Universiteit Utrecht

Climate change in high-income cities: Urban Resilience

Bachelorthesis

Source: Urbanaworld

Den Hartog, C.T.
4140249
Utrecht University
Bachelorthesis Environmental & Physical Sciences
Intervision supervisor: Rietkerk, M.G.
June 30, 2016

Wordcount: 5997
GEO3-2138

Abstract

Climate change is one of the most relevant challenges for our society. However, the high population density makes cities specifically vulnerable. Therefore new solutions to reduce casualties of climate change are needed. Urban resilience gives a new perspective on how to build a 'climate-proof' city. However, this is a relatively new concept which makes it difficult to find a complete overview on how a resilient city is exactly built. This study's main objective was to define the best adaptation strategy for creating urban resilience. This was firstly done by identifying the main threats which cities are facing due to climate changes. It will also to give an overview on the best adaptations to create a city which is resilient against these threats. And eventually the most effective strategy for urban resilience will be discussed. It can be concluded that ecosystem-based adaptation (EbA) is the most effective adaptation strategy when taking the long-term future predictions in account. However, a combination of adaptation strategies could create a higher urban resilience. A more detailed study on the consequences of combining adaptation strategies should be conducted to investigate the possibilities on urban resilience.

Keywords: *resilience, adaptation, urban areas, cities, planning, climate change, high-income*

Contents

1. Introduction

1.1 Problem and main objective

For most part of the environmental literature the focus has been on the existence of the phenomenon of climate change. This has brought science a lot of new knowledge of the anthropogenic influence on the earth's ecosystem. However, the effects of challenges like urbanization and climate change are converging into a new problem in cities. Without changes in policies the anthropogenic effects like greenhouse gas (GHGs) emissions with the associated climate change will continue (Hunt & Watkiss, 2010). The main contributors to the GHG emissions are cities. According to the United Nations cities consume approximately 78 percent of the world's energy and produce more than 60 percent of the world's carbon emissions (UN, 2012). Although cities only cover for 2 percent of the earth's surface, urban areas house more than 54 percent of the human population (UN, 2012; UN, 2014). Due to the density of the human population in cities they are an easy target for climate disasters. Since most cities are the centre for political and economic activity the continuing climate change could lead to significant and wide ranging societal impacts. By taking into account that urbanization in combination with overall growth of the human population leads to an increase of 2.5 billion of the urban population by 2050 (UN, 2014), this leads to the ironic conclusion that cities are both the main contributors as the main victims of climate change.

The impacts of climate change vary in different forms of threats. Alistair Hunt and Paul Watkiss have defined five different potential impacts of climate change on the urban environment (Hunt & Watkiss, 2010):

- Effects of sea level rise on coastal cities
- Effects of extreme effects on built infrastructure
- Effects on health
- Effects on energy use
- Effects on water availability and resources

These effects could have a major impact on the social, economic and political structure within a city. To counteract these problems there are a variety of solutions available. These solutions differ in their mitigating or adapting traits. The main focus of *mitigation* is to reduce GHG emissions and enhance processes that remove GHG emissions from the atmosphere. *Adaptation* focusses on the reduction of the impacts of harmful changes and exploit beneficial changes (Walsh et al., 2010). The standard adaptation approach consists of adjusting policies, practices and plans in order to avoid negative impacts of climate change. However, a number of problems arise when adapting cities to climate change in practice. The climatic conditions will become increasingly variable, dynamic and uncertain which could cause difficulties for these local planners (Tyler & Moench, 2012).

Urban resilience is a term which comes up when researching dynamic climate adaptation in cities. Resilience is defined as the following: "the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity of self-organization, and the capacity to adapt to stress and change."(IPCC, 2007).

However, when defining a resilient city, the vulnerability of the city must be taken into account. A big amount of papers have studied the effects of climate change effects on low- and middle income nation. However, a lot of these low- and middle income cities also have constraints on their adaptive capabilities. These constraints mainly consist of the big amount of other social, economic and political problems that most third-world countries suffer of. It is thus not realistic to integrate adaptation measures in these cities. High-income on the other hand do not have the adaptive constraints and when looking in the future these cities still face climate and population stresses (IPCC, 2014). Therefore this study will focus mainly on high income-cities.

1.2 Research question and sub-questions

This study is conducted to find the answer to the following **research question**:

> Which adaptive strategies are best capable of making a high-income city resilient against multiple climate change effects?

To following **sub-questions** are formulated to answer the research question:

- *What are the effects of climate change on urban areas?*
- *Which adaptation methods are available for these climate change effects?*
- *How can these adaptations methods be used to make a high-income city resilient?*

2. Method

This study is conducted by studying scientific, peer-reviewed, articles. These articles are collected using different search engines as Google Scholar, Scopus and PubMed.

2.1 Analytical Framework

Although the amount of papers studying the use of urban resilience is rapidly increasing, the concept of urban resilience is a relatively new one within the environmental studies. This opens a lot of new doors for new research but this also results in an ubiquity of the use the term 'resilience' (Leichenko, 2011). Therefore it is important to define urban resilience in a precise way so we can measure it. The studies of Wardekker et al. (2010) and Tyler and Moench (2012) have defined urban resilience in three similar categories. In this study we will define these as the following:

1. The amount of change the system can undergo and still retain the same controls on function and structure.
2. The degree to which the system is capable of self-(re)organization to accommodate external changes.
3. The ability to build and increase the capacity for learning and adaptation.

For this study these three categories will be used to measure urban resilience. These categories are based on the 'six principles of resilience' (Wardekker et al., 2010). These principles give a better insight on urban resilience within this study :

- Homeostasis: feedbackloops which stabilize the city when reacting to disturbances
- Omnivory: vulnerability is reduced by diversification of resources
- High flux: a fast rate of movement of resources ensures faster mobilization when dealing with disturbances
- Flatness: cities should be flexible within their society so they can act upon dynamic and surprise effects
- Buffering: thresholds of essential functions within the city or society should never run out.
- Redundancy: overlapping functions; if one fails, others can take over.

In recent years the importance of *community mitigation capacity* within urban resilience has come up. This as opposed to the *traditional hazard mitigation* strategy consists of multiple involved communities which are able to anticipate and respond to disasters. When building a resilient city this could certainly be of worth. However, in this study the focus will be solely on adaptation strategies because the line of interest of this study lies more within the dynamic and *physical* parts of urban resilience.

This use of urban resilience assumes that the climate changes consist of dynamic and variable effects(Tyler & Moench, 2012). However, when reflecting on dynamic and variable climate effects described by Hunt & Watkiss (2010), which were used earlier during the main objective, only the effects of sea level rise, effects of extremes on built infrastructure and effects on health respond. These effects show a certain *dynamic*, *variable*, *direct* and *physical* effect of climate change. The energy use and water availability, though important, are not directly related to urban areas or climate change. The climate does have an effect on energy use, however this does not lie in the study of interest when researching the *physical* effects of climate change. The water availability is also important for the socio-economic state in urban areas, however this is not a direct effect of climate change and this can also differ majorly between cities. Therefore the main climate change effects which will be analyzed in this study are the following:

- Effects of sea level rise. The majority of studies have the common focus on sea level rise because of the fact that many major cities are located in low lying areas (Hunt & Watkiss, 2011)
- Effects on climate extremes on built infrastructure.
- Effects on health.

Although these effects seem to suggest that these occur only due to climate *changes* and not due an temperature increase or decrease most literature does take the trending temperature rise into account. The Fifth Assessment Report of the IPCC (IPCC, 2014) also shows an linear trend of a global warming of 0,85 °C between 1800 and 2012. Therefore this study will focus on only the trend of global warming with an increasing temperature.

The climatic effects on the health within a city is an important and much debated subject. There are a lot of studies which conclude that climate change is an important driver for the increase of spreading of disease (Sattertwhaite et al., 2007) and the detoriation of surface water quality (Whitehead et al., 2009). Although this is an important and complicated matter within the resilience of cities this is mainly important for the lower- and middle-income cities. Therefore will this subject not be treated in this study.

When limiting this study to only high-income cities the different classes of income between cities must be distinguished. This is done by defining high-, middle-, and low-income cities using the definition of the income per nation used by the World Bank and subsequently by the UN. The World Bank defines a high income-nation as of 2015 Gross National Index (GNI) of $12,736 or above (World Bank, 2015).

2.2 Conceptual model

This study consists of an number of importants variables and factors when studying urban resilience. For a clear picture of the relationships between these variables they are represented in figure 1.

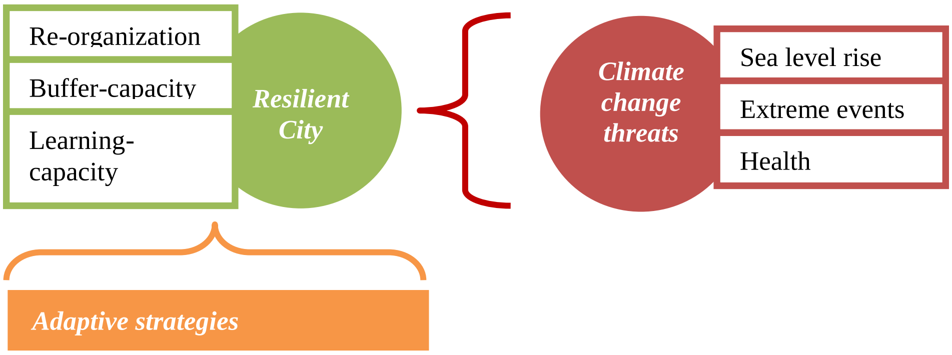

Figure 1. Conceptual model of adaptation strategies and urban resilience.

3. Climate change effects on cities

The increasing temperature of the earth's global surface temperature results in new challenges which cities have to face. In this chapter the following three climate challenges, defined by Hunt & Watkiss (2010), will be explained:

1. Sea level rise
2. Effects of extreme events
3. Effects on health

3.1 Sea level rise

The oceans are for coastal cities very beneficial as it is a source for food, trade and tourism. However, residing near the coast does have a downside which is becoming increasingly more dangerous. The dynamic character of the sea is an constant threat humanity has battled with. In this chapter we will focus on what most of studies consider as the biggest threat humans face of the oceans: Sea level rise.

The rise of the sea level is one of the most common threats which cities have to face due to warming of the global climate (Hunt & Watkiss, 2010). Since 1917 until 2010 the sea level has risen with 0.19 meters globally (IPCC, 2013). The oceans ecosystem is a very complex system which consists of a great variety of mechanisms which do not only influence our way of living but are also one of the biggest drivers of the earth's entire ecosystem. Due to the complexity of this system it is important to globally analyze which mechanism causes the rise of the sea level.

The change in sea level rise is caused by a change of volumetric size of the oceanic water. A increased water volume results in an higher sea level. The water volume is influenced by changes in features of oceanic water such as salinity and temperature. However, data have shown that only an change of temperature can create a significant global sea level rise (IPCC, 2013). Temperature has an effect on almost all components as the ocean is very climate-sensitive. Therefore the main mechanisms behind global sea level rise could be distinguished within two mechanisms:

1. Thermal expansion
2. Melt of glaciers and continental ice sheets

The thermal expansion of the ocean is perhaps the most common known cause of sea level rise. When explaining thermal expansion the term ocean heat content (OHC) is widely used as an parameter for any changes of the recent global warming on the oceanic water temperature. The ocean heat content represents the amount of Joule per square meter of ocean water. When the temperature of the ocean water increases, the ocean heat content increases too. Due to global climate change the ocean heat content increases which results in an expansion of the oceanic water volume.

The effects of the melt of glaciers and other ice sheets are lesser known. However, the importance of these water and ice mass exchanges are widely underestimated. The melting of glacial ice and continental ice-sheets have an direct influence on the global sea level rise (IPCC, 2013) as it increases the amount of water in the oceans. An inflow of fresh water also has an direct effect on the oceanic temperature and thus decreases the ocean heat content.

Coastal cities, especially those located below sea level, are constantly facing the threats of sea level rise. And with future predictions of an increased sea level by 18-59 cm (IPCC, 2013) these risks are cumulating. Due to the high population density of cities the impacts of sea level rise have great impacts on cities. Examples of high-income cities which have to deal with these consequences are Boston and London. Birkman et al. (2010) found that these (near) coastal cities faced loss of coastal land, loss of water supply and drainage systems and increased risk of flood damages due to more severe and increased floodings. Other consequences could be increased salinity, rising coastal water tables and impeded drainage. These consequences could lead to more serious problems like casualties, illness, psychological trauma, disruption of social networks, loss of national competitive strength and market positions, loss of cultural heritage, city attractiveness and economic losses (Hallegatte et al., 2011). An indirect effect of sea level rise is also the flooding of riverbeds, which could endanger cities near rivers too.

3.2 Effects of extreme events

The rise of the sea level consists of an consistent and significant increase. However, an increase in global surface temperature does not always lead to consistent consequences. Extreme phenomena like storm surges, extreme heat or intense precipitation are also consequences of climate variability. These dynamic, short term, processes are much more difficult to study. Due to the limited data available it is much harder to assess their frequency or intensity (IPCC, 2012).

However, the IPCC does report an increase of heat waves, increase of warm days and nights globally since 1950. For high-income nations within Europe this could lead to extreme droughts.

Furthermore the vulnerability of cities due to storm surges is likely to increase (IPCC, 2012). Although tropical storms seem to increase by intensity (+2% to +11% globally) the frequency seems to drop by -6% to -34% by 2100 (Knutson et al., 2010). This represents a slight change in storm characteristics. However, the increased vulnerability of cities is not specifically due to a change in storm intensity or frequency. It is mainly the overall mean sea level rise, explained in the former paragraph, which enhances the vulnerability of urban areas by storm surges (IPCC, 2012; Knutson et al., 2010).

3.3 Effects on health

Although extreme events and flooding are factors for health detoriation within cities, these effects are not year round. These impacts are relatively short-term and have an high intensity. However, global warming could lead also to a decay of the general health.

It is widely recognized that urban areas have an detrimental effect on the environment and thus the climate system. However, this relationship is reciprocal (Kleerekoper, Esch & Salcedo, 2012). Cities evoke global climate change as the main source of GHG but the increase of surface temperature could lead to negative consequences. One of the main problems in big urban areas are the higher surface temperatures which only occur within cities.

The main mechanism behind these effects is formulated as the Urban Heat Island (UHI). More than 48 percent of the world population is directly exposed to urban heating (Memon, Leung & Liu, 2009). This effect was initially described as a regional climate issue. However, recent studies suggested that the UHI is influenced and strengthened by the global warming (IPCC, 2007). With a predicted surface warming between 1.1 and 6.4 degrees for the 21st century (IPCC, 2007), this could be an serious problem. Higher surface temperatures in combination with UHI could lead to an increase in intensity or frequency of heat waves, an increase in mean temperature and hot extremes. These effects have a negative impact on the liveability within an city.

The UHI effect is comprised of an variety of factors within urban areas which contribute to an increase in urban temperatures (Memon et al., 2009):

1. Anthropogenic heat. This heat is comprised of all human activities

within a city. Human metabolism, power plants, vehicles and other heat sources.

2. (Solar) radiation absorption. Building materials have a relatively low albedo, which store an high amount of solar radiation.
3. Heat release. The ability to release heat from the urban materials is difficult because of an decreased sky view, which leads to the *canyon effect*. This is when heat is trapped between two or more objects.
4. Evaporation. Cities exhibit low evaporation, which decreases latent heat significantly. It was reported that evapotranspiration in Tokyo has been reduced by 38% from 1972 to .
5. Convective heat removal. Due to the amount of rough objects within cities, the amount of heat transferred by the wind is decreased.

Although the UHI effect could lead to serious consequences like mortality, most of the related health issues in cities are comprised of an overall detoriation of the liveability. The physical well-being could also be significantly influenced by the climate (Kleerekoper et al., 2012). The term *heat stress* is most commonly used to explain the negative effect of higher surface temperatures on the human well-being. Extreme temperatures could place an significant heat stress on the thermoregulatory system, which could lead to discomfort and heat illnesses like heat syncope, cardiovascular stress and heat strokes (Kleerekoper et al., 2012). Since the predicted population density due to urbanization only increases, it is of great importance to adapt cities to cope with these problems.

4. Adaptation strategies to climate change

With the future predictions of an increase of sea level, extreme events and health risks cities have to face new challenges. In this chapter the most common and the most studied adaptation measures for each challenge will be discussed. Because a lot of adaptation strategies cover more than one specific challenges (some strategies cover both storm surges as sea level rise for example) this chapter is classified per adaptation strategy:

1. Adaptations for sea level rise and storm surges
2. Adaptations for heavy precipitation
3. Adaptations for the heat stress and heat waves

4.1 Adaptations for sea level rise and storm surges

In the previous chapter the risks of an rising sea level were being discussed. Although an increased sea level logically leads to higher risks of storm surges and flooding, the magnitude of these floods is dependent on the vulnerability of the city. Therefore it is of importance to estimate the vulnerability of each city first (Walsh et al., 2004; Aerts et al., 2014). The vulnerability depends upon factors as geographic location, surface permeability, inundation areas, open space etc. Using this knowledge planners, engineers and governments can use different adaptation measures to reduce the flood frequency or magnitude. Walsh et al. (2004) distinguishes two main types of measures which cities use (see Appendix: Table A):

1. Infrastructure-based protection
2. Adaptation (which is defined as an less structural adaptation method as protection)

The use of protection is the most common one among coastal cities. These measures are often called the traditional infrastructure-based approach (Genelleti & Zardo, 2016). These mainly consist out of using robust infrastructure. These measures do not require great institutional changes and are thus easy to implement (Walsh et al., 2004). For protection against storm surges these are considered very sufficient as they give a structural protection against high sea- and wind levels. Although this method is 'old-fashioned' this is still very common within high-income nations. A rise of sea level also increases the vulnerability of cities for storm surges (IPCC, 2012).

In most recent years the use of adaptation measures have been studied. These measures vary in different forms but consist mostly of integrating smart urban planning. Due to the fact that these need more institutional changes, this method is more suitable for high-income cities. One way to reduce the flood risk is the use of water-sensitive planning (WSP), which is a part of the so called green or green-blue infrastructure. The goal of WSP is to incorporate water considerations in regional and urban planning (Carmon & Shamir, 2009). The main measures of WSP are:

- Placement of open places and roads. Roads are an very important part of WSP as they constitute of approximately 70% of the impervious urban area (Carmon & Shamir, 2009).
- Preservation of and rehabilitation of urban streams.
- Delineation of floodplains.

An example of an high-income city implementing WSP is Seoul. The rehabilitation of the river Cheonggyenchion which required the displacement of an high-way but increased the water flow significantly (Carmon & Shamir, 2009). Other measures which can be made are flood proofing of infrastructure or floating communities as proposed in Rotterdam (Birkman et al., 2010). The use of floodplains, or wetlands, between the sea and the city would significantly decrease storm surge risks (Geneletti & Zardo, 2016; Temmerman et al., 2013). However, not all cities have the space for such flood plains and it is thus only suitable for high-income cities like London or New Orleans which are located in deltas and estuaries (Temmerman et al., 2013).

4.2 Adaptations for heavy precipitation

As for sea level rise and storm surges the first step before taking risk managerial measures is by assessing the vulnerability of city. This may be difficult for heavy precipitation as the extreme events are very dynamic and variable. This is why a variety of different measures should be used to adapt cities to these challenges.

One of the main challenges of heavy precipitation are higher frequencies and intensities of so-called storm water. There are an couple of different adaptation measures that could be made to adapt cities to these events.

The use of water-sensitive planning (WSP) was already explained as use for flooding due to higher sea levels and storm surges. However, WSP is also used for the adaptation of cities against heavy precipitation also known as storm water. This part of WSP is the so-called *stormwater management* (Carmon & Shamir, 2009). Measures made using stormwater management can be divided in three categories each comprising of different types of measures (see Appendix: table B):

- urban land use
- land cover design
- constructed facilities(Carmon & Shamir, 2009).

The use of stormwater management and WSP is a part of green-blue infrastructure as previously mentioned. The use of green-blue infrastructure is gaining increasingly more attention. Another adaptation method which could reduce the flood risk due heavy precipitation is Ecosystem-based Adaptation (EbA). This method is defined as using ecosystem services to adapt to the adverse effects of climate change (Geneletti & Zardo, 2016). EbA stimulates the use of vegetation as this is beneficial for reduced peak discharge, increased infiltration, run-off speed and reduced erosion by flooding and heavy precipitation

(Geneletti & Zardo, 2016; Palmer et al., 2009). The measures for EbA flood risk management also exist out of three categories (see Appendix: Table B):

- implementation of green areas
- re-naturalizing river systems
- reducing impervious surfaces.

A new innovational measure is the use of vegetated rooftops, which is a mix of WSP and EbA. Due to the retaining of water in the soil, the run-off will be reduced in comparison to 'hard' roofs (Berndtsson, 2010). The benefits of the green roofs will be further elaborated in the next paragraph.

4.3 Adaptations to heat stress and heat waves

As opposed to heavy precipitation, high sea levels and storm surges the effects the changing climate also provides an increase of heat waves and an intensification of the Urban Heat Island (UHI). As mentioned in the previous chapter the UHI depends on five different factors (Memon et al., 2009): Anthropogenic heat, (solar) radiation absorption, heat release, evaporation and convective heat removal. By altering these factors the UHI effect should be reduced. The most common adaptations strategies are urban planning and green and blue infrastructure, which are also represented in Appendix: Table C.

Anthropogenic heat

The emission of anthropogenic heat is the biggest source of heat within urban areas (Kleerekoper et al, 2012). However, reduction of these heat emissions are for most cities no option as they require an reduction of inhabitants, vehicles or other human induced heat sources.

(Solar) radiation absorption

Building materials such as asphalt and concrete retain an high amount of (solar) radiation (Bowler et al., 2010; Kleerekoper et al., 2012). By using materials which have an higher thermal conductivity or higher reflectivity (albedo) the heat storage in building materials may be reduced. In most recent years an increasing use of green and blue infrastructure or EbA as heat management have been proposed. Implementing vegetation in parcs or rooftops could lead to an increase in reflectivity of solar radiation (Geneletti & Zardo, 2016; Bowler et al., 2010). Water could also function as an heat buffer and it can even transport heat out of urban areas via creeks and rivers (Kleerekoper et al., 2012).

Heat release

Heat is trapped due to the *canyon effect* within urban areas. The built-form of buildings and urban areas is therefore of importance when reducing heat entrapment. By using urban planning the canyon effect could be reduced (Kleerekoper et al., 2012). By creating more open space and designing lower buildings the amount of sky view can be increased which increases the heat release to the atmosphere and decreases the canyon effect.

Evaporation

Transpiration and evaporation (evapotranspiration) are key process in cooling an area. Asphalt and concrete are impervious surfaces with no evapotranspiration capacities. However, do have an significant cooling effect due evapotranspiration (Geneletti & Zardo, 2016; Müller et al., 2014; Bowler et al., 2010) . Vegetation has an average cooling effect of 1–4.7 ◦C that spreads 100–1000 m into an urban area. Water has an average cooling effect of 1–3 ◦C to an extent of about 30–35 m (Kleerekoper et al., 2012). Implementation of urban parcs and forests or creeks could lead to cooling in public spaces. The use of green rooftops also is getting increasingly more attention for the cooling of houses (Berndtsson, 2010).

Convective heat removal

The high density of objects and buildings within cities the amount of heat transferred by convection is decreased which results in an entrapment of heat. Using urban planning the convection could be increased. By designing open spaces, wider streets and building forms will could increase the wind flow (Kleerekoper et al., 2012).

5. Urban resilience

In the previous chapter this paper elaborated on the different adaptation strategies cities use to increase their adaptiveness to climate changes. However, these adaptation strategies are not always effective. In this chapter the following adaptive strategies will be reviewed using the concept of urban resilience:

- Infrastructure-based protection
- Water-sensitive planning (WSP)
- Ecosystem-based adaptation (EbA)

Urban planning is not explicitly mentioned as one of the adaptation methods. It is the overarching term of designing the urban lay-out. Most adaptation methods like WSP and EbA are considered a part of urban planning. However, due to the broadness of the definition of urban planning this adaptation method was not mentioned as a specific climate change adaptation. Urban planning does play a major role when applying these adaptationmeasures.

Infrastructure-based protection

Infrastructure-based protection consists of big robust infrastructures. This adaptation strategy decreases the flatness of a city as infrastructures like sea walls do not leave much space for flexibility. The lack of dynamic adaptation to climate change could be proven costly as both cities and the climate keep changing. The use of robust infrastructure limits the learning adaptation capacity. Most of the constructions like sea walls and dykes have high threshholds but these structures cannot be limitlessly improved. This leaves out the possibility to *co-evolve*; to keep improving adaptiation (Wardekker et al., 2010).

Furthermore the infrastructure-based protection only serves one goal. The absence of any redundant functionality is very inconvenient when facing different climate threats When sea levels and storm surges exceed these threshholds coastal cities lack buffering capacities.

However, in short-term predictions these infrastructure could be helpful when defending coastal cities and preserving the current infrastructure.

Water-sensitive planning

Water-sensitive planning (WSP) consists of integrated water consideration within standard urban planning. WSP could be a helpful adaptation method when increasing resilience. The use of flood plains, retentionbassins and better drainage certainly increases the buffering capacities of water. Measures such as pervious layers, mixed land-use use hydrological feedbackloops, which increases the capability of self-(re)organization to heavy precipitation and flooding. WSP also contributes indirectly to the flatness of cities. An increase discharge and pervious layers within cities can confer to the evapotranspiration and absorption of heat (Kleerekoper et al., 2012).

However, WSP is generally focussed on flood-control. This displays a lack of flexibility (flatness) when facing multiple climate scenarios. Although this sort of adaptation does have a certain learning capacity, the restriction to only water does limit the capacity to improve.

Ecosystem-based adaptation

Ecosystem-based adaptation (EbA) consists of using natural ecosystem services within urban areas. EbA is a sustainable adaptation alternative for disaster risk-reduction (DDR) within urban areas (Huq et al., 2013). The focus is therefore less on the external protection of cities like infrastructure-based protection and in lesser extent WSP.

However, when discussing options for climate change risk reduction the use of EbA is definitely the most promising adaption method. Due to the use of ecosystems there a lot of natural feedbackloops which contribute to a better homeostasis. The biodiversity management is also an important objective of EbA (Huq et al., 2013). Biodiversity results in redundancy and flatness. The use of parcs, trees, vegetated roofs and ponds contributes to a wide variety of different climate events as it increases the discharge of water, convection of heat and evapotranspiration (Geneletti & Zardo, 2016; Palmer et al., 2009; Kleerekoper et al., 2012; Berndtsson, 2010). Furthermore the use dynamic ecosystems in the EbA approach leaves a lot of space for co-evolving. EbA is therefore best capable of self-(re)organization, learning and risk reduction.

6. Discussion

When reflecting on current and future climate change the effects of sea level rise, extreme events and health-related effects could be distinguished as the most common climate threats. When reviewing the possible adaptation options the use of water-sensitive planning (WSP), ecosystem-based adaptation (EbA) and infrastructure-based adaptation are the accepted adaptation methods applied within high-income cities.

As previously stated is infrastructure-based protection the least conventional adaptation method when creating resilient cities. The inflexibility, lack of buffering, and lack of redundancy is unsustainable when facing climate threats on a long-term basis. WSP is a better alternative when facing water-related disasters. However, this method is still limited to certain climate events. EbA would be the best option as the natural ecosystems are employable against multiple climate events and the natural feedbackloops creates a homeostasis.

However, it would be unwise to limit the resilience of a city to only one adaptation method as each of these methods have their stronger and weaker points. An combination of these adaptations options should create an higher resilience as it increases the redundancy and flexibility of adaptation alternatives.

On a short-term prediction the use of infrastructure-based protection could have benefits in preserving the current structures, systems and function of coastal cities. When implementing a WSP and EbA approach by using more vegetation and stormwatermanagement the risks of overheating and heavy precipitation could be reduced. These could be proven more beneficial on a long-term as they have a learning capacity and could be used against a wider variety of climate scenarios. Combining the existing adaptation methods could be interesting for future studies when building urban resilience.

Limitations

It has been this papers objective to focus on the physical and infrastructural aspects of climate adaptation. However, a number of studies also include the social-economic response in their definition of urban resilience (Wardekker et al., 2010). Although engaged communities do benefit the adaptive capacity of cities they are not considered to be an substitute for infrastructural adaptation measures (Davoudi et al., 2012).

Additionally, this paper focus mainly on the adapting capacities of high-income cities. This does display a certain social aspect. However, when reviewing urban resilience it is impossible to focus on certain adaptations without considering the possibilities in relationship to the socio-economic status (Davoudi et al., 2012). Also the difference of the economic, constitutional and spatial constraints within high-income were not taking into account when reviewing adaptation options. However, by excluding middle- and low income cities, this paper has eliminated these constraints for a big part.

Furthermore the lack of consistent and relevant information could be a limiting factor. Due to the relative modernity of urban resilience and climate change adaptation the amount of information available is limited only to models and historical data. The long-term climate effects or adaptation consequences are not clear yet. Therefore combining adaptation measures could even lead to adverse effects in such a way that these measures create a lower resilience of cities (Wardekker et al., 2010).

Other limiting variables of this study could be the exclusion of indirect effects of climate change. Effects of smog, reduced air-quality, water-shortage, increased disease spreading or decrease of water-quality could show to be realistic and significant threats.

7. Conclusion

In more recent times the interest towards climate proof cities has been significantly increasing. The increasing temperature has been an obstacle for several local planners. When reflecting on the increasingly dynamic and unpredictable character of the climate, environmental scientists began to construct the term urban resilience. However, there still adheres a haziness on how to create a climate resilient city. It was this papers objective to review which of the current adaptation options would be the best suitable in terms of resilience when facing multiple climate scenarios. This was done by studying the most common climate threats, the current adaptation options and by comparing these options with the resilience guidelines.

It was concluded that the most common climate threats (sea level rise, extreme events, health-related effects) would be most effectively reduced using ecosystem-based adaptation (EbA). However, it was suggested that a combination of the current adaptation measures (infrastructure-based protection, water-sensitive planning (WSP) and EbA) would be more effective as this would result in a higher flexibility and redundancy of adaptation options.

When looking into the future the climate could cause unpredictable and dynamic threats to human populations. This study has shown that the use of ecosystem-based adaptation in combination with other adaptation methods is the most effective for cities when battling these threats. However, this subject is a relatively new one within the environmental field and still lacks an complete theoretical framework. Therefore it is important to set up new studies on how these adaptation methods interact with each other before any policies are made.

8. References

- Aerts, J. C. J. H., Botzen, W. W., Emanuel, K., Lin, N., de Moel, H., & Michel-Kerjan, E. O. (2014). Evaluating flood resilience strategies for coastal megacities. *Science*, *344*(6183), 473-475.
- Berndtsson, J. C. (2010). Green roof performance towards management of runoff water quantity and quality: A review. *Ecological Engineering*, *36*(4), 351-360.
- Birkmann, J., Garschagen, M., Kraas, F., & Quang, N. (2010). Adaptive urban governance: new challenges for the second generation of urban adaptation strategies to climate change. *Sustainability Science*, *5*(2), 185-206.
- Bowler, D. E., Buyung-Ali, L., Knight, T. M., & Pullin, A. S. (2010). Urban greening to cool towns and cities: A systematic review of the empirical evidence. *Landscape and urban planning*, *97*(3), 147-155.
- Carmon, N., & Shamir, U. (2010). Water-sensitive planning: integrating water considerations into urban and regional planning. *Water and Environment Journal*, *24*(3), 181-191.
- Da Silva, J., Morera, B.E. (2014). City Resilience Framework. *ARUP&The Rockefeller Foundation*
- Davoudi, S., Brooks, E., Mehmood, A. (2013). Evolutionary Resilience and Strategies for Climate Adaptation. *Planning Practice & Research*:28:3:307-322
- Davoudi, S., Shaw, K., Haider, L. J., Quinlan, A. E., Peterson, G. D., Wilkinson, C., ... & Davoudi, S. (2012). Resilience: A Bridging Concept or a Dead End?“Reframing” Resilience: Challenges

for Planning Theory and Practice Interacting Traps: Resilience Assessment of a Pasture Management System in Northern Afghanistan Urban Resilience: What Does it Mean in Planning Practice? Resilience as a Useful Concept for Climate Change Adaptation? The Politics of Resilience for Planning: A Cautionary Note: Edited by Simin Davoudi and Libby Porter. *Planning Theory & Practice*, *13*(2), 299-333.

- Geneletti, D., & Zardo, L. (2016). Ecosystem-based adaptation in cities: An analysis of European urban climate adaptation plans. *Land Use Policy*, *50*, 38-47.
- Gill, S.E., Handley, J.F., Ennos, A.R., Pauleit, S.(2007). Adapting Cities for Climate Change: The Role of the Green Infrastructure. *Built environment*:33:115-133
- Hallegatte, S. (2009). Strategies to adapt to an uncertain climate change.*Global Environmental Change*, *19*(2), 240-247.
- Hunt, A., Watkiss, P. (2011). Climate change impacts and adaptation in cities: a review of the literature. *Climatic Change*:104:1:13-49
- Huq, N., Renaud, F., & Sebesvari, Z. (2013). Ecosystem based adaptation (EBA) to climate change—integrating actions to sustainable adaptation. *Bonn: United Nations University, Institute for Environment and Human Security*.
- IPCC. (2014). Climate Change 2014: Synthesis Report Summary for Policymakers. *Fifth Assesment Report*
- IPCC.(2012). Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Summary for Policymakers. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. *Cambridge University Press, Cambridge, UK, and New York, NY, USA*, pp. 1-19.
- IPCC. (2007). Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. *Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*
- Kleerekoper, L., Van Esch, M., Salcedo, T.B. (2012). How to make a city climate-proof, addressing the urban heat island effect. *Elsevier: Resources, Conservation and Recycling*:64:30-38
- Knutson, T. R., McBride, J. L., Chan, J., Emanuel, K., Holland, G., Landsea, C., ... & Sugi, M. (2010). Tropical cyclones and climate change. *Nature Geoscience*, *3*(3), 157-163.
- Leischenko, R. (2011). Climate Change and Urban Resilience. *Elsevier: Environmental Sustainability*. 3:164–168
- Meerow, S., Newell, J.P., Stults, M. (2016). Defining urban resilience: A review. *Elsevier: Landscape and Urban Planning*: 147:38-49
- Memon, R. A., Leung, D. Y., & Liu, C. H. (2009). An investigation of urban heat island intensity (UHII) as an indicator of urban heating. *Atmospheric Research*,*94*(3), 491-500.
- Müller, N., Kuttler, W., & Barlag, A. B. (2014). Counteracting urban climate change: adaptation measures and their effect on thermal comfort. *Theoretical and applied climatology*, *115*(1-2), 243-257.
- Palmer, M. A., Lettenmaier, D. P., Poff, N. L., Postel, S. L., Richter, B., & Warner, R. (2009). Climate change and river ecosystems: protection and adaptation options. *Environmental management*, *44*(6), 1053-1068.
- Patz, J.A., Campbell-Lendrum, D., Holloway, T., Foley, J.A. (2005). Impact of regional climate change on human health. *Nature*:438:310-317
- Satterthwaite, D., Huq, S., Pelling, M., Reid, H., Lankao, P.M. (2007). Adapting to Climate Change in Urban Areas: The possibilities and constraints in low- and middle-income nations. *Human Settlements Discussion Paper Series*
- Temmerman, S., Meire, P., Bouma, T. J., Herman, P. M., Ysebaert, T., & De Vriend, H. J. (2013). Ecosystem-based coastal defence in the face of global change. *Nature*, *504*(7478), 79-83.
- Tyler, S., Moench, M. (2012). A framework for urban climate resilience. *Climate and Development*:4:311-326
- UN. (2014). World's population increasingly urban with more than half living in urban areas. 10 july 2014 <http://www.un.org/en/development/desa/news/population/world-urbanization-prospects-2014.html>
- UN-Habitat. (2012). Climate Change. <http://unhabitat.org/urban-themes/climate-change/>
- Urban Hazard Mitigation: Creating Resilient Cities (2003)
- Walsh, K. J. E., Betts, H., Church, J., Pittock, A. B., McInnes, K. L., Jackett, D. R., & McDougall, T. J. (2004). Using sea level rise projections for urban planning in Australia. *Journal of Coastal Research*, 586-598.
- Wardekker, J.A., De Jong, A., Knoop, J.M., Van der Sluijs, J.P. (2010) Operationalising a resilience approach to adapting an urban delta to uncertain climate changes. *Elsevier: Technological Forecasting & Social Change*: 77: 987-998
- Whitehead, P.G., Wilby, R.L., Battarbee, R.W., Kernan, A., Wade, A.J. (2009). A review of the potential impacts of climate change on surface water quality.

Hydrological Sciences Journal:54:1:101-123

- World Bank. (2015). New Country Classifications. 2 July 2015. <http://data.worldbank.org/news/new-country-classifications-2015>

9. Appendix

9.1 Table A

Infrastructure-based protection		Water-sensitive planning	
Adaptation strategy	*Implementation*	*Adaptation strategy*	*Implementation*
Placement of open places and roads	*Open areas Pervious roads Retention basins*	*Robust infrastructure*	*Sea walls Levees Coastal hardening Dykes Elevation of endangered area Artificial nourishment of beaches Irrigation systems*
Preservation of and rehabilitation of urban streams	*Creeks Ponds*		
Delineation of floodplains	*Floodplains Wetlands*		

Table A. An overview of infrastructure-based and water-sensitive planning adaptation measures

9.2 Table B

Storm water management		Ecosystem-based Adaptation	
Adaptation strategies	*Adaptation measures*	*Adaptation strategies*	*Adaptation measures*
Urban land use	*Higher-density development. Higher housing density results in an significant decrease of water run-off Mixed land use. By mixing housing, employment and services the need of impervious surfaces as sidewalks can be reduced.*	*Implementation of green areas*	*Using retention basins, swales, and wet detention systems can be designed into open spaces and urban parks*
Land cover design	*Decrease impervious surfaces. Increase pervious surfaces. Maintain pervious surfaces*	*Re-naturalizing river systems*	*Restoring river and flood-plain systems to a more natural state in order to create space for floodwater*
Constructed facilities	*Point structures. Example: a recharge well which receives rainfall from a roof drain or a yard Linear structures.*	*Reducing impervious surfaces*	*Interventions to reduce impervious surfaces in urban environments like porous paving; green parking lots; brownfield restoration.*

	Example: porous underground drainage pipe *Local reservoirs*		

Table B. A schematic overview of the adaptation strategies and measures of WSP storm management and EbA

9.3 Table C

Green and blue infrastructure		Urban planning	
Adaptation strategy	*Implementation*	*Adaptation strategy*	*Implementation*
Vegetation	*Parcs* *Trees* *Green rooftops* *Urban forests*	*Material*	*More use of vegetation* *More use of pervious materials* *More use of materials with high conductivity*
Water	*Creeks* *Rivers* *Small lakes*	*Built-form*	*Open space (parcs)* *Lower buildings* *Wider streets*

Table C. Adaptation strategies and implementations for heat reduction