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ORIGINAL PAPER

A multi-dimensional assessment of urban vulnerability to climate change in Sub-Saharan Africa

Lise Byskov Herslund[1] · Fatemeh Jalayer[2] · Nathalie Jean-Baptiste[3] · Gertrud Jørgensen[1] · Sigrun Kabisch[3] · Wilbard Kombe[4] · Sarah Lindley[5] · Patrik Karlsson Nyed[1] · Stephan Pauleit[6] · Andreas Printz[6] · Trond Vedeld[7]

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Abstract In this paper, we develop and apply a multi-dimensional vulnerability assessment framework for understanding the impacts of climate change-induced hazards in Sub-Saharan African cities. The research was carried out within the European/African FP7 project CLimate change and Urban Vulnerability in Africa, which investigated climate change-induced risks, assessed vulnerability and proposed policy initiatives in five African cities. Dar es Salaam (Tanzania) was used as a main case with a particular focus on urban flooding. The multi-dimensional assessment covered the physical, institutional, attitudinal and asset factors influencing urban vulnerability. Multiple methods were applied to cover the full range of vulnerabilities and to identify potential response strategies, including: model-based forecasts, spatial analyses, document studies, interviews and stakeholder workshops. We demonstrate the potential of the approach to assessing several dimensions of vulnerability and illustrate the complexity of urban vulnerability at different scales: households (e.g., lacking assets); communities (e.g., situated in low-lying areas, lacking urban services and green areas); and entire cities (e.g., facing encroachment on green and flood-prone land). Scenario modeling suggests that vulnerability will continue to increase strongly due to the expected loss of agricultural land at the urban fringes and loss of green space within the city. However, weak institutional commitment and capacity limit the potential for strategic coordination and action. To better adapt to urban flooding and

✉ Lise Byskov Herslund
lihe@ign.ku.dk

[1] University of Copenhagen, Rolighedsvej 23, 1858 Frederiksberg C, Denmark

[2] University of Naples Federico II and AMRA, Via Nuova Agnano, 11, 80125 Naples, Italy

[3] Helmholtz Centre for Environmental Research-UFZ, Permoserstrasse 15, 04318 Leipzig, Germany

[4] IHHS, Ardhi University, PO Box 35176, Dar es Salaam, Tanzania

[5] Geography, School of Environment, Education and Development, University of Manchester, Oxford Road, Manchester M13 9PL, UK

[6] Technical University of Munich, Arcisstraße 21, 80333 Munich, Germany

[7] NIBR, Gaustadalléen 21, 0349 Oslo, Norway

thereby reduce vulnerability and build resilience, we suggest working across dimensions and scales, integrating climate change issues in city-level plans and strategies and enabling local actions to initiate a 'learning-by-doing' process of adaptation.

Keywords Africa · Urban · Climate change · Vulnerability assessment · Dar es Salaam

1 Introduction

Climate change has the potential to severely impact the fast developing cities of the African continent, where by 2014 some 40 % of Africa's population was already estimated to live. Africa's urban population is expected to triple toward 2050 to reach 1.3 billion (UNEconomic and Social Affairs 2014). At the same time, the continent's urban areas will be increasingly threatened by natural hazards such as coastal, riverine and pluvial flooding, heat waves and droughts (Pelling and Wisner 2009). The nature of urbanization in Africa is also part of the problem. For the year 2001, 61 % of the continent's urban population was estimated to live in what has been defined as a slum (UNHabitat 2008).

Many African countries and cities are struggling to implement efficient risk reduction strategies. The general awareness of climate change as a source of hazards is increasing, and there has been considerable international funding raised as a result (e.g., UNHabitat 2014). However, knowledge is still rather thin on the ground about what the specific hazards threatening different cities of the continent are (Giugni et al. 2015), how urban vulnerability can be described and measured in a clear, yet informative way, and how useful risk reduction strategies can be formed and implemented in the often economically and socially fragile conditions (Douglas et al. 2008; Wisner et al. 2004; Satterthwaite et al. 2009).

Urban risk and vulnerability assessments have been mainly centered on accounting for environmental hazards such as floods and coastal erosion and their distribution. The human element, i.e., the vulnerabilities related to land use and socioeconomic issues, has been given less attention (Bulkeley and Broto 2013; Adger et al. 2004). Often both risk and vulnerability are understood to be the occurrence of the extreme event or hazard. However, hazard exposure is just one component of risk. The second component is the fact that somebody or something is at risk, i.e., vulnerable to a hazard (Douglas et al. 2008). This is closely related to the EU Commission's risk assessment guideline in which vulnerability is defined as 'the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard' (UNISDR 2009). Another distinction is whether vulnerability is seen as an end result of hazard exposure, or as a starting point, dependent on the present day conditions and context (Kelly and Adger 2000). This is also referred to in the literature as 'contextual' vulnerability (O'Brien et al. 2007).

The EU FP7 research project *CLimate change and Urban Vulnerability in Africa* (CLUVA) set out to cast light on these questions and develop insights into how they may be answered in the context of Sub-Saharan Africa. The overall objective of the project was to develop methods and knowledge to be applied in African cities in order to assist with the process of managing climate risks, reducing vulnerabilities and improving climate change resilience. The project involved 13 partners from Europe and Africa with a research agenda spanning climate modeling and downscaling of climate change effects to city level, development of methods for multi-dimensional vulnerability assessments and identification of adaptation strategies. The project was based on five case cities across Sub-Saharan

Africa (see Fig. 1), but with Dar es Salaam used as the main case study area. The research was conducted in parallel with research capacity building in local universities, a well-recognized requirement for future development across the continent (Teferra and Altbach 2004). Importantly, there was also a central knowledge exchange element of the work between research partners, practitioners and other stakeholders. This innovative basis made the project well positioned to explore complex problems associated with the sustainable development of African cities in the context of a changing climate.

In this paper, we focus on the development and application of a multi-dimensional vulnerability assessment framework and consider the implications of our findings for related adaptation policies with a particular emphasis on urban flooding. The wider project showed that climate change is generally expected to increase hazards in the coming decades in the case cities. However, it is the overall risk of being negatively affected by climate change which is expected to increase particularly dramatically, largely as a result of the human factors which determine vulnerability (Di Ruocco et al. 2015; Gasparini et al. 2013). Our work addresses these human factors and the multi-dimensional character of urban vulnerability to climate change-induced hazards. We consider how to conceptualize and assess the complexity of urban vulnerability and how best to adapt to climate change in order to reduce vulnerability over the longer term. The focus is on Dar es Salaam as the main case study where we explore the factors that characterize particularly vulnerable areas, consider how vulnerability may develop in the future and assess the opportunities for and barriers to climate adaptation. We conclude with an assessment of the overall potential for adaptation with transferable messages for other parts of urbanizing Sub-Saharan Africa.

2 Theoretical background

2.1 A multi-dimensional approach to vulnerability

Urban vulnerability is complex and made up of several elements. In the literature, four specific aspects or dimensions of vulnerability have received particular attention. We

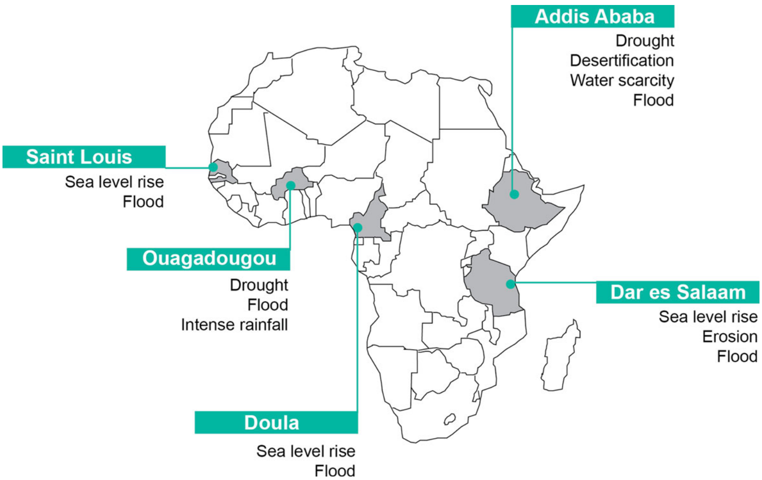

Fig. 1 Five African case cities and the main hazards they face (Jean-Baptiste and Kabisch 2013)

categorize these as *asset, institutional, attitudinal and physical vulnerability* and integrate them in a framework following the work of Moser (1998), Moser et al. (2010), Mustafa (2005), Mustafa et al. (2010) and Bulkeley and Broto (2013) (see Fig. 2). Through this vulnerability framework, we stress the importance of the resources, capacities and attitudes that individuals and groups have when faced with a natural disaster (i.e., *asset* and *attitudinal vulnerability*). We then recognize urban governance as central to any inquiry on vulnerability (i.e., *institutional vulnerability*), and finally, we acknowledge the state of the urban environment as one of the means through which the above dimensions interact (i.e., *physical vulnerability*). Indeed, although these dimensions of vulnerability are separately identified, they are all interconnected through how they influence individuals and communities, local authorities and civil groups and the condition of the physical environment. At the heart of the multiple vulnerability framework, the dimensions interact to form *combined vulnerability*. Combined vulnerability takes into account the factors which influence exposure, susceptibility/sensitivity and adaptive capacity together with factors explaining the ability of the system itself to cope and transform at different spatial scales: the household, the community, the city and beyond (Jean-Baptiste and Kabisch 2013).

Physical vulnerability covers components such as urban ecosystems, green areas and particular land uses as well as the condition of buildings and the nature and type of infrastructure. Certain land uses are highlighted as being especially vulnerable when exposed to climate change hazards and particularly urban flooding. These are land uses of high population density and high concentration of industry and infrastructure (Wang et al. 2009); land uses with a high proportion of surface sealing and lack of green areas (Arnold and Gibbons 1996); and land uses with a low level of technical infrastructure such as drainage and sanitation, waste management, energy and water supply (Douglas et al. 2008). Green areas are valuable as they provide ecosystem services such as the ability to

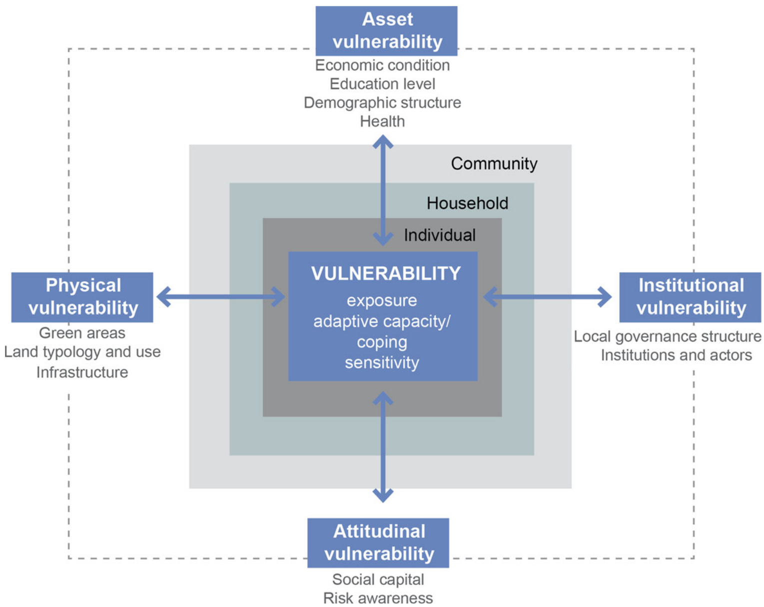

Fig. 2 CLUVA framework for assessing vulnerability (Jean-Baptiste et al. 2011, 2013)

detain water, protect soil and lower temperatures, thus modifying local exposure to hazard and also increasing the local adaptive capacity for individuals and groups (Gill et al. 2008; Matthews 2011). Housing quality, in terms of building materials, structural types and the positioning of buildings relative to the street, can also help determine the extent of damage seen as a result of flood events (Schneiderbauer and Ehrlich 2007; Müller et al. 2011). Finally, the accessibility of service infrastructure such as schools, health clinics and markets can be important for understanding how coping capacity varies across a city (Satterthwaite et al. 2009). Accessibility to service infrastructure and everyday mobility are particularly important factors in Sub-Saharan African cities given that flood events can render much of the road network virtually impassable.

Asset vulnerability can be understood as the human livelihood and material resources of individuals and groups. Asset-based assessments with regard to vulnerability are conducted with the aim of identifying what different resources individuals and households have available to them. The premise is that people with a greater quantity and diversity of assets are less vulnerable (Chambers 1995; Moser 1998). Since the 1990s, a number of frameworks and approaches have emerged adding to an already extensive literature on assets, rights and entitlements. For example, in the Asset Vulnerability Framework, Moser (1998) regroups tangible (i.e., material possessions) and intangible (i.e., good health and education) resources and considers how these and other indicators like household size and structure influence the degree to which households and communities are able to cope with seasonal and/or large-scale disasters (Adger et al. 2004; Cutter et al. 2009). In African cities, where the informal economy represents a large proportion of economic activity, assessment of informal incomes is essential in order to understand the population's vulnerability (Cannon 1994; Vincent 2004).

Attitudinal vulnerability includes attitudes to risk, hazard experiences and relations between people. Social capital such as family support, access to help through social ties, access to resources through information sharing and connections to institutions are all indicators of the immediate local coping and longer-term adaptive capacities which help to lessen vulnerability (Adger 2003). In many urban communities, informal social networks are the only form of insurance available to the poor, and in cases where there is little or no support from official sources these networks become even more critical (Douglas et al. 2008). By extension, the degree of community cohesion and general levels of trust both become extremely important indicators of the different capabilities of people and communities to mobilize collective action and receive help in times of crisis (Pelling and High 2005). Another important determinant is individual and community experience of past hazards. Those who have dealt with a flood or any other type of hazard event and experienced losses or disruption as a result are more likely to take preventive measures to reduce their risk provided that they have the assets and/or assistance to do so (Wachinger et al. 2013).

Institutional vulnerability refers to the local governance mechanisms as well as formal or informal modes of interactions that put people at risk or help them adapt to and cope with risks (Moser and Satterthwaite 2008). Measures of institutional vulnerability can include the effectiveness of the local authorities and civil groups that have a role in helping to resist or adapt to the effects of extreme weather events. The IPCC's contribution on managing the risks of extreme events and disaster suggests that 'adaptive capacities are not created in a vacuum—local institutions provide the enabling environment for community based adaptation planning and implementation' (IPCC 2012: 294). In the absence of institutional capacity, there may be limited knowledge of the relative likelihood of an event, poor dissemination opportunities, low emergency preparedness and little ability to absorb impacts (Adger 2003). As a result, any biophysical event has the potential to turn into a serious threat to communities, in particular those located in hazard-prone areas. According to Moser and Satterthwaite (2008), the quality of government at all levels, both national and local, affect the extent of climate-related risk because governmental institutions have a central role in ensuring the quality of essential infrastructure, the quality of disaster preparedness measures and the quality of land use planning and development control.

Earlier assessments of vulnerability and adaptation have been restricted to impacts with very few also assessing the processes of governance and implementation of climate action (IPCC 2014:8). The approach taken in this project includes institutions and governance as one of its novel integrated elements and therefore makes a contribution to furthering the understanding of the role of institutions in a Sub-Saharan urban context. We consider how impacts and risks related to climate change can be reduced and managed *as well as how improved governance* at different levels and scales can work toward developing a more resilient society. Our approach therefore resonates with what is new in the recent climate assessment literature including assessment across a broader set of topics and sectors and actors (IPCC 2014). The multi-dimensional nature of the assessment approach extends to its handling of spatial scales whereby information is integrated between city, community and household scales. Our approach is therefore also novel in conducting connected local and city-wide assessments on physical, social, institutional and economic themes and considering how underlying processes interact.

2.2 Multiple responses

City adaptation to climate change is a relatively new field, and there is no exact toolkit for how to do it. This is mainly because of the uncertainty, complexity and context dependency of climate change impacts (Bicknell et al. 2009; UN-Habitat 2011; UNIDSR 2012). The literature and guidelines for city climate change adaptation and urban flood management point particularly to three core approaches: (1) direct development away from vulnerable areas (Satterthwaite et al. 2009; Jha et al. 2012); (2) upgrade urban services and infrastructure-like drainage and waste management (Parkinson et al. 2007; Douglas et al. 2008); and (3) promote ecosystem-based adaptation via ecosystem services (Roberts et al. 2012; Mguni et al. 2014). Another core message is that adaptation should address not only content but also process. It is necessary to be aware of the physical/spatial, economic, political and social context for planning, but also to find shared, long-term visions of a desirable future. First of all, the need for climate change adaptation must be recognized as one of the issues that really matters in the cities and must be followed by the intention and commitment to act. Assessment of the expected climatic changes and their impacts in the city are needed, as well as identification of possible adaptation options, which are then prioritized and incorporated into relevant plans. However, this is an ideal, and while each step is important, the process as a whole is full of uncertainties and it is unlikely that impact assessments and the identification of options will ever reach a stage of finality and certainty (Lund et al. 2012). This is especially true when the institutional and political capacity is weak, as is often the case in African cities. As a result, the process must be flexible and allow for the discovery and incorporation of new knowledge and changes in political, economic or physical contexts. Inspired by collaborative planning approaches (Healey 2009), a ‘strategic’ approach is also recommended, meaning that the process of selecting and developing measures identifies the ones which have a realistic chance of becoming implemented as well as the parts of the urban governance system where some support and momentum can be attained, therefore maximizing the chances of success. This is what Healey refers to as transformative strategic planning. Therefore, we look for the main stakeholders, the short- and long-term actions which can gather them, and the ‘champions’ who can turn the visions into reality (Albrechts 2004; Healey 2009; Brown et al. 2013).

3 Materials and methods

3.1 Dar es Salaam

Dar es Salaam was selected as one of the five case studies in the CLUVA project because it was expected to exemplify many challenges for coping with climate change which are held in common with other large Sub-Saharan cities. Dar es Salaam is the largest city of the Republic of Tanzania and an important economic center in East Africa. With an average annual growth rate of approximately 5 %, its population is expected to increase from around 4 million at present to over 8 million inhabitants by 2030. Some 70–80 % of the population of Dar es Salaam is estimated to live in informal settlements (URT 2004) which are characterized by a lack of basic services, poor housing, insecure tenure and overcrowding (Tibaijuka 2007). Dar es Salaam faces severe threats from natural hazards, and these are expected to be exacerbated by climate change (Giugni et al. 2015). Riverine flooding is one notable local hazard. For example, even as recently as 2014, a severe flood event caused major damage to informal settlements and their respective population (Reliefweb 2014). Although we mainly focus on flooding in this paper, it is not the only hazard which affects the city. For example, there are also periods of heat waves and a range of other hazard types (Giugni et al. 2015).

For the assessment of city-scale vulnerabilities, the case study area was taken as the Dar es Salaam administrative zone. It covers some 1500 km^2 in total, including the rapidly developing peri-urban hinterlands of the city toward the north and west of the city center (CBD) (Fig. 3). The city-scale research used an urban morphology framework and local administrative zones, the lowest level of which is the sub-ward (‘Mtaa’), both of which are explained further in later sections. Within Dar es Salaam, two particular flood-prone sub-ward case sites were selected where all project partners could direct their local, i.e., household and community scale, assessments. The case sites were selected mainly based on the local partner’s knowledge of particular flood-prone communities in their city. The two local case sites selected were Suna (case site 1) and Bonde la Mpunga (case site 2). Bonde la Mpunga is on the coast, and Suna is in a downstream section of the Msimbazi River. Due to its position, Suna has been experiencing extremely frequent flooding problems, especially in areas adjacent to the river banks. Both case study areas are low-lying and are affected by standing waters as well as by flooding.

3.2 Vulnerability assessment

The vulnerability assessment consisted of three steps. In the first step, the four dimensions of vulnerability were assessed at both the city and local (household and community) scales using the examples of Suna and Bonde la Mpunga. A variety of data inputs and methods were used, including model-based forecasts, spatial analyses, document studies, interviews and stakeholder workshops. The second step involved combining available data into a city-

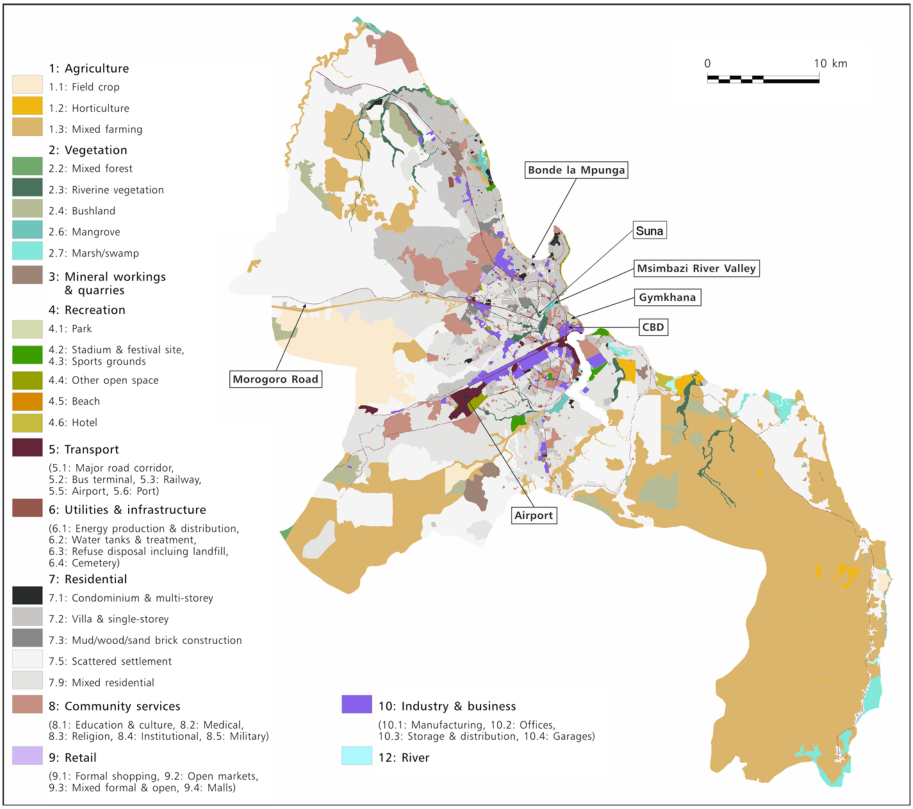

Fig. 3 City of Dar es Salaam characterized by Urban Morphology Types

wide vulnerability map which was then combined with knowledge of the relative likelihood of flood hazard exposure in order to generate a flood risk map for the city. The final step considered vulnerability dynamics and the opportunities for and barriers to the development of adaptation strategies. Vulnerability dynamics were assessed based on a spatial modeling approach, and adaptation strategies were explored through governance and planning studies. The following gives an overview of methods used with further detailed information available in the cited references.

3.2.1 Assessment of each of the four vulnerability dimensions

A main element in assessing the *physical vulnerability* was a spatial framework based on Urban Morphology Type (UMT) units developed for this project (Cavan and Lindley 2012; Lindley et al. 2015). The UMT approach provided information on the nature and form of land use and related structures, such as building type, for 11 high-level and 46 detailed classes mapped over 1681 geographical units (Fig. 3). UMT-based land cover profiles were constructed to further characterize areas, indicating the average proportional cover of vegetated, soil, water and built surfaces. This information provided a basis for assessing several ecosystem services (temperature reduction, capacity for flood retention in flood plains, carbon storage in trees, farmland for food provision), and hence, it gave an indication of how far exposure to hazards would likely be enhanced or offset due to the local environment in a particular area (Lindley et al. 2013). Finally, interviews were used to understand the nature and importance of ecosystem services to households and communities in the local case sites.

For *physical* assessment of the vulnerability of buildings within the selected local case sites, a simulation-based survey was conducted. Probability distributions for the parameters required for calculating the flood vulnerability of the building portfolio were constructed from a limited number of building surveys, taking advantage of the homogeneity observed in the building characteristics within the case sites (De Risi et al. 2013).

The assessments of *asset and attitudinal vulnerability* were conducted at the household level in the local case sites by means of structured interviews and focus group discussions. Quantitative data such as preexisting census data and survey results were combined with more nuanced qualitative findings from in-depth exchanges with key informants in the communities. Interviews with 500 households were carried out across the two selected case sites. These interviews aimed to address residents' livelihood assets and attitudes, their social and demographic characteristics, the impact of flooding as well as their experiences and capacities to cope with flooding. In addition, focus group discussions with local inhabitants centered on the role of local leaders in advocating and driving social mobilization and change, the sociocultural issues that influence adaptation to flooding, and the mechanisms through which flood risk is managed at community level (Jean-Baptiste et al. 2013).

For the assessment of *institutional vulnerability* and capacity, a multi-level governance approach was developed and applied. The governance component considered key drivers and barriers within the governance system which affect its ability to cope with risk, reduce vulnerability and enhance adaptive capacity and resilience at city and local community levels. The work analyzed the vertical and horizontal coordination of state, municipal and non-state actors engaged in the key policy fields of land use planning, environment and disaster management. The study combined reviews of policies, legislation and institutions/networks with semi-structured interviews and field work in the case site communities in order to explore the local encounters between actors across sectors and scales (Vedeld et al. 2013; Herslund et al. 2013).

3.2.2 Vulnerability and risk maps

In order to assess *combined vulnerability* and make the results available for planners and decision makers, a combined vulnerability map was produced by using GIS to map and overlay all four dimensions of vulnerability. The map was based on the idea of a spatial multiple criteria evaluation (S-MCE) process, following a series of steps, whereby the most important indicators of flood vulnerability were selected and weighted[1] by stakeholders from relevant national and city-level administration as well as NGO's and representatives from the case sites (Nyed and Herslund 2013). Various geographical datasets were used; but as only a little statistical data were available, a stakeholder questionnaire was used to help determine how to measure intangible indicators such as trust, social networks and institutional capacity at sub-ward level.[2] Each indicator was transformed into a quantitative measure and mapped before being combined with maps of the other available indicators.

[1] The methodology to determine the weights of the indicators followed the principles and procedures of the Analytical Hierarchy Process (AHP) (Saaty 1980). The AHP is a multi-criteria decision-making (MCDM) approach, which has gained wide popularity in the scientific community.

[2] In Dar es Salaam—it was the sub-ward/mtaa level; comprising approx. 5–15,000 residents.

The map was developed at the resolution of the finest administrative level in Dar es Salaam, the sub-ward. This had the benefit of connecting to existing administrative data holdings and having local resonance, for example for constructing new datasets. The institutions and actors from different levels of governance and sectors proved essential in the translation of the indicators into a meaningful representation of the reality of their city. This was particularly important in terms of representing factors associated with some of the more intangible attitudinal and institutional elements of the assessment (Nyed and Herslund 2013).

In parallel with the vulnerability work, a hazard map was developed to delineate areas potentially exposed to flood inundation. In view of the lack of a detailed, city-wide flood risk map, a proxy indicator of relative flood risk was used based on an assessment of the topographic wetness index (TWI) (Kirkby 1975). The topographic wetness index allows for the delineation of portions of a hydrographic basin potentially exposed to flood inundation by identifying all the areas characterized by a topographic index that exceeds a given threshold. The TWI has a purely topographic interpretation (it basically measures the capability of the land surface to accumulate water) and it is quite straightforward to calculate in a GIS environment for very large areal extents, such as the one used in this study.[3] The TWI map was then overlaid with the city vulnerability map in order to identify sub-wards with the highest overall levels of risk (see Fig. 4). Although the TWI is a rather limited indicator, further local refining was achieved through the inclusion of additional factors affecting flood exposure as part of the physical vulnerability assessment (Nyed and Herslund 2013). For example, this included an indicator of solid waste management, one of the factors known to be highly influential in how flood events develop in local areas (START 2001). Unfortunately, there was no suitable local indicator of drainage networks.

A second, complementary screening tool for the decision makers to identify areas needing immediate or long-term actions was a procedure for delineating flood risk hot spots. Hot spots were identified through the intersection of zones of potentially high susceptibility to flooding (TWI) and zones of potentially high exposure to flooding (Jalayer et al. 2015). The latter was represented through an overlay of the UMT areas classified as either residential or urban corridors (i.e., major roads) with a geospatial census dataset of demographic information (e.g., population density). The UMT areas were used in this instance due to their stronger connection to biophysically discrete urban parcels, i.e., in comparison with most administrative zones.

In addition to the TWI, a more detailed flood hazard map (a local scale inundation map) was produced through the application of a two-dimensional flood propagation model. Due to data availability and the computational effort required, this could only be generated for a relatively small portion of the study area. It was used as the basis for calculating specific flood risks of different return periods for the buildings surveyed in each of the local case sites (De Risi et al. 2013).

3.2.3 Vulnerability dynamics

The dynamics of green areas (past and future) were assessed based on a multi-temporal analysis (comparing data from 2008 and 2002) and an urban scenario modeling approach. The UMT data were used as an input to cellular automata modeling in order to explore how

[3] The TWI threshold is calibrated through a GIS-based probabilistic procedure employing either the hydraulic profile calculated at the microscale (Jalayer et al. 2014b) or information available about the historical flooding extent (De Risi et al 2014).

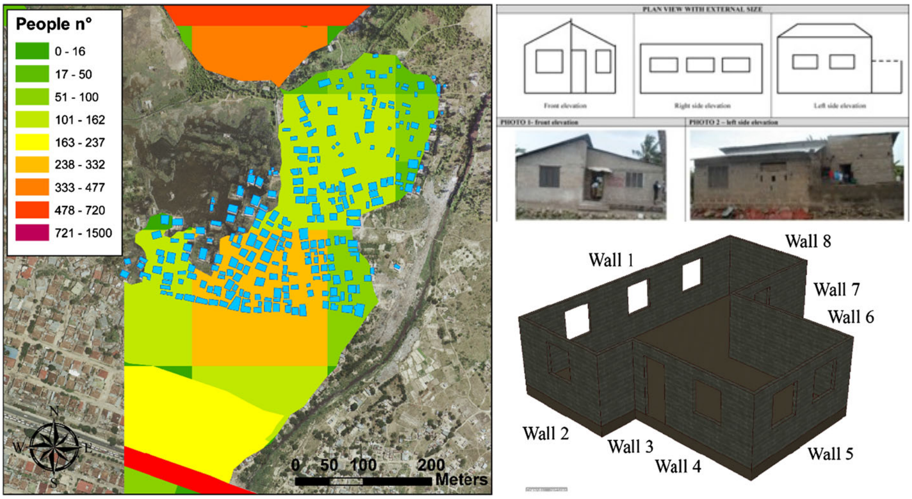

Fig. 4 (*Left*) A zoom in into urban residential flooding risk hot spots in case site 1—Suna, Dar Es Salaam; (*Right*) a typical housing unit surveyed in Suna: (*Right-bottom*) the finite-element model of the surveyed housing unit

the UMTs might change into the future in response to different urban growth scenarios (Pauleit et al. 2013). An approach called Urban Spatial Scenario Design Model (USSDM) was developed to explore the potential impacts of four distinct urban development strategies on green areas and the related provision of ecosystem services until 2025. Scenarios were based on the assumption of continuing strong urban population growth as is predicted for the coming decades. The scenarios modeled the effects of adopting a low-density (i.e., business as usual) versus high-density urban development strategy ('sprawl' vs. 'densification') either with development in flood-prone areas (as is currently the case) or when such development is prohibited (Printz et al. 2015).

The UMTs were also used to model current and potential future surface temperatures in combination with temperature measurements and the regulating ecosystem services of vegetated cover (Cavan et al. 2014). This allowed the dynamics of vulnerability to be assessed alongside climate change drivers. Furthermore, the UMTs provided a basis for connections to be made between hazard types across the urban area of Dar es Salaam.

3.2.4 Response and planning for adaptation

During the last year of the project, the institutions and actors from different sectors and levels of governance, identified through the institutional analyses as potentially influential in climate change adaptation (i.e., possible 'champions'), took part in workshops to identify the main challenges and opportunities to make their cities more resilient to climate change. Workshops began by examining the specific experiences of the stakeholders and their institutions with regard to past flood events and events associated with other climate change-related hazards. This examination led to an investigation of how stakeholders felt their institution already addressed or could address such incidents, what measures they saw important for the city administration to take and how such measures might be implemented. The approach was inspired by 'envisioning workshops' used in transition management (Roorda et al. 2012) where stakeholders reflect on their own role and what possible actions they can take in a transition. The approach was also informed by the concept of transformative strategic planning where the focus is on mobilizing attention and scoping out where the capacity and power to address the challenges lie through the involvement of a wide range of cross-sectoral actors and actors operating at different governance levels (Healey 2009).

4 Results

4.1 Main factors for vulnerability

Results from the local case site surveys showed that large households who are tenants, have a low level of education, and depend on informal incomes are the households that are most vulnerable to flooding. Vulnerable households mainly comprise more than five people with a diverse age structure that includes several dependent household members such as children or elderly people. In one of the case sites, the mean household size was 4.2 (above the municipality average of 4.0). A large household size often implies numerous dependent children or non-family householders, such as tenants. Half of the interviewed households included two to three people below the age of 18.[4] Dependent household members are reliant on others in case of evacuation and less likely to take an active role in flood prevention and reconstruction. This creates further restrictions on the preparedness and resistance level of households in flood-prone areas. Vulnerable households occupied by tenants have less capacity to prevent or adapt to flooding due to their lack of authority over the dwelling unit they occupy. Despite the fact that tenants are directly affected by flooding (e.g., loss of material assets), they are not eligible for compensation as they have no legal rights on the building they occupy. They are also the ones who suffer the most in case of compulsory evictions or relocations (Jean-Baptiste et al. 2013).

Generally, people in vulnerable households have only primary-level education. Low education level is associated with poor remuneration of employees and restricted chances of formal employment. Consequently, these households have fewer economic resources to anticipate, cope with and recover from the effects of floods. Vulnerable households also tend to derive their income from informal, often low-skilled economic activities. In one local case area, 73 %[5] of households were found to derive their income from informal economic activities, largely from small businesses. Such activities are more likely to be associated with fluctuations in wage payments and a higher likelihood of poor health and safety conditions, particularly in flood-prone areas (Kabisch et al. 2015). Activities generally take place in the vicinity of the house, so both household and economic assets are susceptible to damage in case of flooding. Significant variations in income were found. The case site survey revealed that 39 % of households have a monthly income of between 100,000 and 300,000 Tanzanian Shillings (TShs) (~U$ 62.5–U$ 181). Another 24 % have between 300,001 and 500,000 TShs (~U$ 181 to ~U$ 300). Only 9 % have an income level of 1000.000 TShs (~U$ 625) and above (Kabisch et al. 2015).

In addition to social characteristics informing asset vulnerability, the ability of dwellings in the case sites to withstand flooding was also examined. In case site 1, the overlay of the hot spot map with the individual housing units surveyed showed that flood-prone

4 Results from case site 2 where 309 households were interviewed.

5 Results from case site 2.

houses have a proper foundation built with stone/cement/concrete and the walls are constructed with cement-stabilized sand blocks (see Fig. 4 below for an example). However, the buildings generally suffered from low quality of openings (the absence of proper frames for doors and windows). The detailed calculations confirm that even cement buildings on proper foundations (a typical case site building) are barely able to survive a flood event, even one with a 3-year return period (Jalayer et al. 2014b).

The institutional appraisals in the local case sites showed a complex web of stakeholders. The local community-based organizations (CBOs) operate outside legally binding mechanisms and sustain themselves through traditional rules and cultural norms. They are mostly active in coping strategies such as the implementation of simple techniques, awareness campaigns and/or short-term palliative actions during or after a flood. In parallel, local government officials and institutions struggle to undertake more transformative, sustained and long-term implementations (Jean-Baptiste and Kabisch 2013). Coping with flooding when living in an informal area often ends up being a very local matter where it is mainly the community and individuals in the case sites that take action, including, for example, cleaning river areas, organizing paying for a municipal excavator to dig out waste and silt, constructing drainage channels and raising the ground (Herslund et al. 2013). A commonality among the residents and communities investigated is that residents in the case sites, while recognizing the risk they take, do not consider flooding to be a top priority compared to other urgent basic needs. Flood is perceived as a seasonal challenge tackled on an ‘as-needed’ basis in the aftermath of an event.

4.2 Particular vulnerable areas

The city-wide vulnerability mapping in Dar es Salaam indicated that vulnerability is strongly associated with the sub-wards dominated by informal areas. The most vulnerable sub-wards tend to surround the city center. Their vulnerability is especially related to the *Physical dimension* indicators such as low-lying areas, high population density (see density layer map in Fig. 5), lack of urban infrastructure and green areas, dangerous infrastructure or industry and low mobility in times of flooding. This pattern may be related to the attraction of the city center and the job opportunities to be found there. In their quest to find a place for a dwelling closer to the urban core, people have to make do with more compact living conditions and take the risk of settling in the low-lying floodplains (Nyed and Herslund 2013). Combining the vulnerability map with the areas likely to be flooded (topographic wetness index—TWI), these central sub-wards are most at risk due to their low-lying nature (see Fig. 4) as well as the combination of other factors across the attitudinal, asset, institutional and physical vulnerability dimensions.

Vulnerable sub-wards associated with the *Asset Dimension*, i.e., based on assessing indicators such as age (see age layer map in Fig. 4), source of livelihood, house tenure and household size, are mainly situated in the spatially peripheral informal areas. This may be a reflection of the larger efforts needed to make a living in the peripheral areas of the city where the job opportunities are fewer. This may also be an indication that households with many children, and therefore presumably poorer, have no other option than to settle in the fringe areas where housing or available plots are more affordable. In the peripheral areas where urban growth is rapid, a steady flow of new in-migrant dwellers leads to an increasing population, a higher pressure on the environment, an inadequate water and sanitation infrastructure and a weak foundation for beneficial social interactions. Eventually, the increasing demands on available land could force people to settle in the more flood-prone parts of the sub-wards that had originally been avoided (Nyed and Herslund 2013).

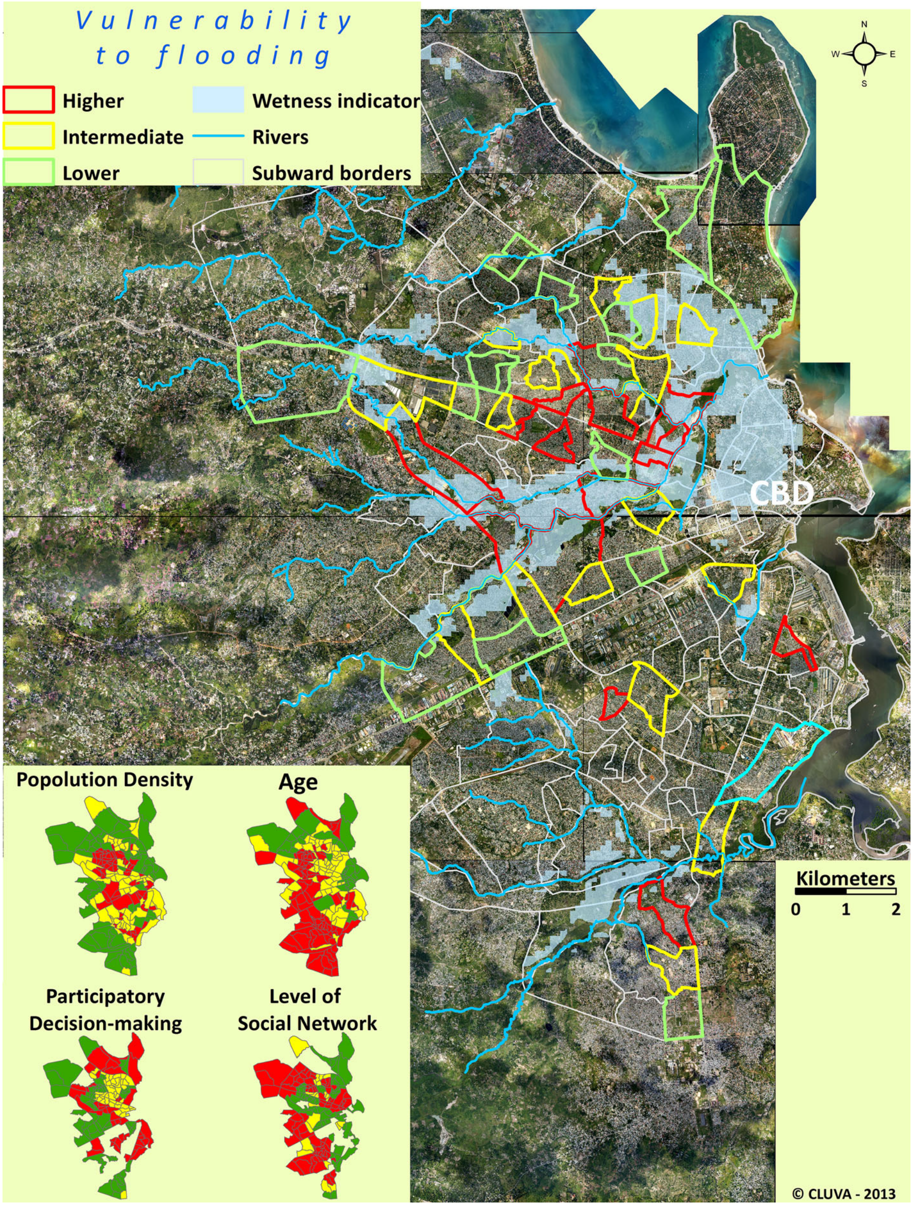

Fig. 5 Vulnerability and high-risk area map of Dar es Salaam. In the *lower left corner* are examples of the separate vulnerability indicator layers, one from each dimension. The estimated multi-dimensional vulnerability to flooding is illustrated by the colored sub-ward polygons. A quantile classification method has been used so that an equal number of sub-wards are associated with each of the three vulnerability classes (high, intermediate and low). The *light blue areas* are the areas more likely to be flooded according to a hydrological model (corresponding to a wetness index of >19.27)

When the more intangible *Attitudinal and Institutional dimensions* are included in the vulnerability mapping, it highlights that formal settlements and more affluent communities can also be vulnerable in certain respects, such as due to a lack of social networks, trust and

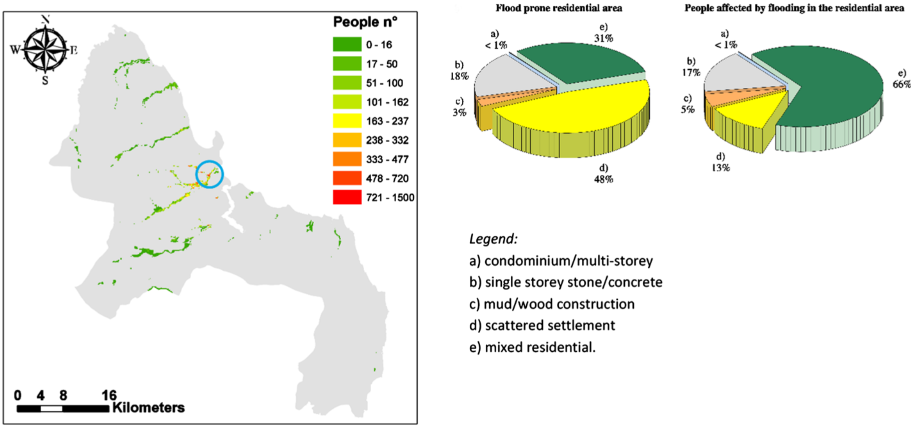

Fig. 6 (*Left*) Map of the residential flooding risk hot spots for Dar Es Salaam (the case site 1 area—Suna, Dar Es Salaam—is marked on the map); (*Middle*) Break down of exposure in terms of areal extent in flood-prone areas; (*right*) Break down of exposure in terms of people affected by flooding in flood-prone areas

participatory decision making (see social network layer and participatory decision-making layer in Fig. 5). Interestingly, it seems as though sub-wards with presumably wealthier residential urban morphology classes (e.g., Villa area and scattered settlements, Fig. 3) were more vulnerable with respect to these indicators. All the same, this indicates that the preparedness may be low in those sub-wards if hazards of unexpected dimensions occur (Nyed and Herslund 2013). The screening method of risk hot spot delineation also revealed differences in exposure characteristics for a range of different residential types, for example, between condominium/multi-story buildings and the informal settlements (Fig. 6).

4.3 Vulnerability trends

Retrospective analyses of UMTs and associated surface covers (Lindley et al. 2013, 2015) suggest that green and blue areas and their ecosystem services continue to be lost in Dar es Salaam. For example, 9–12 % of all woody coverage and around 30 % of woody biomass have been lost between 2002 and 2008. At current rates of change, mixed forest stands could be lost entirely within the next few decades. This has implications for local temperature regulation, shading, timber, carbon sequestration and flood regulation ecosystem services, among others. The impacts of such losses are likely to be felt most acutely by people living in low-income settlements. For example, in the local case sites, 19 different green space types were identified to be of particular importance to local communities (Lindley et al. 2013). They include both private and public elements, including allotments, gardens, woodlands and orchards as well as the sea, beaches, rivers and trenches and provide regulating, provisioning and cultural roles. As a result, adaptive capacity could be eroded and the severity of hazard exposure increased. For example, the loss of green areas results in the loss of provisioning ecosystem services which help to address asset vulnerability through improving the diversity of income and subsistence sources for households and communities.

The potential for green area losses to increase the severity of hazard exposure is illustrated through surface temperature modeling. According to climate modeling carried

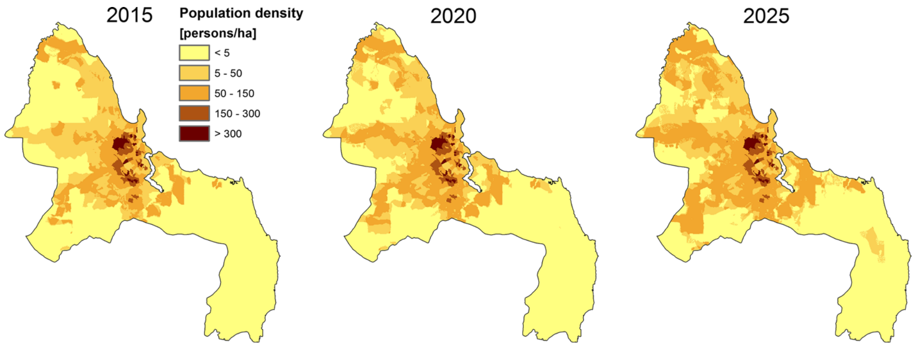

Fig. 7 Potential settlement areas in Dar es Salaam in 2015, 2020 and 2025: the business as usual scenario

out in another part of the CLUVA project, the number of heat-wave events with a maximum length of 5 days could increase from 3 (1950–1970) to 24–33 (2030–2050) in Dar es Salaam. Results suggest that development, specifically the proportion of evapotranspiring cover remaining in an area, could be a much stronger driver of future urban temperatures than climate change (Cavan et al. 2014). Furthermore, the inland penetration of sea breezes, which have historically persisted through the night during the hottest parts of the year (January–March) are increasingly restricted as a result of development within and around the publically owned 60-m beach zone (Nieuwolt 1973; Lindley et al. 2015). Such green area losses and associated increases in the proportion of impervious land covers are also well known to have a strongly detrimental effect on the quantity and quality of runoff (Arnold and Gibbons 1996).

The future scenario modeling clearly indicates the enormous impact of continuing sprawl on the green areas in Dar es Salaam. By 2025, the ‘business as usual’ scenario would increase settlement areas from 47 to 53 % and be associated with an 11 % loss (6886 ha) of farmland (field crops, horticulture, mixed farming) and a 29 % loss of woodlands and wetlands. Riverine areas alone would lose 60 % of their area to urbanization (see Fig. 7).

4.4 Adaptive capacity and multiple responses

Whether the city will keep on the path of ‘business as usual’ or develop in a more resilient way greatly depends on the institutional setup and governance structures. The formal institutional setup in Dar es Salaam is characterized by a lack of clarity in the division of responsibility between national ministries, regional state agencies and the municipality and sub-wards (Vedeld et al. 2013). There are no direct lines of command working from local via city to regional and national levels as well as little collaboration, e.g., within disaster management, environmental and physical planning between different levels of government. Climate change and adaptation are terms found in national-level documents[6] mainly addressed in the environmental ministry. Flooding is addressed in the Unit for Disaster Management part of the Prime Minister’s Office. Decentralization of environmental services to city and local level is limited (Vedeld et al. 2013). At the moment, actions in Dar es Salaam are more geared toward emergency response to floods than they are to

[6] National Adaptation Policy (NAPA).

preparedness and long-term adaptation. Land use planning is ineffective and weakly enforced (Vedeld et al. 2013). Informal settlements do not have legal registration of land titles and thus lack firm planning controls. Decisions about land development are made by individuals, which gives rise to encroachment of the remaining green areas, areas associated with the natural storm water drainage system and other open spaces (Vedeld et al. 2013; Jørgensen et al. 2014).

During the stakeholder meetings, there was a general agreement among stakeholders that flooding was a major problem and that action was needed. Requirements particularly centered on social measures, focusing on helping people living in vulnerable areas. Better law enforcement measures were also high on the stakeholders' list as well as a stronger focus on upgrading of urban services. Local leaders from the case sites called for support from the municipal level to help them cope with floods. However, the usefulness of a possible overall climate change adaptation plan was questioned. Municipal and city stakeholders, especially, felt that the city should not wait for projections of future risks when they actually had many well-known problems to tackle right now, particularly with flooding and the lack of urban services. Waiting for long-term forecasts, plans, and strategies would make it too easy, they felt, for the politicians to avoid acting on the problems because 'thirty years are many years from now.' The city stakeholders also had little trust in the effectiveness of plans. A climate change plan might easily end up like several master plans developed throughout the years, which never got implemented because they were too general, did not include guidelines, resources or tools for implementation, and were ultimately often ignored by policy makers (Herslund et al. 2013).

The task of pointing to possible responsible actors and institutions to take immediate action was difficult. Ministerial officers pointed to municipal officers to be the main stakeholders as municipalities should already be taking appropriate actions, such as enforcing land use planning restrictions and providing urban services. According to the municipal officers, they could not take on new tasks because, as a land use planner expressed, '*It is not us alone that can implement it.*' The reasons given were that they lacked proper plans and maps of vulnerable areas and guidance on how to actually manage such areas. They also lacked resources and found it difficult to enforce land use planning regulations in an environment where the political pressure was to grant large land owners or developers permission to build in vulnerable areas. They acknowledged that engaging in specific 'adaptation projects' in the most vulnerable areas with stakeholders already active in adaptation, such as CBOs, NGO's and local communities as called for by local leaders, could be an effective measure to address the problems of flooding (Herslund et al. 2013).

5 Discussion and conclusions

The main factors causing vulnerability in Dar es Salaam are settlement in flood-prone areas, weak institutional capacity, encroachment of green areas, limited urban services and poverty. Vulnerability is very unevenly distributed across the city. At a more detailed local case level, it is a high share of informal incomes, many children and low education in combination with limited trust and local participatory decision making which particularly underpins vulnerability. Unsurprisingly, the availability of assets in an area is also related to issues like dwelling structures. Buildings in the most flood-prone parts are very likely to be demolished during floods even though they have concrete foundations. Findings from case studies in the other CLUVA cities confirm this picture of the most vulnerable areas being vulnerable in several dimensions (Weets 2014). Interestingly, however, well-off areas within the city of Dar es Salaam can also be vulnerable if they are characterized by limited trust and collective action.

The results from the scenario modeling clearly indicate the enormous impact of continuing sprawl on the green areas in Dar es Salaam. As a consequence, severe negative impacts on the provision of food and timber, the loss of carbon storage as well as negative impacts on regulating services such as temperature moderation and the reduction in stormwater runoff must be feared. Under 'business as usual,' the population exposed to flooding would increase greatly. Overall, continuing on the path of the 'business as usual scenario' of low-density development would further reduce the resilience and the adaptive capacity of the cities to cope with the combined effects of urbanization and climate change.

The results of the many approaches illustrate the complexity of urban vulnerability in content, time and scale. Urban vulnerability is a multiple construct of limited resources, capacities and attitudes of individuals and groups when faced with a natural disaster. It is also inherently connected to the local urban environment. Individuals can be vulnerable if lacking assets and living in the most flood-prone parts of their community. Whole communities can also be vulnerable if situated in low-lying areas characterized by limited green areas to provide ecosystem services, limited urban services, and low trust and involvement. City-level vulnerability is also suggested through heavy encroachment on urban green areas, flood-prone areas and peri-urban land, a lack of priority given to long-term climate change adaptation and a weak city administration. Thus, a main finding is that climate change adaptation must be approached by several different measures and across different scales.

5.1 Content: What measures to take?

Core measures identified in the literature suggested directing development away from vulnerable areas, upgrading urban services like drainage and waste management, and strengthening the cities capacity for ecosystem-based adaptation by developing its green areas strategically. Such an approach for the development of green space networks that provide multiple ecosystem services is increasingly called 'urban green infrastructure planning' (Pauleit et al. 2013; Hansen and Pauleit 2014). The key priority measures from this project are in line with these general measures but also add new ones following the four dimensions of vulnerability across the different spatial scales of households, communities and city level.

At the city level, our findings point to the value of a more compact form of urban development. The dynamic land use scenarios (Fig. 6) show that if urban development proceeds in line with current trends, the space taken up by the city area will double and the loss of green areas within the city will be massive by 2025 (Printz et al. 2015). Combining this with the fragmented institutional structure that is included in a 'business as usual' development, the cities face big challenges in relation to climate change adaptation and future sustainability. Green areas are essential for mitigating climate change-related hazards, so it is essential to secure existing patches of green, protect riverine corridors and blue spaces, and include green on private and institutional grounds by green infrastructure planning (Pauleit et al. 2013; Lindley et al. 2013; Jalayer et al. 2014a). However, such a vision can only become a reality if city governance structures and institutional capacity are improved, e.g., by decentralizing environmental services to the city and local level and promoting horizontal and vertical integration of institutional activities (Vedeld et al. 2013; Jørgensen et al. 2014). This is particularly true since activities not only need to protect remaining green areas, but also ensure that green areas are established or enhanced within more compact development types.

The vision of a compact, but green city must also be accompanied with associated measures of improving and adapting urban services and buildings in vulnerable areas. Buildings must be made better able to resist flooding, for example, through focussing on adaptations which tackle the weakest parts of structures, such as openings. Alternatively, buildings in the most flood-prone parts could be gradually abandoned while densifying the stock of buildings in the less vulnerable parts of a community. Storm- and waste water handling should be improved, particularly in informal areas (Nyed and Herslund 2013; Jean-Baptiste and Kabisch 2013; Jalayer et al. 2015). On top of this, social measures are key, a fact which was also pointed out by the stakeholders. Thus, involving and supporting vulnerable groups particularly in informal areas in integrated projects addressing both flood problems but also everyday needs is essential (Vedeld et al. 2015; Kabisch et al. 2015; Herslund et al. 2015; Lindley et al. 2015).

5.2 Process: How to do it?

The stakeholder sessions in the project showed awareness among stakeholders, which is a main point of departure for successful responses. However, currently there is only limited momentum among stakeholders for a broad city-wide climate change adaptation strategy. For it to have an effect in their daily work, such a strategy needs to have concrete guidelines, delineations of vulnerable areas and also include projects which are useful in the everyday life of the vulnerable groups. For it to achieve longer-term goals, it must also be firmly rooted in the needs of city dwellers in the here and now. City stakeholders already feel overwhelmed and unable to address all relevant issues. Therefore, a more incremental approach could be taken. This implies that the cities start to address those measures which can mobilize a broad range of stakeholders and their resources and create synergistic effects. Efforts have to be explicitly and closely connected to the problems the cities already face like flooding, informal areas, lack of services and social problems in order to be relevant for stakeholders and thereby have a chance of becoming implemented (Herslund et al. 2015). It is important to start now, even if not all impacts are understood and data are lacking or not compiled in one central place. This will initiate a 'learning-by-doing' process of adaptation for a longer-term, city-wide approach.

A two-tier strategy seems relevant. At the strategic level, climate change and related hazards should be specifically integrated into city and sector plans and programs to build awareness and frame the solutions. But action should not wait. At a tactical level, local actions which already exist and new ones which are experienced as most important for daily life should be supported and 'climate proofed.' 'Local-based' actions may provide a promising opportunity for starting efforts. As community groups organize themselves to fill the infrastructural and service gaps left by centralized institutions, adaptation could well start-off here. Communities need support from above and require greater powers and more coordinated support from higher levels to become really effective partners with the municipality if the goal is to enhance resilience at the neighborhood levels, and more so, to ensure local actions have wider impacts.

5.3 Innovation and future research

The multi-dimensional approach chosen in this research has allowed us to gain a better understanding of the complexities of urban vulnerability in the face of climate change. The assessment methods developed in the project have each been innovative in their own way. Furthermore, the application of existing and new methods for assessing the different aspects of vulnerability in an integrated way, and doing so in the difficult African context, is also innovative in its own right. First of all, the vulnerability assessment combined assessment of physical, asset, attitudinal and institutional vulnerability. Second, in the context of Sub-Saharan Africa, the CLUVA project has been the first of its kind to assess the potential role of green areas for climate change adaptation with regard to climate regulation. All of this was based on a methodology which was applied to African cities for the first time (UMT approach, surface temperature modeling, urban growth modeling) (Lindley et al. 2015). Third, the project also involved analysis of the planning and governance context and their policy implications. Few urban studies in Africa (or elsewhere) have focused on combining vulnerability assessments with urban or multi-level governance perspectives to look at implementation and operationalization of the climate agenda. Fourth, the systematic engagement of a wide range of stakeholders in indicator selection as well as in discussions on how to plan for climate change adaptation was also a new and innovative method (Nyed and Herslund 2013) The project 'co-created' data and learning for the use of local authorities in the years to come—data which are relatively simple to update, e.g., through vulnerability mapping which combined different data types and sets in GIS layers. Fifth, a probabilistic flood hot spot methodology was developed and applied to several case study cities, providing a method for flood risk screening which has strong potential for application in other Sub-Saharan urban contexts (Jalayer et al. 2014b; De Risi et al. 2014). Sixth, the integration of the different assessment methods was attempted through multiple studies undertaken at the same case study sites and involving experts in engineering, social science, climate science, geography, ecology and urban and green infrastructure planning. All of this was achieved as a result of close partnership with African universities. This, in turn, has helped to improve the capacities of locally based early career researchers to respond to the emerging research questions that the challenges of climate adaptation and urban development will inevitably generate in their home cities. However, the approach is not without its limitations. It was complex, and the integration between research perspectives and approaches and components was not easy to achieve fully within the multi-dimensional vulnerability framework. One main reason for this was that the different research activities were executed more in parallel than in a genuinely integrated manner with only relatively few opportunities for the cross-fertilization of ideas and findings. The short duration of the research project—combined with many partners, many physical/natural and social research components and many disciplinary perspectives—also made integration difficult in the 3 years. Thus, the involvement of local researchers in the development and application of new assessment methods was a particularly vital element. Further developing the methods and results into a comprehensive, ready-to-use assessment approach and testing its implementation in further local contexts hold obvious possibilities for future research, both within the existing case study cities and also in similar urban contexts across Sub-Saharan Africa.

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