are not yet significant in this region, an expected increase in temperature is likely to have dramatic consequences for Chennai, especially because of its low-lying position, just a few metres above sea level (Revi, 2008).

Chennai's history suggests that the combined power of stresses (risk drivers) and shocks (climate-related hazards) are likely to challenge increasingly its performance during a potential disaster. The CDRI reveals the exact condition of different zones of the city at the moment.

## The scope of the case study and the approach

As stated, the Corporation (city) of Chennai constitutes the scope of this case study and the CDRI aims to measure the resilience of the city's 10 administrative zones. This zone-level approach seeks to assess whether there are variations in resilience levels within Chennai. The key purpose of these administrative zones is to permit the conduct of public work services at a lower level than the overall city level. They deal, for instance, with collecting taxes and approving different requests from residents, such as planning approval. They are regarded, therefore, as an ideal body with which to collaborate in this CDRI study. Accordingly, each zone was asked to complete, between January and February 2010, the aforementioned CDRI questionnaire, which was tailored to the local zonal context. Following this data-collection exercise, the CDRI scores for each zone were calculated using the weighted mean method outlined above, and correlations were drawn between different dimensions, parameters, and variables.

## Results and analysis

### *Quantitative and qualitative interpretation*

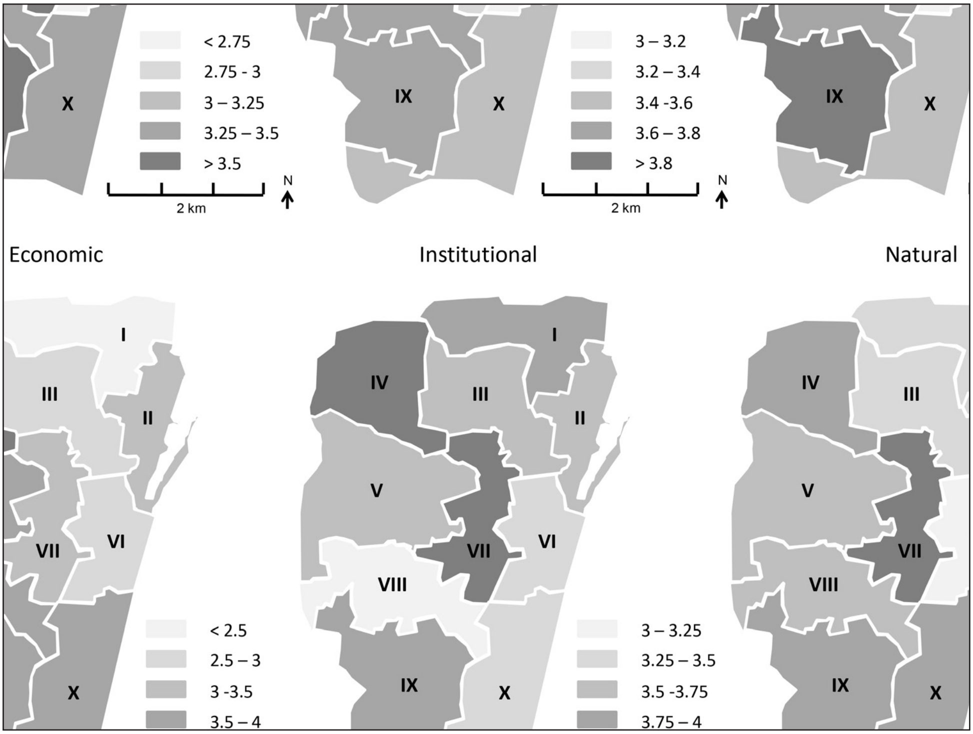
The results of the CDRI assessment are highlighted below: higher scores mean higher resilience (the maximum is '5') and lower scores mean lower resilience (the minimum is '1'). Qualitative interpretations (from observations and discussions with local people) complement the analysis of the quantitative results of the CDRI assessment.

Figure 2 highlights varying resilience levels between the overall resilience of the city and its dimensions. Hence, a comparative city-wide analysis of the results is needed, whether or not the CDRI findings match the actual situation in Chennai.

If one looks at the overall resilience scores (see Figure 2), the northern parts of Chennai (zones I, II, and III) tend to have lower resilience in contrast to the southern, central, and western parts of the city, owing in particular to low economic and natural resilience levels in these areas. Economic resilience is lower because of the high percentage of urban poor and high unemployment rates, producing cumulated effects. Other economic factors, such as the ability of citizens and the zone's administration to supply funding for measures to prevent potential disasters, become limited. The northern areas also shoulder a heavy burden in providing the soil for heavy industries, such as the port (zone II), a large waste collection site (zone I), or a big coal-fired power plant (between zones I, II, and III). This burden is reflected in lower natural resilience in these areas, as the described land use diminishes the quality of ecosystem services and therefore lowers the capacity to absorb further stresses or potential shocks.

Interestingly, the central part of Chennai (zone VII), where little industrial activity takes place, and which is shaped significantly by commercial and residential activities

**Figure 2.** Results of the CDRI




**Source:** authors.

(see Table 2), also has the highest natural resilience of all zones, even though one of the city's main transport corridors lines this area. As comparatively little new development is occurring in the northern parts of Chennai, apart from the flourishing port (zone II), higher economic resilience scores are associated with recent development activities (the establishment of automobile companies and large information technology centres) in the southern and western parts of the city (see Figure 2).

The economic and natural dimensions of the CDRI seem to correspond with the actual situation, in contrast to the social dimension, where certain areas are performing significantly better than others. This may be because of the generally mixed land-use character of the city (CMDA, 2008), or it may be due to the limiting focus of the CDRI tool on the zone level rather than on the household level.

There is no concentration of urban poor communities in just one zone (a conclusion derived from observations), and there is no clearly identifiable single business district (CMDA, 2008); however, the northern areas are composed of more heterogeneous communities (different castes and religions). Furthermore, communities residing in this area benefit less from the economic growth of the city (southern and western parts), which is reflected in their lower socioeconomic capacity. Therefore, the northern areas have lower resilience as compared to other areas of the city because of their economic, natural, and social disadvantages (lower resilience).

On analysing the different dimensions in relation to each other, the CDRI results show more variations in the economic, natural, and social resilience dimensions among the zones with the highest and lowest scores, unlike the institutional and physical dimensions. In the case of the institutional dimension, the small amount of variation is because of the zones' administrative purpose of conducting civic work at a lower institutional level than the entire city level. It is not surprising, therefore, that all zones have similar institutional resilience scores. The small amount of variation in the physical dimension, however, is because of the centralised and equitable provision of electricity and water to all areas of the city. Thus, from the physical perspective, the accessibility of roads, the disposal of solid waste, and land use in relation to housing determine whether a zone is likely to perform stronger or weaker during a climate-related disaster.

The CDRI assessment reveals not only different resilience (dimension-wise) levels among the zones, but also highlights which parameters (see Table 3) are more or less resilient (city-wise). Electricity, for example, as mentioned, is provided from the centre in an equal fashion to all areas (high score) at a relatively high level; water, in contrast, is supplied equally but not yet at the most resilient level. High population density, particularly in old areas of Chennai (see Figure 1 and Table 2), and ongoing population growth in newer areas of the city are reflected in low 'population' resilience. The listing of the different city-wide average CDRI scores for all parameters (see Table 3) is particularly relevant in terms of local government (Corporation of Chennai) understanding of which sectors (parameters) require improvements to become more resilient. Knowing about the sectors with lower resilience may trigger action at different scales, ranging from the community to the institutional level.

**Table 3.** Average city-wide CDRI scores for all 25 parameters (highest to lowest)

| Parameters | Score |
|---|---|
| Electricity | 4.87 |
| Institutional collaboration | 4.09 |
| Accessibility of roads | 4.05 |
| Health | 3.89 |
| Crisis management | 3.86 |
| Good governance | 3.64 |
| Household assets | 3.54 |
| Mainstreaming | 3.45 |
| Community preparedness | 3.44 |
| Finance and savings | 3.43 |
| Housing and land use | 3.43 |
| Education and awareness | 3.33 |
| Water | 3.24 |
| Knowledge dissemination | 3.24 |
| Intensity/severity of hazards | 3.21 |
| Employment | 3.20 |
| Budget and subsidy | 3.17 |
| Income | 3.15 |
| Environmental policies | 3.15 |
| Social capital | 2.88 |
| Sanitation and solid-waste disposal | 2.77 |
| Land use in natural terms | 2.73 |
| Ecosystem services | 2.65 |
| Population | 2.60 |
| Frequency of hazards | 2.49 |

## *Statistical interpretation*

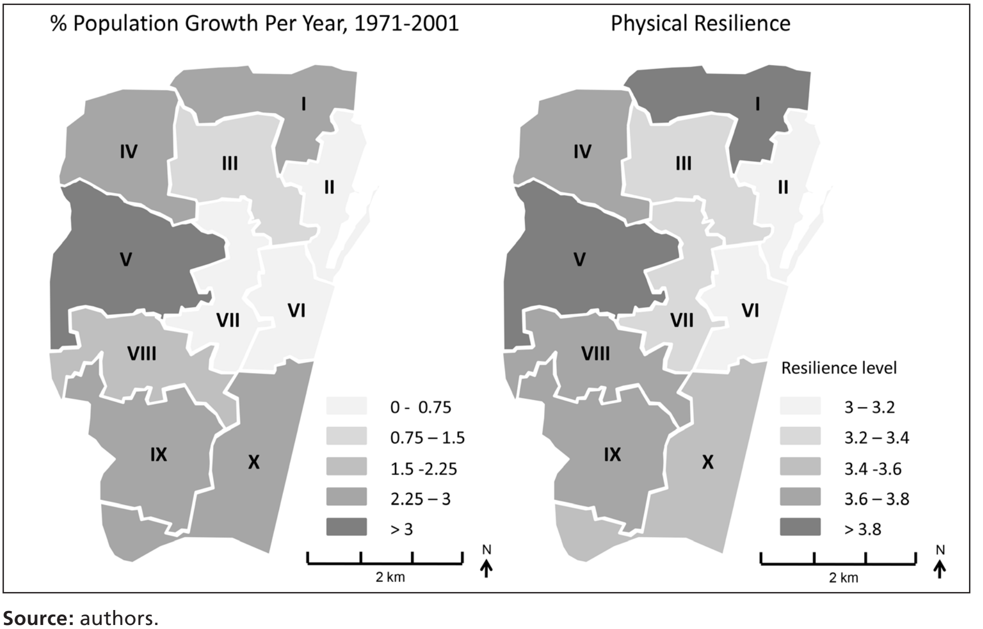
The previous subsection presented the major findings of the CDRI in relation to observed and existing land-use patterns in Chennai. This subsection aims to highlight some findings from the sphere of statistical correlation to determine whether there are connections between different dimensions or parameters.

Since Chennai emerged from scattered villages located in zones II, III, VI, and VII (see Figure 1) over centuries, those areas have experienced relatively little population growth (see Table 2) over the past few decades and are already quite densely populated. As a result, these areas may be seen as the older parts of Chennai as compared to the swiftly developing and relatively new areas along the urban fringe. Some scholars, notably Pelling (2003) and Wisner et al. (2004), suggest that rapidly growing areas may experience weaker performance in terms of providing high physical resilience in an area, but the findings of the CDRI assessment do not support this argument.

The Pearson Product-Moment Correlation Coefficient produces an r sample value of 0.96 for the percentage of population growth per year (1971–2001) and the physical CDRI scores of the 10 zones of Chennai (see Figure 3). This means that areas that experience fast population growth rates (2.54 per cent per annum on average) or urbanisation trends have a better infrastructure and are more likely to respond adequately in the event of a disaster, in comparison to areas with lower population growth rates (0.48 per cent per annum on average).

This statistical finding is supported by the fact that the city's recent developmental activities have been concentrated in areas along the urban fringe and are scheduled to continue (CMDA, 2008). For instance, the ongoing construction of a highway along the western urban fringe, the ongoing extension of the airport (located just outside of Chennai in the southwest), and the development of large information technology parks in the southern urban fringe are but three examples of large-scale

**Figure 3.** Percentage population growth per year (1971–2001) versus physical resilience




**Source:** authors.

development projects that will have a considerable bearing on the shape of the neighbouring environment. However, to conclude that, overall, new developed areas are more resilient would be to miss the point of the CDRI, which includes other dimensions that are less resilient owing, for example, to natural limitations. In many instances, areas along the urban fringe comprise marshland, which can flood quickly after intense rainfall.

The above correlation between population growth and the physical resilience of the CDRI dimension demands an assessment of whether or not other CDRI dimensions correlate with each other. Figure 2 suggests a possible correlation between the economic and natural zones, but this cannot be proven statistically. In contrast, only the natural and social dimensions have a high (relatively) correlation, r=0.84. Consequently, the qualitative presentation of the results (in the form of maps, see Figure 2) may not ultimately reveal all findings and correlations as the scaling of the maps varies (to show relative differences in resilience levels between zones). The relatively high correlation between the natural and social dimensions can be explained by the fact that greater awareness among communities may heighten their sensitivity and their ability to introduce measures to protect the environment. Other scholars, such as Adger (2000) and Cutter et al. (2008), have described the existing linkage between environmental and social issues that shapes people's abilities.

Other interesting findings are the correlation results for the 25 parameters (city-wide). Table 4 lists the parameters with correlation coefficient scores of more than 0.8.

Several significant correlation results may validate the findings of the CDRI, as well as its identification of those sectors and areas that should be targeted first in enhancing resilience to climate-related disasters. The high correlation of income and household assets and finance and savings (see Table 4) makes sense as households are likely to increase their material assets when they can afford to do so; however, the reality of an individual may not always correspond to this simplified pattern. The high correlation of education and awareness and community preparedness reflects the theoretical findings/expectation that more awareness-raising leads ultimately to a better prepared community. Similarly, the same argument accounts for the high correlation of social capital and the implementation of environmental policies.

**Table 4.** Correlations between different parameters of the CDRI, city-wide (Chennai)

| Parameters | Correlation coefficient (> 0.8) |
|---|---|
| Income and land use in natural terms | 0.90 |
| Social capital and environmental policies | 0.88 |
| Income and household assets | 0.86 |
| Income and ecosystem services | 0.83 |
| Household assets and ecosystem services | 0.83 |
| Education and awareness and community preparedness | 0.81 |
| Mainstreaming and knowledge dissemination | 0.81 |
| Crisis management and good governance | 0.81 |
| Income and finance and savings | 0.80 |

## *Summary of results*

The application of the CDRI at the zone level of Chennai highlights two key points: first, fast population growth (urbanisation) does not necessarily lead to a lower physical CDRI, which reflects the condition of the urban infrastructure and the provision of basic urban services; and second, the social and natural dimensions are correlated to some extent.

Returning to the two questions posed in the introduction about urban areas and cities—(i) how can these burgeoning entities meet the basic needs of their citizens, including electricity, sanitation, and water?; and (ii) how are they going to respond if they suffer a disaster?—the CDRI clearly indicates that basic urban services and physical infrastructure are lacking more in older parts of the city as compared to the newly established areas experiencing rapid urbanisation. As for the second question, depending on the zone, the different dimensions/sectors are more or less capable of withstanding a climate-related disaster. For example, communities in northern areas have lower economic resilience than those situated in the southern or western parts of Chennai. Thus, people find it difficult to establish wealth owing to limited employment opportunities.

## Implications of the CDRI in Chennai

Given that the objective of the CDRI is to make cities resilient, local authorities have at their disposal a tool that can help them to plan adequately. It is apparent that disasters in urban areas occur within a physically and socially defined area (Weichselgartner, 2001; Godschalk, 2003; Vale and Campanella, 2005). The ability to avoid a shock or to respond to it depends, therefore, not only on various actors (communities and institutions), but also on whether the physical infrastructure, the social cohesion and economic situation of the communities, and the environmental and institutional capacities are able to withstand climate-related disasters.

The employment of the CDRI at the zone level (to address resilience) reveals differences in the capacity and the potential ability of various zones to respond to climate-related disasters. While some zones achieve a strong CDRI score for the physical component, they perform worse in other dimensions. Hence, the CDRI provides not only insights into all five dimensions, but also detailed, zone-wise results that are particularly relevant for the identification of adequate action measures. In making the zones resilient, the next step is to identify sound initiatives that are appropriate and feasible, such as specific training of local authorities that deal with planning and public works issues. The CDRI should be seen, therefore, as a process tool where the engagement of local government officials is important in determining quantitatively and qualitatively the resilience of Chennai. The CDRI points up critical challenges regarding the functioning of different zones of the city in confronting future climate-related disasters, which should trigger effective DRR measures in a subsequent phase.

For this phase, actions to enhance the resilience of Chennai to climate-related disasters have already been formulated in a Climate Action Plan (CAP) produced in collaboration with the local government. It proposes defined actions (focusing on soft adaptation measures) to be implemented in the short (within two years), medium (up to five years), or long (more than five years) term. The CAP will support the city's planning decision-making process—through DRR measures to fulfil the Hyogo Framework for Action 2005–2015—in order to address the potential impacts of climate change and urbanisation. Adoption of the CAP in the form of a policy by the legislative body of the Corporation of Chennai occurred in 2012.

## Conclusion

The purpose of the CDRI can be summarised in the following two ways:

- first, it serves as a baseline assessment with which to gauge the resilience of a defined area to climate-related disasters by involving (holistically) different elements, including co-existing systems (economic, institutional, natural, physical, and social) of a city; and
- second, it has the potential to trigger actions specific to the local context and needs of the citizens that will enhance their resilience.

Although the CDRI may be similar in some ways to vulnerability studies, such as the hot-spot assessments of the World Bank (2009) or the World Wildlife Fund (2009), it attempts to understand, through adoption of the concept of resilience, a city's ability to reduce the probability of shocks and its capacity to respond to potential climate-related disasters. The lack of available quantitative resilience assessments (Bruneau et al., 2003), or indicators that quantitatively represent resilience in a community (Cutter et al., 2008) located in an urban area, underpins the need for the CDRI. An examination of the current and expected capabilities of communities to confront a potential shock yields understanding of processes in urban areas from another perspective, but with the same goal of enhancing the resilience of cities to disasters. A limitation of the CDRI is its aim to understand all aspects of community resilience, when some variables are better evaluated at the household level. However, it may contribute to a discussion on how to measure a city's resilience to climate-related disasters. In the future, the results of the CDRI need to be linked to community/neighbourhood action planning and analysis. Understanding the different resilience levels of a city may facilitate planning of sector-specific DRR solutions.

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2 Holling, 1973; Rosenthal and Kouzmin, 1996; Adger, 2000; McEntire, 2001; Bruneau et al., 2003; Godschalk, 2003; Kadushin, 2004; Wisner et al., 2004; Vale and Campanella, 2005; Campanella, 2006; Folke, 2006; Huq et al., 2007; Rose, 2007; Satterthwaite et al., 2007; Cutter et al., 2008; World Bank, 2009.

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