Climate change and vulnerability of African cities

Research briefs

CLUVA

SEVENTH FRAMEWORK PROGRAMME

Climate change and vulnerability of African cities

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Edited by
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Contributors
This publication is the result of the collaborative venture between European and African institutions, providing research and guidance on how to best adapt to the impacts of climate change in urban areas within Sub-Saharan Africa. The project requested an integrated research effort which brought together many researchers with expertise in different fields dealing with climate modelling, natural and social risks, and urban planning and governance. The training of African students was at the heart of the project. PhD students from African and European Universities as well had a major role in the CLUVA research process, producing new knowledge and tools.

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FOREWORD

by Paolo Gasparini, Scientific Coordinator and Chief Executive Officer, AMRA S.c.ar.l, Naples

CLUVA is a project on urban vulnerability to the climate change of selected African cities. It is a challenging project under many respects. It had to assemble a multi disciplinary team made up high professional level tiles, each used to look at these issues under a different perspective. It had to work out probabilistic models of hazard and vulnerability with scarce available data. It had to deal with the fact that the effects of climate changes are very complex, as local human factors enhance the consequences of pure climatic factors thus producing a feedback hard to break into the constitutive parts. It had to convey the message of the uncertainties of the proposed scenarios. Finally it had to propose feasible low cost risk reduction actions at physical, social and governance levels.

CLUVA has shown a way to approach all these challenges in a scientifically sound way, touching also issues that traditionally are believed not amenable to probabilistic treatment. It has produced simple tools that can be implemented easily and fully exploited when more local data will be available. It has developed guidelines for reducing the consequences of hazard and vulnerabilities that can be implemented in any of the selected cities (on engineering design and management of storm water systems, on reliability analysis of roadway network, on procedures for emergency response management, on reinforcement measures of adobe houses, on green infrastructure planning and others). Training activity aiming at giving a uniform way to approach the effects of climate change driven hazards has been major effort in the project. We hope that local administrators will find this booklet summarizing the information and recommendations produced by the project as an useful guide to look among the CLUVA deliverables (available at www.cluva.eu) searching the information needed for governance and future development of their cities.

Our project shows that climate changes are not expected to produce dramatic increases of the hazard in the next decades in the selected cities, with the possible exception of St. Louis in Senegal subject to the joint action of desertification and sea level rise. Vulnerability and exposure may increase significantly due to human factors (e.g. increase of urban population, scarce development of urban green areas, etc) so that the overall risk will increase in the next decades.

One exciting aspect of CLUVA has been the chance to discuss lively common issues from very different background, allowing at the end a reciprocal acknowledgment of the different ways of thinking, with a consequent cultural growth of all the members of the CLUVA team. I consider a privilege to have shared this experience with all of them.

INTRODUCTION

by Guy Weets, Principal Investigator of the CLUVA project

According to the IPCC Africa is one of the most vulnerable continents to climate change and climate variability. In spite of this East, West and Central Africa are some of the regions of the world which are the least well covered by climate change studies.
The situation is further aggravated by the interaction of multiple factors such as poverty, health status and rapid urbanisation, resulting in a very low adaptive capacity.
The overall objective of CLUVA was to develop simple methods to be applied by the stakeholders of African cities to manage climate risks and to improve the resilience and the coping capacity to climate induced risks in the long run.
The selection of case studies was driven by the need to validate the methods for the largest possible range of climate risks and vulnerabilities encountered in those regions. The criteria we took into account were the following:

1) the climate: wet, dry, Sahelian and flipping climate;
2) the geographical location: coastal, estuary, low land, high land, west coast, east coast;
3) the type of risk: flood, drought, desertification, heat waves, sea level rise;
4) the capacity of a local university to put in place a multi-disciplinary team not only to contribute to the research but also to offer a long term scientific support to the city authorities in their effort to cope with climate risks.

We ultimately selected five cities: Saint-Louis, Ouagadougou, Douala, Dar-es-Salaam and Addis Ababa.
The most innovative aspect of CLUVA is in the integration of all the facets of climate risks into one coherent set of methods that can be easily implemented at the city level.
The success of CLUVA was therefore strongly dependent on the stakeholder's participation allowing for in-depth situation analysis (environment, social and economic situation, governance structure etc.) and ultimately the integration of urban planning and regional or national climate change policy dimensions.
It is widely recognized that the local level is an increasingly important consideration when dealing with climate risks. Unfortunately none of the 5 selected cities have a local climate strategy or action plan. Any existing climate actions were the sole responsibility of the central government. In addition, climate change was perceived by the city councils as a complex and challenging issue.
Indeed addressing the multiple facets of climate change risks not only required the contribution of several administrative departments but also and above all a strong political commitment. CLUVA in this respect was a high risk project. To alleviate the risk, the decision was made to actively involve the stakeholders from the very beginning of the project and also to empower them by allowing them to influence research priorities.
The research activities have been implemented in five groups, three of them responsible for the core research and two for the implementation:
The climate hazard group worked on regional projections up to 2050 of climate change at high resolution (8km) of an area surrounding the five cities. This gave the possibility to assess the probability of extreme meteorological events: the frequency and intensity of temperature and precipitation over the 5 cities. However the lack of baseline data on past events combined with the lack of recording of land cover change made the task of the researchers extremely difficult. Nevertheless it allows the researchers to make rather robust prediction of flood, heat waves, drought and desertification.
The vulnerability assessment group worked on the multiple dimensions of vulnerability namely: 1) the vulnerability of the physical structures, houses, roads and other critical infrastructure; 2) the vulnerability of green areas and the role of ecosystem services in the mitigation of extreme meteorological events; and 3) social vulnerability. Social vulnerability assessment received more attention than initially foreseen. This was

important due to the critical issue of highly vulnerable households and communities living in high risk areas. The method developed a four dimension approach to vulnerability namely physical, institutional, asset and attitudinal dimension of vulnerability. This approach allowed integrating the different elements in one single concept and in addition linking naturally to the governance work carried out by the '**land use and governance strategies'** group. The final element of the group's work was to develop a multi-risk framework. This enables an assessment to be made of the impact of a combination of disaster events on the essential infrastructure of urban areas and an exploration of how the associated risk changes over time.

The 'innovative land use and governance strategies development' group on the one hand analysed the general government structure and worked on measures that can be implemented locally; and on the other hand combined vulnerability indicators and land use indicators to identify especially vulnerable, high risk areas and communities.

The city implementation group: in addition to the three main research groups, for each city an implementation group has been put in place with three objectives: 1) to manage the interaction with the stakeholders, 2) to adapt the methods to specific local conditions and 3) to help identify other specific risks considered important by the local stakeholders and not covered by the main research groups. This group is also responsible for producing the city reports and to support their stakeholders during a post-CLUVA implementation phase.

The capacity building group: the consortium also made a significant investment in research capacity building by 1) offering the young researchers and PhD students associated with the project a bespoke set of training workshops and 2) by closely integrating them in the research teams and work programme.

AN INTERDISCIPLINARY AND MULTI-REGIONAL PROJECT

CLUVA comprised a partnership of interacting researchers with expertise in several different fields from a range of African and European institutions dealing with climate modeling, natural and social risks, urban planning and governance. The heterogeneity of the available expertise enabled the project team to apply a strong set of multi-scale and multi-disciplinary quantitative and probabilistic methods to the five African test cities.
Furthermore, the cooperation between African and European partners over a period of three years and the outcomes of the project have significantly advanced the research capacity in Africa with the potential for long lasting effects.

Guido Augustino Uhinga
PhD Student at the Centre for Information and Communication Technology (CICT), Ardhi University, Dar es Salaam

«The CLUVA project increased my **scientific capacities** to carry out research as it provided an opportunity to get more training on scientific research writing methods which enhanced and consolidated my knowledge and skills to conduct scientific research.
Climate projections done in CLUVA for Dar es Salaam will improve risks predictions in Tanzania on the sense that the methods developed in CLUVA can be replicated elsewhere in Tanzania especially on the areas with the same conditions as Dar es Salaam for risks assessment and predictions».

Consortium

AAU (Addis Ababa University), Addis Ababa, Ethiopia: architecture, urban design, urban planning and environmental planning.

AMRA (Analysis and Monitoring of Environmental Risk), Naples, Italy (coordinator): environmental hazard assessment, physical vulnerability studies, multi-hazard and multi-risk methods.

ARU (Ardhi University), Dar es Salaam, Tanzania: Land and natural resources management; regularization and improvement of low income settlements; environmental resources management.

CMCC (Centro Euro-Mediterraneo sui Cambiamenti Climatici), Lecce, Italy: development and applications of models of climate dynamics, impacts of climate change.

CSIR (Council for Scientific and Industrial Research), Pretoria, South Africa: research and innovation of products and services based on Information and Communication Technology, climate change models.

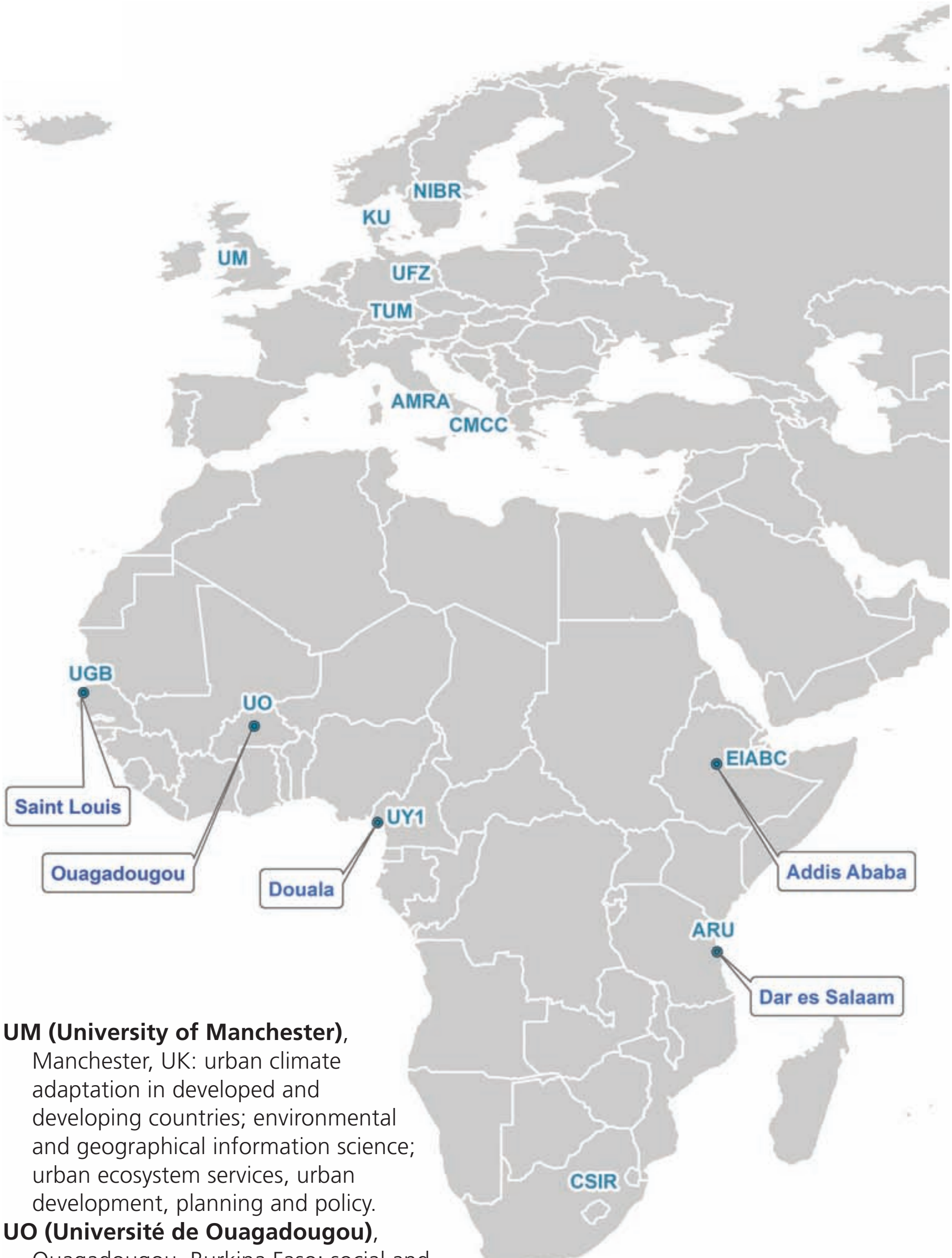
KU (Københavns Universitet), Copenhagen, Denmark: spatial analysis using GIS, urban planning, governance including participative planning, and green space management.

NIBR (Norsk Institutt for By- Og Regionforskning), Oslo, Norway: urban planning, governance, welfare, migration and social dimensions of environmental and climate change.

TUM (Technische Universität München), München, Germany: urban ecology and green infrastructure planning, land use modelling, interpretation of remote sensed data.

UFZ (Helmholtz-Zentrum für Umweltforschung), Leipzig, Germany: social resilience of societies to natural hazards as the basis of analysing the vulnerability of communities.

UGB (Université Gaston Berger de Saint Louis), Saint Louis, Senegal: geographical information systems (GIS), mathematical models, platforms of information management (dataweb).



UM (University of Manchester), Manchester, UK: urban climate adaptation in developed and developing countries; environmental and geographical information science; urban ecosystem services, urban development, planning and policy.

UO (Université de Ouagadougou), Ouagadougou, Burkina Faso: social and economic risks in urban context.

UYI (Université de Yaoundé I), Yaoundé, Cameroon: telecommunications/remote sensing applied to natural hazards management.

MAIN NATURAL HAZARDS FOR THE SELECTED CITIES

Floods

Flooding is one of the major natural hazards which disrupts the prosperity, safety and amenity of human settlements. The term *flood* refers to a *flow of water over areas which are habitually dry*. Sources of floodwater can arise from the sea (in the form of storm surge or coastal degradation), from glacial melt, snowmelt or rainfall (which can develop into riverine or flash flooding as the volume of water exceeds the capacity of watercourses), and from ground infiltration. Failure of man-made water containment systems (e.g. dams and reservoirs) can also induce floods (The World Bank, 2012).

Flood hazard is generally assessed through the evaluation of its impact parameters, such as water depth and velocity, and its associated probability of occurrence.

Flooding in urban areas is not just related to heavy rainfall and extreme climatic events; it is also related to changes in the built-up areas themselves. Urbanization restricts where floodwaters can go by covering large parts of the ground with roofs, roads and pavements, thus obstructing natural channels. Large-scale urbanization and population increases have led to large numbers of people, especially the poor, settling and living in floodplains in and around urban areas. As people crowd into African cities, human impacts on urban land surfaces and drainage intensify. Even moderate storms now produce quite high flows in rivers because of surface runoff from hard surfaces and drains (Douglas et al., 2008). Such situations frequently arise when poor people build on low-lying floodplains, over swamps or above the tidewater level on the coast (McGranahan et al., 2007).

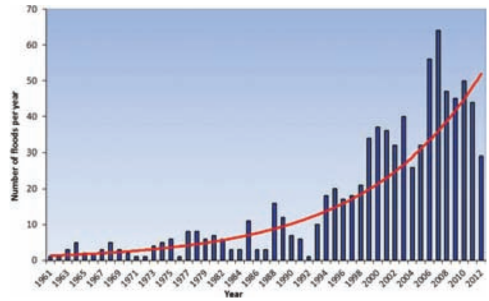


Figure 1. Number of floods per year in Africa during the past half century (source: EM-DAT, 2013).

According to the CRED Dataset (EM-DAT, 2013), the number of flood-related disasters in Africa shows an increasing trend over the past half century (Fig. 1).

The effects of climate change are superimposed on people-driven local land surface modifications and could intensify the impact of urban growth on flooding.

Droughts

Drought is a deficiency of precipitation from an expected or "normal" amount that, when extended over a season or longer period of time, is insufficient to meet demands.
Three main types of droughts can be considered:

- *meteorological drought*, defined as a deficiency of precipitation from an expected or "normal" amount over an extended period of time (general definition);
- *agricultural drought,* defined as a deficiency in water availability for crop or plant growth;
- *hydrological drought*, defined as a deficiency in surface and subsurface water supplies that lead to a lack of water availability to meet normal and specific water demands.

Climate is a primary contributor to hydrological drought through the excessive build up of heat on the earth's surface, resulting in a reduction of rainfall and cloud cover and, consequently, in greater evaporation rates. The resultant effects of drought are exacerbated by human activities such as deforestation, overgrazing and poor cropping methods, which reduce the water retention of the soil, and improper soil conservation techniques, which lead to soil degradation.
Statistics per continent show that the highest numbers of reported droughts were registered for Africa (Table 1).

Drought monitoring is generally based on the analysis of drought indices that assimilate thousands of bits of data on rainfall, snowpack, streamflow, and other water supply indicators into a comprehensible big picture. There are several indices that measure how much precipitation for a given period of time has deviated from historically established norms. Although none of the major indices is inherently superior to the rest in all circumstances, some indices are better suited than others for certain uses (Table 2).

Table 1. Summarised table of droughts disasters sorted by continent from 1900 to 2012 (EM-DAT, 2013).

	# of Events	# of Death	Total Affected pers.	Damage (000 US$)
Africa	291	847,143	364,294,799	2,920,593
Americas	131	77	69,417,226	50,271,139
Asia	152	9,663,389	1,707,836,029	34,251,865
Europe	42	1,200,002	15,488,769	25,481,309
Oceania	20	660	8,027,635	10,703,000
World	636	11,711,271	2,165,064,458	123,627,906

Table 2. Summary of main drought indices (Tsakiris et al., 2007).

Index	Description and Use	Strengths	Weaknesses
Meteorological Drought Indices			
Percent of Normal Precipitation and Accumulated Precipitation Departure	Simple calculation Used by general audiences	Effective for comparing a single region or season	Precipitation does not have a normal distribution Values depend on location and season
Deciles Gibbs and Maher (1967)	Simple calculation grouping precipitation into deciles Used by the Australian Drought Watch System	Accurate statistical measurement Simple calculation Provides uniformity in drought classifications	Accurate calculations require a long climatic data record
Standardized Precipitation Index (SPI) McKee et al. (1993)	Based on the probability of precipitation for any time scale. Used by many drought planners	Computed for different time scales, provides early warning of drought and help assess drought severity	Values based on preliminary data may change Precipitation is the only parameter used
Palmer Drought Severity Index (PDSI) Palmer (1965) Alley (1984)	Soil moisture algorithm calibrated for relatively homogeneous regions Used in the USA to trigger drought relief programs and contingency plans	The first comprehensive drought index, used widely Very effective for agricultural drought since includes soil moisture	PDSI may lag emerging droughts. Less well suited for mountainous areas of frequent climatic extremes Complex Categories not necessarily consistent, in terms of probability of occurrence, spatially or temporally
Crop Moisture Index (CMI) Palmer (1968)	Derivative of the PDSI Reflects moisture supply in the short term	Identifies potential agricultural droughts	It is not a good long-term drought monitoring tool
Recoinnaissance Drought Index (RDI) Tsakiris (2004)	Similar to SPI Basic variable P/PET	Drought is based on both precipitation and potential evapotranspiration Appropriate for climate change scenarios	Data needed for calculation of PET
Hydrological Drought Indices			
Palmer Hydrological Drought Index (PHDI) Palmer (1965)	Same as PDSI but more exigent to consider a drought end. The drought terminates only when the ratio of Pe (moisture received to moisture required) is 1	Same as PDSI	Same as PDSI
Surface Water Supply Index (SWSI) Shafer and Dezman (1982)	Developed form the Palmer Index to take into account the mountain snowpack	Represents surface water supply conditions and includes water management Simple calculation Combines hydrological and climatic features. Considers reservoir storage	Management dependent and unique to each basin, which limits inter-basin comparisons Does not represent well extreme events

Desertification

Desertification, as defined by the International Convention on Desertification, is the degradation of the land in arid, semi-arid and sub-humid dry areas caused by climatic changes and human activities. It is accompanied by a reduction in the natural potential of the land and a depletion in surface and ground-water resources. But above all it has negative repercussions on the living conditions and the economic development of the people affected.

Even though the cycles of drought years and climatic changes can contribute to the advance of desertification, it is mainly caused by changes in the ways humans use natural resources, mainly by over-grazing, land clearance, the over-cropping of cultivated and woodland areas and more generally using land in a way that is inappropriate for the local conditions (Fig. 2).

It is estimated that two-thirds of African land is already degraded to some degree (Fig. 3) and land degradation affects at least 485 million people or 65% of the entire African population (United Nations ECA, 2008). Since most of the economies of African countries are primarily agro-based, most of the desertification problems in rural areas are a result of poverty related agricultural practices and other land use systems. Deforestation, especially to meet energy needs and expand agricultural land is another serious direct cause of desertification in the region.

Heat waves

The World Meteorological Organization and the World Health Organization have not yet issued a standard definition of a heat wave even though there is a consensus on two qualitative requirements for an event to be called a heat wave: high temperatures and

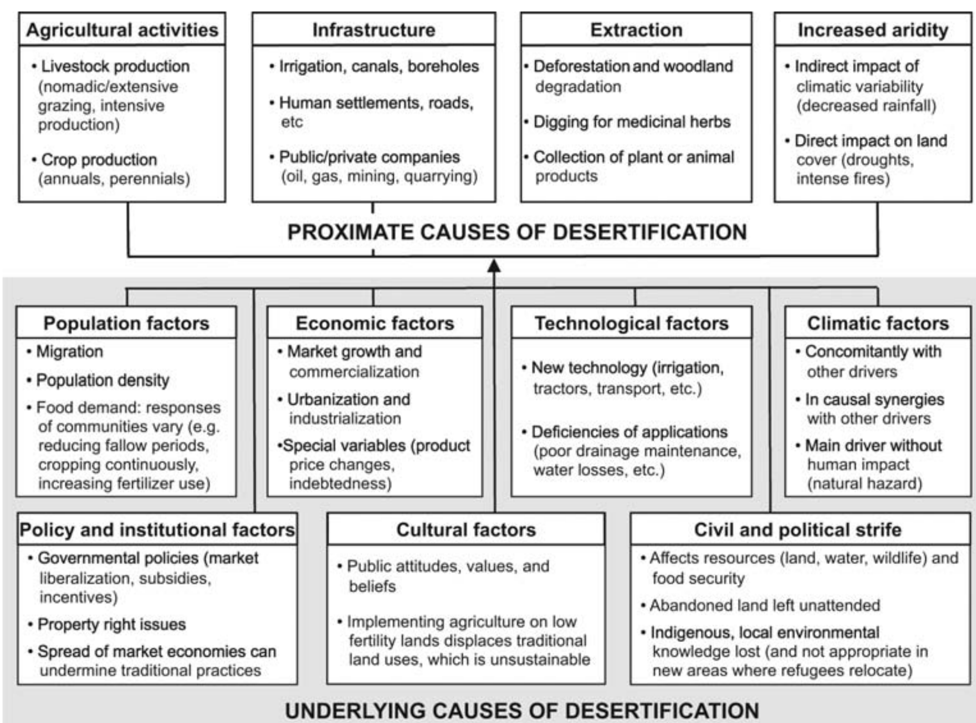


Figure 2. Framework of the different cause of desertification (Reynolds et al., 2011).

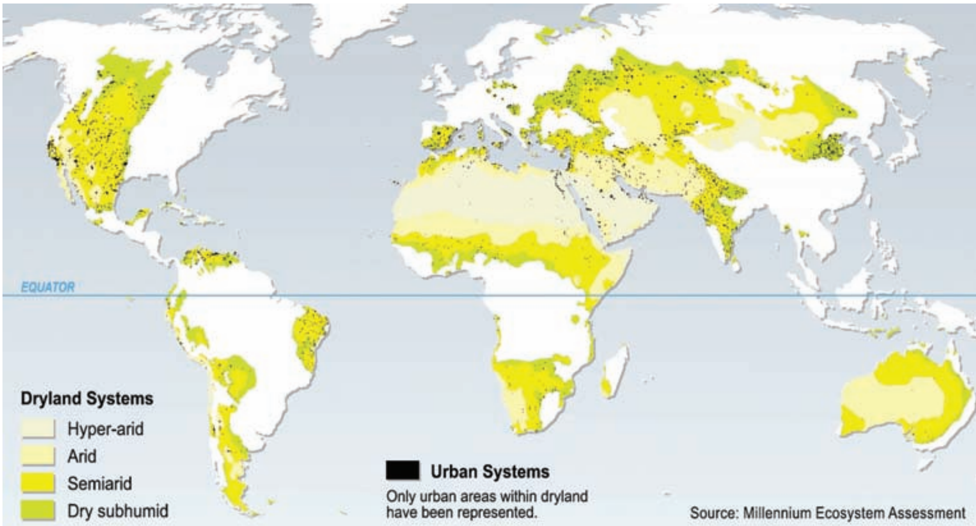


Figure 3. Present-day drylands and their categories (dry subhumid, semiarid, arid or hyper-arid), based on Aridity Index values. (Source: Millennium Ecosystem Assessment Desertification Synthesis Report (2005), based on data from UNEP Geo Data Portal, 2000).

extended duration. These characteristics are the result of the interaction between atmospheric, oceanic and land surface processes frequently accompanied by humid conditions and low precipitation.

Heat waves can induce serious impacts on public health causing heat stress and temporary changes in lifestyle and may have adverse health consequences for the affected population, producing an increase in mortality and morbidity especially for those most vulnerable to them. In addition, heat waves have a strong impact from a social and economic point of view, increasing forest fires, losses in agricultural resources and ecosystems and inducing a strain on infrastructure (like power generation, water supply, transportation, etc.) (Kuglitsch et al., 2010).

There are at least three different ways to identify heat waves: a) definition of a threshold based on the statistical assessment of historical meteorological baselines, for example based on the highest values observed in the time series for a meteorological station in a specific area; b) definition of a threshold derived from statistical analyses of the relationship between weather indices and mortality; or c) definition of a threshold derived from biometeorological studies of human comfort under conditions of high temperatures and high humidity.

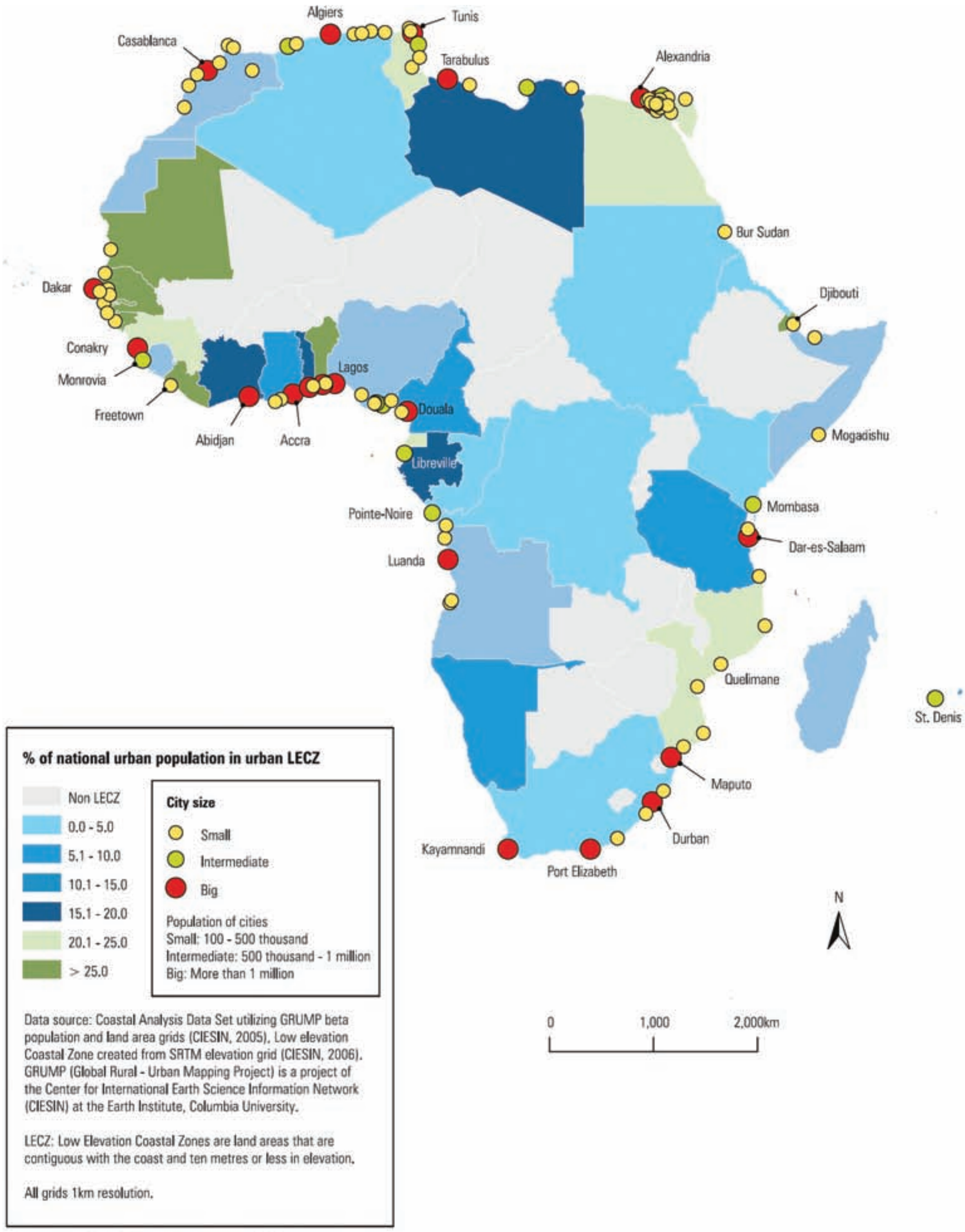
Since the 1960s, temperature measurements over southern and western Africa show that there has been a warming trend that has continued to the present, with an increase in the number of warm spells over these regions.

Sea level rise

Knowledge about past climate changes in Earth's history tells us that they may cause large changes in sea level. Due to the warming up of the climate with our emissions of greenhouse gases, we can expect a similar phenomena today. To assess how much and how fast the global mean sea level rises, scientists have come up with two fundamentally different approaches to model sea level rise.

The first approach is based on physical models, which aim to describe quantitatively the physical processes that contribute to global sea level rise, i.e. thermal expansion of

the ocean water by warming, mass addition coming primarily from melting land ice and depths' change of the global ocean basins by movements of the Earth's crust.
The second approach is based on models, which try to exploit the link between observed sea level rise and observed global temperature changes in the past in order to predict the future.
To understand sea-level change at a particular coastal location, the sum of global, regional and local trends related to changing ocean and land levels must be known. Indeed, sea level changes can locally differ by some tens of centimetres (or even more in some special cases) from the global mean sea level change making some locations, like low-lying delta cities on subsiding ground, particularly vulnerable. There are a number of reasons for this deviation between global and local sea level change, including as a result of local wind effects and vertical land movement, related to tectonic processes or anthropogenic causes (e.g. oil extraction) (Rahmstorf, 2012).
Previous studies indicate that most African coastal countries are highly vulnerable to sea-level rise, leading to increased rates of coastal erosion and flooding of low-lying coasts (Fig. 4). This could endanger large areas and place significant populations at risk. The impacts of sea-level rise, which in many places such as deltas may be accentuated by local subsidence, could exacerbate existing problems through increased coastal erosion, more persistent flooding, wetland loss, and increased salinisation of aquifers and groundwater, all of which would impose significant impacts on African communities and economies.



Source: UN-HABITAT Global Urban Observatory 2008

Figure 4. Percentages of urban populations in African cities which are located in low elevation coastal zones (LECZ) (source: UN-HABITAT Global Urban Observatory, 2008).

CLIMATE CHANGE PROJECTIONS FOR AFRICA

A changing climate may lead to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and can result in unprecedented extreme events. The need for climate change information at the regional-to-local scale is one of the central issues within the global change debate, due to the requirements of policy-makers and decision makers. In order to assess how the climate is going to evolve in the future, it is necessary to have an idea of the concentrations of greenhouse gases in the years to come, and their emissions from natural as well as man-made sources. For this purpose, the Intergovernmental Panel on Climate Change (IPCC) has defined a set of "emission scenarios", describing future releases (until 2100) into the atmosphere of greenhouse gases, aerosols, and other pollutants. The possibility that any single emissions path will occur as described in scenarios is highly uncertain, so multiple instances are needed to provide the clearest view possible of the potential range.
Until 2007, future climate projections were made through 40 scenarios, according to the Special Report on Emissions Scenarios (SRES). Each one of these represents different demographic, social, economic, technological, and environmental developments. Afterwards, a new set, the Representative Concentration Pathways (RCP), has been developed. Named after their hypothetical 2100 radiative forcing level, they are a new way to provide inputs to climate models. Basically they consider possible changes to each of the components (particularly atmospheric composition) known to influence the balance between incoming and outgoing radiation and therefore climate. So far, four RCP scenarios exist and each assumes a different level of radiative forcing by the year 2100: 3, 4.5, 6 and 8.5 W/m^2.
In the CLUVA project, the IPCC emission scenarios considered are the A2 of the SRES set of scenarios, and the 4.5 and 8.5 of the RCP set.
Figure 5 shows examples of projected seasonal changes of temperature and precipitation found in an area around

Gilles Ambara
PhD Student at the Department of Electrical and Telecommunications Engineering, University of Yaoundé

«New technologies can help the mitigation of risks in Cameroun in various ways. Let's take the example of flood risks, which are studied in CLUVA. It is now possible to determine flood prone areas using a set of software packages and methodologies. This helps to find mitigation strategies and to prevent casualties: new technologies enable better weather forecasting, and people leaving in flood prone areas can be asked to leave in advance when there is a risk of flooding».

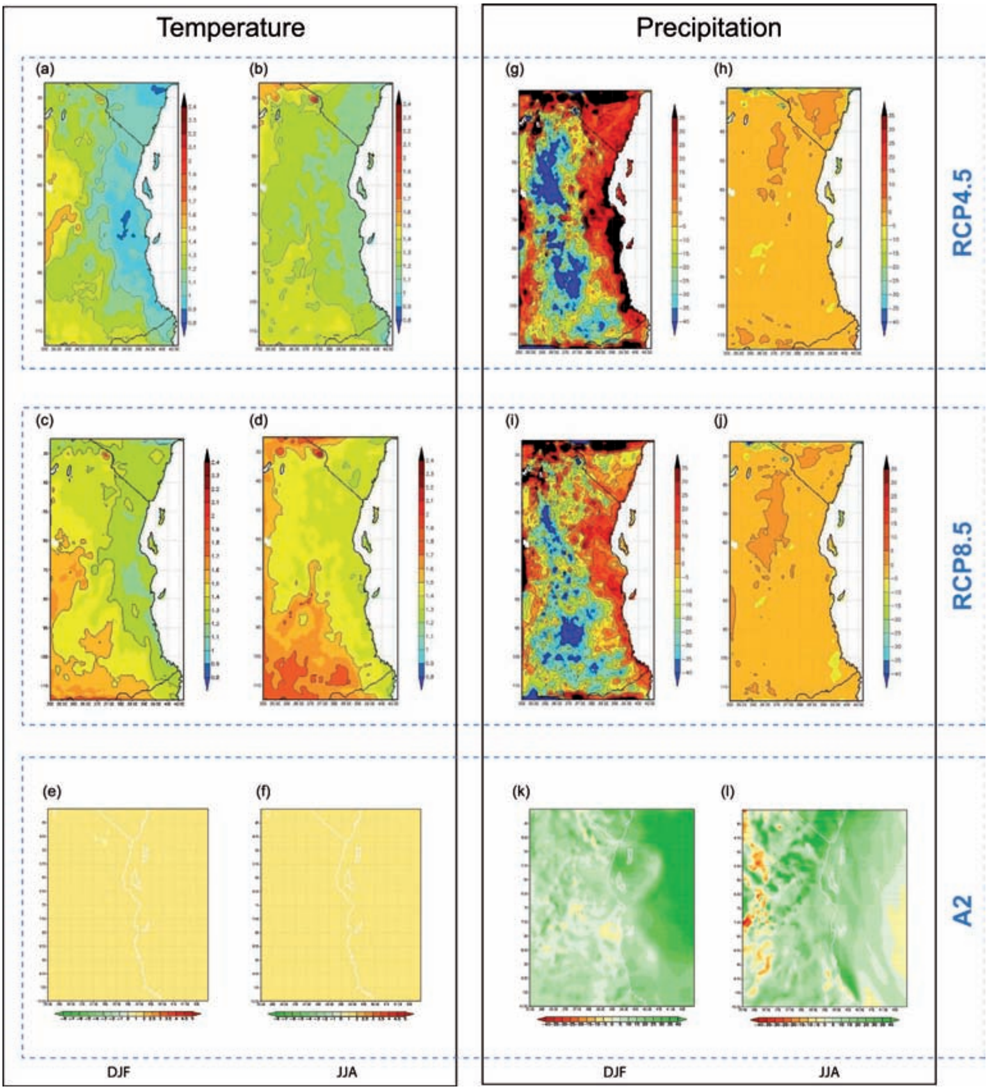


Figure 5. Seasonal changes of mean temperature at 2 meters from ground (left) and percentage change of seasonal precipitation (right) for the time period 2021-2050 with respect to 1971-2000, considering three emission scenarios (A2, RCP4.5, and RCP8.5). For each case the results are presented for two seasons: DJF (December, January, February) e JJA (June, July, August).

Tanzania for the time period 2021-2050 compared to 1971-2000. The seasonal changes of mean temperature are shown for a height of 2 meters from the ground (Figures 5a to f, in °C). Figures 5g to l show the percentage change in seasonal precipitation between the two time slices. The figures show the plots for two seasons: DJF and JJA. The first row shows the results considering the RCP4.5 scenario, and the second row the results considering the RCP8.5 scenario.

RISK ASSESSMENT METHODOLOGIES IN CLUVA

Risk defining parameters

From a quantitative point of view, *Risk* can be considered to be the combination of the consequences of an event (damage) and the associated probability of its occurrence (hazard). The science of risk assessment needs to integrate the uncertainties arising at each step of the assessment process in a logical and rational way. Therefore, it is generally based on probabilistic analyses. Conceptually, risk is the result of the operation:

Risk = Hazard * Vulnerability * Values at risk

The *hazard* term is understood to be the probability that a given adverse event of a given intensity will occur in a certain area within a defined time interval. The *vulnerability* term is a multi-dimensional concept interpreted and applied in various ways depending on different discipline areas. In quantitative terms, it is generally considered to be a measure of the probable damage to an element at risk as a result of an adverse event at a given level of intensity. Finally, the *values at risk* term is considered to be a measure of the total value of elements exposed to risk in a given area.

Note that, beyond these basic components, more holistic risk assessments may require also to consider elements as the resilience and the coping capacities. Resilience can be defined as the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including the preservation and restoration of its essential basic structures and functions. Likewise, the coping capacities are related to the ability of people, organizations and systems to face and manage adverse conditions, emergencies or disasters using available skills and resources. Distinguishing resilience and coping capacities from global vulnerability aims at identifying intrinsic characteristics of the system (generally positive elements) that already exist and therefore could encourage the stakeholders to pursue their effort in risk reduction.

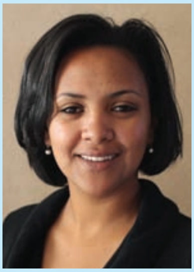
Conceptualizing Social vulnerability

The term 'social vulnerability' describes in a general sense how susceptible people are to a hazard. This view is closely linked to understanding "the characteristics of a person or group in terms of their capacity to anticipate, cope with, resist, and recover from the impact of a natural hazard" (Blaikie et al., 1994). The CLUVA research highlights both the social and temporal dimensions of extreme events and focuses on the question of how individuals and social groups anticipate, resist and cope with, as well as recover from a disaster:

Social vulnerability in CLUVA: The ability of an actor to anticipate, cope with and recover from the impact of a hazard

Framework for assessing vulnerability in CLUVA cities

It is generally agreed that the most acute impacts from flooding are caused as a result of very dynamic socio-economic, demographic and physical conditions. Such conditions tend to be particularly characteristic of settlements inhabited by the urban poor. The root causes of climate-related disruptions are unplanned and rapid urbanization in high risk areas, together with local and wider environmental degradation. Climatic events add a new layer of concerns in the CLUVA cities. The communities which are frequently exposed are those growing along coastal settlements and /or located in proximity to a river/water channel due to their need for fresh water sources. The impact in these communities has been well-documented; we know that flash floods cause severe physical damages to buildings and sanitation facilities, as well as road damage and the disruption of daily social lives across all settlements investigated.
In light of these realities we consider the core elements of vulnerability to include:



Rebka Fekade
Lecturer/Architect at the Ethiopian Institute of Architecture, Building Construction and City Development, Addis Ababa University

«In CLUVA, I was able to learn from the overall process of the project from participatory approach how to obtain information and process data: understanding indicators identified by researchers, collecting the appropriate information both qualitatively and quantitatively, approaching local communities. The workshop in Leipzig came in handy not only to get methodologies but also to transfer this knowledge in some of the courses I teach. With CLUVA I am now aware of the necessity to have a higher level of sensitivity toward local values to collect information and to mitigate risks».

- **Exposure**, describing the physical precondition to be affected.
- **Susceptibility**, involving the precondition to suffer harm because a person or a group experiences some level of fragility or disadvantageous condition.
- **Coping and adaptive capacities**, referring to the ability of individuals or social groups to come to terms with stressing, threatening or damaging events by coping with or adapting to them (Fuchs et al., 2011; Kabisch et al., 2012).

Assessing social vulnerability requires considering contextual circumstances. This means highlighting and interlinking relevant factors/indicators encompassed in four key dimensions as shown in Figure 6:

- **Asset vulnerability** which encompasses the human livelihood and material resources of individuals and groups.
- **Institutional vulnerability** which refers to the state of local authorities and civil action groups that operate to prevent, adapt or reduce the effect of extreme weather events.
- **Attitudinal vulnerability** which represents the perception and risk management attitude of individuals and groups.
- **Physical vulnerability** which accounts for the natural and/or man-made characteristics of the built environment and land cover (Jean-Baptiste et al., 2011).

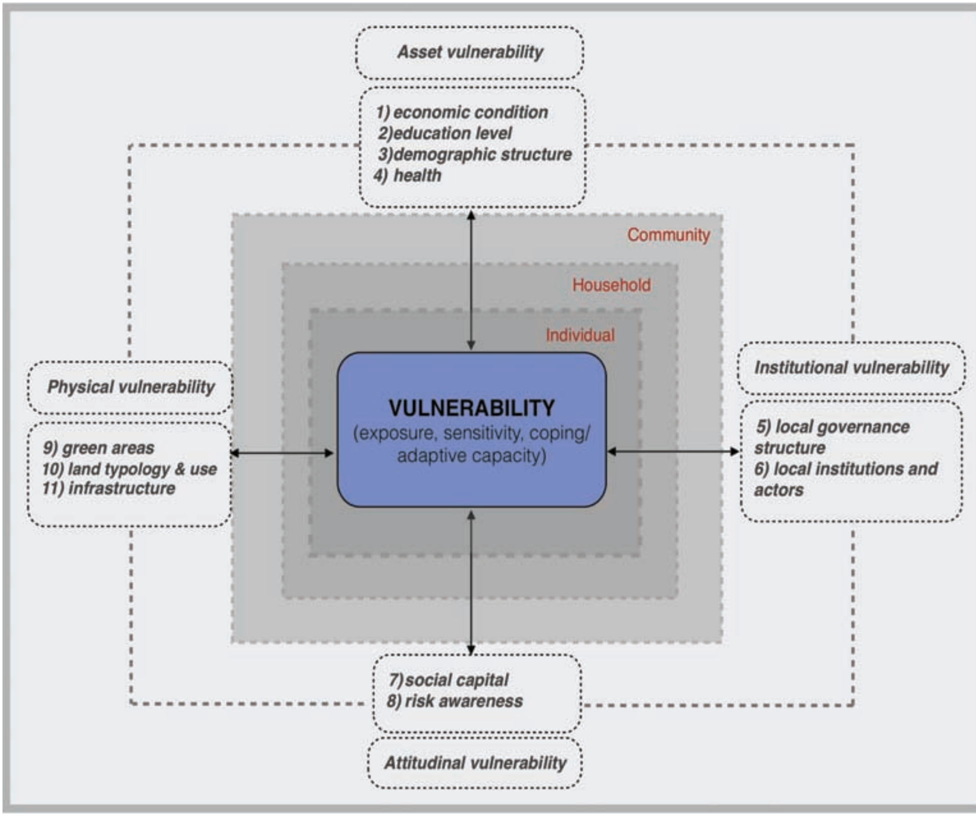


Figure 6. CLUVA framework for assessing social vulnerability.

Figure 7. Traditional leader showing the impact of flooding (closure of a place of worship) in Ouagadougou (photo by Nathalie J.B.).

Figure 8. Focus group with residents and community leaders in Bonde, Dar es Salaam (photo by Sigrun Kabisch).

Concept of the urban hot-spot areas

The 'hot-spot' concept has been used in various disciplines in order to indicate the concentration or the intensity of a certain phenomenon in a limited geographical context.
Flooding risk hot-spots can be defined as zones that are particularly likely to be exposed to flooding. Figure 9 illustrates a schematic representation of a flooding risk hot-spot. The hotspot 'R' (Risk) is identified as an area in which a high probability of flood occurrence 'H' (Hazard) coincides with an area of high exposure 'E'.
Considering that around half of the world's population lives in urban areas, identifying urban flooding hot-spots is a fundamental step in urban planning and risk management. Arguably, the delineation of urban hot-spots does not only provide information for policy makers but can also be useful as supporting information for indicating future urban dynamics and trends for researchers.
Mapping of urban flooding risk hot-spots provides a quick screening tool for the urban planner in order to efficiently identify the zones that need immediate or long-term actions as for example, the adoption of more accurate small-scale risk assessment procedures and the undertaking various prevention strategies. The prevention strategies range from planning for structures that help in mitigating the flood risk, to relocation policies (if advisable), territory restriction measures and actions that aim to increase public awareness.
The procedure adopted in CLUVA for delineating the flooding risk hot-spots identifies the intersection between zones of high flooding susceptibility and high exposure. The latter is represented through intersection of geo-morphological and population density datasets. In particular, urban hot-spot identification is done by overlaying a map of potentially flood prone areas (identified by the topographic wetness index, TWI), a map of urban morphology types (UMT) classified as residential or as urban corridors (i.e. major roads), and a geo-spatial census dataset for demographic information (e.g. population density).

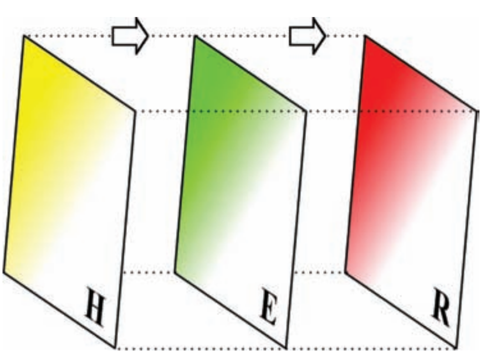


Figure 9. Hazard (H), Exposure (E) and Risk (R), the concept of a hot-spot.

Vulnerability and adaptation potential associated with urban ecosystems

Urban ecosystems provide a crucial 'life-support' for cities. They provide food and materials for urban populations; they regulate and support local urban environments for the benefit of residents; and they allow space for recreational and cultural activities. Many different types of vegetation and areas of water provide these services and they exist everywhere in the city, from street trees and vegetable patches through to municipal parks and river valleys.
These 'green' structures have been mapped using a specially developed land classification system based on 'urban morphology'. The maps provide a basis for assessing the multiple ecosystem services that are already provided in different parts of the city and the functions which ideally need to be provided in those areas. This provides some insight into the adaptation potential which exists. However, the extent to which this potential can be realised depends on the pressures that the structures face now and into the future. One important pressure is development related, and layered onto this, is the additional stress from climate. A model has been used to estimate changes in surface temperatures as a result of land cover and climate change. In addition the basic sensitivity – or susceptibility to damage – of horticultural and field crops

Katja Buchta
Research Associate at the Technical University of Munich, Chair for Strategic Landscape Planning and Management

«With CLUVA I understand that one priority to mitigate climate risks in the African cities is raising awareness on climate risks and explaining how urban planning is connected to this topic. Further settlement activities in risk areas (e.g. flood prone areas) should be limited and the losses of farmland and green areas reduced to a minimum. Hence, high density settlement structures in well selected, attractive, low-risk areas need to be supported including also green areas and urban farming. Transforming flood prone areas into urban farming areas hinders settlement development in these areas, improves the city's food security and revives some of the ecosystem services».

to different climate-related events like floods and heat-waves has been assessed through consultation with local experts. The work helps to make a robust basis for 'green infrastructure' planning. More information on the data, methods, models and outputs associated with this part of the CLUVA activity is available in a dedicated practitioner summary available on the CLUVA website.

Development of measuring tools in a multi-risk perspective

The multi-risk concept refers to a complex variety of combinations of risk (i.e. various combinations of hazards and various combinations of vulnerabilities). The multi-hazard perspective implies considering different independent hazard sources or assessing possible interactions or cascading effects. Conversely, the multi-vulnerability perspective implies considering the response of the different kinds of exposed elements (such as the built environment, green elements representing urban ecosystems, or the social context) to the effects of the different hazards considered.

Given the complexity of processes that the multi-risk problem is associated with, the multi-risk framework developed in CLUVA involves two levels of analysis: a **first-level analysis**, in which an evaluation of potential physical damages is performed (e.g., for buildings, infrastructure and urban ecosystems); and a **second-level analysis**, in which a set of *social context conditions* representing indirect losses is considered. Two complementary alternatives that can be considered at this second level are:

1. a generally hazard-dependent assessment of tangible indirect losses, and
2. an indicator-based assessment with the objective of identifying hotspots of critical areas in which the social context may amplify the losses. Figure 10 shows the two levels of multi-risk assessment developed as the general framework for the CLUVA project.

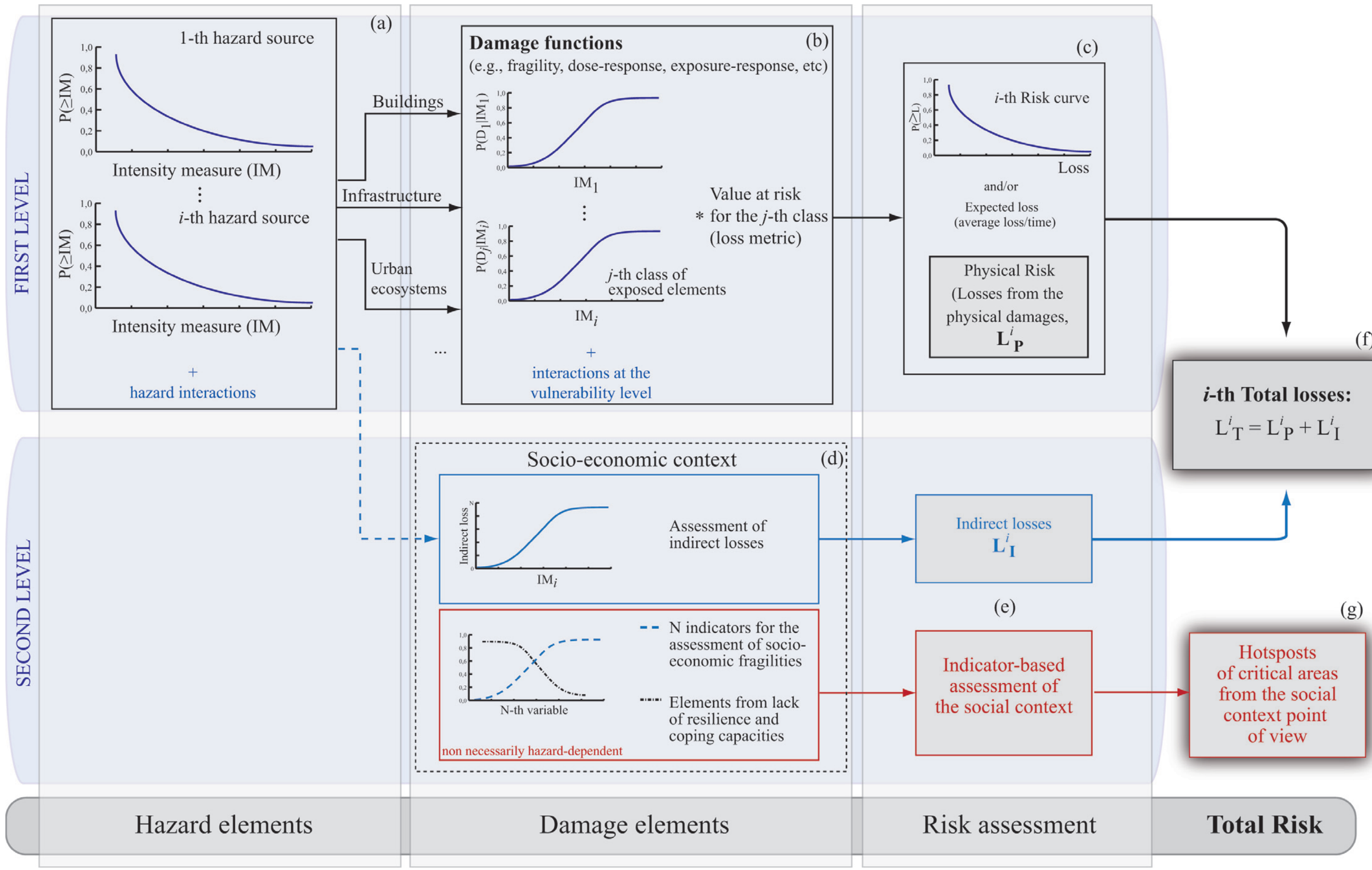
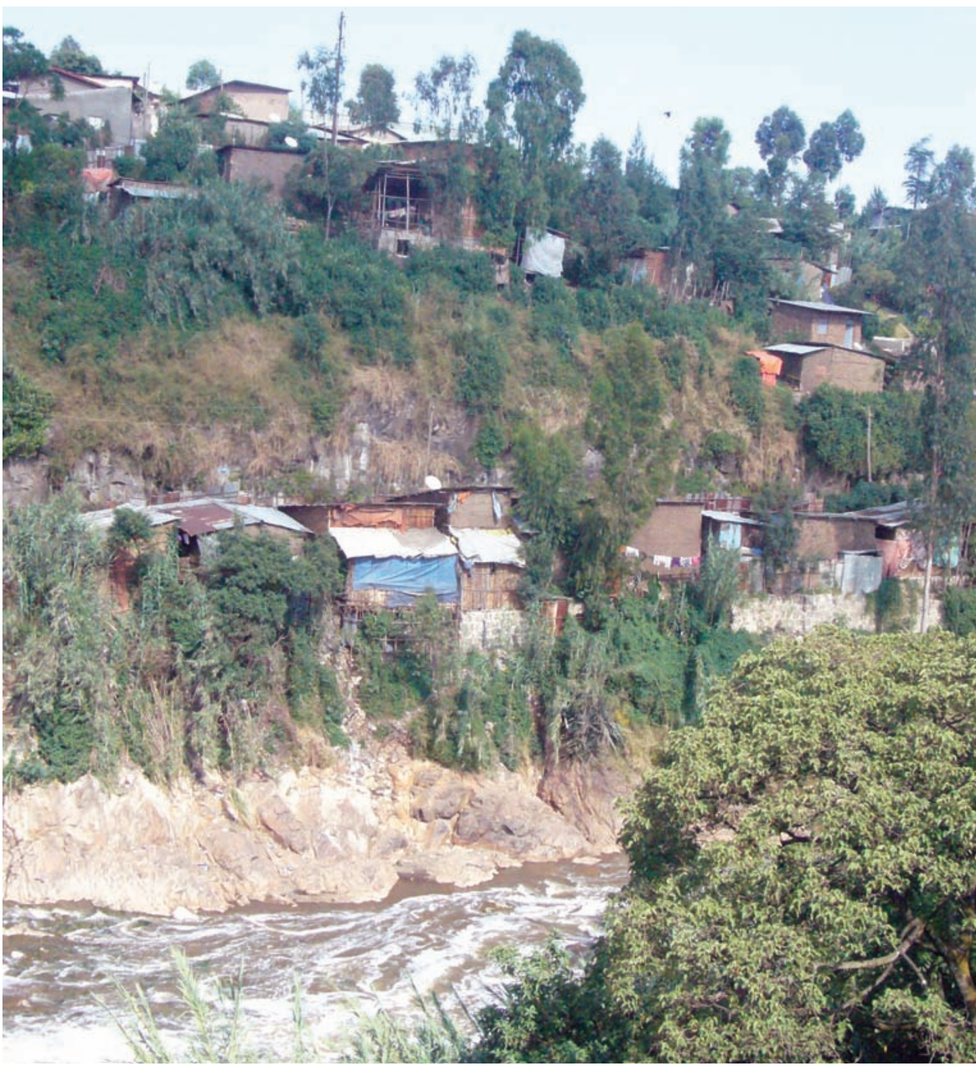


Figure 10. Schematic representation of the two levels of risk assessment for the CLUVA project.

This framework has also been translated into a web-based system to assist with performing the related multi-hazard and multi-risk calculations. The prototype system, which is named MASAi (Multi-hAzard and multi-risk aSsessment tool), can be found and tested at the following link: http://www.amracenter.com/masai.htm.

As a fundamental tool for risk-based decision-making, the quantitative risk and multi-risk assessment system generally builds on the existence of uncertainties and implies the use of probabilities. A multi-risk analysis can provide different outputs of interest for risk-based decision-making. On the one hand, the quantitative results in terms of loss exceedance curves and expected annual losses (or consequences) can be used for comparing and ranking the risks, and assessing the effects of different risk mitigation options. On the other hand, the qualitative output using indicator-based analyses provides complementary information that highlights areas of particular social context conditions.



RECOMMENDATIONS FOR RISK MITIGATION STRATEGIES

Regulating roles of urban ecosystems in planning processes

In fast growing African cities, urban ecosystems provide vital ecosystem services such as prevention of soil erosion, provision of food and fuelwood, moderation of the heat island, reducing flooding risks and providing social spaces for urban dwellers. The CLUVA project has produced evidence that urban ecosystems are an important way of mitigating the negative impacts of urbanisation and climate change in African cities.

Some key messages for the integration of urban ecosystems into urban development strategies, and for an improved understanding of the services urban ecosystems provide can be drawn out:

– **Compact urban development** is of prime importance to reduce the pressures on urban ecosystems and their services. Urban development scenario modelling shows that creating high density settlement structures around urban nodes in well selected, low-risk areas located in the periphery of the city is the most effective means for safeguarding valuable farmland and woodlands.
– A coherent network of green spaces should be developed that combines multiple ecosystem services. This **Urban Green Infrastructure** is just as important as technical and social infrastructures for urban sustainable development and resilience to climate change. Strategy development should be based on a comprehensive assessment of the entire urban green structure and its ecosystem services.
– **River corridors** are the backbones of a green infrastructure network. River corridors need to be kept free from development and the functions of floodplains should be improved where impaired to reduce the risk of flooding in urban areas.
– **Urban agriculture** should be properly recognized in urban planning as self-production of food is of great importance for the sustenance of urban dwellers. Moreover, urban farming also provides other important ecosystem services such as retaining water on the land and reducing local air temperatures. Safe land tenure and supporting farmers in establishing practices that are environmentally sound are some key issues for urban planning.
– The **urban stock of trees** is most important for mitigation of the heat island effect, carbon sequestration but also for provision of timber and other products such as fruits. In coastal locations mangrove forests protect from storm surges. Therefore, special attention should be given to protecting urban woodlands and trees as well as establishing new woodlands and tree planting within urban areas.

Bettering engineering design and management of storm water systems

The design and management of stormwater systems are difficult issues in developing countries, given their characteristics of rapid urban development, unplanned urban settlement patterns, – and severe poverty. In cities in these countries, the sewer systems are often inadequate in coverage and in performance, especially because of inadequate waste management (Fig. 11). Urban areas tend to be dominated by unplanned settlements, and these constitute a major obstacle for urban drainage. The key way to resolve most of these problems is to undertake an integrated planning and management approach through which the two primary requirements of land and water are considered together. A programme of sustainable urban development is needed to ensure that drainage issues are considered in advance and continue to be considered into the future.

The design and management of stormwater systems should include:

– assessment and planning of operational activities which potentially affect stormwater quality or quantity;

Figure 11. Drainage system in an informal settlement in Dar es Salaam (left, photo by M.E. Topa); drainage system in Ouagadougou (right, photo by A. Di Ruocco).

- development of stormwater quality management plans for the local government area;
- planning, implementation and maintenance of new drainage infrastructure; and
- identification of opportunities for upgrading existing infrastructure to improve environmental performance.

Figures 12 and 13 below describe the traditional and recommended approaches to stormwater management in urban contexts. Stormwater Best Management Practices (BMPs) are methods of managing stormwater drainage for adequate water transfer and flood control that are economically acceptable to the community. BMPs are stormwater management methods that retain as much

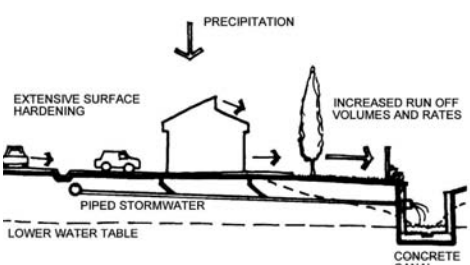


Figure 12. Stormwater traditional management approach (City of Cape Town Manual).

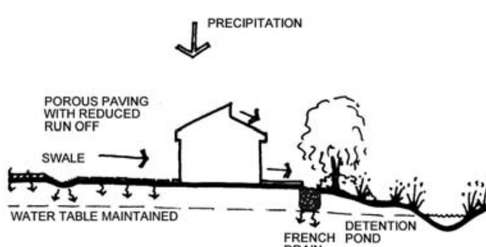


Figure 13. Responsible approach to stormwater management (City of Cape Town Manual).

of the "natural" runoff characteristics and infiltration components of the undeveloped system as possible and reduce or prevent water quality degradation. The selection and design of stormwater BMPs therefore must incorporate water quantity and water quality concerns. BMPs that address source controls such as street sweeping, catchment cleaning and anti-litter regulations should be a component of specific drainage plans. Source controls can have a significant effect on the total contaminant load discharged to a receiving water body, but alone do not reduce the total contaminant loads to acceptable levels in most development areas. It is important to consider further treatment and runoff controls in the selection of BMPs.
A considerable reduction of peak flow can be achieved through the use and integration of the BMPs, as for example, permeable pavements, infiltration beds, different detention methods. It's important to note, however that the BMPs are stormwater management practices that could integrate with and do not necessarily replace the traditional approaches which are already in place.

Improving the analysis of roadway network reliability

The impact of climate change on the road network is significant, especially for effects induced by high rainfall, floods and landslide. The road network elements that are more prone to damage can be divided into two main categories: **roads and drainage elements** and **waterway crossings**.
Damage to roads and drainage elements (Fig. 14a) can occur as a consequence of a river or stream flooding, or as a result of heavy runoff that exceeds the capacity of drainage roadside ditches and underdrains. Damage to waterway crossings (Fig. 14b) include erosion and scour of drainage ditches, washout of approaches to waterway crossings and undermining of abutments when ditch capacity is exceeded.
The assessment of network reliability following natural disasters is a complex issue that involves several physical and functional factors. Generally the methodology adopted in order to evaluate the road network performance must be chosen in relation to the importance of the role played by the network itself and the availability of data and information about the network.
The principal scope of a risk analysis is to enhance the resilience of the road network (i.e. its ability to restore functionality after a natural disaster) and this objective can be obtained through adaptation and mitigation actions (e.g. planning, design, operation or maintenance). Regarding floods, adaptation responses in the short term (listed in Table 3) should focus on the systematic collection of data on extreme

Figure 14. Examples of road (a) and waterway crossing damage (b) (FEMA, 2005).

Table 3. Example of possible alternative adaption options (adapted from Bennet, 2011).

Roads	Bridges
Increase the capacity of all drainage.	Strengthen all bridges.
Increase the capacity of drainage in areas that are most likely to flood.	Strengthen bridges crossing rivers that are most likely to flood.
Increase the capacity of drainage in areas where flooding will cause the most damage or delays.	Strengthen bridges that carry the most traffic.
Review the type of drainage and its maintenance regime; determine ownership and maintenance responsibilities.	Assess the bridges which are most at risk to scour.
Improve the effectiveness of drainage by more frequent or targeted cleaning.	Prepare contingency plans to communicate with drivers about alternative routes and close bridges that are most at risk when flooding is predicted.

weather events that cause disruption/damage to the network, and more detailed flood risk studies for those parts of the network that are currently prone to flooding. Catchment-based flood modeling should be considered in high-risk areas to refine risk assessments for critical assets, and to identify areas not currently affected but which could be in future.

Another key component of disaster resilience is the concept of **redundancy** or in general terms how flexible a system is to still perform its primary function when affected by a hazard. For a road network, for example, the degree of redundancy is related to the existence of alternative road routes so that alternatives for diverting traffic flows can be identified if there is a blockage on one part of the network. Without a full consideration of these issues alongside the other recommendations disaster events occurring in one part of a city can have a far-reaching effect on the whole of the urban population.

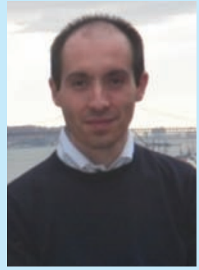
Measures for reinforcing adobe houses

Informal settlements are particularly vulnerable to flooding due to a generally low quality of construction and the fact that they are frequently located in areas with high flood susceptibility.

The risk mitigation strategies proposed in the context of the CLUVA project are focused on the predominant housing categories identified in the informal settlements in three case-study cities: namely, adobe houses for Ouagadougou, houses made of cement bricks for Dar es Salaam and mud and wood houses for Addis Ababa. These strategies often have their roots in adaptation measures already in practice by the local community. Some examples of the suggested structural mitigation strategies are: constructing a raised foundation, constructing barriers, sealing the windows and doors against infiltration, improving the properties of materials and protecting walls from direct contact with water.

Cutting-edge analytical tools show 1) how the vulnerability of a typical structure can be affected by adopting the suggested risk mitigation strategies and 2) how the adoption of the suggested mitigation strategies helps to reduce city-wide flood risk.

While this is important it must also be recognised that making an informed choice about locations for new buildings is perhaps the most effective risk mitigation strategy.



Raffaele De Risi

Post-doctoral researcher at the Department of Structures for Engineering and Architecture, University of Naples Federico II

«Working on the CLUVA project, I learned to understand and appreciate the social aspects of vulnerability and risk. Therefore, in addition to the incredible wealth of technical knowledge that I have been able to develop for problem-solving, I have had the possibility to develop a consciousness of what are the real problems that can affect a society like the African one. Needless to say, the possibility to work in an interdisciplinary environment full of bright and motivated people, taught me what it means to be a good researcher and increased my desire to improve».

Therefore, for each of the three case-study cities, a two class map has been produced to show safe and unsafe areas in relation to flooding. These provide a useful way for local decision-makers to identify residential areas at risk and also to identify suitable construction sites for future.

Governance strategies and policies and data improvements

City-level adaptation is a new area within urban planning, and there are no set standards for how to do it. A number of important measures have been identified that can be used as a checklist for evaluating how a city is performing, where more attention should be placed and where synergies could be found between different fields (Table 4).
As climate change adaptation is a complex and cross-cutting problem, it also needs a combined multi-level and cross-sectoral approach. Making cities more resilient also requires different types of knowledge. Cities should prioritize high resolution terrain data and vulnerability mapping. Relevant information should be compiled in one place. However, exact assessments need not necessarily to be finished before *any* planning can occur. Start now!
The main barrier for getting climate change adaptation to become part of city planning in CLUVA cities is that adaptation tends to be weak at the city level. The basic services and land use management necessary is poorly handled as the city administration cannot keep up with demands of fast urbanisation.

Ndeye Marème Ndour
PhD Student in Science Geography and Ecosystems Environment, University Gaston Berger of Saint-Louis

«The effort made by CLUVA to integrate decision-makers in all research processes from data collection, analysis of information, elaboration and validation of tools and models of management is a positive approach that has broken the practices of a "fragmented research".
This model of partnership will improve **decision-making processes** in Senegal through a better understanding by policy makers, of the phenomena and the availability of data in accessible and understandable formats.
Efforts should be pursued in this sense in order to face risks and disasters situations, in all the country».

Table 4. Check list for city performance.

Main measures	Associated measures	Conditions for implementation
Improved land use management and higher building standards	Affordable housing and upgrading	Owner/drivers of process and champions
Upgrading of urban drainage and storm water management	Enhancing solid waste management	Variety of stakeholders to be involved
Enhanced environmental planning with focus on the city green infrastructure and its ecosystem services	Disaster management and emergency preparedness	Multilevel and horizontal coordination between stakeholders
	Mainstreaming into city planning	Awareness raising and participatory local planning
	Multi-benefits and synergies between measures	Increase knowledge and data and compile already available relevant data – store it all in one place

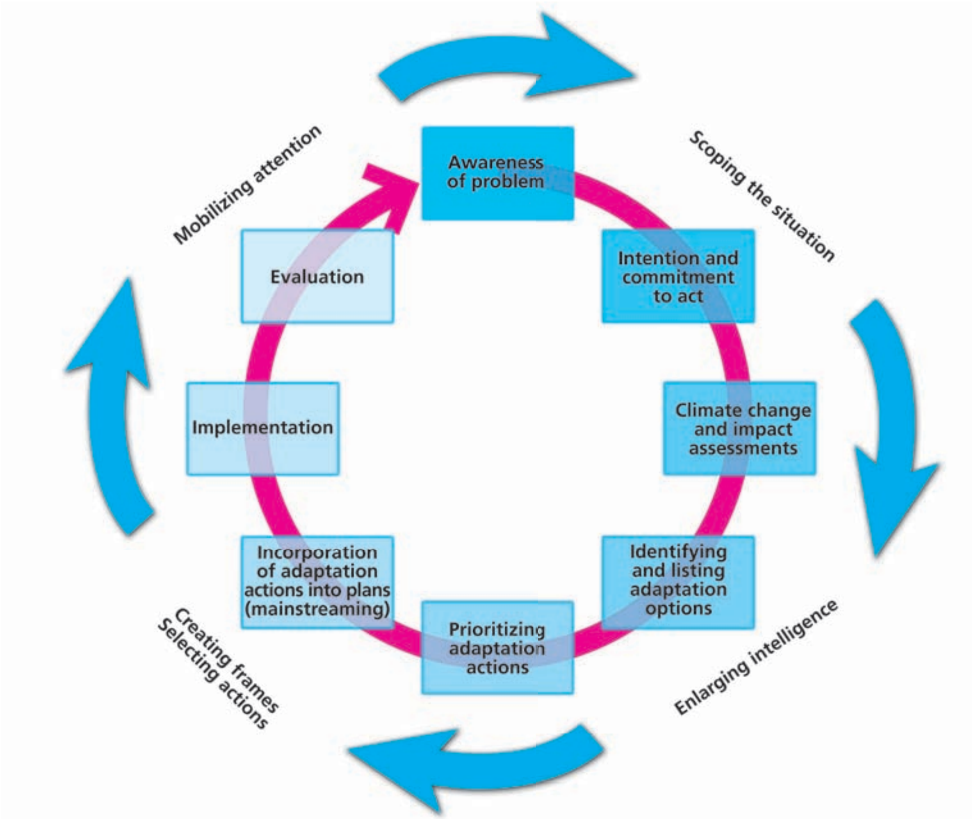


Figure 15. Typical elements of adaptation planning (inner circle) and dimensions of strategy making (outer circle).

Figure 16. Stakeholder talks in Addis Ababa.

The main opening for getting climate change adaptation into city development is the urgency of flooding problems that both citizens and professionals already face. There is an awareness of the problems and some of the solutions, but many measures from the checklist are simply not realistic for the whole city at the present time. However, decision-makers do feel that they might be able to address some strategic measures: especially those that can mobilize a range of stakeholders and which resonate with the problems which are already experienced in the cities. Stakeholder sessions in CLUVA cities suggest that framing adaptation as **'integrated water management'** is a good way forward. This allows for better water management through a city-wide approach based on the common interests and possible synergies across a range of city sectors and levels. In the cities where the governance system is currently too fragmented to drive a city-wide institutionally-led adaptation effort, **'integrated local projects'** in the most vulnerable areas addressing land management as well as upgrading and livelihood projects seems to find resonance among stakeholders and could initiate a 'learning-by-doing' process of adaptation for the city level.

RECOMMENDATIONS ON DATA NEEDS

- Up-to-date and high resolution terrain data of the city
- Reliable long term reference data from ground observation stations
- Information on important elements for adaptation, like solid waste management, drainage, water provisioning etc., at neighbourhood/subward scale, also in informal areas
- Compilation and storage in one place of the available relevant data for climate change adaptation
- Hazard and vulnerability maps at a detailed spatial level

RECOMMENDATIONS ON GOVERNANCE STRATEGIES TO ENHANCE RESILIENCE OF URBAN AREAS TO CLIMATE CHANGE

- Develop and/or improve upon the national, sub-national and city-wide government system for disaster risk management and climate change adaptation
- Ensure that urban planning, law and policies, and organisations integrate disaster risk management, adaptation and development approaches
- Improve land use management, planning and enforcement
- Upgrade urban drainage, waste water and stormwater management
- Adopt urban development strategies aiming at avoiding a large increasing of surface impermeability, and consequently of floods' intensity, caused by large settlement expansion at the expense of mainly agricultural land and other vegetated areas. This can be obtained by increasing current settlements' density in a well-balanced manner in order not to have negative impacts on living conditions
- Develop environmental planning (avoid encroachment and extend open green areas) combined with the associated measures of:
    1. improvement of solid waste management
    2. housing policies with alternatives to settle in vulnerable areas
    3. upgrading of informal areas
    4. resettlement strategies such as livelihood restoration, screening for vulnerabilities and upgrading efforts
    5. vulnerability mapping and identification of high impact areas
    6. decentralize more competences and resources to the municipal level
    7. focus awareness raising and capacity building at lower levels particularly municipality level

CLUVA – CLIMATE CHANGE AND URBAN VULNERABILITY IN AFRICA PROJECT WORKPLAN

Project Coordinator, *Guy Weets*

WP1 Climate change and natural hazard models, *Paolo Gasparini*
Task 1.1 Model projection of climate change, *Pasquale Schiano*
Task 1.2 WEB Climate Mapping Services, *Ingo Simonis*
Task 1.3 Probabilistic scenarios of natural hazards, *Maurizio Giugni*

WP2 Vulnerability and Risk assessment, *Stephan Pauleit*
Task 2.1 Vulnerability of urban structures and lifelines, *Iunio Iervolino*
Task 2.2 Vulnerability and adaptation potential associated with urban ecosystems, *Sarah Lindley*
Task 2.3 Assessing Social Vulnerability, *Sigrun Kabisch*
Task 2.4 Multi-risk models, *Warner Marzocchi*

WP3 Improving the resilience of the urban systems towards climate change, *Gertrud Jørgensen*
Task 3.1 Governance and planning systems: capacity to cope with land use and climate change induced disasters, *Trond Vedeld*
Task 3.2 Land use indicators, *Lise Herslund*
Task 3.3 Development of innovative land use and governance strategies to enhance resilience of urban areas towards climate change, *Lise Herslund*

WP4 Research Capacity Building and Dissemination, *Anwar Vahed*
Task 4.1 Research Capacity Building, *Anwar Vahed*
Task 4.2 Educational programmes as long term capacity building, *Stephan Pauleit*
Task 4.3 Dissemination to researches and practitioners, *Paolo Gasparini*

WP5 Case studies, methodologies and tools assessment, *Guy Weets*
Task 5.1 Ouagadougou Burkina Faso, *Hamidou Toure*
Task 5.2 Douala Cameroon, *Emmanuel Tonyé*
Task 5.3 Saint Louis Sénégal, *Adrien Coly*
Task 5.4 Dar es Salaam, *Wilbard Kombe*
Task 5.5 Addis Ababa, *Kumelachew Yeshitela*
Task 5.6 Consolidation of the 5 cases, revised methodology, assessment of the tools, *Guy Weets*

WP6 Project coordination and management, *Alfonso Rossi Filangieri*

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CLUVA

SEVENTH FRAMEWORK PROGRAMME

According to the IPCC, Africa is one of the most vulnerable continents to climate change and climate variability. In spite of this East, West and Central Africa are some of the regions of the world which are the least well covered by climate change studies. The situation is further aggravated by the interaction of multiple factors such as poverty, health status and rapid urbanisation, resulting in a very low adaptive capacity. The Climate Change and Urban Vulnerability in Africa (CLUVA) project was conceived to address this issue.

CLUVA's primary aim was to develop methods which can be applied by African cities, to help them to manage climate risks and to reduce their vulnerability to the impacts of climate change. The researchers have explored these issues within five selected cities (Addis Ababa in Ethiopia, Dar es Salaam in Tanzania, Douala in Cameroon, Saint-Louis in Senegal and Ouagadougou in Burkina Faso) and promote improvement in the capacity of local institutions, such as universities and local councils, to cope with climate change and the risks it poses.

This was achieved through an integrated research effort between both European and African experts in the knowledge-specific areas of climate, risk management and urban planning who usedtheir expertise to assess the environmental, social and economic impacts of climate change. Among the key risks that CLUVA has been focusing on, flooding appears to be the most devastating, as it is a risk shared by all cities. Other hazards include erosion, heat waves, drought and long-term risks, such as desertification.

Innovative methodologies have been developed for the five selected cities, both for climate change vulnerability assessment, and for the definition of new risk mitigation and adaptation strategies, aiming to provide planners and policy makers with tools for the development of more climate change resilient cities.

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analysis and monitoring of environmental risk
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