CLUVA FINAL REPORT

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Name of the scientific representative of the project's co-ordinator, Title and Organisation:

Prof. Paolo Gasparini

AMRA – ANALISI E MONITORAGGIO DEL RISCHIO AMBIENTALE SCARL

Via Nuova Agnano, 11

Tel: +39 081 7685125

Fax: +39 081 7685144

E-mail: paolo.gasparini@na.infn.it

Project website address: http://www.cluva.eu/

4.1 Final publishable summary report

Executive summary

CLUVA (CLimate change and Urban Vulnerability in Africa) is a 3 years project, funded by the European Commission in 2010. It has the general objective to estimate the impacts of climate changes in the next 40 years at urban scale in Africa.
The mission of CLUVA is to develop methods and knowledge to assess risks cascading from climate-changes. It downscales IPCC climate projections to evaluate threats to selected African test cities; mainly floods, sea-level rise, droughts, heat waves and desertification.
The project evaluates and links: social vulnerability; vulnerability of in-town ecosystems and urban-rural interfaces; vulnerability of urban built environment and lifelines; and related institutional and governance dimensions of adaptation.
A multi-scale and multi-disciplinary quantitative, probabilistic, modelling is applied. CLUVA brings together climate experts, risk management experts, urban planners and social scientists with their African counterparts in an integrated research effort focusing on the improvement of the capacity of scientific institutions, local councils and civil society to cope with climate change.
The CLUVA approach was set-up in the first year of the project and developed as follows: an ensemble of eight global projections of climate changes is produced for east and west Africa until 2050 considering the new IPCC (International Panel on Climate Changes; http://www.ipcc.ch/) scenarios. These are then downscaled to urban level, where territorial modeling is required to compute hazard effects on the vulnerable physical system (urban ecosystems, informal settlements, lifelines such as transportation and sewer networks) as well as on the social context, in defined time frames, and risk analysis is then employed to assess expected consequences.
An investigation of the existing urban planning and governance systems and its interface with climate risks is performed.
With the aid of the African partners, the developed approach is applied to selected African case studies: Addis Ababa – Ethiopia; Dar es Salaam - Tanzania, Douala – Cameroun; Ouagadougou – Burkina Faso, St. Louis - Senegal.

Summary description of project context and objectives

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 estimate the impacts of climate change on African urban areas in the next 40 years and 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 taken 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.

The five selected test cities are Saint-Louis in Senegal, Ouagadougou in Burkina Faso, Douala in Cameroun, Dar-es-Salaam in Tanzania and Addis Ababa in Ethiopia.

In order to achieve its overall scope, CLUVA focused on the following scientific objectives:

(1) **Downscaling of IPCC scenarios to local urban (and urban-rural) regions simulating plausible climate change impacts on the occurrences of hazards at the 2050s time horizon.** High resolution climate models have been used to provide scenarios of climate change at sub-regional scale that are consistent with the global change scenarios obtained from the global models and suitable for input to impact models by covering a sufficient number of variables at an appropriate spatial and temporal scale. Simulated variables have included: precipitation; solar radiation; wind speed; and air temperature downscaled from global models to case study sites. From these variables, the projected change in the occurrence of extreme weather events that influence African cities, such as heat waves, floods, drought, desertification have been analysed.

(2) **Assessment of the multiple vulnerabilities of African cities.** The emphasis has been on understanding the factors that make people and infrastructure vulnerable to climate related hazards. To this end a novel approach has been adopted for integrative assessment of both outcome and contextual vulnerability. Multiple vulnerabilities have been also considered, including the

vulnerability of the built infrastructure including housing, lifelines and other critical infrastructures; the urban and urban-rural ecosystems; the exposed population according to their socio-economic characteristics. Integration of different risk- factors in a multi-risk model has increased understanding of combined hazards and cascading effects.

(3) **Development of innovative strategies for urban development to reduce the vulnerability of African cities to climate change.** Specific objectives have been to analyse and assess the current role of urban planning and land use governance to cope with climate change and to propose innovations; to develop relevant indicators and methods for spatially explicit mapping of risk prone areas; and to develop innovative adaptation strategies for African cities based on a participative and stakeholder based approach.

(4) **Improvement of African R&D capacity in the projects fields and disseminate results to practice.** Adaptation to climate change and mitigating the impacts of extreme events and disaster requires the capacity to design and manage large scale long term projects demanding in turn a supporting education- and research infrastructure. The fourth objective of CLUVA has been to significantly strengthen this capacity at least in the five African universities involved. PhD and post doctoral training of African students has been part of the project. To secure a long term effect, the project has also develop master programmes and new university courses in the various disciplines active in the project.

Thanks to a multi-disciplinary team, made up high professional level tiles, the CLUVA scientific objectives have been successfully achieved.
The research activities of CLUVA has been implemented in six groups, four of them responsible for the core research and two for the implementation:

- The ***climate driven hazard group*** worked on the 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 allowed 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.

- The ***multi-risk assessment group*** worked on the development of a probabilistic multi-risk framework in order to consider the various combination of hazards and vulnerabilities in the African urban context. The developed approach has allowed to include in a common framework the evaluation of physical damages and social context conditions representing indirect losses.

- 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 has been 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.

CLUVA has achieved several innovative results:

- ✓ It has downscaled climate change projections to a resolution of 8 km for the test cities, unprecedented in the African continent.
- ✓ It worked out probabilistic models of hazard and vulnerability with scarce available data.
- ✓ It dealt 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 conveyed the message of the uncertainties of the proposed scenarios.
- ✓ It has proposed 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.

The project has shown 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.

Main S&T results/foregrounds

✓ *HIGH- RESOLUTION CLIMATE CHANGE PROJECTIONS AVAILABLE FOR THE FIRST TIME IN AFRICA*

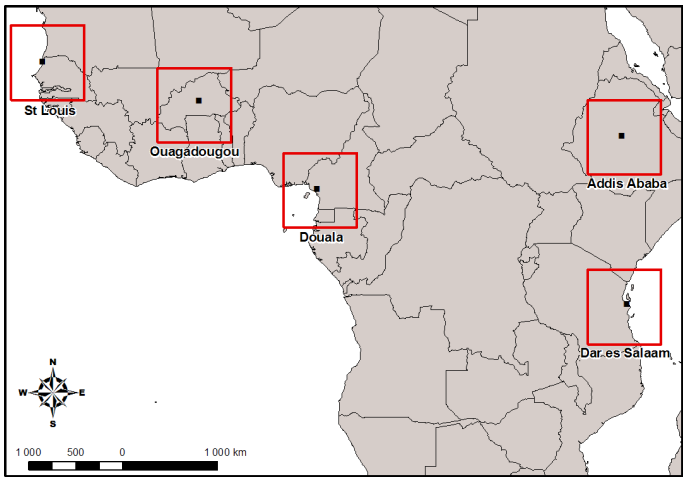
The current urban growth rate in Africa is 3.5 per cent per year on average. It is the highest in the world, resulting in more urban areas with bigger populations, as well as an expansion of the existing ones. The changing climate could lead to changes in the frequency, intensity, spatial extent, duration, and timing of weather and climate extremes, and could result in unprecedented extreme events affecting the growing urban areas in Africa. Thus, urban and land use planners, managers and researchers within the African context need reliable forecasts of the local impacts of climate change and better equipment for strengthening the coping capacities of urban communities.

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. In particular, the last Assessment Report of IPCC considers four scenarios (RCP scenarios), each assuming a different level of radiative forcing by the year 2100: 3, 4.5, 6 and 8.5 W/m^2.

Before the start of the CLUVA project the real impact on local scale of the IPCC scenarios was still poorly understood in Africa because only based on Global Circulation models with low spatial resolution (250 km^2 per grid cell) which fail to represent local particularities such as rain shadow or wind tunnel effects caused by topographic particularities.

Thanks to the CLUVA Project, downscaling techniques have been applied for the first time to the global models in some African regions selected among those facing the most serious climate risks (Fig.1).

(a)



(b)

Figure 1. The five African regions where climate projection data with high spatial resolution are now available for the SRES A2 (a) and for the RCP 4.8/8.5 (b) scenarios

CLUVA has made available climate data with resolutions of 50x50 to 8x8 km^2 for 3 IPCC emission scenarios: the A2 of the SRES set of scenarios, and the 4.5 and 8.5 of the RCP set.

All data produced by CLUVA has been made available directly on the Internet (Fig.2) and can be accessed by everyone free of charge!

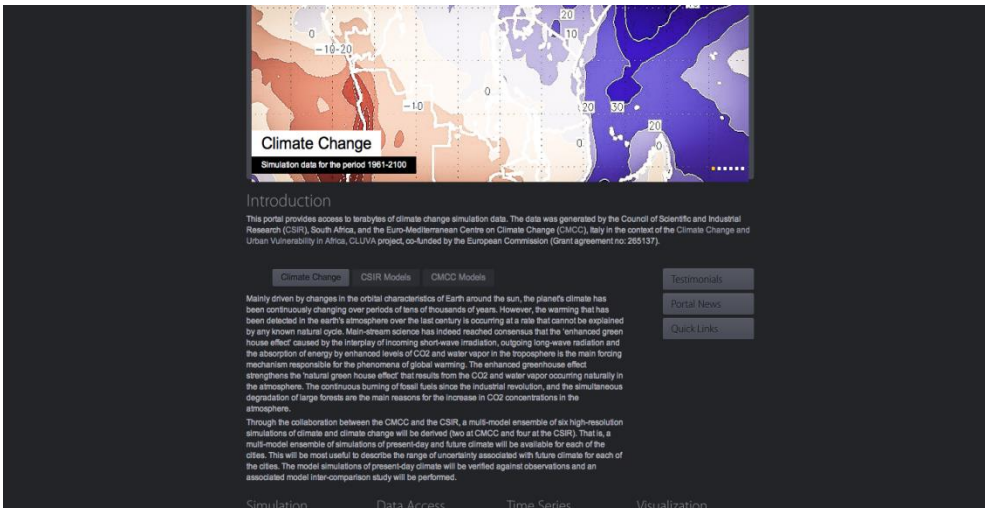


Figure 2. The CLUVA Climate Web Portal (http://ict4eo.meraka.csir.co.za/anonftp/CLUVA/)

Figure 3 shows examples of projected seasonal changes of temperature and precipitation found in an area around 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 3a to f, in °C). Figures 3g 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

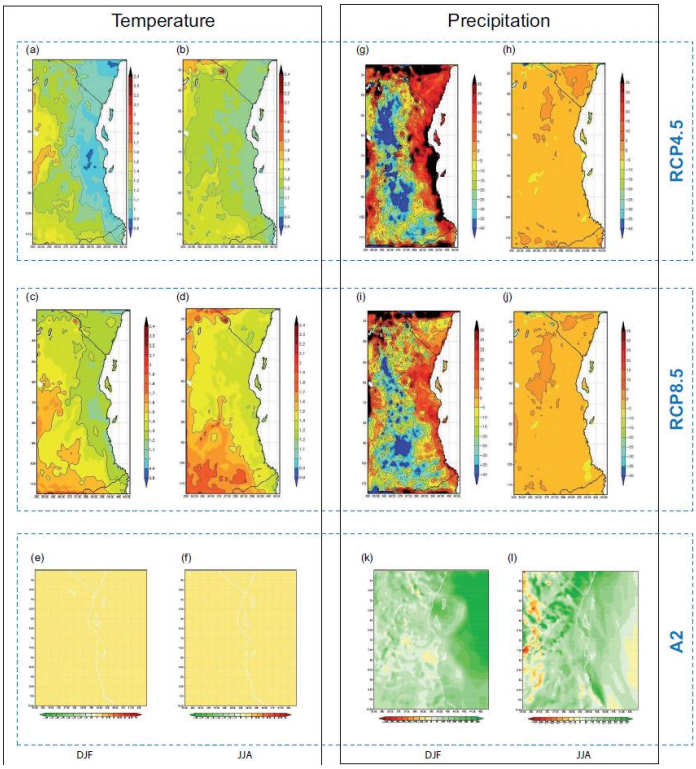


Figure 3. Seasonal changes of mean temperature at 2 meters from ground (left) and percentage change of seasonal precipitation (right) for the time period 2021-2050 with respect to 1971-2000, considering three emission scenarios (A2, RCP4.5, and RCP8.5). For each case the results are presented for two seasons: DJF (December, January, February) e JJA (June, July, August).

✓ *SUSCEPTIBILITY TO FLOODING IS AVAILABLE FOR THE FIVE TEST CITIES*

Specific mitigation strategies of flooding risk for the African urban areas are difficult to formulate unless studies on flooding hazard are undertaken at urban scale. Flood hazard is generally assessed through the evaluation of its impact parameters, such as water depth and velocity, and its associated probability of occurrence. In order to assess these parameters high resolution digital maps are needed not only for the urban area, but also for the surroundings. The lack of this data is one of the major constraints to a reliable assessment of flood hazard and risk in the urban areas of developing countries, especially in the African context.

In order to overcome this constraint, CLUVA has applied an easily implemented method to detect all potential flood prone areas in a urban area without the need of detailed digital map for such a large area. Based on simple geomorphological criteria, this method allows to assess the spatial distribution of a topographic index, the so called Topographic Wetness Index, identifying the areas most susceptible to be flooded where proper mitigation strategies must be addressed by the local decision makers.

CLUVA has made available these maps for all five test cities. The local stakeholders in Addis Ababa, Dar es Salaam, Douala, Ouagadougou and Saint Louis can now rely on this practical and useful tool to develop mitigation strategies of flooding risk at urban scale.

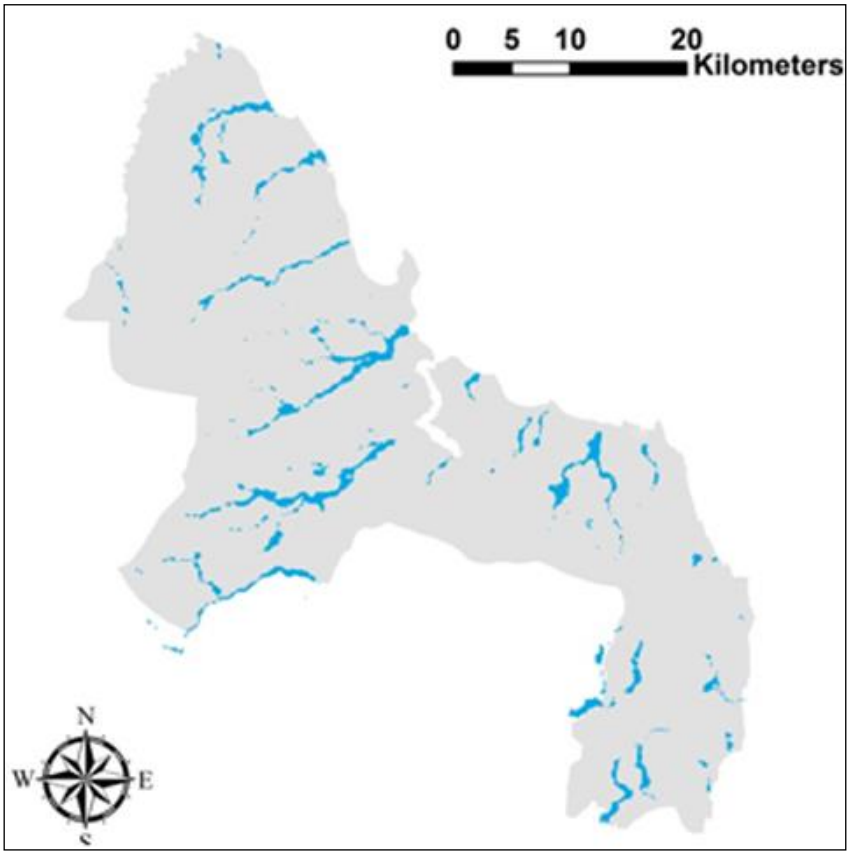


Figure 4. Map of the Topographic Wetness Index for the Dar es Salaam city

✓ *A NOVEL APPROACH TO DESERTIFICATION ASSESSMENT IN AFRICA*

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 estimated that two-thirds of African land is already degraded to some degree (Fig. 5) and land degradation affects at least 485 million people or 65% of the entire African population.

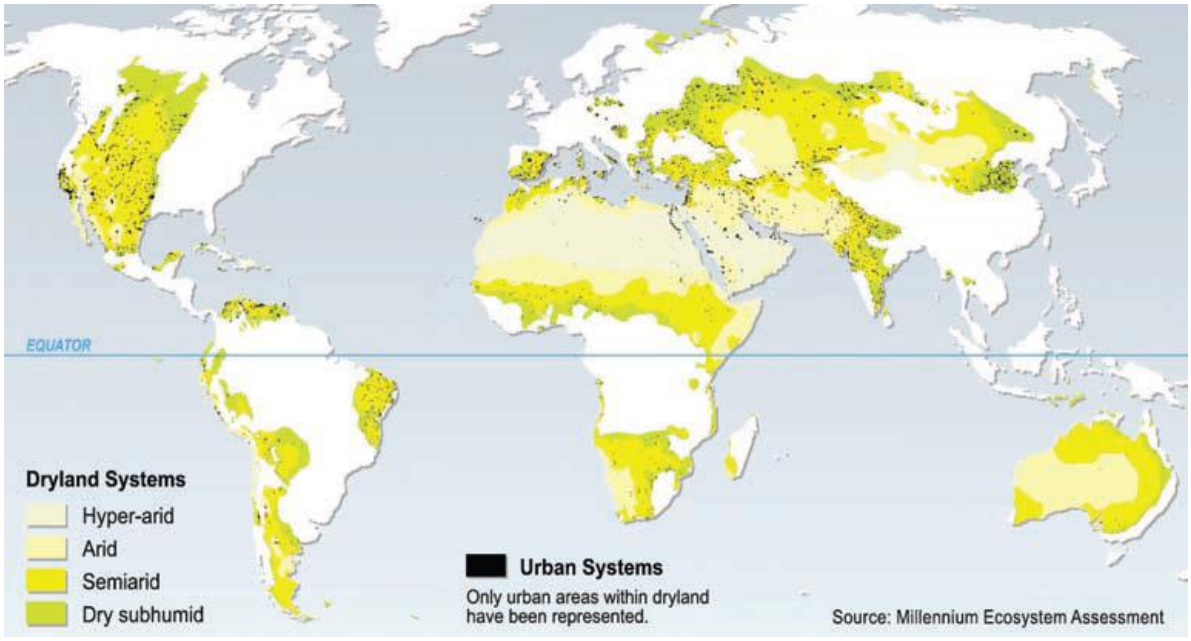


Figure 5. Present-day drylands and their categories (dry subhumid, semiarid, arid or hyper-arid), based on Aridity Index values. (Source: Millennium Ecosystem Assessment Desertification Synthesis Report (2005), based on data from UNEP Geo Data Portal, 2000).

CLUVA has proposed, for the first time in Africa, an approach based on the definition of the Environmentally Sensitive Areas (ESAs) to desertification through the evaluation of an Index of Environmental Sensitivity (ESAI).

The key indicators for defining ESAs to desertification, which can be used at regional or national level, can be divided into four broad categories defining the qualities of soil, climate, vegetation, and management (stress indicators). Each index results from a set of parameters, shown in Figure 6 obtained from databases and thematic cartography at different scales.

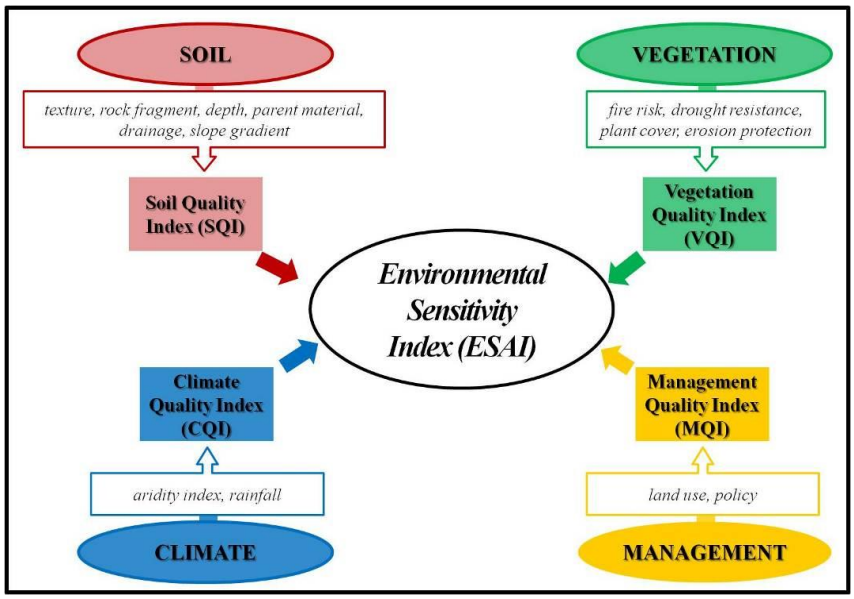


Figure 6. Flowchart of developed model.

CLUVA has used this approach to assess the sensitivity to desertification in peri-urban areas of Ouagadougou (Burkina Faso) and Saint Louis (Senegal) cities. In Ouagadougou peri-urban area, the zones poorly vegetated and overexploited as a result of heavy demographic pressure were found as the most sensitive to desertification (Fig. 7). The northern part of Saint Louis area resulted critically sensitive to desertification mainly due to the overexploitation of natural resources by grazing and domestic use (Fig. 8).

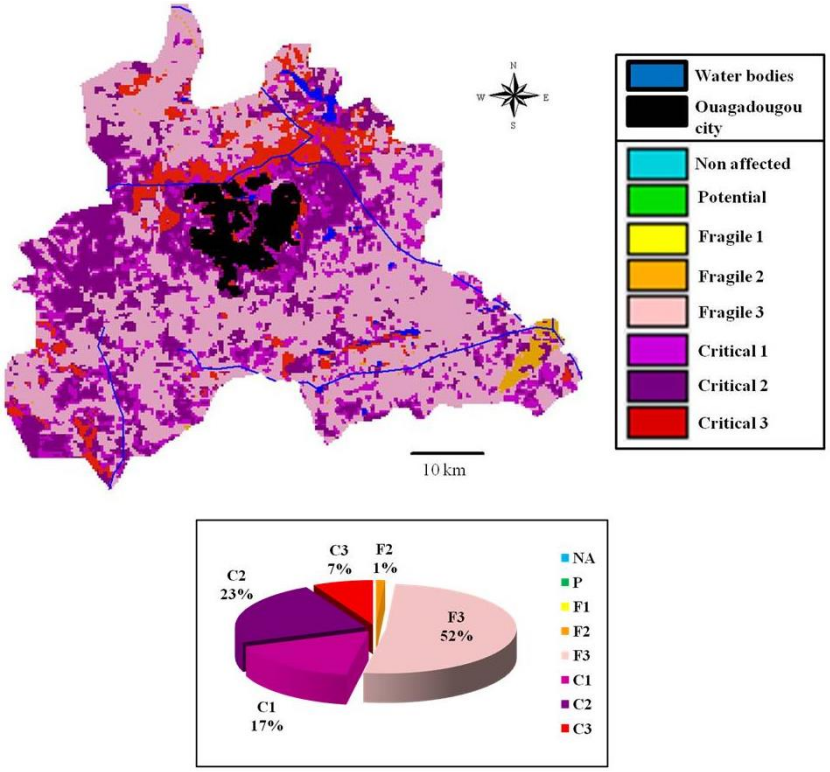


Figure 7. Ouagadougou desertification risk

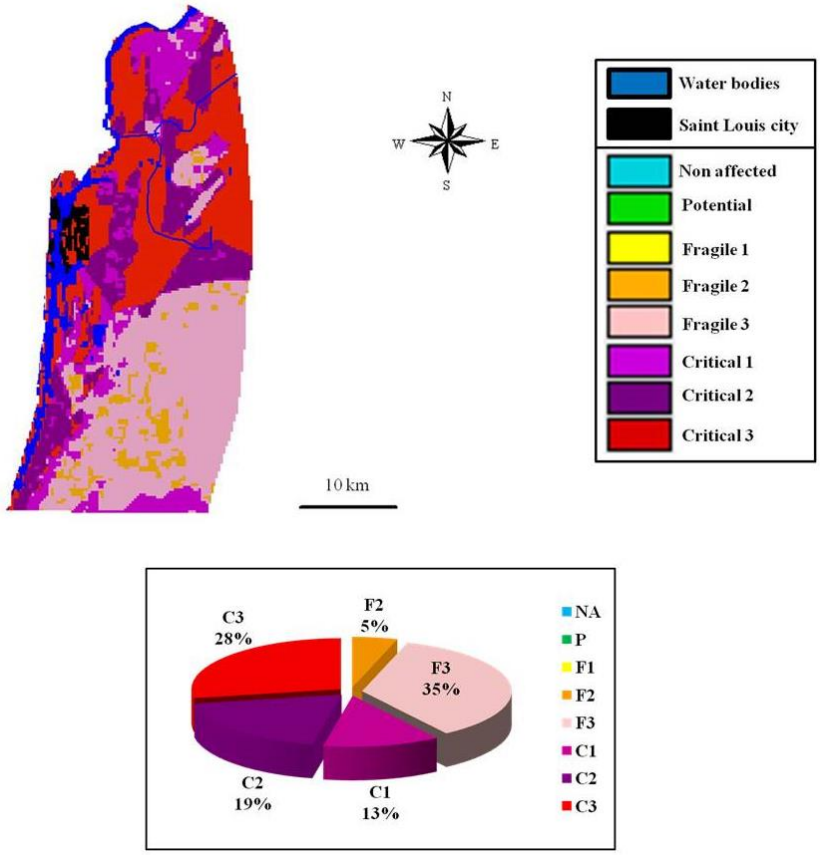


Figure 8. Saint Luis desertification risk

✓ *SHORT-TERM ACTIONS TO FACE VULNERABILITY OF INFRASTRUCTURES*

Vulnerability of urban infrastructures in African cities represents a main issue for urban development, due to poor infrastructural systems and due to extreme events threatening cities, exacerbated by climate change. In particular, in CLUVA attention was focused on stormwater systems and road systems, whose vulnerability represents a main concern.

The authorities of the five test cities can now take advantage of the following guidelines and recommendations developed in CLUVA to define a quantitative planning of risk mitigation:

- ***Guidelines on engineering design and management of storm water systems***
- ***Guidelines for reliability analysis of roadway network including procedures for emergency response management***

✓ *MULTI-RISK ASSESSMENT TOOL*

The multi-risk concept refers to a 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 and 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 the multi-risk problem is associated with, CLUVA has developed a multi-risk framework involving 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 9 shows the two levels of multi-risk assessment developed as the general framework for the CLUVA project.

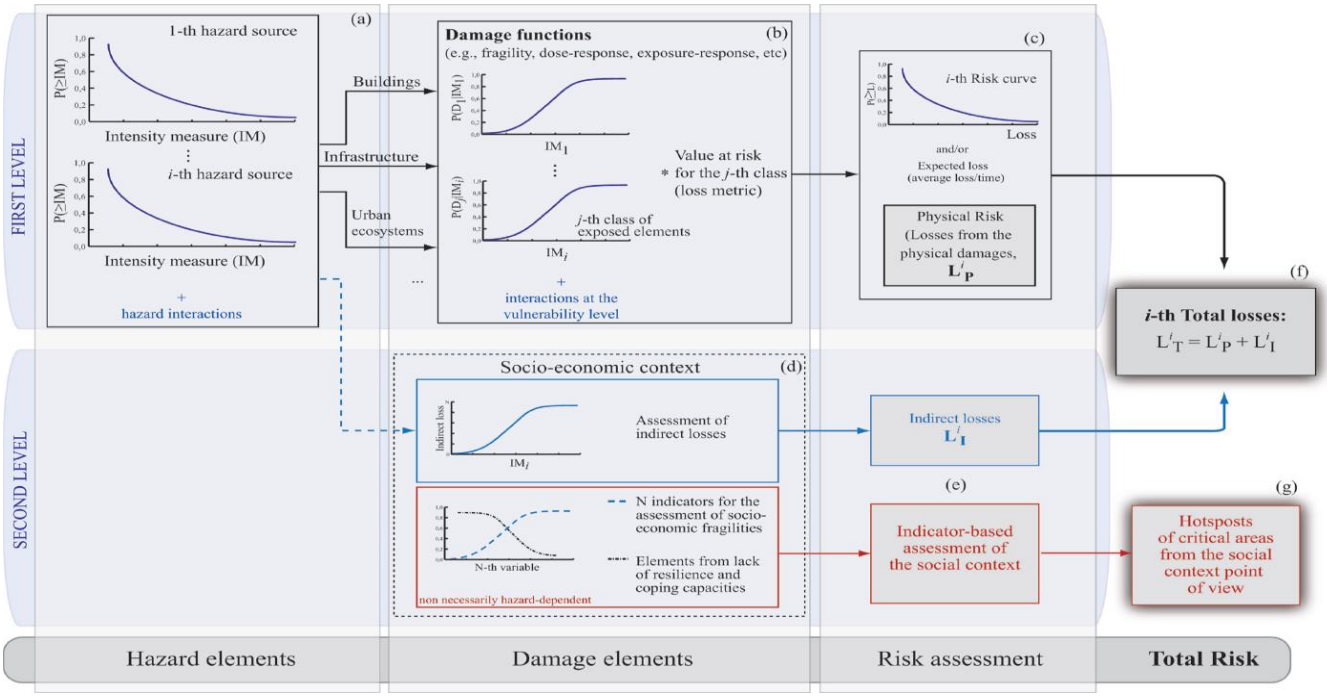


Figure 9. Schematic representation of the two levels of risk assessment for the CLUVA project

This framework has also been translated into a web-based system to perform the related multi-hazard and multi-risk calculations. This 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 (Fig. 10).

MASAI can provide outputs in terms of

- loss exceedance curves and expected annual losses (or consequences) that can be used for comparing and ranking the risks, and assessing the effects of different risk mitigation options

- maps identifying hotspots of critical socio-economic contexts

CLUVA has applied the proposed multi-risk analysis tool to a pilot area in Dar es Salaam demonstrating that decision-makers can take advantage of this web-platform to perform cost/benefit analysis and to decide where and how to operate more effectively considering the available resources!

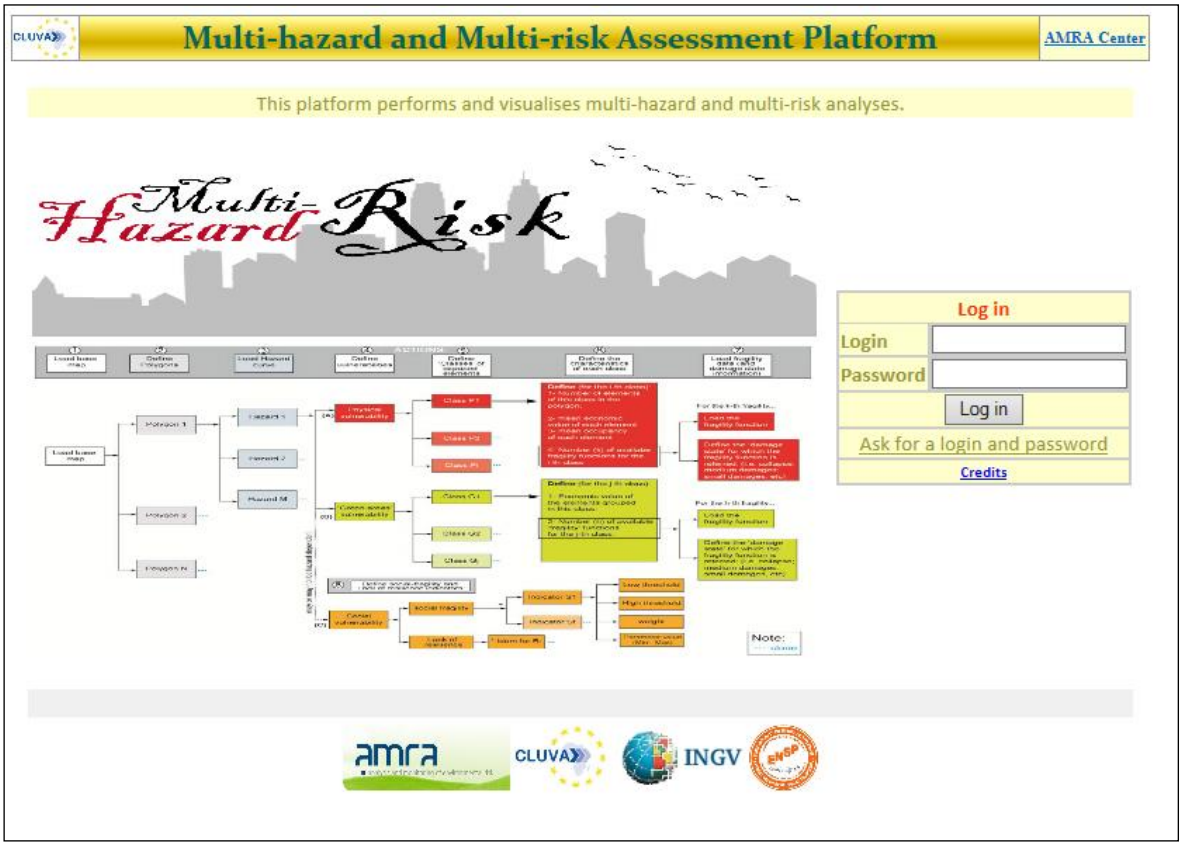


Figure 10. The MASAI web-tool developed in CLUVA

✓ *LOW-COST MEASURES FOR REINFORCING ADOBE HOUSES*

Informal settlements are particularly vulnerable to flooding due to a generally low quality of construction. Several areas of high flood susceptibility have a high concentration of informal settlements.

CLUVA has demonstrated that it is possible to upgrade the houses conditions in these at-risk settlements also through low-cost measures.

The risk mitigation strategies proposed by CLUVA 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 (Fig. 11).

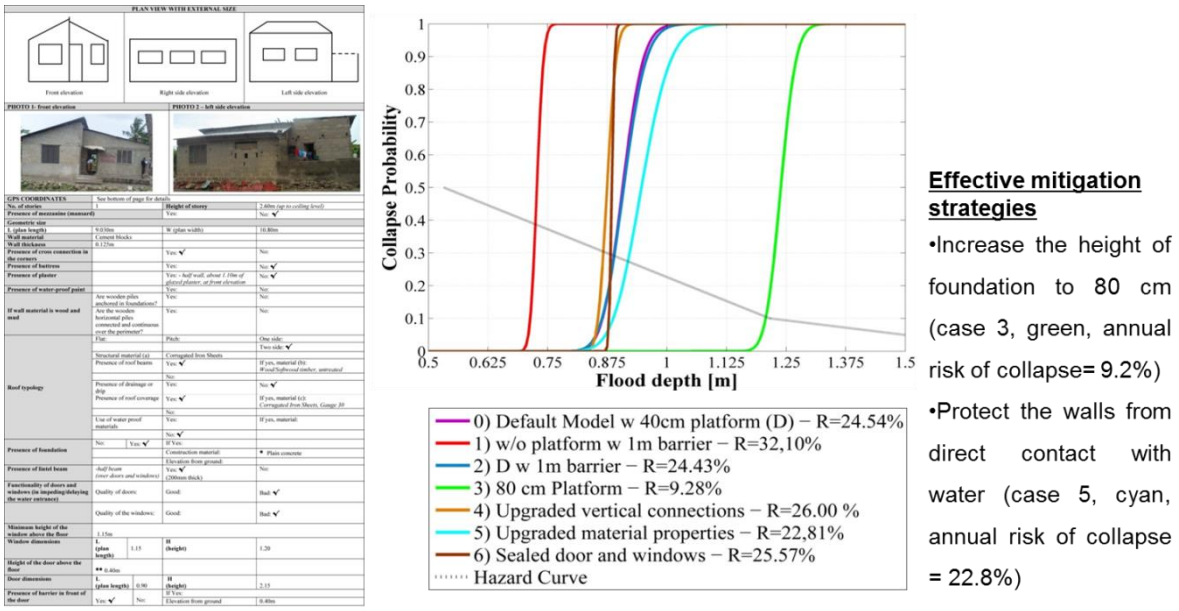


Figure 11. Adaptation strategies for informal settlements: building made of cement and bricks

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.

To support decision makers in detecting areas threatened by flooding risk, CLUVA developed VISK, a tool allowing to put together probabilistic, vulnerability and risk assessment modules for flooding in order to generate detailed (microscale) risk maps for building stocks (Fig 12).

VISK reports results both in terms of building vulnerability (i.e., fragility curves) and point-wise risk estimates (i.e., expected costs, expected number of people exposed, etc.). The output of this software is produced in the GIS-compatible format. One of the advantages of VISK is that it can be used also by non-experts in the GIS environment.

A two class map has been produced to show safe and unsafe areas in relation to flooding in test areas in Addis Ababa, Ouagadougou and Dar es Salaam. These provide a useful way for local decision-makers to identify residential areas at risk and also to identify suitable construction sites for future.

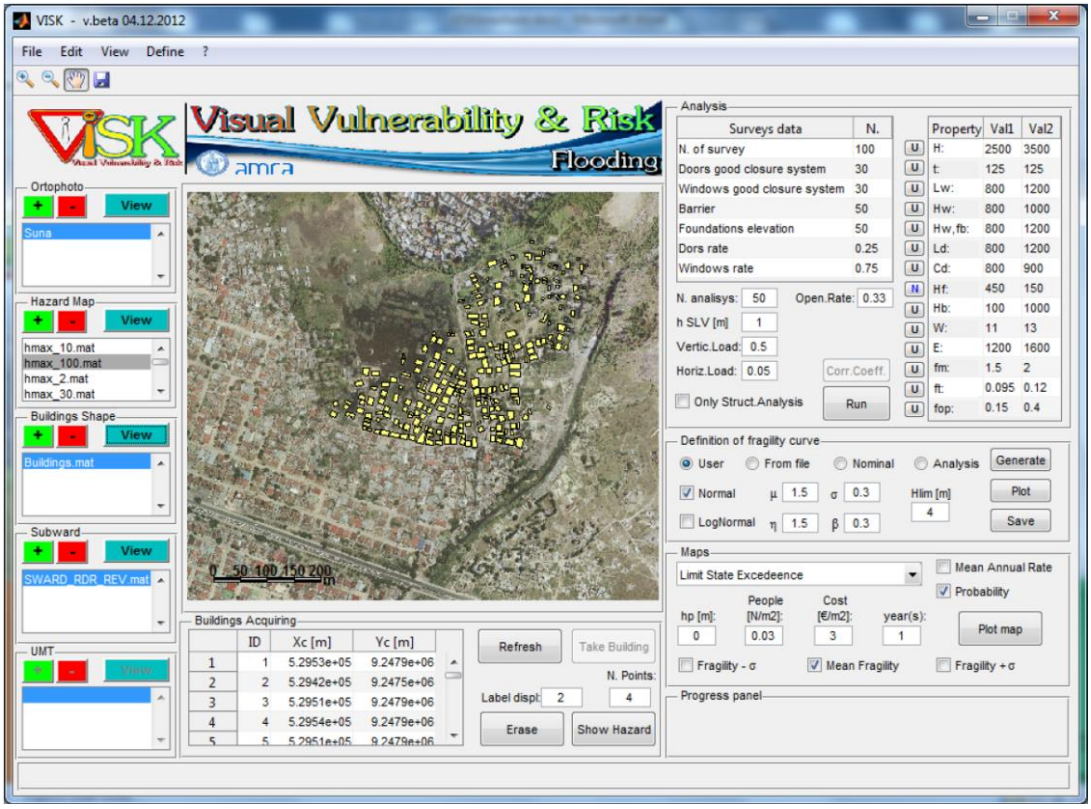


Figure 12. VISK – Visual Vulnerabiltiy and Risk

Decision makers can also take advantage of the following guidelines developed in CLUVA:

- ✓ ***Guidelines for vulnerability assessment and reinforcement measures of adobe houses***

- ✓ ***IDENTIFICATION OF FLOODING RISK HOTSPOTS: A FUNDAMENTAL STEP IN URBAN PLANNING AND RISK MANAGEMENT***

Flooding risk hot-spots are zones with a high probability to be exposed to flooding. The delineation of urban hot-spots provides information for policy makers and can also be useful as supporting information for indicating future urban dynamics and trends for researchers.
CLUVA has developed a GIS-based framework for the delineation of flooding risk hot-spots based on 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).
Thanks to CLUVA flooding risk hot-spots maps are now available for the cities of Addis Ababa and Dar es Salaam!
These maps provide a quick screening tool for the local 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 of 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.

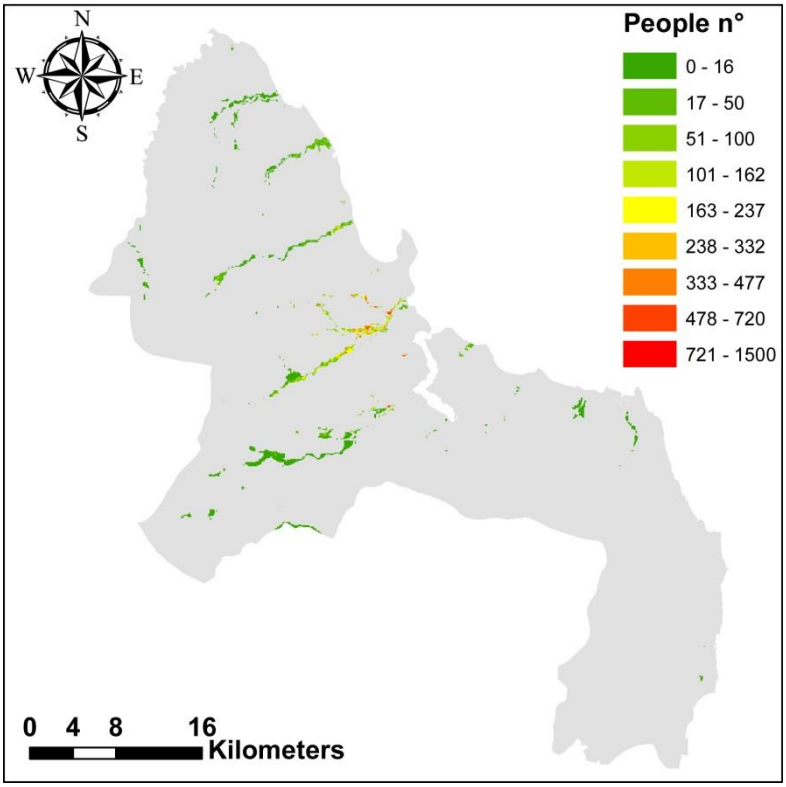


Figure 13. The urban residential hot-spots for flooding in Dar es Salaam

✓ *A MULTIPLE DIMENSION FRAMEWORK TO ASSESS SOCIAL VULNERABILITY TO FLOODS*

The term "social vulnerability" in CLUVA refers to "the ability of an actor to anticipate, cope with and recover from the impact of a hazard".

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 concern 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; 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 CLUVA has considered the core elements of vulnerability to include:

– 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.

Assessing social vulnerability requires considering contextual circumstances. Therefore CLUVA has developed a new framework to assess social vulnerability highlighting and interlinking relevant factors/indicators encompassed in four key dimensions as shown in Figure 14:

– 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.

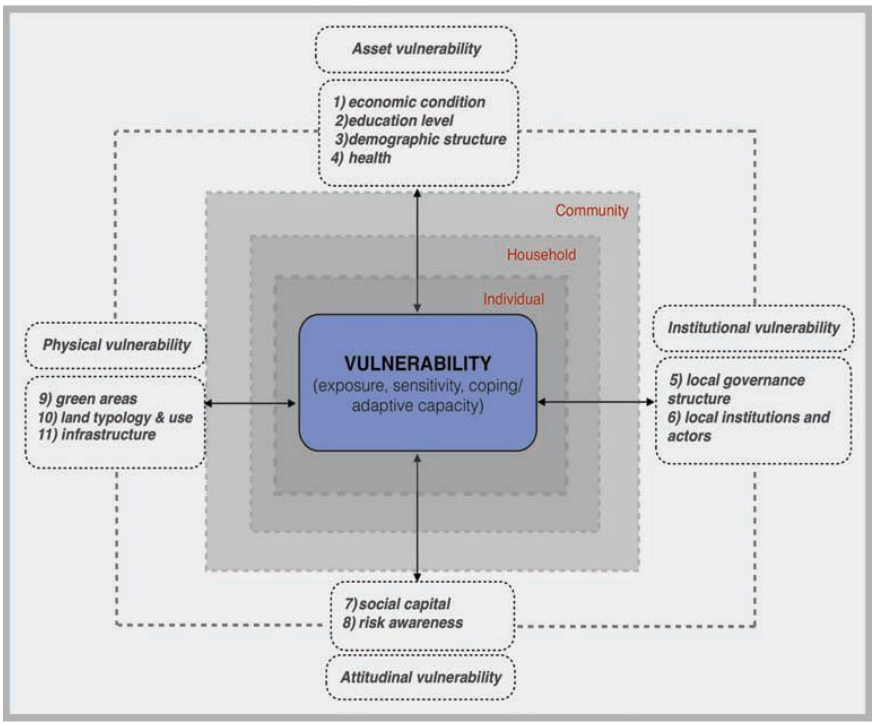


Figure 14. CLUVA framework for assessing social vulnerability

✓ *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.

CLUVA has mapped these "green" structures in five test cities using a specially developed land classification system based on 'urban morphology' types. Data are already being actively used for city planning in Addis Ababa.

These 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 by CLUVA to estimate changes in surface temperatures as a result of land cover and climate change. It has shown that both climate change and urban development alter surface temperature, but land surface cover differences are associated with land surface temperature ranges of more than 25°C whereas the range for climate change projections is less than 1.5°C. Therefore in terms of local temperature change, urban morphological change has the potential to have a much greater effect overall than temperature increase due to climate change. Increasing green structure cover in the 'urban matrix' is likely to considerably offset climate change induced increases in temperature. Green structures also provide other temperature regulating benefits for urban residents, including shade and the provision of cool air corridors, neither of which is considered in the model.

In addition the basic sensitivity – or susceptibility to damage – of horticultural and field crops 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.

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.

The following priorities themes for green infrastructure planning have been identified by CLUVA:

- Green infrastructure planning should develop a comprehensive vision of the urban green structure based on sound evidence of its character, the ecosystem services it provides and its dynamics to develop locally adapted strategies for protection of existing assets and improvement where deficits exist. Areas prone to impacts from hazards such as flooding, landslides, storm surges, local flooding after rainstorms and where temperatures are elevated due to the heat island effect should be prioritised, especially where these hazards coincide with high population densities. It is suggested that the methodological approach developed and applied in this research is suitable for developing a comprehensive approach to green infrastructure planning.
- Adopting a compact urban development strategy is a prerequisite for safeguarding the present and future green structure and its ecosystem services. However, densification still needs to ensure that there is an adequate supply of green areas and green cover so that the needs of the urban population can be properly met. This is particularly important for residential/community areas.
- Maintaining green space within cities and increasing it where necessary is a priority. For example, this could include protecting productive areas near to where people live, reducing stormwater runoff, and moderating the negative impacts of the heat island effect.

- River corridors should be protected and rehabilitated where necessary as the multifunctional green backbones of the urban green structure. In the case study cities, they are increasingly built over by informal settlements, thus exposing more and more people to flooding and pollution. These trends need to be halted and reversed.
- Moreover, protection of the remnants of natural areas such as the mangrove forests in coastal cities is vital for reducing risks from hazards such as storm surges but also for carbon sequestration and, not least, for the protection of biodiversity.
- Urban agriculture and urban forestry are key priorities for securing survival of the fast growing population in African cities. Urban agriculture has a range of different forms, from growing vegetables in the backyard or keeping a few animals on small commons within informal settlements, to cooperative and commercial farming in peri-urban areas. All of these activities are highly important for the subsistence of the urban population, but they sometimes face great difficulties such as unsecure land tenure and lack of means for improving production. Similarly, urban forestry should be promoted (e.g. for producing timber, energy and environmental benefits). Large trees are a valuable resource for climate change adaptation.

Practitioners can take advantage of the following guidelines in order to repeat the methods used in CLUVA:

✓ ***Green infrastructure: An essential foundation for sustainable urban futures in Africa.***

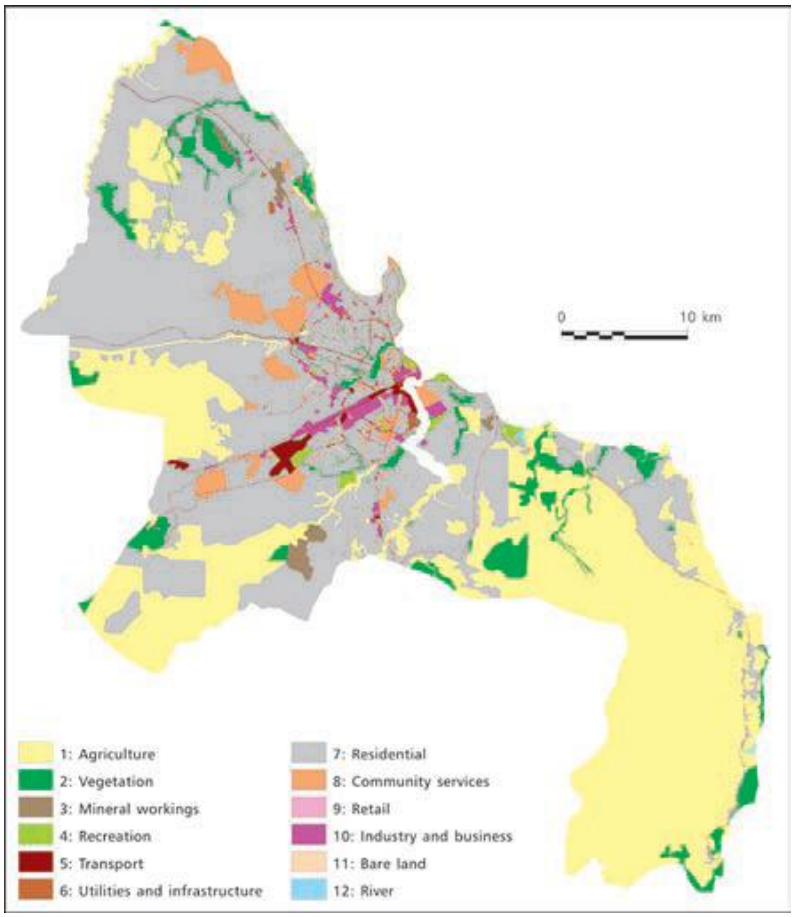


Figure 15. Urban morphology types in Dar es Salaam

✓ *GOVERNANCE STRATEGIES AND POLICIES*

CLUVA has explored the possibilities and barriers for getting climate change on the agenda and into city planning, pointing to needed measures and searching for the momentum in order to point to the most realistic measures and a possible starting point from where to proceed with making the cities more resilient.

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. 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 have suggested 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.

✓ *CLUVA RECOMMENDATIONS: A CHALLENGE FOR THE FUTURE*

The vulnerability of developing countries, particularly those located in Sub-Saharan Africa, is "dynamically complex" because related to a combination of socio-economic, physical and environmental factors rapidly changing in a growing urbanisation. In this context, even small hazardous events can strongly affect the urban environment causing serious impacts because the high vulnerability enhances their effects. Consequently climate change could play a role as an aggravating factor of a situation already highly vulnerable.

The crucial issue is therefore to act to reduce the vulnerability of African cities to climate related hazard, in order to foster the resilience of urban areas to climate change.

In order to enhance resilience of African urban areas to climate change, data and information gaps need to be filled to support research activities on climate change impacts. Furthermore specific measures should be used to promote urban governance systems able to drive a city-wide institutionally-led adaptation effort to climate change.

Based on the research activities performed for its test cities, CLUVA has produced specific recommendations on data needs and governance strategies to enhance resilience of African urban areas to climate change:

❖ ***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:***

- 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

The potential impact (including the socio-economic impact and the wider societal implications of the project so far) and the main dissemination activities and exploitation of results

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.

Several methodologies developed in CLUVA are innovative; in particular, those aiming at an integrated probabilistic multi risk framework of urban vulnerability including harmonized hazard assessment, the multi facets aspects of vulnerability and social components. A special care has been devoted to vulnerability assessment. The approach followed in CLUVA has considered vulnerabilities related to the physical, social, economic and eco-systems related characteristics of urban areas. This has considered development and climate related threats, including some retrospective and prospective analyses of change and its impact. Through the application of this innovative approach, CLUVA has provided researchers and governments of African cities with information on "outcome vulnerability", as considered in the climate change community, and "contextual vulnerability", as considered in the hazard and disaster community and in the social sciences.

Scientific and technological innovation of African institutions have been pursued by assisting with the application of methodologies to make them locally relevant, implementing tools and giving guidelines to improve the observation of the parameters needed for the improvement of reliability of climate change related hazards and vulnerabilities.

In response to the assessed climate vulnerabilities and risks, CLUVA has also formulated innovative urban planning and land use strategies to help African cities to manage climate risk, to reduce vulnerability and to improve coping capacity and resilience towards climate change. Both general and specific recommendations have been developed which are supported by local evidence drawn from the development of new qualitative and quantitative datasets, associated spatial analyses and scenario modelling.

The innovative methodologies adopted for the 5 test cities, both for the climate change vulnerability assessment, and for definition of new governance strategies, aim at providing policy makers with tools for the development of urban structures resilient towards climate change. Capacity building has been fostered at local level for sustainable African cities development, linking adaptation and risk mitigation measures and providing the basis for improving livelihoods and quality of life for the urban population.

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:

1. Build up of research groups of excellence in five African countries. These groups are now part of a critical mass for climate change research on the continent.
2. Improvement in significant ways of the capacity of European partners to work in the African context. Thus, as a major outcome, the project has developed a network of competence of European research organisations on climate change adaptation in Africa which will continue to contribute to research and capacity building in Africa after the end of the project.

3. PhD students have significantly contributed with new knowledge and tools to mitigation of and adaptation to climate change in African cities. The training of these young researchers has been at the heart of CLUVA.
4. Development of curricula for postgraduate studies at African universities which has generated highly qualified African students.

The dissemination and exploitation of the CLUVA results has been ensured by several mechanisms built into the project structure as the Climate Web Portal, the official project website and one Work Package completely devoted to capacity building and dissemination. Results have been communicated in technical and non-technical forms to build capacities in the research and stakeholder communities respectively. With this aim several deliverables have been produced in the form of guidelines or research briefs, for example del. 4.5 "Research briefs/work books, study guides, screen casts", del. 2.17 "Report describing the developed methods and its possible relevance for planning and decision-making" and del. 2.10 "Evaluation of the potential of urban ecosystem services".

These mechanisms have been the main tools enabling CLUVA to achieve 3 important objectives:
1. to disseminate the CLUVA results to the scientific community;
2. to improve the capacity of policymakers and city-administrators to face climate related disasters. The direct beneficiaries of this effort are stakeholders in the CLUVA case study cities. However, many methods, tools and guidelines are applicable to other cities facing similar pressures;
3. to strengthen research capacity of the climate change related issues that CLUVA covers in the African universities involved and in the scientific community of Africa in general, and specifically to train rapidly a critical mass of researchers and University teachers.

In order to pursue the above mentioned objectives CLUVA has developed a program of outreach activities in order to provide information to the wider public. One of the main instruments for this has been the Project Web-site (http://www.cluva.eu) which is active since the beginning of the project and is receiving an average of about 9500 visits per month.

a) CLUVA and the Scientific Community

The CLUVA achievements were and will continue to be presented to several international meetings of climatology, civil engineering, sociology, geography, geophysics, governance and urban planning.
A special session on climate change impacts on urban areas was organised by CLUVA at the General Assembly of the European Geosciences Union in April, 2013.
More and more frequently, in several non-European contexts CLUVA is addressed as a qualified European group of researchers active at the frontier of knowledge about climate change and its impact. For instance, the participation of CLUVA representatives to present the results achieved in Africa was specifically asked by the organisers of the Radcliffe Seminar – Harvard Humanitarian Initiative at the Harvard University on "Climate Change and Rapid Urbanization: Crossroads of a Disaster", December, 2011.
The contributions of CLUVA have relevant part on scientific journals, as Natural Hazards (De Risi et al., 2013), special issues of Ecological Indicators (Cavan et al., in press), Water SA (Engelbrecht et al., 2011) and of an incoming Springer book on climate change and urban vulnerability in Africa.

CLUVA has collaborated closely with the FP7 MATRIX project on the themes of implementation of Multi-risk maps and the development of web-tool to implement multi-risk procedures.
An interchange of information is also occurred with another European project dealing with vulnerability to natural hazards, particularly with the FP7 CATALYST project, through the participation to common workshops. CLUVA has also directly led to new research funding, for example work in Addis Ababa and Dar es Salaam funded by the Danish and UK research councils.

b) CLUVA and the Policymakers/City-administrators

The main vector to disseminate the CLUVA results at political level has been the liaison between CLUVA and UN-Habitat.
In fact, a MoU between CLUVA and UN-Habitat was signed for providing a framework of cooperation in activities focused on:

- Enhancing Urban Education with particular emphasis on climate change;
- Improved urban climate change research capacity,
- Policy advice, knowledge Management and Awareness

Thanks to this cooperation CLUVA has been presented to a vast public during the UN-Habitat 6th World Urban Forum, held in Naples on September 2012, where CLUVA representatives have been also invited to present the main project's result during several networking events.
Policymakers and city-administrators from the five CLUVA test cities have been invited to take part to the local/technical workshops held in the cities during the project and to the final international meeting held in Addis Ababa at the African Union Headquarters where the main project's outcomes have been presented.
A dedicated high-quality brochure has been produced for the local stakeholders in order to describe the main project products and summarise the results from the applications to the five test cities.

c) CLUVA and the African researchers

CLUVA strengthened the research capacity at the African partner cities and started building a critical mass of researchers in climate change issues relevant to CLUVA. This was done by working in African-European teams. Research was conducted cooperatively and resulted in many publications produced by heterogeneous research teams. This process was supported by the early organization of four training schools.
The first school was held in Naples, Italy, October/November 2011 and focused on mathematical modelling mathematical modeling for probabilistic risk and multi-risk assessment. The second training schools was held in Leipzig in December 2011 and focused on "Urban Participatory Climate Change Adaptation Appraisal Methodology, Social Vulnerability, Institutions and Governance". The third training school was held in Munich, April 2012. This training school focused on the ecological assessment of urban morphology types. The fourth training school was organized by Copenhagen University in November 2012 and addressed strategic thematic aspects such as planning, pluricentric coordination, multi-level governance and stakeholder involvement processes. Additional training sessions have been held, including in other partner institutions (University of Manchester) and in most of the case study cities.
Six teaching modules on Master's level have been also developed and summarized under the umbrella of UN Habitat's Cities and Climate Change Academy (CCCA). These modules were worked out in constant and close cooperation with all CLUVA partner universities in order to enrich their curricula by the desired Climate Change-relevant contents in a flexible and cost-efficient, thus sustainable manner.

CLUVA developed new knowledge related to climate change and vulnerability as well as skills to mobilize the knowledge, know-how and behaviours to face climate change and climate change adaptation strategies. CLUVA was very successful in developing a self-sustained capability to access and leverage climate change research data and knowledge by installing new educational approaches to transfer knowledge at all stakeholders regardless of the prerequisites mentioned.
In total, 14 PhD students started their work as part of CLUVA. Three theses have been already submitted and the remaining students are mostly close to concluding their work within the next months. In addition, 14 Master theses on topics related to CLUVA have been elaborated. Coordinated supervision from African and European researchers has ensured the high quality of the various theses.