Annexure B –Lecture Notes
Module 2: The Practice of Urban Climate Change Adaptation and Mitigation

Contents

GLOSSARY OF TERMS AND CONCEPTS

This section contains an alphabetical list with brief definitions or descriptions of the terms and concepts that are central to the module:

Concept	**Description/definition**
Adaptation: climate change	'Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. *anticipatory* and *reactive, private* and *public,* and *autonomous* and *planned.* Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc.' (IPCC, 2007). '*Many disaster risk reduction measures can directly contribute to better adaptation'* (UNISDR, 2009).
Climate change	'A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods' (UNFCCC, 2010).
Climate change impacts	'The effects of climate change on natural and human systems. Depending on the consideration of adaptation, one can distinguish between potential impacts and residual impacts: – Potential impacts: all impacts that may occur given a projected change in climate, without considering adaptation. – Residual impacts: the impacts of climate change that would occur after adaptation' (IPCC, 2007).
Climate variability	'Refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability)' (IPCC, 2007).

Disaster	‘A progressive or sudden, widespread or localised, natural or human-caused occurrence which causes, or threatens to cause, death, injury or disease; damage to property, infrastructure or the environment; or disruption to the life of a community; and is of a magnitude that exceeds the ability of those affected by the disaster to cope with its effects using only their own resources’ (RSA, 2002). *‘Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences’* (UNISDR, 2009).
Extreme weather event	‘An event that is rare at a particular place and time of year. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. Single extreme events cannot be simply and directly attributed to anthropogenic climate change, as there is always a finite chance the event in question might have occurred naturally. When a pattern of extreme weather persists for some time, such as a season, it may be classed as an extreme climate event’ (IPCC, 2007).
Global warming	‘Global warming relates to the increase in the average temperature of the Earth's surface that has been observed in recent years, and it is projected to continue. It is debated as to whether this is a natural occurrence or whether human activity has impacted or accelerated it. However evidence is overwhelming that human activity since the industrial revolution is responsible’ (Aggregate Industries, 2010).
Greenhouse gas	‘The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO2), methane (CH4) and nitrous oxide (N20). Less prevalent --but very powerful -- greenhouse gases are hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur

	hexafluoride (SF6)' (UNFCCC, 2010).
Land-use planning	'The process undertaken by public authorities to identify, evaluate and decide on different options for the use of land, including consideration of long term economic, social and environmental objectives and the implications for different communities and interest groups, and the subsequent formulation and promulgation of plans that describe the permitted or acceptable uses. Land-use planning can help to mitigate disasters and reduce risks by discouraging settlements and construction of key installations in hazard-prone areas, including consideration of service routes for transport, power, water, sewage and other critical facilities' (UNISDR, 2009).
Mitigation: climate change	'A human intervention to reduce the sources or enhance the sinks of greenhouse gases. Examples include using fossil fuels more efficiently for industrial processes or electricity generation, switching to solar energy or wind power, improving the insulation of buildings, and expanding forests and other 'sinks' to remove greater amounts of carbon dioxide from the atmosphere' (UNFCCC, 2010).
Resilience	'The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions' (UNISDR, 2009).
Sea level change/rise	'Sea level can change, both globally and locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass of water and (iii) changes in water density. Factors leading to sea level rise

	under global warming include both increases in the total mass of water from the melting of land-based snow and ice, and changes in water density from an increase in ocean water temperatures and salinity changes. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence' (IPCC, 2007).
Sustainable development	'Development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland Report). Disaster risk is associated with unsustainable elements of development such as environmental degradation, while conversely disaster risk reduction can contribute to the achievement of sustainable development, through reduced losses and improved development practices' (UNISDR, 2009).
Vulnerability	'The degree to which a system (community) is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system (community) is exposed, its sensitivity, and its adaptive capacity' (UNFCCC, 2010). 'There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Vulnerability varies significantly within a community and over time' (UNISDR, 2009).

1. INTRODUCTION

More than half of the world's population now live in urban areas. Urbanisation in the developing world continues at rapid rates, and 90% of the world's urban population growth taking place in low- and middle-income countries, particularly in Asia. Most of this urbanisation is unplanned and located in unsafe spaces that are exposed to multiple and compound risks, exacerbating household vulnerability (Roberts, et al., 2012 p. 4). According to the World Economic Forum (2010 p. 6) the gravest threat may however be from highly interlinked creeping risks such as climate change that develops over decades. The impact of climate change on human settlements ranges from insignificant to catastrophic, but many agree that cities in the developing world are affected most severely by the impacts of climate change – cities that are already challenged by a range of socioeconomic development stresses (IPCC, 2007; Parnell, et al., 2007 p. 359) and that lack the adaptive capacity to deal with climate variability and change as a result of underdevelopment, poverty, poor governance and lack of skills (Roberts, et al., 2012 p. 4).

Planners are in an ideal position to contribute to the fight against climate change, but have been slow to get involved. Few strategies, plans or frameworks analyse and monitor hazard and vulnerability factors or contain risk assessments of the present and future effects of climate change on urban areas. This can be explained by the many other short-term developmental challenges demanding immediate action. But planning cannot ignore the warning signals of climate change projections, and needs to mainstream climate change adaptation and mitigation measures into development planning policies, strategies and interventions (Faling, et al., 2012).

2. HOW CITIES ARE AFFECTED BY CLIMATE CHANGE

2.1 Human settlements

Human settlements are arguably one of the most important battlefields in the fight against climate change with their higher concentrations of people, economic activity and infrastructure. Unpredictable and rapid-onset disasters such as flash floods, storm surges and cyclones will pose some of the biggest threats to human settlements and infrastructure. The poorest sections of human settlements will be hit worst by the impact from climate change due to poverty, the deteriorated physical environment, ill health, and social tension. The negative impacts from regional climate conditions or sea level rise may result in many climate refugees migrating to urban areas for shelter and employment, placing additional stress on housing and service provision. (Boko, et al., 2007 p. 450; Roy, 2009 p. 276; Stern, 2007 p. 129).

2.2 Economic development

Climate change is likely to set back growth and development prospects of cities in many developing countries to affect their long-term economic growth potential. Climate change threaten the basic elements of city life such as access to water, food, health and the use of land and the environment, thereby reducing the amount of resources available per person that have significant impacts on lives and livelihoods (Stern, 2007 p. 65).

Though the actual monetary loss of extreme weather events may be higher in the developed world due to the monetary value of infrastructure, the proportion of GDP loss in developing countries is much higher, causing great setbacks in economic and social development. Slower growth could cause increasing poverty as income levels, health and mortality rates are impacted negatively by climatic changes (Stern, 2007 p. 114).

2.3 Ecosystems

Humankind depends on the services provided by natural systems, but poor people particularly depend on environmental assets and the ecosystem services they provide. Climate change threatens ecosystems that are already under pressure from human activities such as urbanisation, changes to land uses, overharvesting of selected species, hunting and deforestation and the introduction of alien species. Urban areas are often rich in species diversity and contain a wide range of habitats, but they are often in competition with socio-economic activities, placing stress on the species as well as habitat formation. These threats constraint social and economic development and expose a greater number of poor people to the effects of climate change (Ruth, et al., 2006 p. 37; Boko, et al., 2007 p. 439; Stern, 2007 p. 110).

2.4 Infrastructure and energy

Cities are dependent on power, water, waste removal and transportation infrastructure. In the case of severe weather, centralised infrastructure such as electricity sub-stations or sewerage treatment plants may become dysfunctional, with consequences for the whole urban system. Urban travel is likely to be disrupted as a result from intense rainfall and flooding, exacerbated in coastal cities by sea level-rise and storms (Suarez, et al., 2005 p. 232). The longevity of protective infrastructure, roads and railway lines too close to the sea is reduced, due to the combined effects of sea-level rise and increased storms (Theron, et al., 2008 p. 4). Development will increase the runoff to be handled by storm water systems, already strained by the increasing severity of events. Refugees fleeing the negative impacts of climate change in one region will migrate to other regions, placing additional demands on housing and infrastructure (Boko, et al., 2007 p. 450) while large parts of the existing population are still not connected to a public sewage disposal system. This, combined with poor supplies of drinking water, may lead to deaths from diarrhoeal diseases (Munich Re Group, 2004 p. 30).

Continued population and economic growth will lead to increased energy demands, and thus also emission levels, while the supply will be impacted by climate change. As the climate changes, patterns of energy use will also change. Households living in cold regions will require more energy to keep warm, whereas households living in warm regions will require more energy to keep cool. In arid regions more energy will be required for irrigation (Ruth, et al., 2006 pp. 30-31; Hardy 2003 p. 158).

2.5 Food and water insecurity

The climate, inappropriate or inadequate coping strategies, and a lack of governance are among the most important drivers of food and water insecurity (Gregory, 2010 p. 4). It is projected that climate change will result in overall reduced food production in many water-stressed developing countries (Behnin, 2006) as water scarcity will be exacerbated by a combination of increased demand, reduced groundwater recharge and deteriorating quality (Meadows, 2006 p. 142). Changes in temperature and precipitation, coupled with continued emissions of greenhouse gases, will bring changes in land suitability and crop yields, which will result in some cultivated areas becoming unsuitable for crops, and others requiring more irrigation. However, many farmers in developing countries cannot afford irrigation systems, thus when rainfall is late, early or low, it has wider consequences for national food security (Francesco, 2007 p. 22; Mannak, 2008 p. 24). Temperature increases will also enhance the ability of alien populations to survive the winter and attack crops in spring (Francesco, 2007 p. 17; Nehme, 2004 p. 5).

Urbanisation and population growth will further strain water sources and challenge food security as more land is needed for urban expansion whereas the demand for food will increase. Food chains have complex linkages: the dependence on long international food supply chains, fuel and other goods, make populations vulnerable to rising food and fuel prices. Adding climate change impacts to the equation makes urban food security even more vulnerable. Climate change-induced disasters also disrupt food demand and supplies, placing particularly low-income households at risk from food shortages or staple food price rises (Satterthwaite, et al., 2010 pp. 2816-2819; Mann, et al., 2009 pp. 10-13).

2.6 Health

Human health could be negatively impacted by climate change and variability by altering the ecology of some disease vectors, and consequently the transmission of such diseases. For example, it is expected that the spatial and temporal transmission of malaria, cholera and meningitis will change in future, affecting more people (Boko, et al., 2007 p. 435). Populations in dense informal settlements are particularly exposed to vector- and waterborne diseases because they have limited access to clean water, and suffer from poor air quality and heat stress. Climate variability also interacts with other socioeconomic stresses such as HIV/AIDS, crime, conflict and war, to increase vulnerabilities. Urban heat waves will become increasingly dangerous, as increased temperatures together with the urban heat island effect will lead to extreme temperatures and air pollution incidents (Stern, 2007 p. 87; Boko, et al., 2007 p. 447).

2.7 Coastal cities

Sea level rise will result in increased coastal flooding, raise the costs of protecting the coastline, increase the amount of land lost and the people displaced due to permanent inundation. Coastal cities are amongst the most densely populated areas and are home important ecosystems and critical infrastructure such as ports, power stations and oil refineries (Stern, 2007 p. 90). Some impacts already prevalent from sea-level rise include the increased erosion of the shoreline, loss of wetlands, inundation of low-lying property, expansion of flood zones, increased cost of maintaining infrastructure, and salinisation of surface- and groundwater (Purvis, et al., 2008 p. 1063; Ruth, et al., 2006 p. 22).

3. HOW CITIES CONTRIBUTE TO CLIMATE CHANGE – ASSESSING GHG CONTRIBUTIONS

Cities are major contributors to greenhouse gas emissions. Cities consume more than 80% of energy production worldwide. This figure is set to increase – particularly among cities in developing countries. Urban populations are expected to double by 2030, but the built-up area is expected to triple during the same time. Sprawled cities increase the energy requirements and the cost of new infrastructure. Poorly managed cities have a bigger energy demand than well-managed cities. Rich cities, cities that are less dense, and cities that rely on coal power for energy all emit more GHGs (The World Bank, 2010).

3.1 Energy

The energy sector contributes approximately 26% to GHG emissions. Fossil fuels are the major contributor as it is used throughout the world for generating energy. Since urban systems rely heavily on energy, most of the generated energy is consumed in cities. Energy may be the highest contributor to GHG emissions in those cities dependent on goal-fired power stations compared to other sources of power (UN-Habitat, 2011).

3.2 Transport

Transport is among the top five energy-consuming sectors of the economy. Only a small fraction of transportation’s needs are met by non-petroleum sources, such as methanol and ethanol, and many of these require significant fossil fuel use in their production and delivery. The predominance of fossil fuel in transportation makes the transportation sector’s GHG emissions 2nd only to those of electricity generation. Pollution from motor vehicles contributes heavily to CO2, CFCs and nitrogen oxides. In many countries such as the USA, Australia and South Africa, decades of suburban development have led to urban sprawl and a high dependency on private-owned vehicles. People have to commute long distances to work and contribute to high levels of carbon emissions. Other important environmental impacts include health-related air pollution and hazardous materials and oil spills, many of which occur in urban areas. Modification or destruction of habitat by the expansion of transportation infrastructure, transformational impacts on land-use, a series of social costs associates with congestion, noise pollution, accidents and changes in lifestyle towards lower physical activity levels and their associated adverse health effects further exacerbate the situation (Ruth, et al., 2006 p. 27).

3.3 Other sectors

Other big GHG emitters are industrial activities, waste, agriculture and forestry.

- Industry: Industrial activities are energy-intensive, e.g. the manufacturing of iron, steel, fertilizers, cement, paper, chemicals, etc.

- Buildings: the need to heat or cool buildings, and energy usage contribute to the 8% GHG emission by residential and commercial buildings.
- Waste presents only about 3% of the GHG emissions, but the production of waste is growing.
- Agriculture and forestry presents 31% of GHG emissions worldwide. Urbanisation threatens agricultural land that absorbs CO2, and the growing needs of cities (as they become more affluent) place significant demands on agriculture outside urban boundaries (UN-Habitat, 2011).

3.4 Assessing GHG contributions

Measuring GHG emissions are important for a number of reasons. It is important to consider specific urban sectors' contribution to GHG emissions; the inward flow of food, water and consumer goods from outside the city result in GHG emissions; it provides a basis for comparison with other cities and cooperation to reduce emissions; it is a vital step in identifying potential ways to reduce GHG emissions; and lastly, it is also important to highlight the differences between production- and consumption-based analyses of GHG emissions (UN-Habitat, 2011). (See module 1 for examples of methods.)

Protocols for GHG emission inventories for cities were prepared by the IPCC according to a detailed set to criteria. These principles for the protocols include among others:

- Inventories must be transparent, comparable, accurate and complete. They should be disaggregate and consistent to allow for effective policy development;
- The most recent IPCC guidelines should be used for determining emissions of energy, industrial processes, agriculture and forestry and other land uses, and waste.
- Emissions for all 6 Kyoto gases and other relevant GHGs should be reported per calendar year;
- Carbon dioxide equivalent emissions should be reported using the most recently published IPCC global warming potentials (IPCC, 2010).

Cities also give rise to the production of GHG emissions outside of their boundaries. Out-of-boundary emissions driven by activities in cities should thus also be included. It would be impossible to quantify all the emissions of goods and services in cities, but the following is a good starting point:

- Out-of-boundary emissions from electricity generation and heating that are consumed in cities;
- Emissions from aviation and marine vessels carrying freight or passengers away from cities;
- Out-of-boundary emissions from waste that is generated in cities;
- GHG emissions embodied in fuels, food and building materials consumed in cities should also be reported (IPCC, 2010)

Mitigating GHGs is crucial in reducing the future climate change threat for cities. Setting emission targets are therefore important.

4. INTRODUCTION TO CLIMATE CHANGE RISK AND VULNERABILITY ASSESSMENTS

4.1 Challenges of urbanisation and urban management

Urbanisation is continuing unabated in the developing world. Urbanisation itself is not negative, for urbanisation is often a necessary catalyst for economic growth; but political choices, and not a lack of resources mean that not everyone shares in the benefits of urban areas. The inadequate response by governments results in many poor households becoming increasingly vulnerable to a number of socioeconomic risks (Satterthwaite, et al., 2010 p. 2810) such as the consequences of climate and demographic changes, under-development, natural hazards, competition for scarce resources, food scarcity, environmental degradation, and epidemics such as HIV/Aids (IPCC, 2007; UNISDR 2005; World Bank 2008).

Most of the urbanisation in developing countries is unplanned, resulting in informal settlements appearing overnight in high-risk zones such as floodplains or low-lying and coastal terrain prone to flash floods, steep slopes that are susceptible to landslides, or fault zones vulnerable to sinkhole formation. This is often the closest to urban opportunities and transportation routes or the only vacant land available (Pharoah, 2009; World Bank, 2008). The majority of poor households are located furthest from socio-economic opportunities – denying the most vulnerable of the population access to employment opportunities, wealth creation and social infrastructure. Many cities in developing countries therefore experience urban sprawl that create capacity problems for the provision of network infrastructure and increase the cost of new service connections. It also means that mass-transit systems are not viable, placing huge transaction costs on the poor by them having to commute increasingly longer distances to and from work. Thus, poor households that are priced out of safe areas into high-risk zones – which can cause loss of lives and livelihoods, as well as aggravating poverty and the destruction of productive assets – have less income and time to invest in assets that could protect them from climate change (Du Plessis, et al., 2003 p. 243; Boraine, 2006 p. 278; Behrens & Wilkinson 2003).

This combination of high population densities, substandard or lack of housing and infrastructure, and projected climatic changes produce cities in the developing world that are disaster hotspots (Roy, 2009 p. 277; Laukkonen, et al., 2009 p. 287). The situation is furthermore aggravated by the interaction of multiple development stresses at various levels such as complex governance and institutional dimensions; endemic poverty; limited access to capital, including markets, infrastructure and technology; ecosystem degradation; and complex disasters and conflicts (Scholes, et al., 2008 p. 4; Boko, et al., 2007 p. 435).

Over the past 40 years, 80 000 people have been killed on average each year and 200 million people have been affected by natural disasters (UNISDR, 2010b; World Bank & United Nations, 2010 p. 23). The increasingly clear prognosis from the United Nations International Strategy for Disaster Reduction (UNISDR) and the Intergovernmental Panel on Climate Change (IPCC) is that the risk for natural hazards and extreme climatic events will increase in future and these event will become more severe (UNISDR, 2010a; IPCC, 2007).

Thus, if climate change and its effects are left unchecked, the plight of millions of poor households will worsen in future and major setbacks in hard-won economic development will be experienced (IPCC, 2007; World Bank 2006). Moreover, should climate change go unabated, it could undermine or even reverse attempts toward achieving sustainable development (IPCC 2007).

4.2 Urban disaster risk

Urban disaster risk is a consequence of countless feedback loops and thresholds and competing ideas. A relatively minor catalyst can breach the critical threshold and initiate a series of knock-on events with repercussions throughout the urban system (Pelling, 2003 p. 7). Climate change might be just such a catalyst. As urbanisation challenges and the impacts of climate change collide, a ‘strange new urban world’ (IFRC, 2010 p. 8) is developing – one in which the vulnerability of people to disasters is progressively increasing and that is increasingly beyond many local authorities’ experience and ability to manage and control (ICLEI, 2010).

Notions of risk have been another important driver in climate change adaptation, significantly influenced by, and directly related to, hazards theory. Risk is a core concept in hazards theory. Some would argue that due to these deep connections between the concepts of hazard and risk, considerations of risk in the field of climate change adaptation are merely an extension of the hazards approach.

In particular in the Anglophone world, risk management has become a dominant practice for dealing with uncertainties of all kinds, which is particularly well-established in the local government sector. Risk management is often the trigger for governments to embark on adaptation processes.

Risk management approaches have strong operational roots in management theory and practice, where risk management is considered a key mechanism for private and public organisations to deal with various kinds of uncertainties, mainly to minimise any negative consequences. Risk management approaches are common, for example, in project management, engineering, financial management and actuarial practice, industrial process design, and in occupational health and safety. While the definitions, methods and goals of risk management vary greatly across sectors, common strategies employed as part of risk management processes include risk avoidance, risk acceptance, risk transfer and risk minimisation.

Central to the notion of risk are notions of uncertainty and perception. In management theory, risk has been defined as ‘the effect of uncertainty on objectives’ (Standards Australia, 2009).
In the hazards literature, risk has been defined as the product of hazards and vulnerability – a definition that can readily be applied to climatic risks (Blaikie et al., 1994, Wisner et al., 2004, Downing and Patwardhan, 2005):

- Risk = Hazard (climate) x vulnerability. This definition underlines once again that vulnerability is considered a key condition for a particular climate hazard having an actual effect on social, ecological or coupled socio-ecological systems;
- In organisational management, as well as in adaptation planning, risk has been operationalized as a function of magnitude (or consequence) and probability (or likelihood) of expected impacts (McCarthy et al., 2001, Standards Australia, 2009);
- Risk = Consequence x Likelihood. Likelihood is used to describe the probability of a climatic change taking place at some point in the future and its expected frequency, whereas consequences refers to the expected impacts of a climatic stressor on organisational goals and objectives.

The links between climate change and risk are typically explained as a 'chain of consequences' (Australian Government, 2006). A climate variable, such as average temperature experiences a change due to global warming, e.g. an increase in very hot days over 35 degrees Celsius. This has a range of specific impacts, such as higher electricity demand for cooling, which in turn leads to a risk for electricity providers to be unable to meet peak demand.

4.3 Urban vulnerability

Vulnerability refers to the degree to which a household or urban system is unable to cope with the adverse effects of climate change, including climate variability and extremes (UNFCCC, 2010). The terms vulnerability and urban vulnerability can be defined in many different ways. This definition focuses on the exposure to hazards (of any kind, not just climate change). It underlines that vulnerability relates to experiencing some form of harm, whether physical, emotional (in the context of human beings) or technological (e.g. damage to buildings).

Vulnerabilities precede disasters, contribute to their severity, and continue afterwards. Neither are all households or cities equally vulnerable to the impacts of climate change. The root cause of vulnerability is embedded in ideological, social, and economic systems, demographic pressure and specific sets of unsafe conditions that are unevenly distributed in society (Oliver-Smith, 2002 pp. 28,36; Anderson, et al., 1998 p. 10).

A large number of alternative definitions of vulnerability exist. Common to most definitions, however, is the notion that vulnerability is a product of exposure and/or sensitivity to external stressors such as climate change impacts, and adaptability or adaptive capacity (McCarthy et al., 2001, Adger, 2006, Smit and Wandel, 2006).

- *Exposure* refers to a system being subject to the experience of climatic stressors, such as changing rainfall patterns, increasing average temperatures, and changes in the frequency of extreme weather events.
- *Sensitivity* is about a system's responsiveness to climatic stressors, where it is assumed that the higher the sensitivity of a system, the higher will be an impact resulting from a stressor.
- *Adaptive capacity*, on the other hand, refers to a system's ability to reduce its exposure and sensitivity as well as the capacity to respond to existing impacts, e.g. by changing how the system operates in a way that impacts resulting from climatic stressors are reduced. Adaptive capacity is an important concept for adaptation planning in a social context, which

relates to issues of resource availability (e.g. time, financial and human resources), institutional barriers (e.g. political will), as well as the expertise, knowledge and experience of individuals.

Urban vulnerability can be understood as 'contextual vulnerability'. A contextual framing of vulnerability considers vulnerability as embedded in a multi-dimensional context of climate-society interactions (O'Brien et al., 2007), where it can be a starting point for exploring options for adaptation specific to the local context. Using vulnerability as a starting point takes adaptation to be on-going socio-ecological change that, while it may be triggered by particular climate change impacts, is part of a broader process of social development, political and institutional change, and environmental transformation.

Such a contextual understanding of vulnerability is largely consistent with a political economy approach (Füssel, 2007) to climate change. A contextual vulnerability approach is essentially about devising measures that reduce a system's and its components' (i.e. people, infrastructure, institutions) vulnerability to climate change *as well as* to on-going socio-economic and political processes of change.

A contextual vulnerability approach assumes that the systems under consideration are of a highly complex nature, consisting of a set of political, institutional, economic and social structures that are constantly changing, which interact with climate change and climatic variability. Vulnerability therefore is considered a place-based phenomenon that needs to be investigated in a particular geographic location, with the aim to understand the 'interaction of the hazards of place […] with the social profile of communities' (Cutter, 1995).

4.4 Increasing urban disaster risk and vulnerability

Vulnerability causes an urban risk divide to develop in cities as they become increasingly unjust, polarised, divided and fragmented: the well-connected elite barricade themselves in well-serviced and regulated high-security villages (Watson, 2005 p. 286; Todes, 2011 p. 116), while the poor struggle to survive along the fault lines of urban risk (IFRC, 2010 p. 8).

The urban poor are disproportionately more vulnerable to suffering from the impacts of climate change because:

- They are more exposed to hazards (e.g. through living in makeshift housing on unsafe sites)
- They lack hazard-reducing infrastructure (e.g. drainage systems, roads allowing emergency vehicle access)
- They have less adaptive capacity (e.g. the ability to move to better quality housing or less dangerous sites)
- The have less access to state provision for assistance in the event of a disaster (indeed, state action may increase exposure to hazards by limiting access to safe sites for housing)
- They have less legal and financial protection (e.g. a lack of legal tenure for housing sites, lack of assets and insurance). (Dodman and Satterthwaite 2008: 69).

Poverty and vulnerability to climate change are closely linked – the most poor are usually amongst the most vulnerable. Statistics indicate that the number of poor people in urban areas is rising faster than in rural areas, as many poor people migrate to the city in search of opportunities to improve their well-being (Coetzee, 2002 pp. 4-6). Because their capacity to exploit urban opportunities is limited, and their traditional network of family and village society no longer functions, their ability to cope with the adverse effects of climate change is inadequate (Oliver-Smith, 2002 pp. 37, 42; Pelling, et al., 2009a p. 5). Even when risks are perceived and experienced, poor households may not be in a position to mitigate or prevent the occurrence of a disaster, or will place themselves in harm's way because they are consumed by the immediate demands of survival (Oliver-Smith, 2002 pp. 37, 42; Pelling, et al., 2009a p. 5). Moreover, households in developing countries are not only prone to major catastrophic events, but have to also content with everyday risks as a function of their daily existence. As everyday risk becomes an acceptable part of life, it lowers people's coping threshold and makes people less willing to prepare for catastrophes. Each succeeding event erodes the resources of a household to cope with and recover in time for the next shock, resulting in a 'ratchet effect' of vulnerability (Pelling, 2003 p. 16; Oelofse, 2002 p. 43; Faling, 2012). 'Climate change will almost certainly make the process of eradicating poverty … more difficult because of direct effects on poor people's livelihoods and the assets upon which they depend' (Laukkonen, et al., 2009 p. 288).

Addressing urban disaster risk and vulnerability through climate change adaptation and mitigation measures are critical in protecting the lives and livelihoods of people, as well as the infrastructure and development gain. Risk and vulnerability assessments assist in understanding which measures to prioritise and adopt.

4.5 Introduction to risk and vulnerability assessments

Assessing risk and vulnerability is no longer purely an academic exercise, but has become a political necessity. There has been a shift in research from an impacts-led approach to a vulnerability-led approach. A vulnerability-led approach studies the underlying socioeconomic and institutional factors, as well as cultural and political factors that determine how people respond to and cope with hazards although knowledge of the hazard may not be perfect – as in the case of climate change impacts (Adger, et al., 2004 p. 4).

Risk and vulnerability indicators are very useful to synthesis complex state-of-affairs that can be easily used in policy development (Hinkel, 2011 p. 198). To effectively reduce the losses from climate change events, a spatial assessment of risk and vulnerability is required. This involves the assessment of the vulnerability of the people likely to be affected and the identification of the hazard likely to affect a given place (Collins, et al., 2009), and is a multi-layered analysis of individual indicators that represent a range of hazards and vulnerability (Taubenböck, et al., 2008 p. 410). Such assessments encompass both qualitative and quantitative methods to describe risks and vulnerabilities (Birkmann, 2011 p. 20). Quantitative indicators of vulnerability can be used to determine development priorities and allocate resources, while qualitative indicators can present trends (Adger, et al., 2004 p. 14).

Risk and vulnerability assessments have six purposes: 1) to identify particularly vulnerable people, places or sectors; 2) to raise awareness of climate change; 3) to identify mitigation targets; 4) to select local adaptation measures; 5) to monitor the performance of adaptation policy; and 6) to conduct scientific research (Hinkel, 2011). Since vulnerability is a function of processes at many scales – from local to global, the scale of the analysis can be from household to global level. While processes may manifest itself on a community level, a national level indicator may aim to capture the processes that shape local level processes (Adger, et al., 2004 p. 20). Risk and vulnerability theory therefore needs to be well-understood in order to be able to verify the indicators and to be able to update the information if new insight into vulnerability becomes available. An iterative and participative process is required to develop the conceptual models of vulnerability (Adger, et al., 2004 p. 23).

4.6 Compiling risk and vulnerability assessments

Natural risks are assessed in terms of its major components: hazard, exposure and vulnerability. A hazard is the probability that an event will occur in a certain place at a certain time, given the characteristics of the phenomenon. Exposure is the presence of people and assets in a certain area, and vulnerability is the intrinsic capacity of people to resist a hazard. Risk assessments are carried out through the assessment of factors related to a hazard and the vulnerability of the people (Lucia, Beniamino, Francesco, Marco, & Angelo, 2012).

A risk assessment is the result of a multi-layered analysis of individual indicators – in the ideal case representing the complete range of components contributing to hazards and vulnerability. Elements of risk can be measured through, for example, using remote sensing. (Taubenböck, Post, Roth, Zosseder, Strunz, & Dech, 2008). Vulnerability is measured using vulnerability indices. These can be single or multi-criteria.

Selecting indices can be based on a conceptual understanding of relationships derived from theory (deductive), or based on statistical relationships (inductive). A deductive approach entails: 1) understanding the phenomenon and the main processes involved; 2) identifying the main processes to be included and how they are related; and 3) selecting indicators for these factors and processes and assigning values and weights. A strong conceptual framework can form the basis for identifying vulnerability indicators (Adger, Brooks, Bentham, Agnew, & Eriksen, 2004).

An inductive procedure to select indicators involves relating large numbers of variables to vulnerability to determine the ones that are statistically significant. The statistical relationships are then used to build a model. Through statistical analysis the different contributions of variables to vulnerability can be assessed (Adger, Brooks, Bentham, Agnew, & Eriksen, 2004). For more information see Adger, W., Brooks, N., Bentham, G., Agnew, A., & Eriksen, S. (2004). *New Indicators of Vulnerability and Adaptive Capacity.* Norwich: Tyndall Centre for Climate Change Research.

4.7 Vulnerability indicators

Enhancing an understanding of vulnerability and ways to reduce vulnerability entails a focus on the causes of and the processes shaping vulnerability. Human adversity occurs in a broad political, economic and ecological context (Adger, et al., 2004 p. 16). Below are a number of qualitative and quantitative proxies for indicators of vulnerability as identified by Adger, et al. (2004 p. 45):

Economic well-being

- Poverty
- Living in slums (density, informality)
- Access to services: water, sanitation, electricity, refuse removal
- GDP per capita
- Gini index
- Debt repayments as a percentage of GDP

Health and nutrition

- Ill-health
- Health expenditure per capita (USD PPP or % of GDP)
- Disability adjusted life expectancy
- Calorie intake per capita
- AIDS/HIV infection (% of adults)

Education

- Education expenditure (% government expenditure or % of GNP)
- Literacy rate (% of population over 15)

Physical infrastructure

- Quality of settlements (rural-urban migration rates)
- Commercial infrastructure
- Elements of the transport infrastructure (quality and density of roads, isolation of rural communities)
- Access of rural populations to markets
- Population without access to sanitation (%) and clean water

Institutions, governance, conflict and social capital

- Social capital (ability to act collectively, social networks, density of trust)
- State institutions (corruption, vs. democracy and accountability, effectiveness, political accountability and stability)
- Security of property rights
- Regulatory environment
- Internal conflict
- Internal refugees (% of population)
- Control of corruption
- Government effectiveness
- Political stability

- Voice and accountability

Geographical factors
- People living in flood plains and low-lying coastal areas (e.g. a certain number of km from the coast, 100m above mean sea level)
- Population density
- Length of coastline (scaled by land area)

Natural resources and ecosystem
- Land availability
- Ecosystem services
- Pollution
- Protected land area
- Per cent forest cover
- Water resources per capita
- Groundwater recharge per capita
- Unpopulated land area (%)
- Forest change rate (% per year)

Technical capacity
- R&D investment (% GNP)
- Scientists and engineers in R&D per million population
- Tertiary enrolment.

4.8 Risk and vulnerability assessments - conclusion

It is generally very important to clarify terminology throughout a process. However, it is more important to understand the underlying processes that contribute to risk and vulnerability and how to intervene in those processes than to get stuck in an attempt at differentiating 'risk' and 'vulnerability', especially given that 1) many settlements are at risk of compound, everyday risks (complexity) rather than major events and that 2) many people involved in planning resilient cities are not experts in either disaster reduction or resilience (capacity). In practice, the difference is fuzzier – risk is often vulnerability under different circumstances (Van Huyssteen, Le Roux & Van Niekerk, 2013).

In countries that does not have sufficient funds or capacity to do a risk and vulnerability analysis for every potential risk and vulnerability from a national to local scale, it is important to rather identify those proxies that reflect numerous socio-economic vulnerabilities, for many of the spatial characteristics overlap to a great extent (e.g. poverty and social grants will have a strong correlation). It is important to have a clear indication of the overall risk and vulnerability of places that can be made available and is easily accessible to municipal and other role players and decision makers (Van Huyssteen, Le Roux & Van Niekerk, 2013).

If one concentrates on individual analysis of risks and vulnerabilities, one is at risk of thinking about interventions in the same way. However, composite analyses allow for more strategic interventions in building resilient cities that start to address a number of underlying processes.

Strategic interventions based on composite analyses become more pro-active and less reactive in mitigating the risks (Van Huyssteen, Le Roux & Van Niekerk, 2013).

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5. CLIMATE CHANGE ADAPTATION AND MITIGATION: RATIONALE, OBJECTIVE AND MEASURES

5.1 Rationale for climate change adaptation and mitigation: reducing vulnerability

Urban planning can play a key role in reducing vulnerability to climate change and other natural and anthropogenic hazards. From a sustainable urban development point of view, reducing the vulnerability of socially and economically disadvantaged groups, as well as other sustainable development goals such as protecting urban biodiversity, are well aligned with the goals of climate change adaptation. In light of climate change, urban planning can become more adaptive by adopting a long-term view and taking future climate change into account in the design and location of new urban space.

5.2 Rationale for climate change adaptation and mitigation: sustainable development

Rumsey, et al. (2009 p. 1049) warn that the impacts of climate change may unravel the efforts undertaken by a variety of stakeholders to achieve sustainability. Climate events are already a major stress to development, but threaten to undermine sustainable urban development in developing countries through additional burdens it lays on poverty eradication and other development goals (Halsnaes, 2009 p. 83). To achieve the objectives of sustainability, a drastic shift from a business-as-usual approach is required (Rumsey, et al., 2009 p. 1048), which could be achieved by addressing climate change through adaptation and mitigation in areas such as spatial planning, energy, urban design, public transportation and water and sanitation (Hjerpe, et al., 2009 p. 242).

Climate change, being highly interconnected with the environment, economy, politics, poverty, food security, access to water, the built environment, etc., necessitates a systemic and integrated approach to build resilient cities when planning for adaptation and mitigation (Bulkeley, et al., 2005; Halsnæs, et al., 2007).

5.3 Objective of climate change adaptation and mitigation: climate resilient cities

The concept of resilience increasingly appears in climate change adaptation discourse, and it is often seen as directly related to the notion of vulnerability. In contrast to vulnerability, the term resilience has its origins in ecology and environmental sciences where it has been used widely to analyse processes of disturbance and change in ecosystems. From these origins, the resilience perspective soon gained currency in other disciplines such as ecological economics, environmental psychology, human geography, and the broader social sciences. This also included hazards research, where resilience has become influential in the analysis of natural hazards on coupled socio-ecological systems.

In the context of climate change adaptation, the origins of the resilience perspective as one of the theoretical foundations of adaptive ecosystems management continue to influence climate change adaptation processes outside the ecosystems domain (Folke, 2006).

The notion of ecosystem resilience emerged in the 1960s and 1970s, defined as: 'the capacity of a system to absorb and utilize or even benefit from perturbations and changes that attain it, and so to persist without a qualitative change in the system's structure' (Holling, 1973). Translating this fundamental definition into the realm of social science and the analysis of social systems, 'social resilience' has been described as: 'the ability of groups or communities to cope with external stresses and disturbances as a result of social, political, and environmental change' (Adger, 2000).

When relating the resilience concept to social processes of climate change adaptation, at least three different meanings can be discerned (Folke et al., 2002, Turner II, 2010):

- Resilience understood as response to disturbance;
- Resilience understood as a system's capacity to self-organise;
- Resilience as the capacity to learn and adapt.

Each of these interpretations bear direct relevance to central challenges of climate change adaptation in an urban context, e.g. the questions of what perturbations we are adapting to, and how such adaptation is going to occur. The third point strongly resonates with understanding adaptation as a process for social learning. In this context, resilience has been defined as a system's 'capacity for renewal, re-organization and development' (Folke, 2006). In this context, resilience has also been described by some as a 'loose antonym for vulnerability' (Adger, 2000: 348) in that it increases adaptive capacity, although this view has been contested.

Resilience is perhaps a new metaphor to many disciplines to describe and frame a counter-response to threat, but resilience has always preoccupied the inhabitants of cities as they sought to defend and secure their interests. The rise of resilience is ascribed to a growth in political action against a number of perceived threats and events such as climate change related events, disease pandemics and global terrorism (Coaffee, et al., 2009 p. 1; Todes, 2011 p. 118). Resilience has become a trans-disciplinary concept that integrates socio-political and physical aspects (Coaffee, 2009 p. 87) and is becoming a common frame for the policy goals of socio-ecological systems such as cities (Hamin, et al., 2009 p. 239; Coaffee, et al., 2009 p. 114).

Climate resilience is popularly understood as the capacity to accommodate, absorb, bounce back from, or adapt to climate change perturbations (Vale, et al., 2005 p. 335; World Bank, 2008 p. 32; Hamin, et al., 2009 p. 239). If resilient, a system has a degree of elasticity to withstand a shock and reorganise itself when necessary (World Bank, 2008 p. 32) and is thus forgiving of external shocks (Hamin, et al., 2009 p. 239). Resilience is indicated by the continuation of particular functions at an acceptable level (Pelling, 2011 p. 42) during severe weather events. Moreover, it includes the ability to learn by continuously adapting to the constantly changing risks and vulnerabilities caused by climate change (Collins, 2009 p. 106; Hamin, et al., 2009 p. 239).

Resilience is ‘the overarching goal achieved through adaptation and mitigation’ (Hamin, et al., 2009 pp. 238-239).

5.4 Climate change adaptation and mitigation

Climate change adaptation and mitigation are two distinct processes, though they have a bearing on one another (Blanco et al., 2009 p. 156). Mitigation refers to the reduction of greenhouse gas emissions to counter global warming (UNISDR, 2009 p. 19), and is more effective when driven by national initiatives over a long term. Adaptation to climate change ‘entails taking the right measures to reduce the negative effects of climate change (or exploit the positive ones) by making the appropriate adjustments and changes’ within the local context (UNFCCC, 2007 p. 10). E.g. adaptation involves improved health care, infrastructure development, housing, food security, and water and resource security (Hjerpe, et al., 2009 p. 241). Both adaptation and mitigation are necessary to avoid climate change impact (Martens, et al., 2009 p. 16).

In developing countries the issue of climate change adaptation and mitigation is overshadowed by immediate development priorities, i.e. housing, poverty eradication, energy access, water and food security, health, transportation needs, natural resource management, and air and water pollution. However the effectiveness of development strategies may be reduced and vulnerability enhanced if climate change adaptation and mitigation are not integrated with development planning (Halsnæs, et al., 2007 p. 666).

5.5 The link between disaster risk reduction and climate change adaptation and mitigation

Disaster risk reduction (DRR) and climate change adaptation (CCA) are often considered one and the same thing. This is not correct, because CCA takes a specific long-term strategic view on how harm resulting from future climate change impacts can be avoided and how positive opportunities can be harnessed. This includes all climate change impacts, including sudden events (such as extreme weather events) as well as slow-onset changes such as sea level rise and changing rainfall patterns.

Disaster risk reduction has a slightly different focus, namely to reduce exposure of humans to natural and anthropogenic hazards. DRR is highly complementary to CCA when it comes to planning for extreme weather events, and vice versa.

Ideally, climate change considerations should be taken into account in any DRR, and the consequences of exposure to hazards should be considered one key element in CCA planning. This is why, increasingly, DRR and CCA are merging from being separate fields to being dealt with in a more integrated way. Urban planning can be a conduit for facilitating such integration between CCA and DRR.

Disaster risk reduction (DRR) is well established within the international development community (Mercer, 2010 p. 247). It is defined as 'the systematic development and application of policies, strategies and practices to minimise vulnerabilities, hazards and the unfolding of disaster impacts throughout a society, in the broad context of sustainable development' (Faling, et al., 2012). DRR policies and strategies are well established at grassroots level and focus is on the underlying root causes of community vulnerability. Successful strategies build resilient communities, whilst ensuring vulnerabilities are not increased through development efforts (Mercer, 2010 pp. 247-249).

A number of authorities have compared DRR and emerging climate change adaptation and mitigation measures. Some like Parnell, et al. (2007) and Blanco, et al. (2009) argue for climate change adaptation and mitigation to be directly integrated with existing urban development efforts, while others advocate for increased convergence or even imbedding adaptation and mitigation into wider DRR strategies, which should in turn be mainstreamed into wider development planning (Mercer, 2010 p. 250). This is because it is very hard to disentangle social, environmental and technological hazards from each other, and disaster risk reduction offers an 'integrated approach towards intervening in human vulnerability and resilience, instead of focussing on mitigating a single threat' (Pelling, 2003 p. 5).

6. CLIMATE CHANGE MITIGATION AND ADAPTION MEASURES FOR SUSTAINABLE URBAN PLANNING

The manner in which developments are designed and planned will have a significant impact on future GHG emissions, as well as on settlements' ability to adapt to potential climate change (Roy, 2009 p. 276; Bulkeley, et al., 2005 p. 176). Sustainable development planning could mitigate the negative effects of climate change. However, even if GHG emissions are drastically reduced soon, the earth's climate will continue to warm for some time. Many argue that we will inevitably have to adapt to climate change, though adaptation will not solve the long-term problem of damage and increased costs from continued GHG emissions. 'It is not sufficient to concentrate on either mitigation or adaptation, but a combination of these results in the most sustainable outcomes' (Laukkonen et al., 2009 p. 287).

Adaptation and mitigation responses have a strong spatial dimension, synergies and trade-offs, hence spatial planning is called the 'switchboard' for implementing adaptation and mitigation measures at local and regional level (Biesbroek et al., 2009). According to Blanco, et al. (2009 p. 158) 'adapting to climate change is at its core a call for planning' and adaptation is the 'type of planning that fits naturally the agenda of urban and regional planning'.

The following spatial planning measures have been suggested to promote compact cities and thus help mitigate global warming and adapt to climate change. For more climate change adaptation measures, consult the case study on the City of Durban in the Annexure of this module.

6.1 Urban transportation

Urban transport is one of the biggest contributors to GHG emissions. The functional separation of land uses has increased journey distances and traffic volumes. This decentralisation and dispersion of land-uses require an elaborate road network – which has become a bottomless pit of investment, and prevent clusters of high densities that can support public transportation from developing (Belzer, et al., 2002; Newman, et al., 1996). The poor bear the brunt of the economic and social costs by having to travel far distances between home and place of work. Urban planning can therefore have great mitigative impact in the long-term by integrating land-use and transport planning. The objectives should be to reduce the demand for private transportation, transport volumes and travel distances. This is done by optimising – and often densifying – the spatial distribution and connectivity of urban activities to minimise the distances between land uses. Greater diversity of and accessibility to land uses in walkable and cycleable neighbourhoods will result in lower automobile traffic volumes. Planning for adequate city-wide public transportation, or restructuring the existing system will also reduce traffic volumes (Grazi, et al., 2008 pp. 630,634,637; Hamin, et al., 2009 p. 240; Ruth, et al., 2006 pp. 13, 28-29). These options may require new transport modes and infrastructure, which is an opportunity for adapting critical infrastructure to climatic changes such as severe weather and sea level rise (ALNAP & ProVention, 2009 p. 25). The planning and implementation of appropriate infrastructure should be done thoroughly as transport infrastructure is particularly costly to install and complex to alter once in position (Kithiia, et al., 2010 p. 8; Coaffee, 2008 p. 4633).

Cities that have spatially integrated land use and transportation for the sake of climate change, and give priority to pedestrians and cyclists, will greatly benefit the livelihoods of poorer households. A range of income levels will have more equal access to various land uses and opportunities (Rabinovitch, 1996). Injuries sustained in accidents and health effects from pollution will be reduced (Pelling, et al., 2009b p. 50), and healthier lifestyles are encouraged through active travelling (Barton, 2009). Low-income households will spend less time travelling and less of their disposable income on transport, consequently they will have more time and capital available to invest in assets (Behrens, et al., 2003).

Transportation not only contributes to CC, but CC also has several potential adverse effects on transportation. Current CC models show that rising sea levels and changing coastlines could, over the long-term, require the relocation of roads, rail lines or airport runways, and could have major consequences for port facilities and coastal shipping. Underground tunnels for transit systems, road and rail could be subject to more frequent or severe flooding, which may result in large economic damages and fatalities. Thawing permafrost and heat kinks because of extreme heat could damage roads, rail lines, pipelines and bridges. An increase in extreme weather events, and changes in rain, snowfall and seasonal flooding pattern would have implications for emergency evacuation planning, facility maintenance, and safety management for surface transport, marine vessels and aviation (Ruth, et al., 2006 p. 27).

Since many of these development already occur and are likely to be exacerbated over long periods of time, long-range transportation planning process should now consider the anticipated effects of CC on the existing or new infrastructure, potentially build in more resilience to climate variability while recognising that there will be different impacts in different areas (Ruth, et al., 2006 pp. 27-28).

6.2 Urban growth management

Built-up areas worldwide will triple by 2030 if average densities continue at the current trend. Some of this growth is a result of urban population growth, but inefficient spatial planning policies are to be blamed for urban sprawl (World Bank, 2008 p. 6). Urban sprawl increases journey distances and traffic volumes (Newman, et al., 1996). It thus disadvantages poor households as explained above and contributes to GHG emissions (DoH, 2004). It takes more resources to adapt sprawled settlements to the impacts of climate change than compact cities, for example by building storm surge protective infrastructure. Urban sprawl furthermore encroaches on productive agricultural land, thereby threatening livelihoods and food security (Bart, 2009).

Limiting urban sprawl through strategies such as compaction, culturally-appropriate densification, urban growth edging, transit orientated development (TOD), and infill development, may result in higher densities and mix of land-uses (Lau, et al., 2005 p. 153). These strategies hold benefits for climate change adaptation and mitigation, food security and asset adaptation. This is because they promote greater interconnectivity between land-uses; restructure a fragmented, inequitable and inefficient urban form; achieve social and economic diversity and vitality; protect natural and agricultural landscapes; promote optimal and efficient use of resources and infrastructure; reduce the cost of service delivery; allow for poor households to live closer to economic opportunities; intensify land-uses; and reduce greenhouse gas emissions (Jenks, et al., 2005a p. 298; Ruth, et al., 2006 p. 30; Banister, 2005; Swilling, et al., 2008; Watson, et al., 2004 DoH, 2004). Moderate densities on the other hand allow for ventilation between single units as well as for significant green spaces, and may be more effective under certain conditions where heat island effects can develop. It may also place less stress on local service provision (Hamin, et al., 2009 pp. 240-241; Ruth, et al., 2006 pp. 41-42).

A polycentric spatial model cluster city features – particularly those that provide a service to the community – in strategic nodes and corridors. Public transit along these corridors connects the nodes to form a highly accessible, connected city. Dense, mixed land use nodes afford choice of lifestyle and location, encourage shared facilities and infrastructure, and prioritise the needs of pedestrians and cyclists (Jenks, et al., 2005 p. 417). Thus, low-income households living in close proximity to nodes and public transportation networks, have better access to economic opportunities, employment, wealth creation and social services than those households living on the periphery, and have more opportunities and resources available for asset adaptation. They are also better able to withstand the effects of climate change, for close to nodes, they rely on already existing critical infrastructure such as stormwater, sewage, energy, roads and emergency services. Adapting key urban activities to the impacts from climate change such as increased temperatures, different precipitation patterns and rising water levels is also more efficient when clustered, than when dispersed (Ruth, et al., 2006 p. 30; Banister, 2005; Swilling, et al., 2008; Watson, et al., 2004).

6.3 Green space and urban agriculture

If not well planned then high densities may result in a loss of permeable surfaces and tree cover that help keep cities cool, threaten the carrying capacity of ecological systems, and increase the risk of urban flooding and heat islands formation (Laukkonen, et al., 2009 p. 289). Urban parks, forests and greenery should be maintained, expanded and linked to cool cities and to sequester carbon. The green spaces and corridors should have multiple uses such as urban agriculture, recreation and leisure that can adapt to the impacts from climate change, e.g. serving as flood retention areas in the case of severe weather (Hamin, et al., 2009 pp. 241-242).

Urban agriculture is often practised by low-income households for subsistence or to augment their income. Natural food production and increased subsistence production has the potential to improve food security in both rural and urban areas by increasing food supply and by reducing dependence on purchasing food (Hendriks, 2005 p. 104; Baiphethi et al, 2009 p. 459-460). Spatial development plans therefore ought to better protect productive agricultural land, as well as make provision for urban agriculture in appropriate parts of the city (Brown & Crawford, 2009 p. 18; Boko et al, 2007 p. 450).

If implemented, the spatial interventions described above would not only have a significant impact on the environment when compared to developments in the 19th and 20th century in terms of reduced greenhouse gas emissions, but would also contribute to climate change adaptation, and benefit low-income households significantly.

6.4 Water

Water supply administration and management are very important to strengthen the water supply in cities. Water losses should be limited and conservation should be stimulated. Some adaptation options include the desalination of sea water, the expansion of rainwater storage, the removal of invasive and alien vegetation, reusing wastewater for various purposes such as watering parks. Water can be recycled and pipes can be retrofitted for better efficiency. Water metering and pricing should encourage water conservation (The World Bank Group, 2011).

6.5 Energy

A sustainable energy system is required in building the resilient city. Energy efficiency, low carbon urban development and renewable energy sources are some ways to achieve this. Renewable sources of energy will reduce the GHG contribution the energy sector makes to GHG emissions, thus mitigating climate change while also stimulating economic development. Energy conservation measures in other sectors such as buildings, land use and water resource management should also be adopted. Green infrastructure and buildings with natural forms of shading and reflective surfaces can reduce energy demand for heating or cooling. Land use planning should be used to decide on where to locate energy infrastructure, e.g. away from vulnerable locations. River-basin management can protect hydropower potential (The World Bank Group, 2011).

6.6 Housing & buildings

Building codes and zoning help to regulate the mitigation and adaptation of the housing sector directly and indirectly influence other sectors such as transport and the housing market. A wellenforced land use plan is the most effective tool in regulating the mitigation and adaptation measures as well as infrastructure investment choices for more resilient cities. Enforcement and monitoring of buildings codes are very important in this regard. Relocation is also an alternative that has to be considered for the most vulnerable locations.

Structural adaptation such as building elevation, resilient designs, and protective infrastructure is more cost-effective and easier to implement for new developments. Other retrofitting approaches include green roofs, sun shading, water storage space and smart ventilation. Tax incentives and credits can be offered to those who incorporate green building measures (The World Bank Group, 2011).

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