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Final Report

Linthipe and Lingadzi River System Study
Central Region River Basin, Malawi

Lilongwe, Malawi
Salzburg, Austria
29/02/2012

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The Linthipe and Lingadzi River System Study involved wide consultations with key governmental, UN and non-governmental stakeholders at both national and district level in Malawi.

Without the precious advice, input and support of these stakeholders and various experts, this report would not have been possible. Therefore, the consultants would like to express their gratitude to all those who contributed to this study with their expertise and knowledge.

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Acronyms	
CC	Climate Change
CCA	Climate Change Adaptation
COOPI	Cooperazione Internationale
CPC	Civil Protection Committee
DoDMA	Department of Disaster Management Affairs, Malawi
DoDMA TC	Department of Disaster Management Affairs – Technical Committee, Malawi
DEM	Digital Elevation Model
DFO	Dartmouth Flood Observatory
DIPECHO	Disaster Preparedness ECHO
DRR	Disaster Risk Reduction
DRM	Disaster Risk Management
EA	Enumeration area
ECHO	European Community Humanitarian Office
EPA	Expanded Plan Area
ENSO	El Niño-Southern Oscillation
EWS	Early Warning System/s
F-EWS	Flood Early Warning System
FP7	Seventh Framework Programme
GCM	Global Climate Model
GPS	Global Positioning System
GPWv3	Gridded Population of the World
GVH	Group Village Headmen
IPCC	International Panel for Climate Change
IWRM	Integrated Water Resources Management
LRC	Land Resource Centre
LULC	Land use land cover
MOVE	Methods for the Improvement of Vulnerability Assessment in Europe (EC FP7 research project)
NDVI	Normalized Difference Vegetation Index
NGO	Non-governmental organisation
NSDI	National Spatial Data Infrastructure
NSO	National Statistical Office, Malawi
SDI	Spatial Data Infrastructure
TA	Traditional Authority
UNISDR	UN International Strategy for Disaster Reduction
USGS	United States Geological Survey
VNRMC	Village Natural Resource Management Committees
Z_GIS	Centre for Geoinformatics, Paris-Lodron University Salzburg (PLUS), Austria

Table 1: Abbreviations

For a **glossary** of terms please refer to the terminology developed by the UN International Strategy for Disaster Reduction (UNISDR): http://www.unisdr.org/we/inform/terminology.

1 INTRODUCTION

1.1 General background

A range of natural hazards threatens lives and development. Climate extremes, exposure, and vulnerability are influenced by a wide range of factors, including anthropogenic climate change (CC), natural climate variability, and socioeconomic development. The character and severity of adverse impacts are considered disasters when they produce widespread damage and cause severe alterations in the normal functioning of communities or societies (IPCC 2011). Disaster risk management and adaptation to climate change focus on reducing exposure and vulnerability, and increasing resilience. Even though risks cannot fully be eliminated, by understanding and anticipating future hazard events, communities, public authorities and development organisations can minimise the impact of disasters. Failure to do so can be highly damaging to development programmes and projects. Yet development planners often fail to consider the threat of natural hazards sufficiently, and hazard and disaster risk management is often carried out independently of development activity. Even where hazards are taken into account, proper assessments are often thought to be too costly and time-consuming (Provention 2007).

Programme and project planners and managers should understand the characteristics, location, frequency and magnitude of hazards and their potential impact on property and people. They should understand which hazards present a risk in the places where they work and the main characteristics of those hazards. They do not need to be hazards specialists, though they may need to work alongside them and, therefore, should know how to identify and contact experts in this field.

The concept of vulnerability in disaster risk management (DRM), disaster risk reduction (DRR) and climate change adaptation (CCA) research is underpinned by multiple disciplinary theories based upon natural or social science epistemologies. Many assessment approaches characterize vulnerability by the degree of susceptibility or fragility of communities, systems or elements at risk and their capacity to cope under hazardous conditions.

In the context of this study the consultants underline the importance of investigating and understanding vulnerability in order to comprehend risk and to develop appropriate adaptation strategies. Hazards which might trigger and reveal vulnerability and disaster risk, can be of natural or socio-natural origin, while the vulnerability in its multi-faceted nature is mainly linked to societal conditions and processes, however, acknowledging that both elements, (natural) environment – including hazards - and society, coexist and are characterized by constant interactions among them (MOVE 2010).

Malawi, located in Southern Africa, is influenced by a high variable climate. This is on one hand characterised by the regional climate conditions, but also influenced by the ENSO which results in frequent recurrent droughts and floods and strong inter-annual and -seasonal climate fluctuations. According to statistics available from Prevention Web[1] (see Fig. 1) the highest number of natural disasters in the past (1980-2010) includes floods, epidemics and droughts. Major flood events occurred in the years 2007, 2002, 2001 and 1997, whereas especially (i) the Shire basin in the Southern region towards the Zambezi and (ii) the river catchments in the Central region had been affected most.

[1] See http://www.preventionweb.net/english/countries/statistics/?cid=104

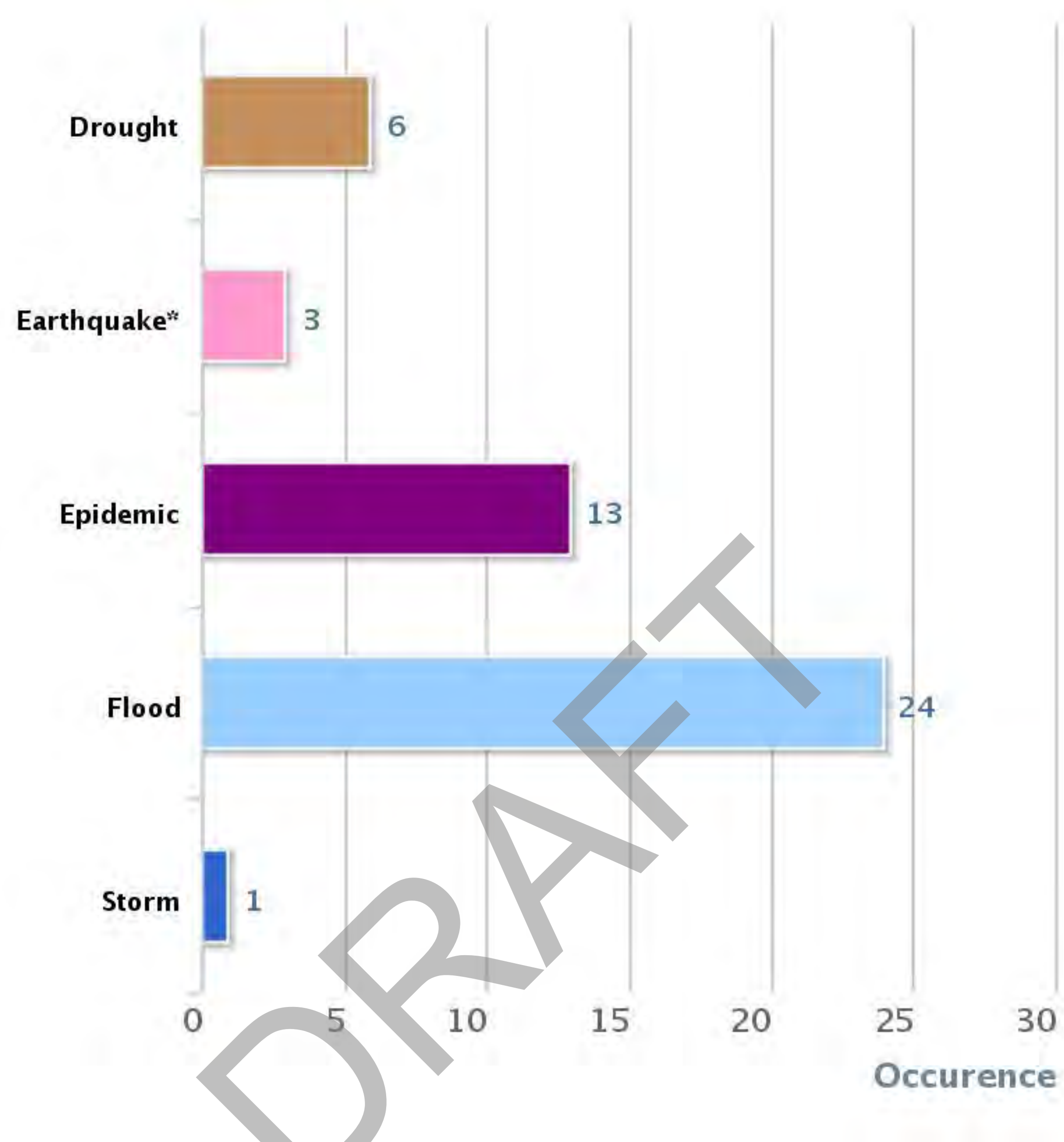


Figure 1: Natural Disaster Occurrence Reported for Malawi (1980-2010; Source: PreventionWeb)

1.2 Climate change scenarios relevant to Malawi

The Copenhagen Diagnosis of 2009, designed as an update on the IPCC's fourth assessment report (Christenesen 2007), identified the potential for a temperature rise by 2100 of as much as 7ºC if there were no action to cut emissions. Newly emerging science is in many ways pointing to so-called ‘tipping points’ - sudden and perhaps irreversible changes accompanied by feedback mechanisms. Both observations reinforce the need for planning adaptation measures in good time.

Concerning food security, temperature rises alone may be more severe in impact than previously thought. A paper this year in Nature Climate Change (Lobell et al. 2011), has tapped previously unused data from more than 20,000 maize trials in Africa. It has concluded that roughly 65% of present maize-growing areas in Africa would experience yield losses following a 1ºC warming, even under optimal rain-fed management.

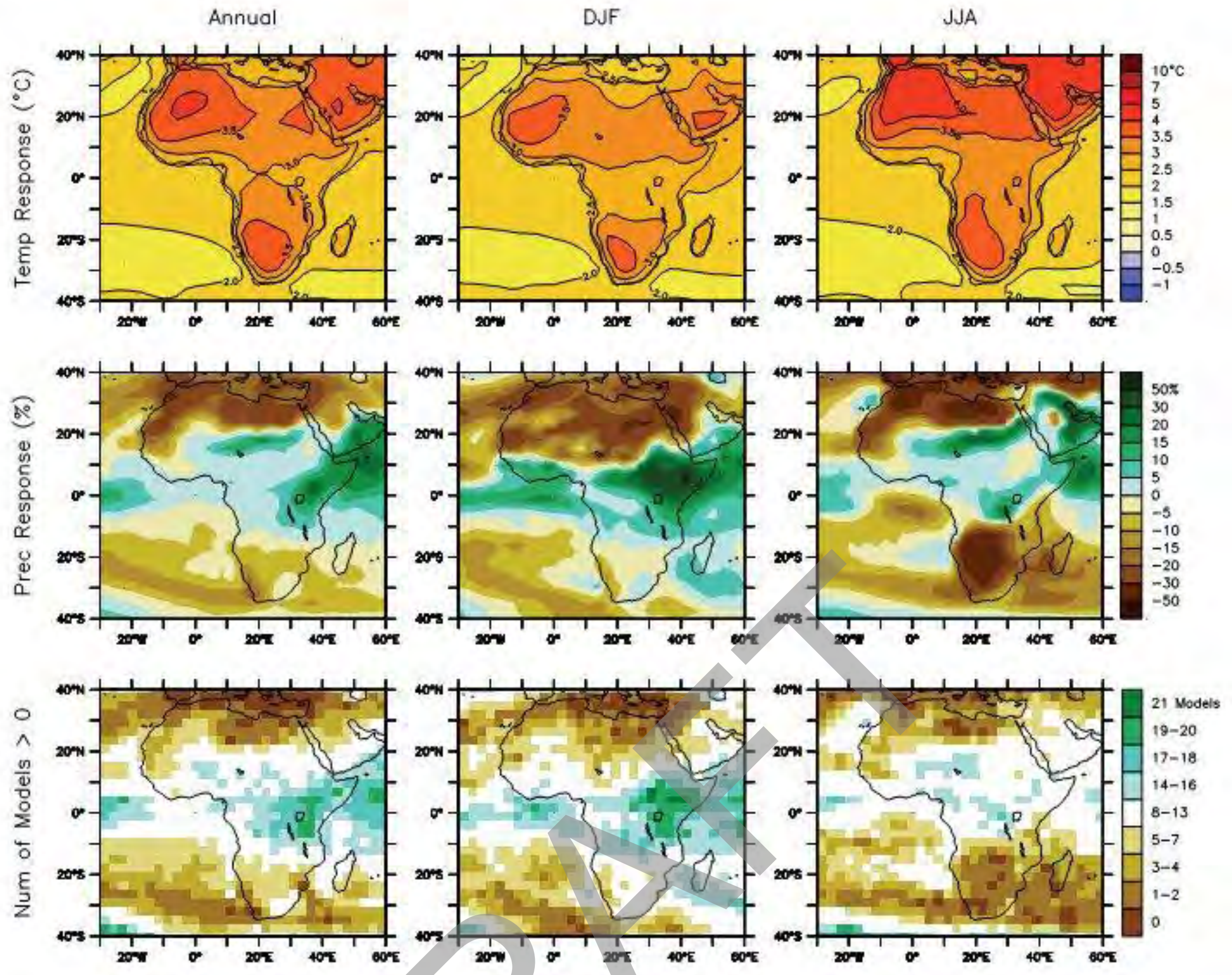


Figure 2: Temperature and precipitation changes over Africa from the MMD-A1B simulations. Top row: Annual mean, DJF (December, January, February) and JJA (June, July, August) temperature change between 1980 to 1999 and 2080 to 2099, averaged over 21 models. Middle row: same as top, but for fractional change in precipitation. Bottom row: number of models out of 21 that project increases in precipitation (Christenesen 2007; see also Hewitson 2006). Note: summer rainfall predictions are specifically heterogeneous for Southern Africa including Malawi.

In Southern Africa, the frequency of extremely dry winters and springs increases to roughly 20%, while the frequency of extremely wet summers doubles in this collective model. To an extent, this can be thought of as a delay to the onset of the rainy season. This spring drying, suppresses evaporation, contributing to the spring maximum in the temperature response.

The key responses to reduce the likely impact of these climate scenarios (Fig. 2) are the adoption of mitigation measures to address one of the causes of the change, which is the increase of greenhouse gas emissions, and planning adaptation measures. Many experts however argue that climate change will aggravate or amplify existing security concerns and give rise to new ones, especially - but not exclusively - in already fragile and vulnerable nations.

Natural disasters
"Sudden natural disasters" displaced some 42 million people in 2010. Many millions of people are also displaced annually as a result of climate-related, slow-onset disasters such as drought" (iDMC 2010).

Key impact dimensions related to hydrology and water resources
State: Of the 19 countries around the world currently classified as water-stressed, more are in Africa than in any other region - and this number is likely to increase, independent of climate change, but as a result of increases in demand resulting from population growth, degradation of watersheds caused by land-use change and siltation of river basins.

Change: The reduction in precipitation projected by some global climate models (GCMs) for the Sahel and southern Africa - if accompanied by high inter-annual variability - could be detrimental to the hydrological balance of the continent and disrupt various water-dependent socio-economic activities.

Adaptation options include water harvesting, management of water outflow from dams and more efficient water usage.

1.3 Conceptual framework for vulnerability assessment

Risk reduction to hazards of natural origin is a major challenge at present and in future regarding global environmental change. It is increasingly recognized that natural hazard induced risk and threats to human security cannot be reduced by focusing solely on hazards. Societies will have to live with changing environmental conditions and therefore they need to build resilience by reducing vulnerabilities to natural hazards. Against this background a conceptual framework (cp. Fig. 3) that addresses vulnerability and risk to natural hazards from a holistic and multidimensional point of view has been developed by the EC FP7 research project MOVE (Methods for the Improvement of Vulnerability Assessment in Europe; www.move-fp7.eu).

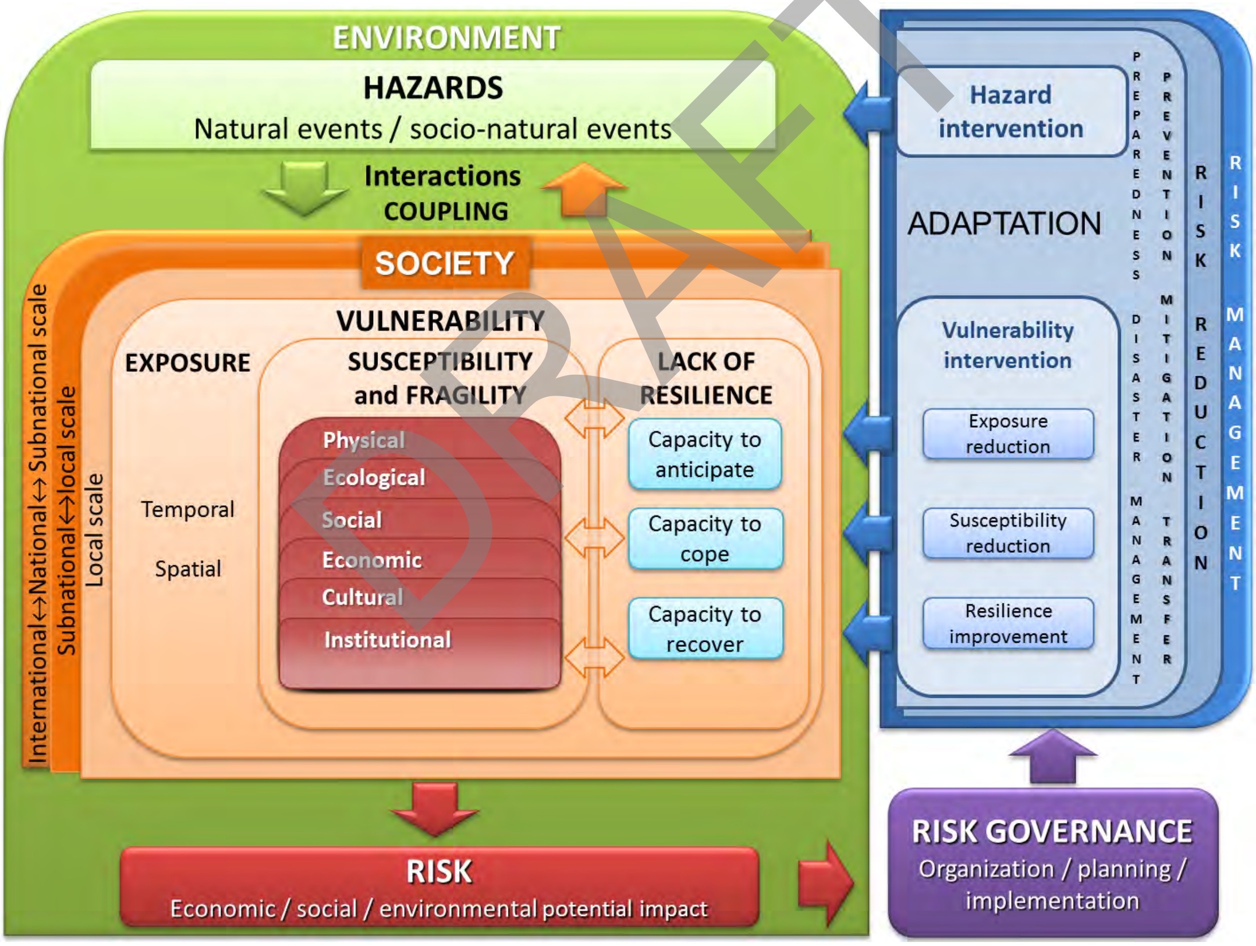


Figure 3: MOVE conceptual framework.

A key goal when developing the MOVE framework was to provide an improved conceptualization of the multi-faceted nature of vulnerability, accounting for key causal factors, such as exposure, susceptibility/fragility and lack of resilience characterised by different dimensions of vulnerability such as the physical, social, ecological, economic, cultural and institutional dimension. The framework underlines that society and nature/environment are coupled through various linkages. Additionally, the framework incorporates the concept of adaptation into the context of disaster risk reduction, and by this explicitly differentiates coping from adaptation.

Overall, the conceptual MOVE framework underlines the importance of investigating and understanding vulnerability in order to comprehend risk and to develop appropriate adaptation strategies. Hazards which might trigger and reveal vulnerability and disaster risk, can be of natural or socio-natural origin, while the vulnerability in its multi-faceted nature is mainly linked to societal conditions and processes, however, acknowledging that both elements, (natural) environment – including hazards - and society, coexist and are characterized by constant interactions among them. Therefore, the society is also embedded into the broader context of environment (Birkmann et al. under review).

1.4 Scope and objectives

This study was carried out in the context of the European Community Humanitarian Office (ECHO) Disaster Preparedness Programme (DIPECHO) in South Eastern Africa to facilitate the implementation of the EU Strategy supporting Disaster Risk Reduction in developing countries. This Strategy commits the EU to integrate Disaster Risk Reduction (DRR) considerations more effectively into EU development and humanitarian policies. The DIPECHO programme has been designed to demonstrate measures and initiatives at community-level and can serve as components of integrated disaster risk reduction strategies for a municipality, district or even at national level. However, DRR is a long-term development effort; the challenge ahead is to ensure that disaster risk reduction becomes an integral part of sustainable development policy – in particular in countries at high risk.

Despite recurrent flood events in the Linthipe and Lingazi River basin, there are scattered and insufficient observational data available to support the Department of Disaster Management Affairs (DoDMA) and local stakeholders in assessing vulnerabilities and planning risk reduction measures.

Against this background this chapter provides an overview of the **objectives (OBJ)** and **sub-objectives (S-OBJ)** of the study conducted by COOPI and ZGIS in the central region river basin in Malawi from April to October 2011.

OBJ_1 To provide an overview of historic flood disasters in the Central River Basin focusing on the Linthipe and Lingadzi river systems

- S-OBJ_1.1 To examine and present an overview of floods with emphasis on those that occurred in the last 30 years,
- S-OBJ_1.2 To conduct a stakeholder analysis in order to summarize institutional arrangements and roles among key public, donors and NGOs stakeholder institutions in the Central River basin flood risk management with linkages to the overview of the floods (focusing on Lingadzi and Linthipe river systems).

OBJ_2 To undertake a hydrologic analysis and a flood modeling, including an overview of the extent and impact of catchment degradation, anthropogenic impacts and sedimentation

- S-OBJ_2.1 To compile and construct a database comprising (i) hydro-meteorological data, (i) current land use, (iii) land use changes, (iv) appropriate digital elevation and other information related to flooding in the Lingadzi and Linthipe rivers and its tributaries and present an overview of its adequacy and appropriateness for use in flood risk management,
- S-OBJ_2.2 To identify and model major floods,
- S-OBJ_2.3 To identify and characterize relevant socio-economic factors in the study area,
- S-OBJ_2.4 To describe the degree to which public and private interventions have an impact on flood risk in the study area.

OBJ_3 To provide an overview and to analyse the social and economic circumstances of stakeholders affected by flooding in the central river basin (focusing on Salima District)

S-OBJ_3.1 To review the interventions made by the Government of Malawi, donors, communities and NGOs in flood disaster risk reduction and recovery and to document their strengths and weaknesses,

S-OBJ_3.2 To assess the effectiveness and appropriateness of messages on flood warnings, evacuation and relocation appeals,

S-OBJ_3.3 To identify and to propose measures in order to improve the effectiveness of existing interventions.

OBJ_4 To propose specific flood disaster risk reduction (DRR) and recovery activities focusing on Linthipe and Lingadzi river systems

S-OBJ_4.1 To identify interventions and respective investments,

S-OBJ_4.2 To prepare and to analyse feasible development scenarios or alternatives,

S-OBJ_4.3 To scrutinize and to propose at least three alternative investment proposals from the scenarios above. The alternatives should address requirements that would (i) reduce the frequency and severity of flooding and (ii) mitigate the consequences of flooding, with each alternative proposal having its summarized background, objectives, expected post project outputs, activities and required inputs and budget.

1.5 Structure of the report

Following this **introduction**, providing information on (i) the general background, (ii) the MOVE conceptual framework for the integrated assessment of vulnerability and disaster risk, (iii) the scope and objectives of the study, **chapter two** gives an overview of the methodological approaches that were applied to collect, analyse and validate all relevant information and data. Besides providing detailed information on the study area and the datasets and materials used, the expert-based hazard mapping as well as the vulnerability assessment is described. Moreover, the chapter also includes a section where the key stakeholders involved in Disaster Risk Reduction (DRR) and Management (DRM) at both national and district level that have been consulted for semi-structured expert interviews are listed. Furthermore, major challenges that the consultants faced during the in-country assessment are also mentioned. **Chapter three** presents the major findings and results of the study. Building on that, **chapter four** proposes development scenarios, recommendations and intervention options how to approach flood risk and reduce vulnerability in the study area.

2 METHODOLOGY

This chapter provides detailed information on the **methodological approaches** and **methodologies** that were applied with regard to the aforementioned scope and objectives of the project. Building on the MOVE conceptual hazard, risk and vulnerability framework (cp. Fig. 3), figure 4 provides an overview of the overall methodological workflow of the project.

As a first step, a comprehensive flood modelling exercise (cp. chapter 2.3.2 and 2.3.3) was performed in cooperation with the geomer GmbH building on existing digital elevation data in order to generate information on areas exposed to flooding (hazard domain). At the same time, current land use land cover (LULC) properties, LULC changes (cp. chapter 2.4.1) and recent population dynamics (cp. chapter 2.4.2) were assessed for the past two decades (1990-2009/2010) using time series of freely available remote sensing and population datasets (vulnerability domain). The results of both the flood hazard and vulnerability assessment were then validated and refined based on expert interviews and in-situ measurements (cp. chapter 2.5). Finally, a stakeholder/expert workshop (cp. chapter 2.6) was conducted in Salima district, Malawi where the results of the previous work were presented and discussed in order to come up with development scenarios, recommendations and intervention options to foster disaster risk reduction (DRR) measures in the study area.

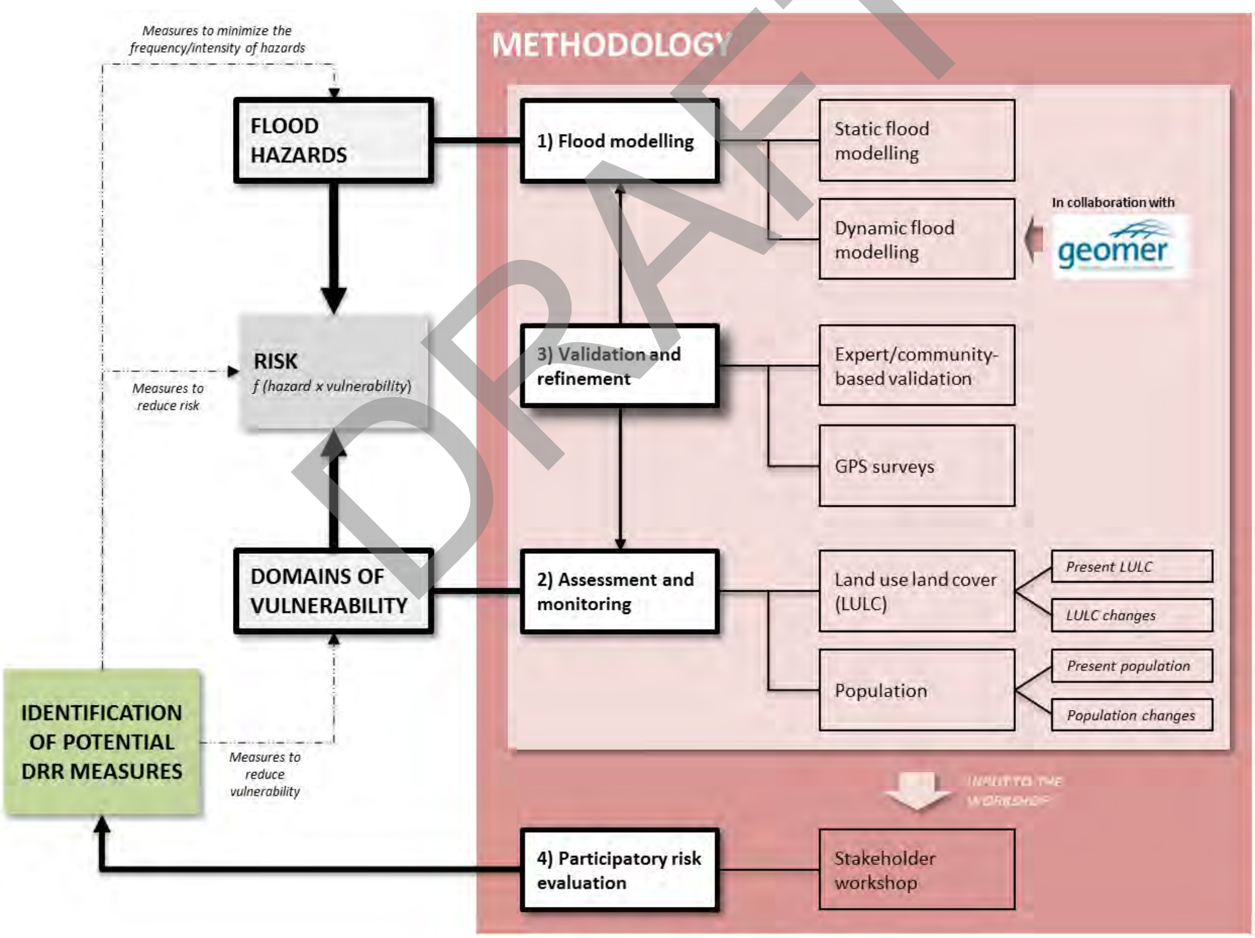


Figure 4: Conceptual and methodological workflow of the project

2.1 Study area

The **Central Region of Malawi** covers an area of approximately 35,592 square kilometres. Its capital city is Lilongwe, which is at the same time also the capital of Malawi. The region verges on Lake Malawi and borders both Zambia and Mozambique. Of the 27 districts in Malawi, nine are located within the Central Region: (1) Dedza, (2) Dowa, (3) Kasungu, (4) Lilongwe, (5) Mchinji, (6) Nkhotakota, (7) Ntcheu, (8) Ntchisi and (9) Salima. Figure 5 shows the **location of the study area** and depicts the **boundaries of the catchments** under investigation (displayed as dashed red lines):

1. Linthipe catchment (larger catchment in the southern part),
2. Lingadzi catchment (smaller catchment in the northern part).

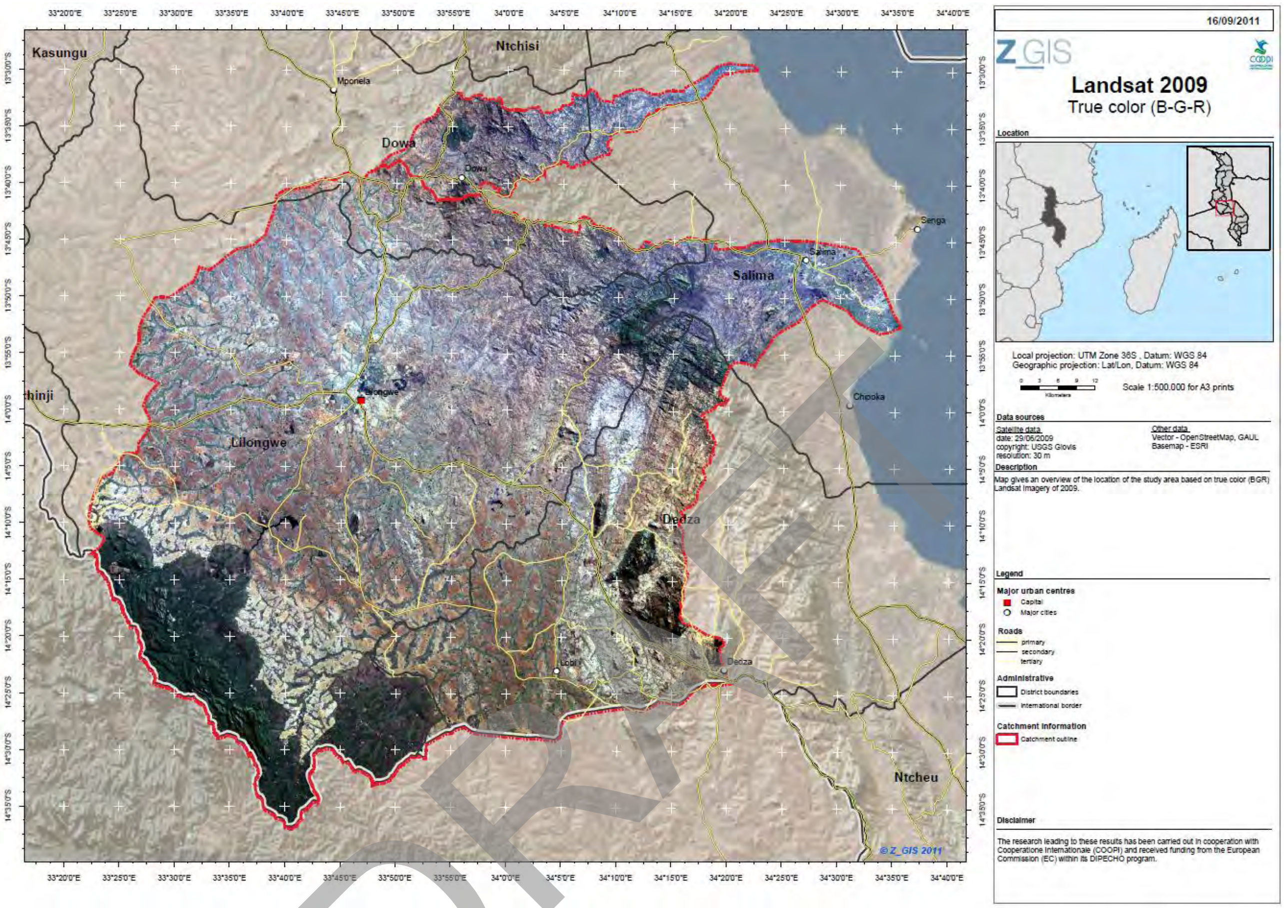


Figure 5: Location of the study area (Linthipe and Lingadzi catchments)

As the downstream areas of both rivers (i.e. Linthipe and Lingadzi river), and thus the most flood-prone regions, are located in the eastern part of the Central River Basin, the core focus of the study was placed on **Salima district** where the rivers discharge into Lake Malawi (cf. Fig. 5).

2.2 Datasets and data management

This chapter gives an overview on the **datasets** utilized within this study and provides additional information on their spatial **resolution**, available **time series** and their **sources**. All relevant input datasets and output layers were stored in a **file geo-database** (*.gdb) in order to ease the management and sharing of data and information.

Topic	Resolution	Date (time series)	Data sources
Elevation (DEM)	25 x 25 m	-	Department of Forestry, Government of Malawi
Land use land cover	30 x 30 m	1990; 2009	Landsat 5 (USGS GLOVIS)
Population	2.5 minutes -	• 1990; 2010 • 1998; 2008	• Gridded Population of the World (GPWv3) • Population census data (NSO, Malawi)
Flood events	-	1985-2010	Dartmouth Flood Observatory (DFO)
Flood frequency		-	UNEP/GRID-Europe

Background vector data			
World physical	-	-	ESRI
World terrain	-	-	ESRI
Major rivers	-	-	OpenStreetMap (OSM)
Major roads	-	-	OpenStreetMap (OSM)
Admin boundaries (GAUL – Global Administrative Unit Layers)	-	2008	FAO GeoNetwork
Settlements	-	2004; 2008 (estimated)	GRUMP (alpha), OpenStreetMap (OSM)

Table 1: Datasets and sources

Based on table 1, the following sub-sections provide more detailed information on the individual datasets used within this study.

The **digital elevation model (DEM)** which was utilized for the flood modelling exercise was provided by the Department of Forestry (Government of Malawi). According the Forestry Department the dataset was created by staff of the department based on available topographic paper maps (scale 1:50.000) of the early 1970s by converting them to digital format and mosaicking the tiles. Finally, the contour lines were digitized and interpolated in order to delineate the final DEM (see Fig. 6).

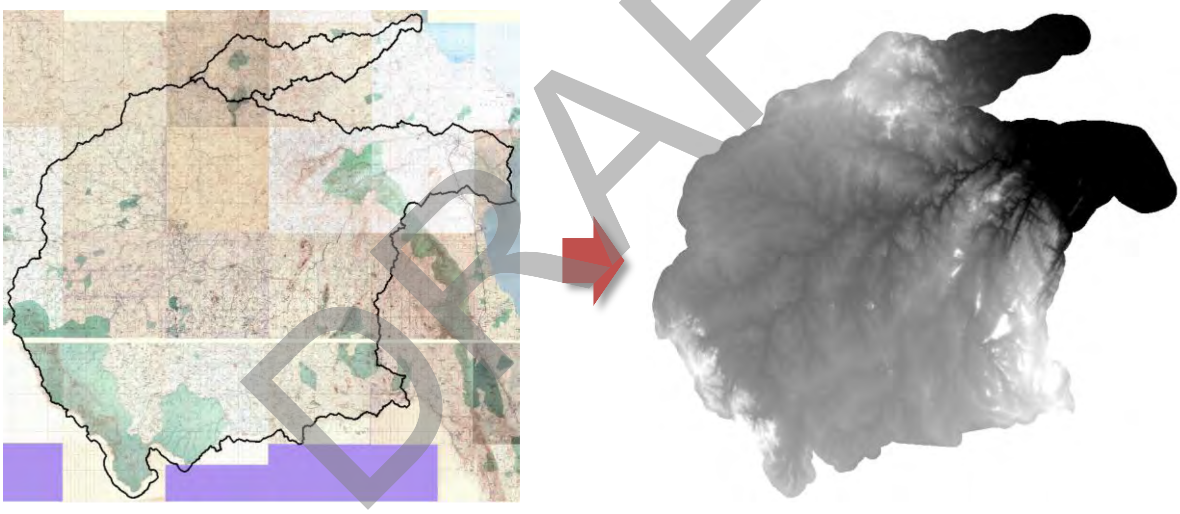


Figure 6: DEM of the study area provided by the Department of Forestry, Malawi (right) based on mosaicked topographic maps of the 1970s (left)

For the object-based land use land cover (LULC) classification (cp. chapter 2.4.1) for the years 1990 and 2009 the Landsat Thematic Mapper (TM) **satellite imagery** (see Fig. 7), downloaded via the USGS Global Visualization Viewer from the U.S. Geological Survey (http://glovis.usgs.gov) were used. Table 2 provides more details and specifications of the datasets.

	Sensor	Acquisition date	Landsat scene ID
LULC 1990	Landsat5 TM	11.07.1990	LT51680691990192JSA00
	Landsat5 TM	11.07.1990	LT51680701990192JSA00
	Landsat5 TM	12.05.1989	L51690701989132JSA00
LULC 2009	Landsat5 TM	29.06.2009	LT51680702009180JSA00
	Landsat5 TM	29.06.2009	LT51680692009180JSA00
	Landsat5 TM	04.06.2009	LT51690702009155JSA00

Table 2: Landsat imagery used for LULC classifications

Except the thermal band, which has a spatial resolution of 120 m GSD (Ground Sample Distance), the other spectral channels (three visible bands [blue, green, red], and three near-/mid-infrared bands) have a spatial resolution of 30 m.

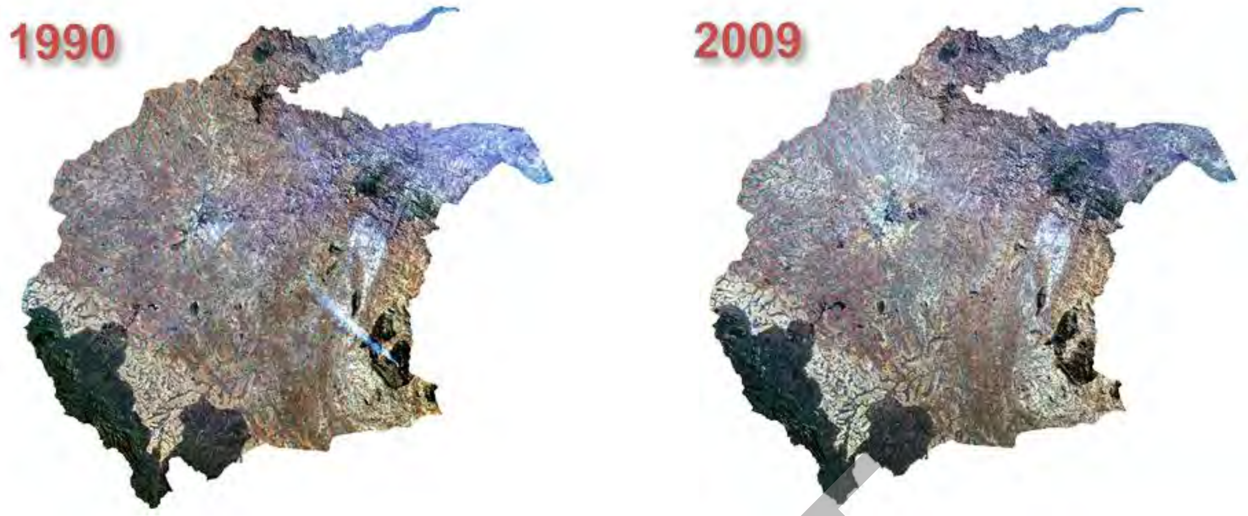


Figure 7: Landsat 5 (true colour) images of 1990 (left) and 2009 (right)

Moreover, additional **population data** based on the **1998** and **2008** national **census** was acquired from the National Statistical Office (NSO) and COOPI. A first comparison of the datasets revealed significant deficiencies. While the population census data of 1998 was provided as a shapefile (*.shp) for the entire country, the data of the 2008 census was only provided for Salima district. Moreover, while for 1998 the number of households was assessed per enumeration area (EA), for 2008 the total population per EA was registered. Lastly, it became obvious that both the spatial delineation and ID (identification number) of the enumeration areas of the 2008 data was different to the 1998 data (cf. Fig. 8), impeding a sound assessment of population dynamics or changes in the region.

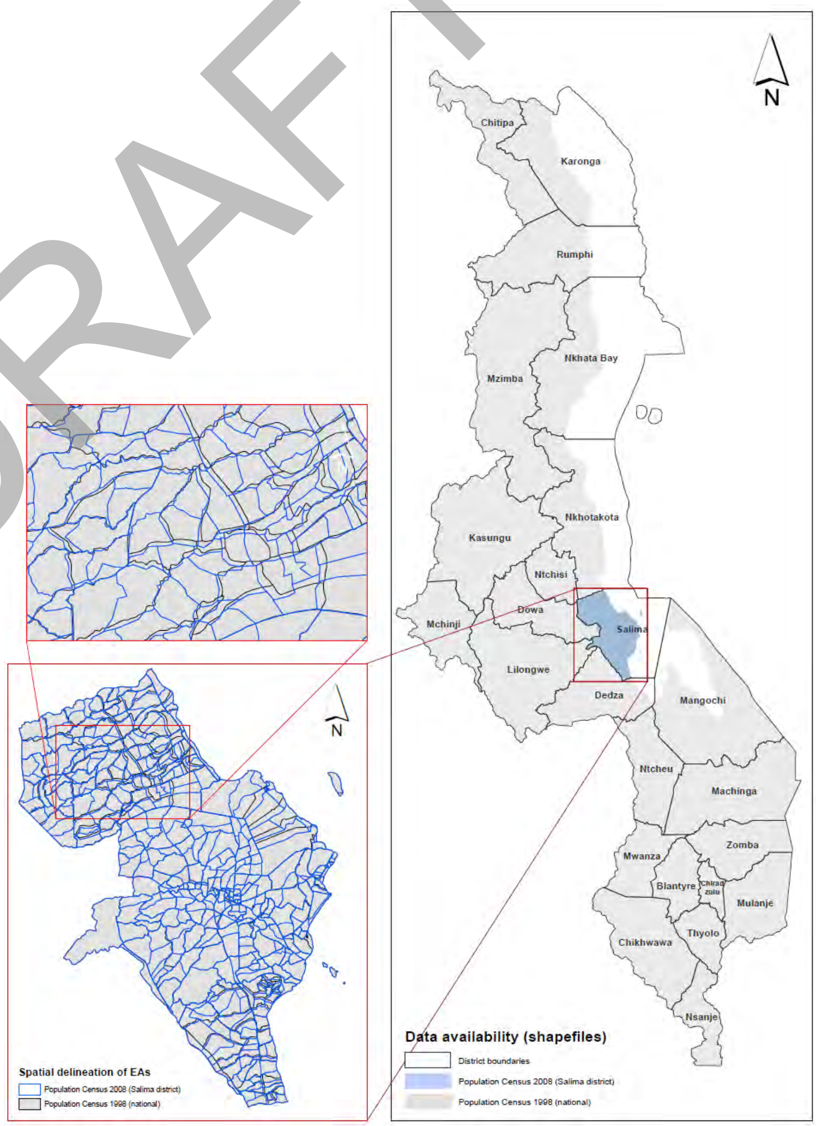


Figure 8: Population census data (1998 and 2008) provided by NSO and COOPI

For this reason alternative sources of population data had to be acquired and utilized to assess the actual population dynamics/changes in the study area.

The Gridded Population of the World (GPWv3) **population datasets** (Fig. 9) present the third edition of a large-scale product that demonstrates the spatial distribution of human populations across the globe. The output is unique in that the distribution of human population is converted from national or sub-national spatial units (usually administrative units) of varying resolutions, to a series of geo-referenced quadrilateral grids at a resolution of 2.5 arc minutes. As outlined in table 1, population data estimates were downloaded for 1990 and 2010 from the GPWv3 data portal (http://sedac.ciesin.columbia.edu/gpw/).

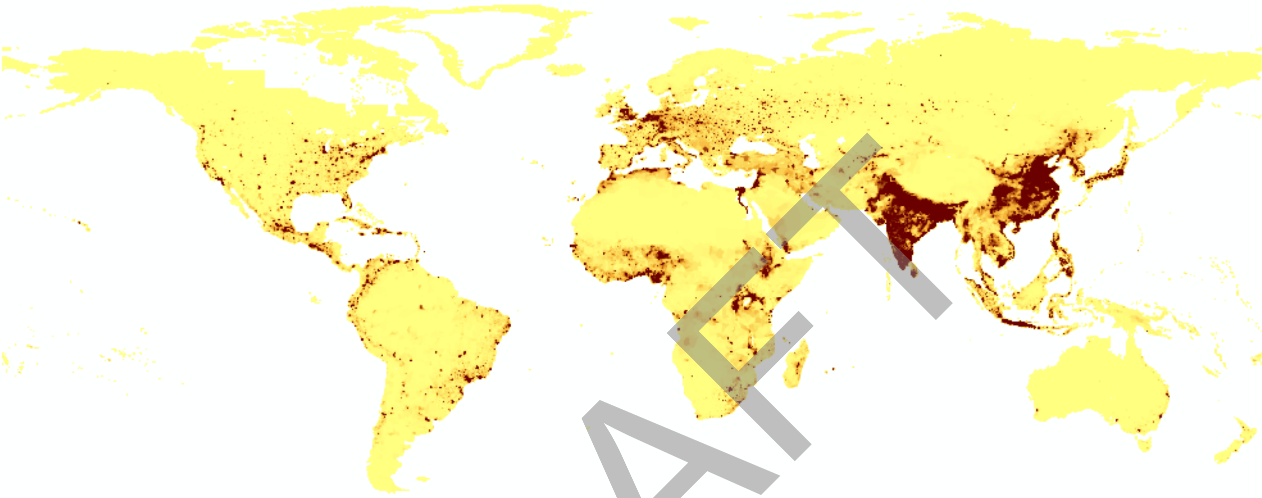


Figure 9: GPWv3 global gridded population counts for 2010

The DFO (Dartmouth Flood Observatory) **major flood event data** (cf. Fig. 10) comprises a global time-series (1985-to date) of major flood events which are represented as approximated polygons. The polygons reflect the estimated areas affected by flood rather than the actual inundated areas (see Fig. 11). According to DFO the flood affected areas (polygons) are delineated based on various sources, such as online news reports, governmental and international relief agency web sites and satellite imagery. In order to obtain more information on historic flood events in the study area, flood event data was downloaded from the DFO portal (http://floodobservatory.colorado.edu/) for the years from 1985 to 2010.

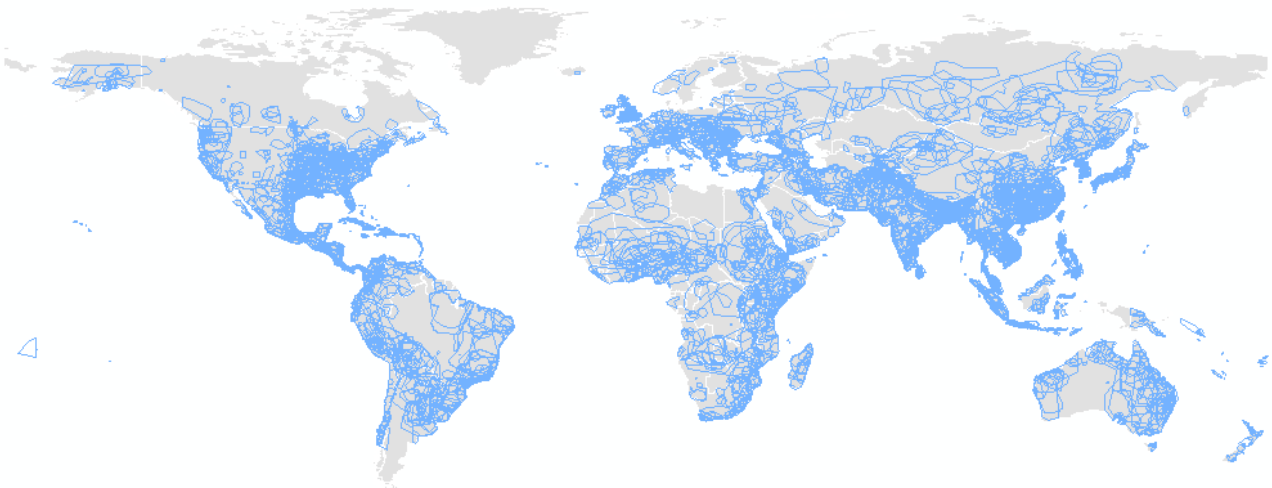


Figure 10: DFO global flood events (1985-2010)

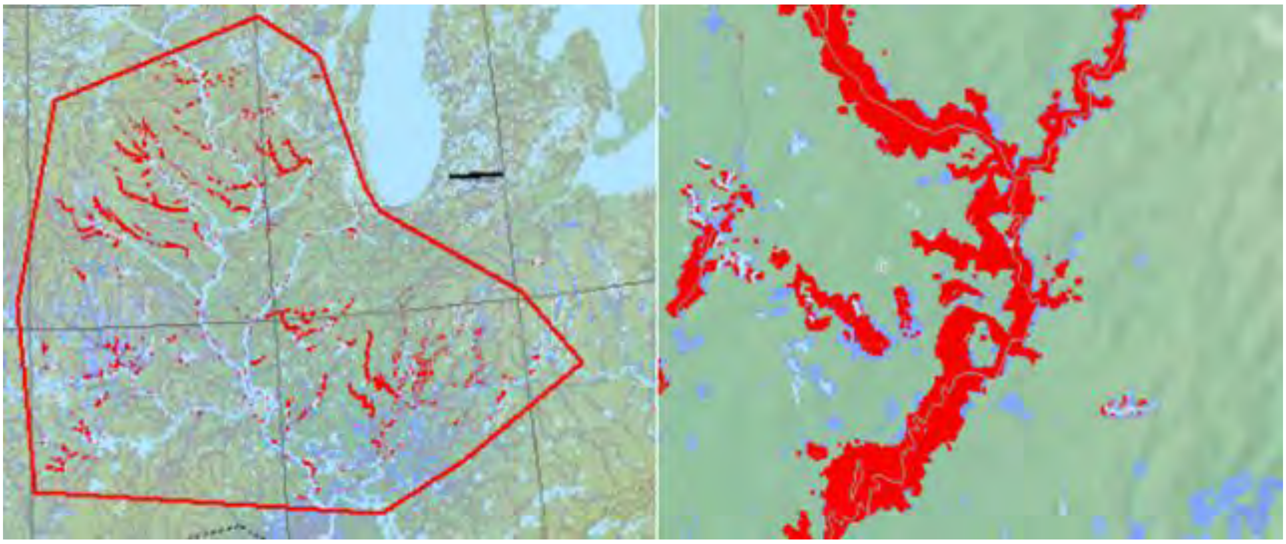


Figure 11: Flood affected (left) vs. actually inundated areas (right)

An additional flood frequency (see Fig. 12) layer was downloaded from the UNEP-UNISDR joint Global Risk Data Platform (http://preview.grid.unep.ch/index.php). The dataset was designed by UNEP/GRID-Europe and is based on different sources:

- A GIS modelling using a statistical estimation of peak-flow magnitude and a hydrological model using HydroSHEDS dataset and the Manning equation to estimate river stage for the calculated discharge value,
- Observed flood from 1999 to 2007, obtained from the Dartmouth Flood Observatory (DFO).

The frequency was set using the frequency from UNEP/GRID-Europe PREVIEW flood dataset. In area where no information was available, it was set to 50 years returning period.

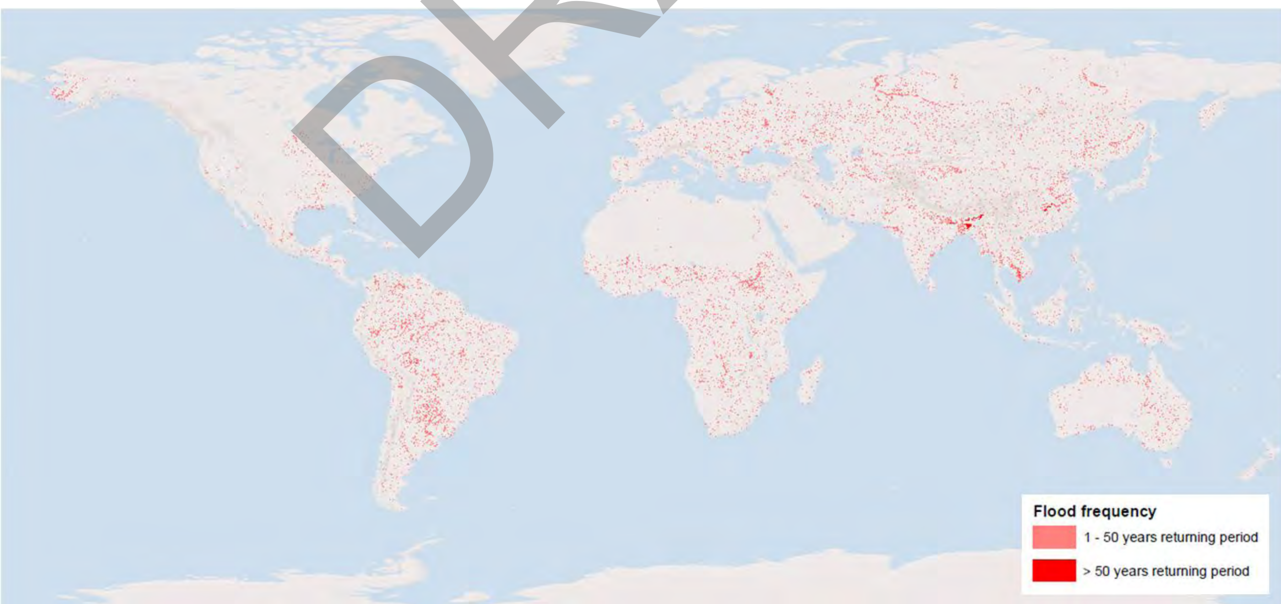


Figure 12: UNEP/GRID-Europe flood frequency layer

2.3 Hazard mapping

Building on the MOVE conceptual framework (cf. Fig. 3) and the overall conceptual framework of this study (cf. Fig. 4), a comprehensive flood hazard mapping exercise was conducted in the study area. Thereby the focus was placed on both (i) analysing **historic flood hazards** (cp. chapter 2.3.1) and (ii) modelling the depth and extent of potential flood events making use of **static** (chapter 2.3.2) and **dynamic flood modelling** approaches (chapter 2.3.3). The following sections provide more detailed information on the assessment of historic flood events as well as on the flood modelling exercises.

2.3.1 Analysing historic flood events

With regard to sub-objective 1.1 (*S-OBJ_1.1*) an in-depth **analysis of historic flood events** in the Central River Basin was carried out. Thereby time-series (1985-2010) of major flood events (cp. chapter 2.2) as provided by the Dartmouth Flood Observatory (DFO) was utilized to get an overview of major flood events which have affected the study area in the past decades. In addition **flood frequency** data was mapped for both a 1-50 years and a >50 year returning period based on flood frequency data provided by UNEP/GRID-Europe. Moreover, more detailed tabular data on historic flood events was acquired during the in-country assessment from both (i) the Department of Disaster Management Affairs (DoDMA) and (ii) the international NGO COOPI. The results of this exercise are described in chapter 3.1.1.

2.3.2 Static flood modelling

With regard to sub-objective 2.1 (*S-OBJ_2.1*) an identification of potentially flooded areas has been carried out for both catchments. First a static modelling approach has been chosen, which was then extended by a dynamic modelling (see chapter 2.3.3). Static models are used when input and output correspond to the same point in time. Contrary to that, dynamic models are applied, if the output includes a later point in time than the input. Additionally within a dynamic model this can include additional parameters which may require several iterations of the model and is then able to include different coupling effects.

Within the static modelling approach the core idea of identifying the vertical distance and elevation above the river bed. This should indicate for instance the areas being inundated when a 1m flood occurs. It has to be noted that this is a very limited approach and shows only potential areas of being flooded not including such effects as dynamic run-off or blocking at bridges or similar. However, it was thought that this approach would indicate first potentially flooded areas and will provide an overview of certain hot spots.

As input data the 25 m (spatial resolution) digital elevation model and the river network data was used. Additionally, satellite data (such as the Landsat data, and high resolution data available via Google Earth/Bing Maps) and topographic map sheets were utilized to improve data quality and for first indicative validation of results.

The analysis was carried out in ArcGIS and especially using the open-source GIS software SAGA GIS (http://www.saga-gis.org/), which includes a predefined algorithm to calculate the overland flow distance. Applying this algorithm, however, requires a well-defined and so-called hydrologic correct elevation model (same applies for the dynamic modelling). Most of the time invested in this task, went into improvement and preparation of a correct elevation model, which was the most challenging and limiting task within this objective. Roughly, the major steps include the filling of sinks in the elevation data (to avoid the identification of 'lakes' where there are not). In a second step, and this is again a most critical one, a proper river network had to be delineated. As a pre-existing river network was provided this was checked on a first instance, but showed major lacks in accuracy (positional accuracy, shifts due to projection and low quality) which required the calculation of a river channel network out of the existing elevation data. This was then manually merged and corrected with the pre-existing ones, and 'burnt' into the elevation model to represent a correct river network directly in the elevation data. Additional enhancements such as the smoothing (done through low pass filters) of the elevation data was carried out. As mentioned above, the preparation of a ‘correct’ elevation data set is most critical and time intensive as it requires manual editing and different iterations to allow a satisfying result. These steps have been carried out both in ArcGIS and SAGA GIS.

The final calculation of the overland flow distance was then calculated in SAGA GIS indicating the vertical distance above the river bed on a 25 m level. An assessment of the quality of the results will be provided in the results section (cp. chapter 3.1.1).

2.3.3 Dynamic flood modelling

In contrast to static flood modelling or static floodplain delineation, the **dynamic flood modelling** approach is based on physical principles of channel hydraulics and overland flow. In common flood hazard mapping one-dimensional or two-dimensional modelling approaches and tools exist. For this study the two-dimensional approach of the software-tool FloodArea for ArcGIS (FloodArea is a 2D model completely integrated in ArcGIS for the calculation of flood areas) was used. It implements a 2D modelling concept based on the Manning-Strickler equation:

$$V = k_{St} * r^{2/3} * I^{1/2}$$

with V being the discharge, r the hydraulic radius, I the gradient, and K_{st} a roughness coefficient for which values can be looked up in various engineering reference tables. The equation is implemented in FloodArea as a raster based algorithm and operates on a digital elevation model. Model input, i.e. the flow information can be included in the modelling process in one of three ways or their combination:

- In the form of water levels attached to a rasterized river network. Usually such information is the result of 1D hydraulic modelling and represents water levels one or several return periods,
- Discharge information attached to individual point locations representing flow volumes over time (e.g. outflow from a dam failure),
- Or a rainfall weight raster ion combination with a rainfall distribution.

In this study the latter option was used, because no detailed river channel model was available and no detailed digital elevation model. The creation of the finally used digital elevation model used was described above. As input for the rainfall distribution a synthesized rainfall distribution was created by merging and averaging the daily time series of six climate stations in and around the area. The daily time series represent a period of 2 weeks in March 2006 (01-15 March, 2006).

The **modelling process results** (cp. Fig. 20) are raster data representing water levels for the entire area at certain time intervals. Thus, the dynamic nature of the flooding process can be modelled and visualized over time. This allows for better identification of ‘hotspots’ where flooding occurs earlier in time, providing important information for emergency management purposes and disaster preparedness.

2.4 Vulnerability assessment (socio-economic factors)

Besides collecting information on historic flood hazards and modelling the extent and depth of potential flood hazards in the study area, specific components of the **vulnerability** dimension of the MOVE conceptual framework (cp. Fig. 3 and Fig. 4) were assessed as well. Although no comprehensive assessment of vulnerability and its specific dimensions (i.e. physical, ecological, social, economic, cultural and institutional) was performed, the study incorporated relevant **socio-economic factors** which play a key role concerning the vulnerability to flood hazards in the study area, namely:

- Land use land cover (LULC) characteristics and LULC changes from 1990 to 2009,
- Population dynamics/changes from 1990 to 2010.

The approach was chosen as the availability of detailed census data for the case study region, especially being homogenous and comparable over different time frames was extremely limited. However, given the project context, important drivers of vulnerability - as later identified in the stakeholder workshop - had proven to be appropriate for this context. Data on population, but also land use/land cover provide important indicators for establishing quantitative and spatial measures of vulnerability (Kienberger et al. 2008, Kienberger et al. 2010).

2.4.1 Land use land cover classification

This chapter describes the overall workflow of the object-based land use/land cover (LULC) classification which was performed based on time series of freely available optical satellite imagery, including a detailed description of the actual data pre-processing, the object-based LULC classification, change detection and the accuracy assessment that was carried out within this context.

2.4.1.1 Pre-processing

Pre-processing encompassed the stacking of the single Landsat bands in ERDAS Imagine software, resulting in a stacked file with seven spectral bands and 30 m spatial resolution. As the study area was not covered by one Landsat scene, three images in each case three were mosaicked together. The majority of the study area was covered by two scenes: (i) for 1990 from 11th July (cf. Fig. 13) and (ii) for 2009 from 29th June (cf. Fig. 14). Only for a small part in the west either no image from this date was available or images were cloud-covered. Therefore the most suitable images in terms of acquisition year and season were used as substitute for this small part. Before mosaicking, co-registration had to be performed as the respective Landsat scenes did not match ideally. The pre-processed and mosaicked images represented the input data for the semi-automated object-based classification in eCognition software (http://www.ecognition.com/). Additionally an existing vector data set showing the river network in the study site was used during classification.

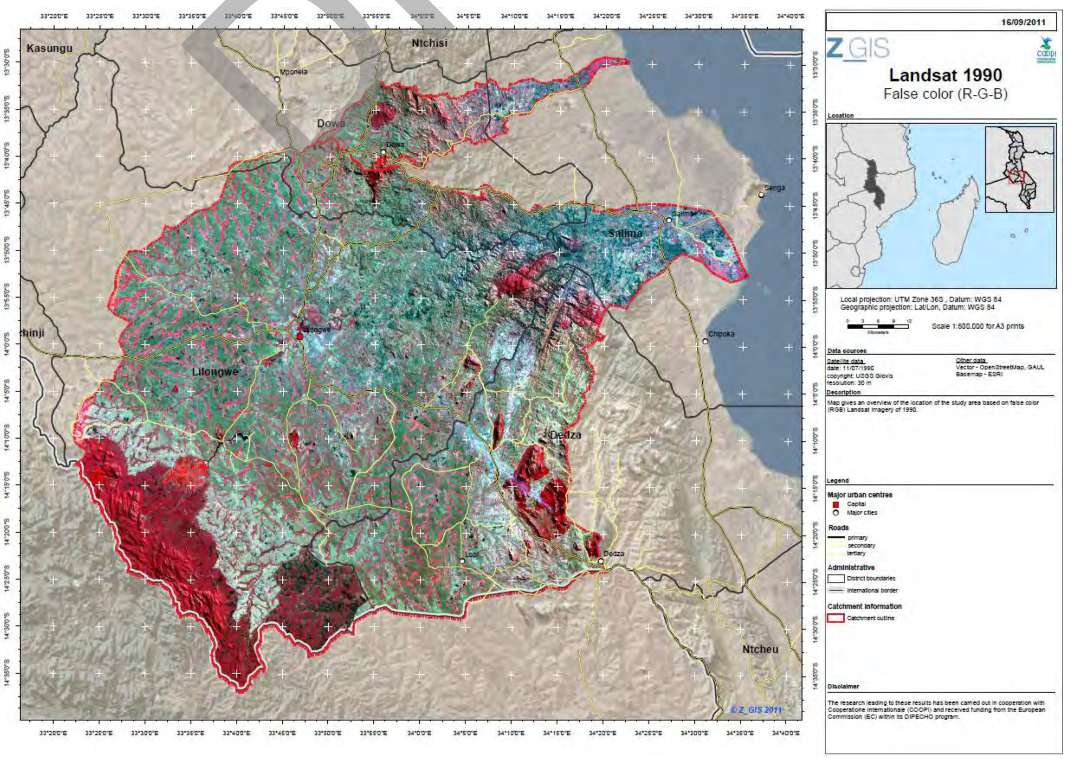


Figure 13: Landsat 1990 (false color)

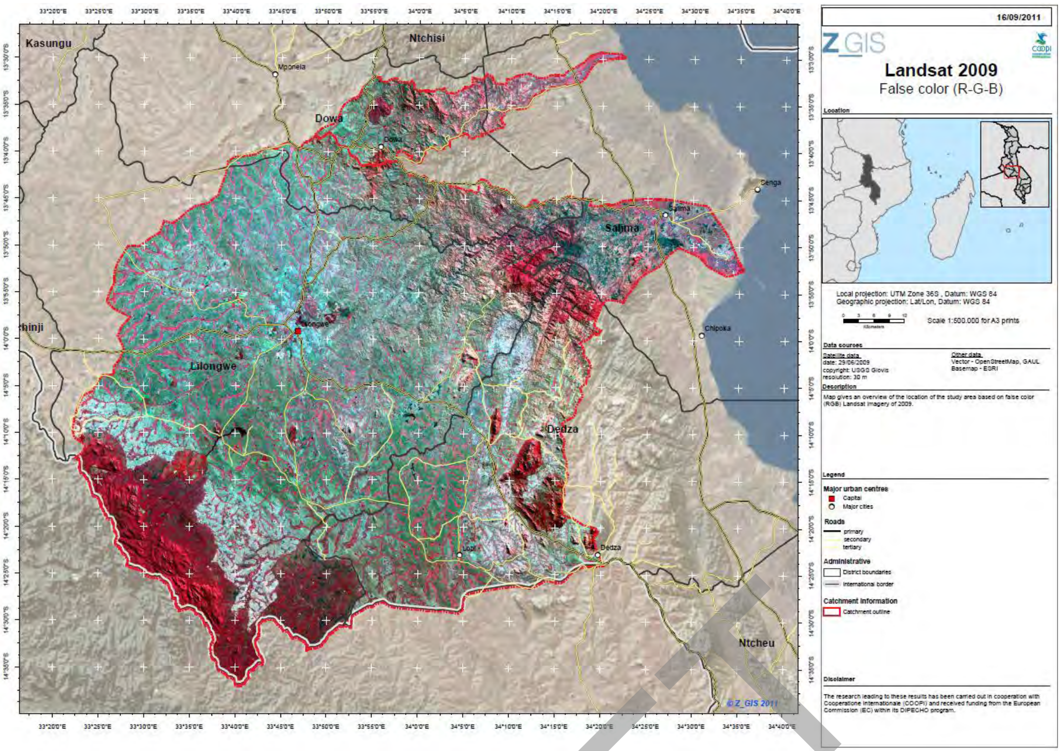
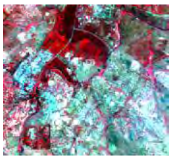
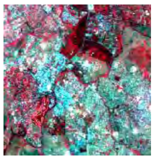
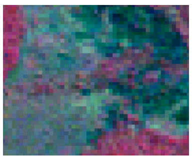
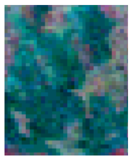


Figure 14: Landsat 2009 (false color)

2.4.1.2 Object-based land use land cover classification

The **land use/land cover classification (LULC)** of the Linthipe and Lingadzi catchments relies on object-based image analysis (OBIA, Blaschke 2010). OBIA provides scaled representations of an image scene by two- or more-dimensional segmentation and uses rule-based classifiers for addressing complex information classes, defined by **spectral**, **geometrical** and **contextual** properties, as well as **hierarchical** and **spatial relationships** (Lang 2008). Intuitive expert knowledge is represented through rulesets coded in CNL (Cognition Network Language) in the software eCognition 8, which offers a modular programming environment for object handling (Tiede et al. 2011). Objects may be addressed individually through class modelling, a cyclic process of segmentation and classification (Tiede et al. 2008). By its iterative nature, the process is highly adaptive and open to the accommodation of different categories of classes from specific domains, with different semantics, etc. (Lang et al. 2010).

For the land use/land cover (LULC) classification the following eleven classes were defined (Table 3):

Class	Example Landsat 1990	Example Landsat 2009
Built-up		
Burnt area	 	 

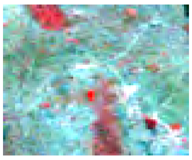
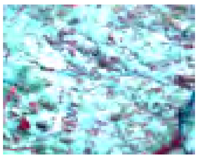
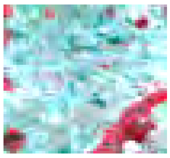
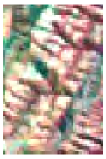
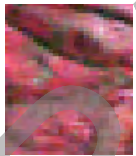
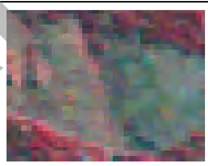
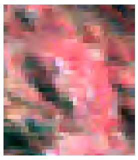
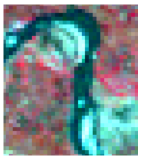
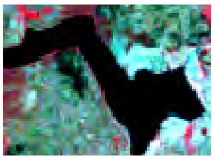
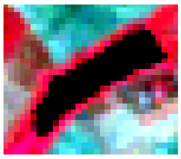
Cropland fertile soil		
Cropland infertile soil	 	 
Forest		
Forest Plantation		
Open shrubs/grassland		
Shrubland	 	 
Riverine vegetation		
River		
Water body		

Table 3: Classes used for land use/land cover classification

The land use land cover classification of both years (1990 and 2009) was performed by a combination of sample-based, rule-based and manual classification. The major part of the classification was carried out using sample-based classification (see Table 4). For the sample-based classification absolute spectral values and standard deviations of the blue, green, red and NIR/MIR bands as well as the NDVI (Normalized Difference Vegetation Index) were taken into account. The results were further refined using rule-based classification, especially taking into account neighbourhood relations to eliminate falsely classified objects (e.g. water classified as burnt area). For the classification of *riverine vegetation* and *rivers* a pre-existing river data set was included. Besides the neighbourhood to rivers, NDVI and shape parameters (e.g. Length/Width) additionally improved the classification accuracy, especially of the class *riverine vegetation*.

Main class	Sub-class	Sample-based	Rule-based	manual
Built-up				x
Burnt area		x	x	
Cropland	Fertile soil	x		
	Infertile soil	x		
Open shrubs/grassland		x		
Forest	Forest	x		
	Forest plantation			x
Shrubland		x		
Riverine vegetation			x	
Water	River		x	
	Water body	x		

Table 4: Overview of land use/land cover classes and classification method used

2.4.1.3 Change detection

Change detection has been conducted between the two classification results from 1990 and 2009 to get an overview of the LULC changes, with a focus on forest and woody vegetation change, during this time span. Change detection has been performed by applying geo-processing algorithms (e.g. select, clip, erase) on the two LULC classification layers in ArcGIS software.

2.4.1.4 Accuracy assessment

A visual evaluation of the classification accuracy has been carried out by assessing each class individually for both points in time (1990 and 2009) and accordingly assigning accuracy values (from 1 to 3) to them.

2.4.2 Mapping population dynamics

Besides mapping current land use land cover (LULC) properties and LULC changes an assessment of the actual population dynamics or changes was performed, based on existing global gridded population data of 1990 and 2010 (cf. chapter 2.2). In addition to mapping the actual population counts for the respective years, also the population change from 1990 to 2010 was mapped in a spatially explicit manner. The results of this task are presented in chapter 3.1.2.

2.5 Validation, refinement and collection of additional information

As outlined in figure 4 (conceptual workflow), the outcomes of the analysis were validated and refined making use of both **expert-based interviews** and a detailed **GPS** (Global Positioning System) **survey**.

2.5.1 Expert-based interviews and mapping of flood prone areas

Within the context of the validation exercise a **semi-structured questionnaire** (cf. Annex 3) was developed and used to collect qualitative and quantitative information at both (i) national and (ii) district level. The questionnaire covers major aspects such as:

- historic flood events in the country (*related to S-OBJ_1.1*),
- the role of anthropogenic impacts on flood risk (*related to S-OBJ_2.3 and S-OBJ_2.4*),

- an overview of disaster risk reduction (DRR) and recovery activities (*related to S-OBJ_3.1*), information on existing early warning systems (EWS) and their strengths and weaknesses (*related to S-OBJ_3.2*).

The developed questionnaire facilitated interviews with key governmental, UN and non-governmental experts and stakeholders involved in disaster risk reduction (DRR) and disaster risk management (DRM) activities at both national and district levels. Thereby, the stakeholders were selected by the consultants according to their official mandate and relevance as an actor in the field of DRR/DRM and CCA in Malawi. The focus was set to the DRR focal points (FPs) listed on the 'Malawi DRM Stakeholder Contact Details' list that was provided by the Department of Disaster Management Affairs (DoDMA). Tables 5 and 6 give an overview of the stakeholders that were consulted during the in-country assessment.

ID	Stakeholders (national level)	Location	Type	Date/s
01	Geological Survey Department	Lilongwe	Government	29.07.2011
02	Geological Survey Department , HQs	Zomba	Government	08.08.2011
03	Department of Disaster Management Affairs (DoDMA)	Lilongwe	Government	29.07.2011
04	Climate Change and Meteorology Department	Lilongwe	Government	01.08.2011
05	Land Survey Department	Lilongwe	Government	02./03.08.2011
06	Ministry of Irrigation and Water Development	Lilongwe	Government	04.08.2011
07	Ministry of Natural Resources, Energy and the Environment	Lilongwe	Government	05.08.2011
08	Ministry of Agriculture and Food Security: 1. Technical Secretariat 2. Department of Land Resource and Conservation	Lilongwe	Government	 26.08.2011 28.11.2011
09	Ministry of Local Government and Rural Development	Lilongwe	Government	24.08.2011
10	Department of Forestry	Lilongwe	Government	05./09.08.2011
11	National Statistical Office (NSO)	Zomba	Government	08.08.2011
12	Training Research Institutions/Universities 1. Bunda College of Agriculture (Lilongwe) 2. Mzuzu University, (Mzuzu) 3. The Polytechnic, (Blantyre) 4. Chancellor College (Zomba)	Lilongwe	Government	 14.09.2011 18.11.2011 21.11.2011 22./23.11.2011
13	UNICEF	Lilongwe	UN	15.09.2011
14	World Bank	Lilongwe	UN	02.08.2011
15	United Nations Development Programme (UNDP)	Lilongwe	UN	03.08.2011
17	World Food Programme (WFP)	Lilongwe	UN	26.08.2011
16	EU Delegation	Lilongwe	EU	15.09.2011
18	FEWS NET Malawi	Lilongwe	Civil society	09.08.2011
19	MVAC	Lilongwe	Civil society/government	24.10.2011

Table 5: Stakeholders (national level)

As shown in table 5 a total of twelve key governmental institutions, five international and one civil society (i.e. NGOs) organisations were visited during the consultancy at national level. In addition several key stakeholders involved in DRR or CCA activities were consulted within Salima district.

ID	Stakeholder s (district level)	District	Type	Date/s
01	Ministry of Irrigation and Water Development	Salima	Government	12.08.2011
02	Department of Disaster Management Affairs (DoDMA)	Salima	Government	15.08.2011
03	Forestry Department	Salima	Government	16.08.2011
04	Cooperazione Internationale (COOPI)	Salima	Civil society	15.08.2011

Table 6: Stakeholders (Salima district)

The procedure for all interviews followed a previously defined and standardised sequence. As a first step, **before the meeting took place,** an appointment for an interview was requested and scheduled by the team of consultants via telephone. As a follow-up activity the developed semi-structured questionnaire (see annex 3) were sent to the interviewees in order to give them some time to prepare themselves for the upcoming interview and to gather all necessary information that was requested by the consultants. The actual face-to-face interviews were conducted jointly by the two implementing agencies involved in the consultancy within the last week of July and the first two weeks of August 2011. In addition to using hard copies of the semi-structured questionnaires for the taking of notes, all face-to-face interviews were recorded on digital voice recorders. Prior to the interview, the stakeholders were informed that all information would remain completely confidential and would not be used for other purposes than the project.

During the interview and in line with the developed semi-structured questionnaire the interviewees were asked to provide detailed information on:

- Their agency's contact details and mandate,
- Historic flood events and areas which are particularly prone to flood hazards,
- Existing early warning systems (EWS) and related activities,
- The role of anthropogenic impacts or factors on increased flood risk (e.g. degradation, Population growth, etc.),
- Past and present DRR and recovery activities.

Building on a previously created base map of the study area, an **expert-based mapping exercise** was conducted during the interviews with selected key stakeholders involved in DRR/DRM and CCA (see tables 5 and 6) in order to come up with a final aggregated map showing areas which are particularly prone to flood hazards in the study area according to the interviewed experts. This exercise has been based on a methodology for participatory flood hazard and vulnerability mapping at the community level in Mozambique (Kienberger 2010, Kienberger in press).

Figure 15: Expert-based hazard mapping (© Michael Hagenlocher)

Moreover, the experts were, if available, asked to provide pictures of previous flood events in the catchments.

2.5.2 Institutional mapping

In line with sub-objective 1.1 (*S-OBJ_1.1*) an **institutional mapping** of stakeholders (i.e. key public, international and civil society organizations, donors, etc.) that are coordinating and/or implementing DRR/DRM and CCA related activities in the Central River basin was conducted. This was achieved through institutional analysis that was conducted as part of the semi-structured interviews with key stakeholders at both national and district level. The institutional analysis explored official mandates, responsibilities and existing capacities within the relevant agencies/offices as well as institutional arrangements between stakeholders.

2.5.3 GPS survey

In order to **validate** the **results** of both (i) the **LULC classifications** and (ii) the **flood modelling exercises** (i.e. the static and the dynamic flood modelling exercise) a **GPS** (Global Positioning System) **survey** was planned and conducted in the study area. Making use of a NIKON **GPS camera** as well as of an additional TRIMBLE Juno ST Handheld **GPS receiver** (incl. external GPS antenna), detailed **ground information** was collected in selected areas, comprising:

- ID (identification) of the GPS points,
- Coordinates (x, y, z),
- Time and date when the information was collected,
- Two to four geo-references pictures per location,
- ID (identification) of the GPS pictures,
- Short description of the location.

During the field mission the focus was set to specific LULC categories which revealed a higher degree of uncertainty during the classification process compared to other categories (cp. tables 11 and 12) as well as to low lying downstream areas along the two rivers under investigation. Thereby, the later should help to validate if the results of the flood modelling exercise are realistic or not in terms of the terrain and topography along the rivers.

2.5.4 Challenges during the in-country assessment

During the four-week in-country assessment the consultants faced some minor **methodological challenges**, which are briefly summarised in this chapter. One particular challenge arose from the fact that in general only one, or in rare cases, two, key experts were available for the interviews within the relevant offices; this made it difficult in some cases to fully cover all aspects listed in the semi-structured questionnaire. Consequently, not all stakeholders were able to provide sufficient answers to all questions, as some of them were beyond their personal expertise. A second challenge arose due to the format of the semi-structured questionnaire itself. Taking almost two hours to discuss all relevant aspects, some of the experts interviewed lost motivation to provide detailed information on all questions.

Moreover, the team faced additional challenges with regard to the **GPS survey** due to the severe **lack of fuel** (i.e. both petrol and diesel) in the country during the in-country assessment. As a result ground truth information was collected only to a very limited extent in previously selected areas.

2.6 Participatory risk assessment

The methodology applied by the consultants to arrive at adequate intervention options is based on a two stage approach. The first phase comprises the assessment and analysis of hazard and vulnerability components, which were presented to all relevant stakeholders and discussed in depth during a two day workshop. Actors residing in the river basin or responsible for certain thematic aspects concerning the area were already involved during the assessment phase by interviews or expert inputs.

Figure 16: Participants at the expert workshop in Salima, Malawi (© Peter Zeil)

In a second step, resulting actions were derived from working group discussions during the concluding sections of the workshop. These actions are compiled in three components: development scenarios, recommendations and interventions.

Alternative intervention options suggested by stakeholders address requirements that would (i) reduce the frequency and severity of flooding and (ii) mitigate the consequences of flooding.

3 RESULTS

This chapter presents the results of the study. The first chapter discusses the findings of the flood hazard and vulnerability assessment, while the second chapter provides an overview of the outcomes of the participatory risk evaluation exercise.

3.1 Flood hazard and vulnerability assessment in the Central River Basin

3.1.1 Flood hazard assessment

3.1.1.1 Historic flood events (disasters)

As indicated in the introduction of this report (cp. chapter 1.3) one objective of the study was to provide an overview of historic flood events (disasters) in the Central River Basin focusing on the Linthipe and Lingadzi river systems.

Figure 17 shows **historic flood events** that had affected **Malawi** in the years from 1985 to 2010 based on archived global flood event data as provided by the Dartmouth Flood Observatory (DFO). It becomes obvious that particularly the southern region (i.e. Chikhwawa, Thyolo and Nsanje district) was affected by more than ten flood events in these 25 years. However, several districts in the Central Region (e.g. Salima, Dedza, Lilongwe district) and in the Northern Region (i.e. Rumphi and Karonga district) had also been severely affected (5-10 flood events in these years). More details on these particular flood events are provided in table 7.

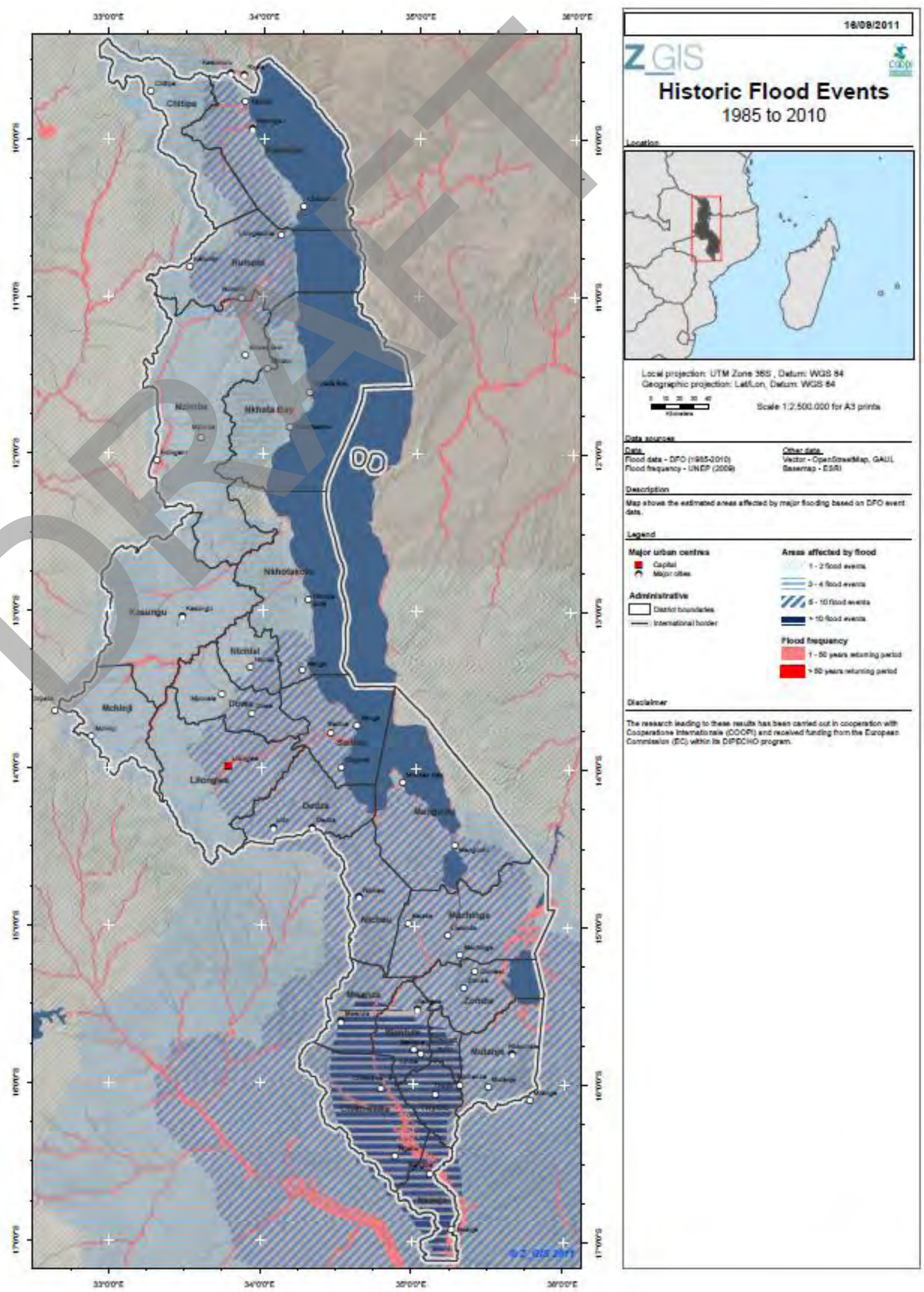


Figure 17: Historic flood events (1985-2010)

Date	Duration	District/s
September, 1989	11 days	Chikwawa, Nsanje, Machinga, Mangochi, Salima, Balaka, Zomba, Mulanje, Nwanza, Chiradzulu
December, 1997	6 days	Nkhotakota
January, 1998	17 days	Karonga, Nkhotakota, Phalombe
January, 2003	48 days	Salima, Balaka, Dedza, Machinga, Ntcheu, Dowa, Phalombe, Lilongwe, Mwanza, Rumphi, Nsanje, Shire, Chikwawa, Nyungwe-Wovwe
March, 2006	8 days	Mangochi, Salima
December, 2007	82 days	No information on affected districts

Table 7: Profile of flood events in Malawi (according to DFO)

Based on historic hazard data as provided by the Malawian Department of Disaster Management Affairs (DoDMA), table 8 provides a more detailed 'zoom-in' perspective on **historic flood events in Salima** district from 19980 to date. Besides date and location (affected region), the extent of damage is also listed.

Date	District	Location (TAs, GVHs, etc.)	Extent of damage
December, 1980	Salima	Boma & Maganga areas	334 families affected (ca. 1,326 people), 112 houses damaged
March, 1983	Salima		7 villages affected, 180 houses damaged
January, 1996	Salima		12.5 hectares of maize crop damaged
March, 1997	Salima	59 villages in TAs Ndindi, Pemba, Maganga, Kalonga	5,226 households lost their maize gardens (i.e. 1,894 ha)
April, 1997	Salima	38 villages in TAs Kalonga, Maganga, Pemba	3,842 households lost their maize gardens (i.e. 1,096 ha)
March, 1999	Salima	Villages in TA Kalonga and GVH Mphunga	500 households: houses damaged, 720 households: gardens damaged, 334 ha of maize affected
February, 2001	Salima	23 villages in TAs Khombedza, Chikombe, Kuluunda, Sub Chief Ndindi and STA Msosa	9,000 households (45,000 people) affected; 6,048.4 ha of maize, 962 ha of rice and 762,6 ha of cotton affected. 3 people lost their lives.
January, 2002	Salima	GVH Nkhwidzi and Ngodzi areas	185 households affected: crops and livestock washed away
January, 2003	Salima	TAs Ndindi and Maganga	3,000 households: houses damaged; 24,568 families: gardens washed away
March, 2006	Salima	TAs Ndindi, Maganga, Pemba	250 households affected; 367 ha of crops flooded
November, 2006	Salima	3 villages in TA Pemba and Ndindi	85 households displaced
February, 2007	Salima	5 GVH in TA Ndindi and Khombedza	41 households: houses damaged; 100 ha of crops and livestock washed away
March, 2010	Salima	TAs Karonga, Kambwiri, Maganga and Pemba	6 households had their houses and property destroyed

Table 8: Profile of flood events in Salima district (according to DoDMA, Malawi)

Finally, table 9 presents the observations of COOPI in the downstream areas of the two river networks under investigation on a local scale (i.e. community level). Besides the year when the flood has occurred, the affected GVHs (group village headmen) or communities are listed. The location of these GVHs is also displayed.

Year	Affected GVHs (Group Village Headmen)	Location of the affected GVHs in Salima district
1979	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho	
2000	Same GVHs as in 1979	
2001	Same GVHs as in previous years	
2003	Same GVHs as in previous years	
2004	Same GVHs as in previous years	
2005	Same GVHs as in previous years	
2006	Same GVHs as in previous years	
2007	Same GVHs as in previous years	
2008	Same GVHs as in previous years	
2009	Same GVHs as in previous years	
2010	Same GVHs as in previous years	
2011	Same GVHs as in previous years	

Table 9: Profile of flood events in Salima district (according to COOPI)

3.1.1.2 Hydrologic analysis and flood modelling

Figure 18 shows the results of the **static flood modelling** exercise (cp. chapter 2.3.2). Results from this modelling approach have shown limits in quality originating from the pre-defined river channel network as well as the digital elevation source.

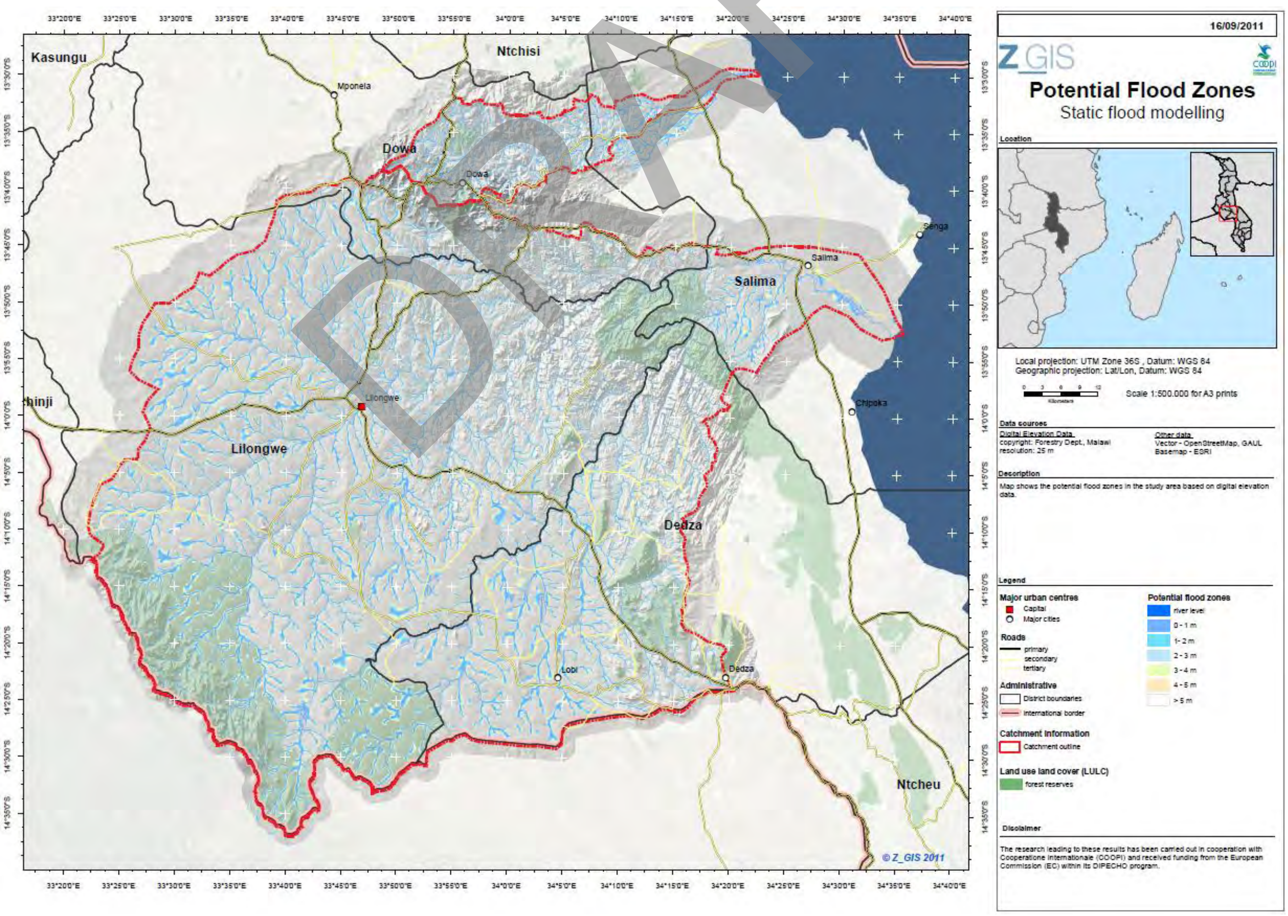


Figure 18: Potential flood zones (according to the static flood modelling exercise)

In general, the results of the modelling show a strong focus of potentially flooded areas mainly in the downstream areas, which is also in line with the outcomes of the expert-based mapping exercise. Limitations arise in the detailed model accounts also in downstream areas, where river benches could not be well separated into the flood plains. For a final ‘better option’ of model results, the dynamical modelling approach has been chosen.

The **dynamical modelling** approach was based on a past flood scenario. As floods have been quite significant during March 2006 for the case study area, this time frame has been chosen. Precipitation data for six measuring stations could be identified and accessed for the period shown below. It can be noted that quite some significant precipitation occurred after March 3rd, which shows also strong increases in two stations in the E and SE section of the case study. This may be due to some strong localised rain. However, data quality and limits within the measurement of precipitation could apply here as well, so results have to be taken critically. However, the amount of stations available in the region was quite good, so therefore an estimation based scenario for the dynamical modelling could be applied.

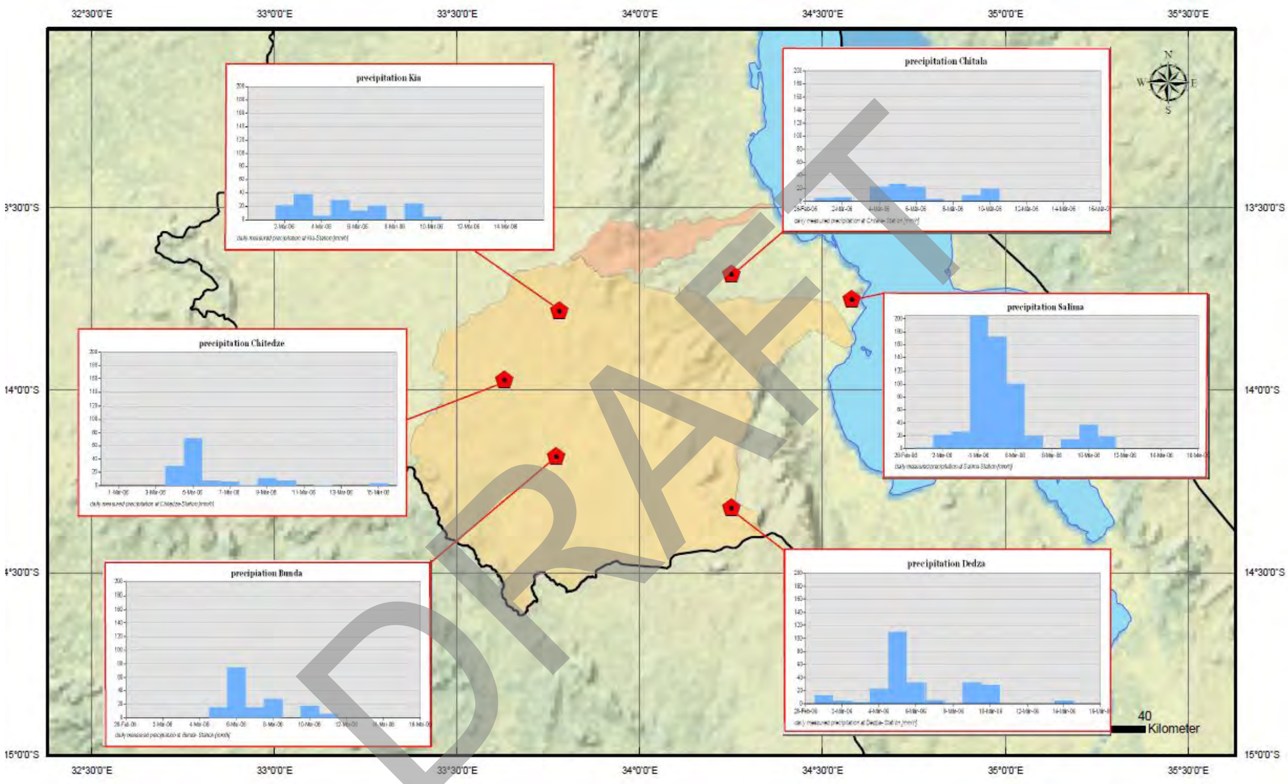


Figure 19: Precipitation in the study area (01-15 March, 2006)

The results of the dynamical modelling have been visualised as an animated time series, based on mean hourly rates of precipitation as well as a summary of all flooded areas during the given period within a map (see Fig. 20) The model allowed to visualise the development of the floods during the event, which reaches the downstream area within several hours. As the input data (elevation model) is the same for both modelling approaches, the more advanced one - namely dynamical modelling - identifies well the downstream flat area as the most hazard prone. This is also in line with the observations gained during the in country-assessment and different expert workshops. Results of the dynamical modelling, however, have to be evaluated critically, as they show a scenario-based event and do not consider the morphometric properties of the river course/river bed valley, and is therefore limited to show exact flood hazard zones, which can be used for further spatial planning issues. Additional limitations arise from the quality of the elevation model, which can be seen very well in the larger flood zones where ‘zebra stripes’ are visible, which again are result of the limited quality of the elevation model. This is especially due to the fact that the elevation model was derived from digitising contour lines, which often then leads to these ‘step effects’.

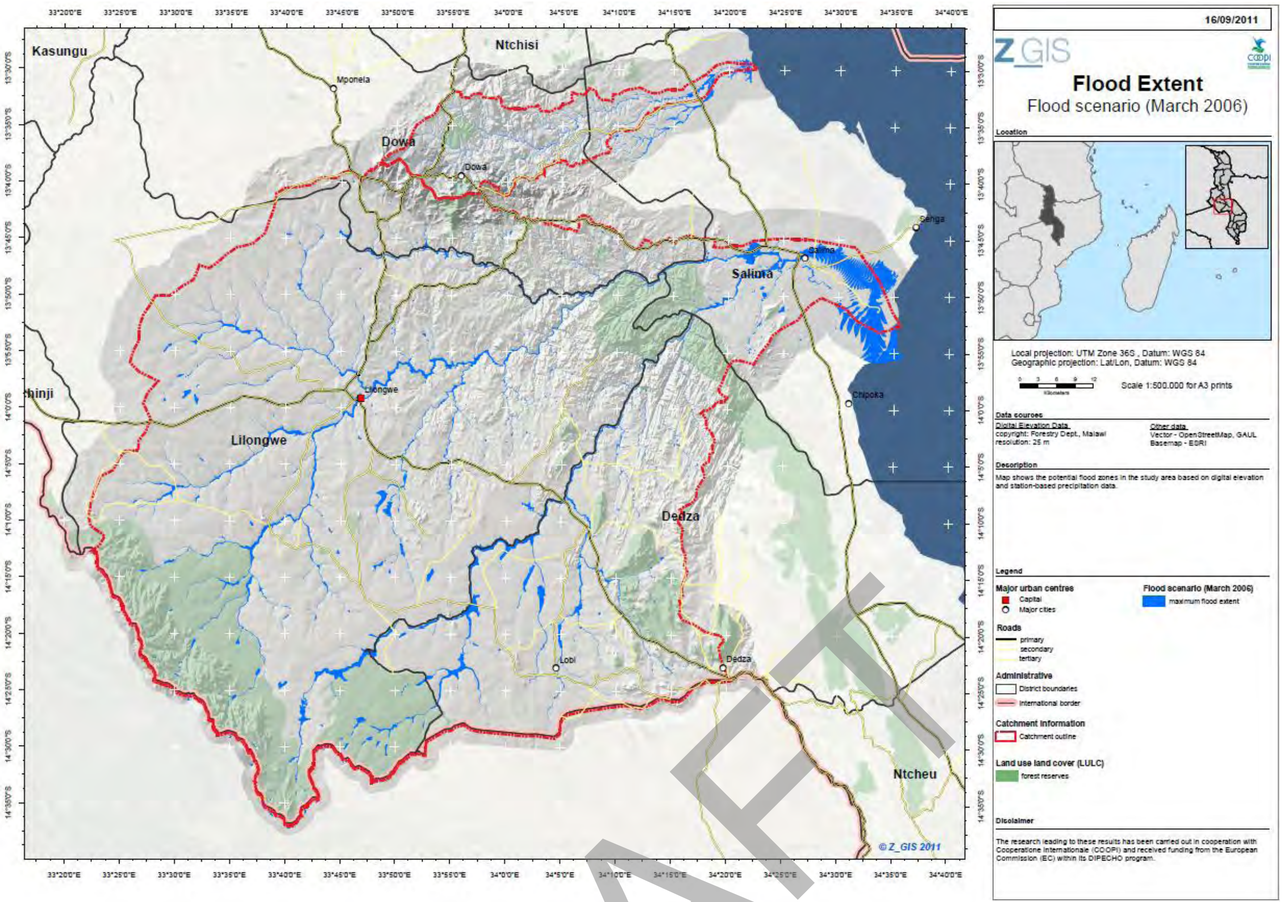


Figure 20: Flood extent (flood scenario: March, 2006)

Based on the results of the expert-based mapping exercise (cp. chapter 2.5.1), figure 21 shows those communities in Salima district which were marked as flood prone by the experts. It becomes obvious that especially communities in the lower lying downstream areas of Linthipe, Lingadzi and Linfidzi rivers are particularly flood prone.

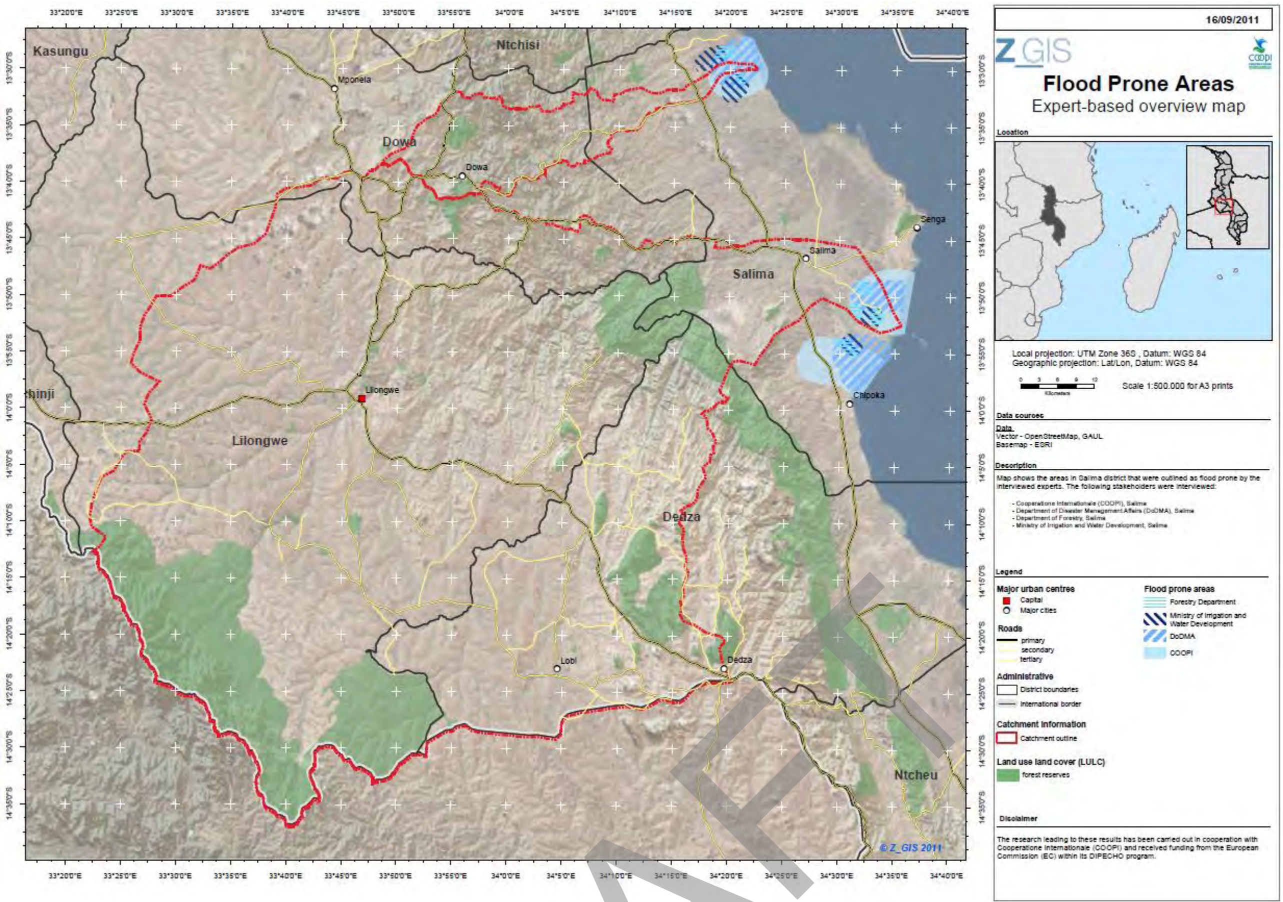


Figure 21: Flood prone areas (expert-based overview map)

3.1.2 Vulnerability assessment (socio-economic factors)

3.1.2.1 Land use land cover (LULC) and LULC changes

Land use land cover (LULC) classification

The following two figures show the results of the object-based land use/land cover (LULC) classification for July 11, 1990 (cf. Fig. 22) and June 29, 2009 (cf. Fig. 23), while table 10 list the calculated area statics (in hectares and per cent) for both classifications.

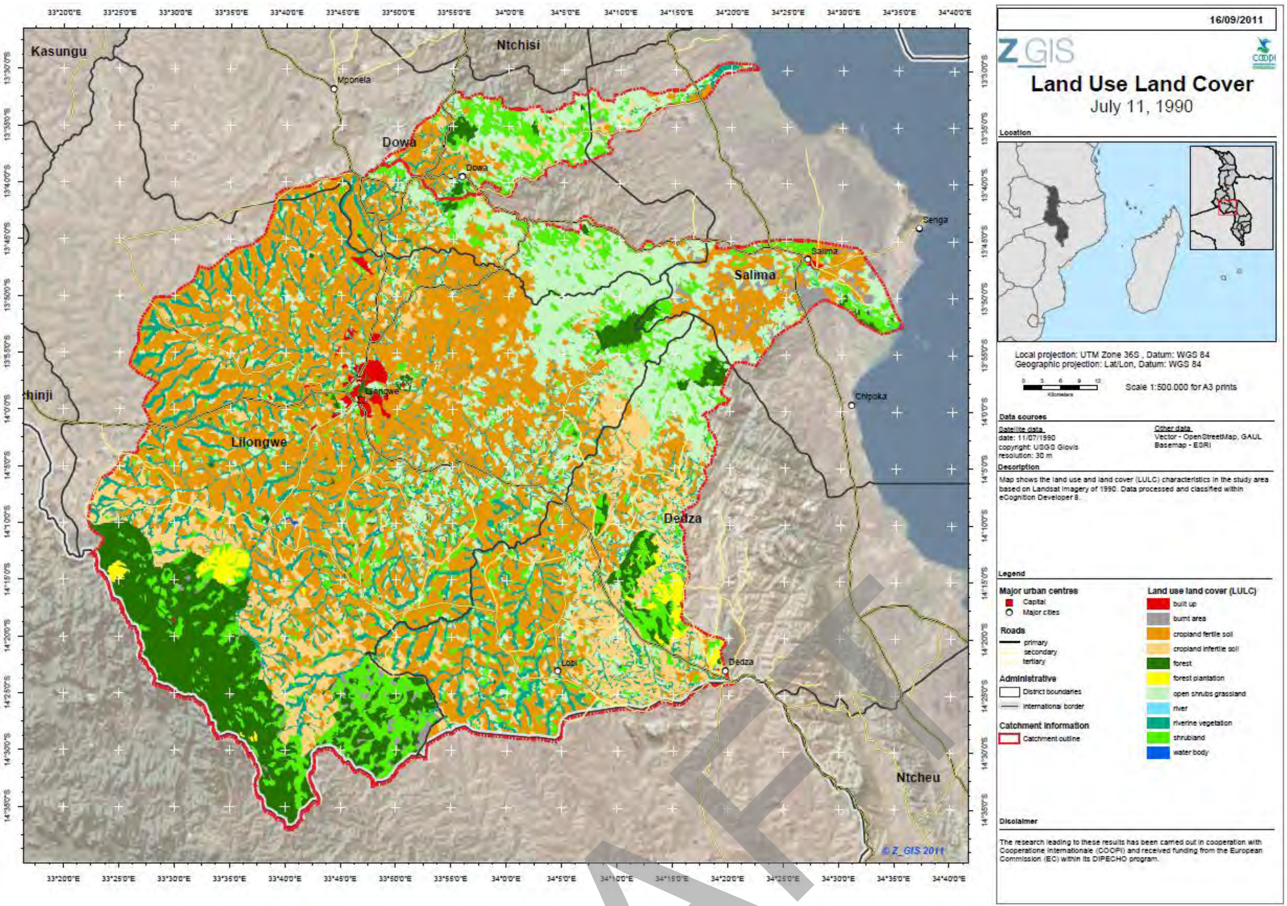


Figure 22: Land use/land cover (1990)

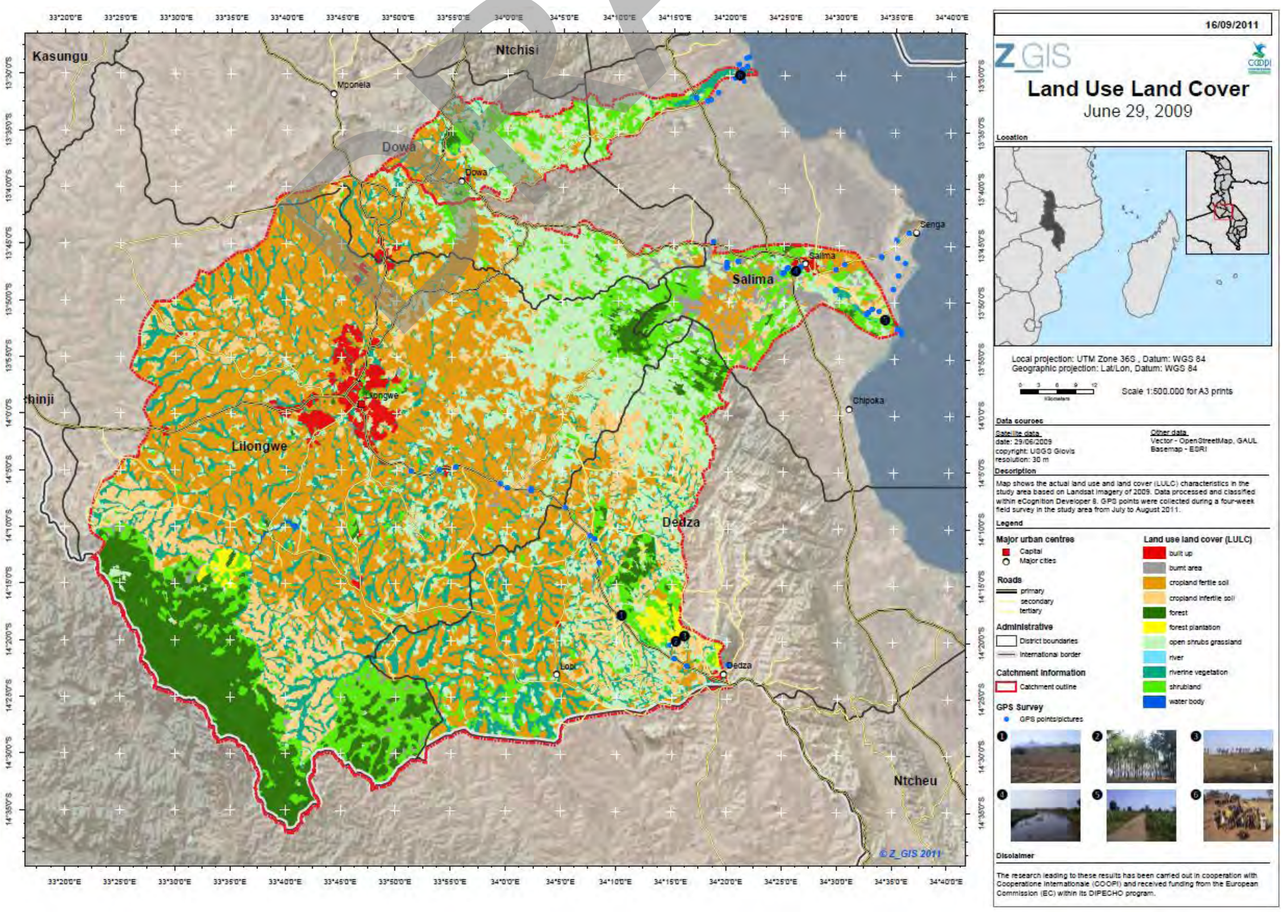


Figure 23: Land use/land cover (2009)

Class name	Area 1990 [in ha]	Area 1990 [in %]	Area 2009 [in ha]	Area 2009 [in %]
Built-up	5.361.84	0.61	14.938.11	1.71
Burnt area	11.072.43	1.27	14.856.66	1.70
Cropland fertile soil	332.064.22	37.98	299.093.09	34.21
Cropland infertile soil	101.600.06	11.62	99.829.89	11.42
Forest	81.237.65	9.29	73.421.67	8.40
Forest Plantation	7.812.27	0.89	5.617.08	0.64
Open shrubs/grassland	147.824.89	16.91	167.890.25	19.20
Shrubland	102.800.99	11.76	96.539.50	11.04
River	389.79	0.04	575.37	0.07
Riverine vegetation	83.764.08	9.58	101.046.15	**11.56**
Water body	368.73	0.04	443.61	0.05

Table 10: Area statistics – LULC (1990 and 2009)

Accuracy Assessment

Tables 11 and 12 show the results of the visual accuracy assessment as well as additional comments on the classification result, which also have been taken into account during on-site validation. Due to the low spatial resolution of the Landsat images (30 m) and spectral similarities some overlaps between classes were unavoidable: for example the class *open shrubs/grassland* was not clearly separable from some others (e.g. *cropland* shows similar spectral properties on the Landsat imagery).

Class (LULC 1990)	Accuracy (range 1 to 3)	Comments
Built-up	1	Based on manual classification; minor settlements not classified (e.g. settlement in the north of the airport)
Burnt area	2.5	Partly confusion with shadow areas; could partly be extended; check on the ground if burnt areas are feasible in this region (maybe these areas could also be swampy areas?)
Cropland fertile soil	2	Parts (e.g. in the North, Lingadzi) not classified (due to heterogeneous landuse); partly confusion with infertile soil and open shrubs/grassland
Cropland infertile soil	2	Partly confusion with fertile soil and open shrubs/grassland
Forest	1.5	Partly confusion with shrubland and forest plantation
Forest Plantation	1.5	Has to be checked on the ground
Open shrubs/grassland	2.5	Major confusion with cropland, but also with shrubland and partly with burnt areas
Shrubland	2	Partly confusion with forest, open shrubs/grassland and burnt areas (mainly in the south)
River	1	Only major parts of the river Lilongwe; for a detailed river network an already existing data set could be integrated; minor confusion with water body
Riverine vegetation	1	
Water body	1	Minor confusion with river

Table 11: Visual evaluation of LULC 1990 classification accuracy for each class using a range from 1 (= high accuracy) to 3 (= medium accuracy)

Class (LULC 2009)	Accuracy (range 1 to 3)	Comments
Built-up	1	Based on manual classification; minor settlements not classified
Burnt area	2	Partly confusion with shadow areas, shrubland, open shrubs/grassland and cropland
Cropland fertile soil	2	Parts (e.g. in the North, Lingadzi) not classified (due to heterogeneous landuse); partly confusion with infertile soil and open shrubs/grassland
Cropland infertile soil	2	Partly confusion with fertile soil and open shrubs/grassland

Forest	1.5	Partly confusion with shrubland
Forest Plantation	1.5	Has to be checked on the ground
Open shrubs/grassland	2.5	Major confusion with cropland, but also with shrubland and partly with burnt areas
Shrubland	2	Partly confusion with forest, open shrubs/grassland and burnt areas
River	1	Only major parts of the river Lilongwe; for a detailed river network an already existing data set could be integrated, minor confusion with water body
Riverine vegetation	1	
Water body	1	Minor confusion with river

Table 12: Visual evaluation of LULC 2009 classification accuracy for each class using a range from 1 (= high accuracy) to 3 (= medium accuracy)

Land use land cover (LULC) change detection

The following two figures show the results of the object-based land use/land cover (LULC) change detection concerning changes in forest and woody vegetation. Thereby the first figure shows the change in forest from 1990 to 2009 (cf. Fig. 24), while the second figure shows the change in woody vegetation (forest and shrubland) for the same time span (cf. Fig. 25).

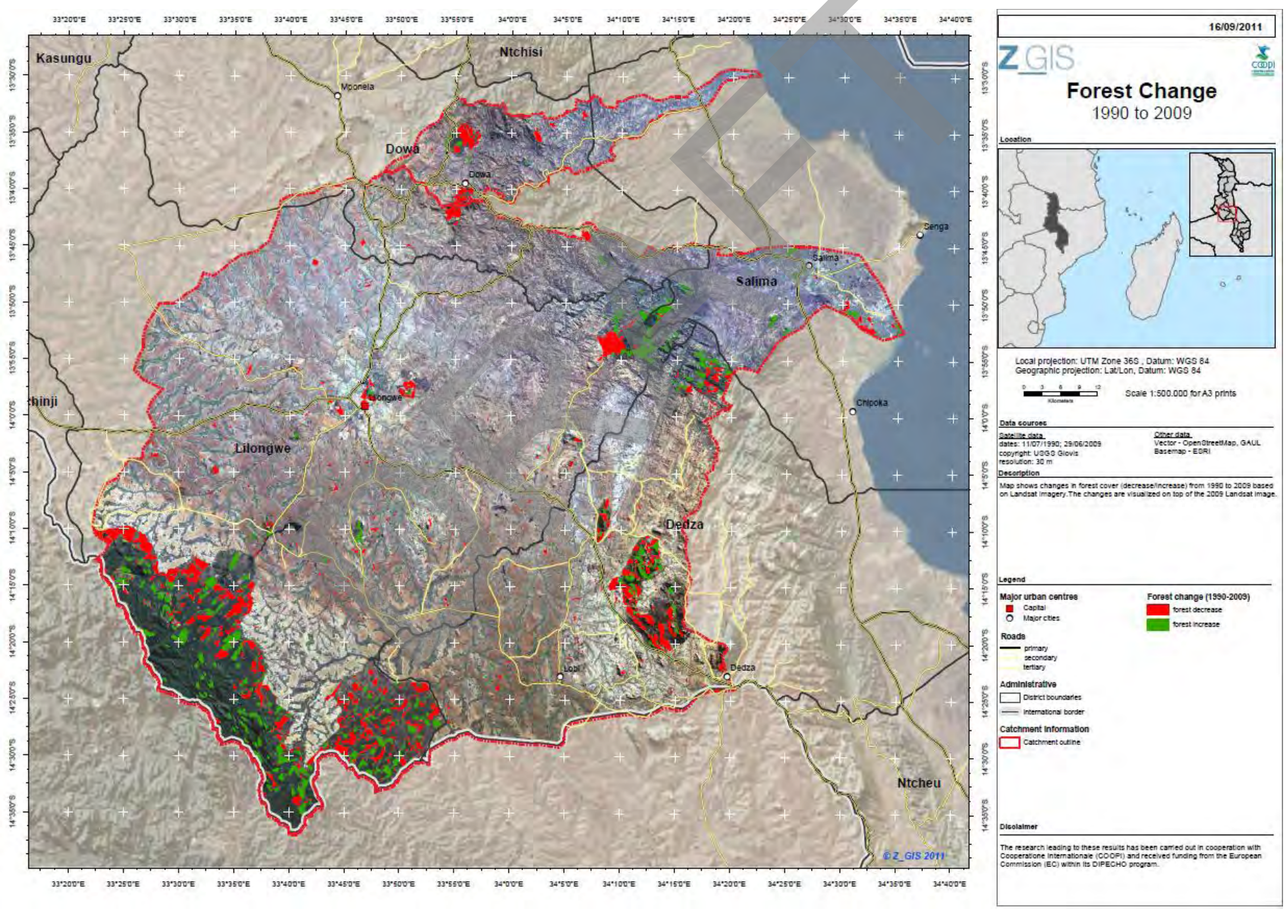


Figure 24: Forest change (1990-2009)

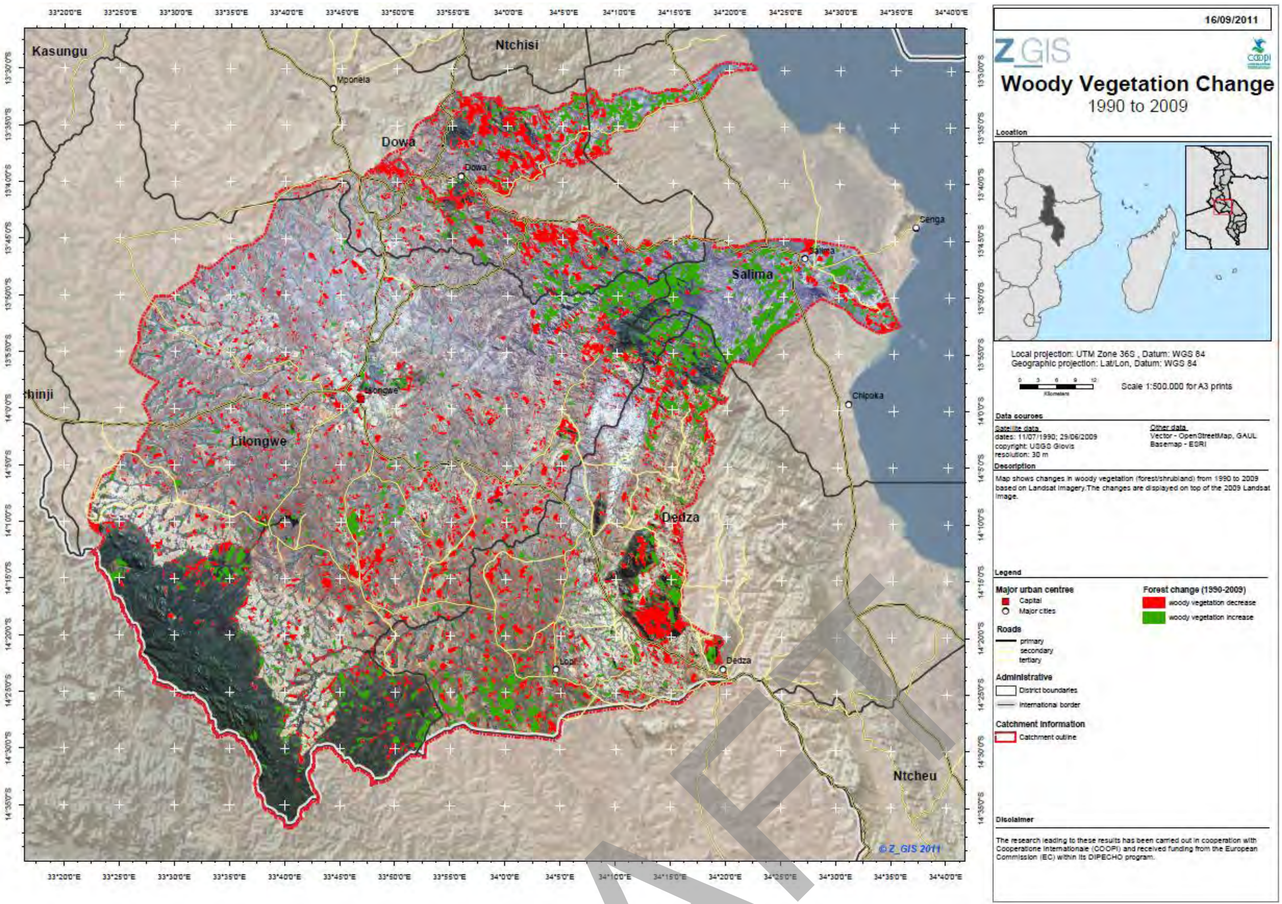


Figure 25: Woody vegetation change (1990-2009)

Table 13 shows the change (i.e. the decrease) of *forest* and *shrubland* from 1990 to 2009. It becomes obvious that a major decrease in both forest cover (approx. -10%) and shrubland (-6%) has affected the region within the past two decades. Such deforestation may also be linked to an increase in flood prone areas or flood risk in general. This fact has especially being highlighted by several stakeholders during the interviews and the final workshop.

Class	1990 (in km²)	2009 (in km²)	Decrease in km²	Decrease in %
Forest	812.377	734.216	-78.161	-9.621
Shrubland	1028.010	965.395	-62.615	-6.091
Forest & shrubland (woody vegetation)	1840.387	1699.611	-140.775	-7.649

Table 13: Results of the change detection between 1990 and 2009 showing the decrease of forest and shrubland

Besides assessing the changes in forest and woody vegetation cover, additional analysis was performed in order to assess the actual land use/land cover changes in more detail. The following two figures present the results of the in-depth analysis. Figure 26 shows the change of *forest* in 1990 to other LULC classes in 2009, while figure 27 gives an overview of the area per class, which transformed to forest in 2009.

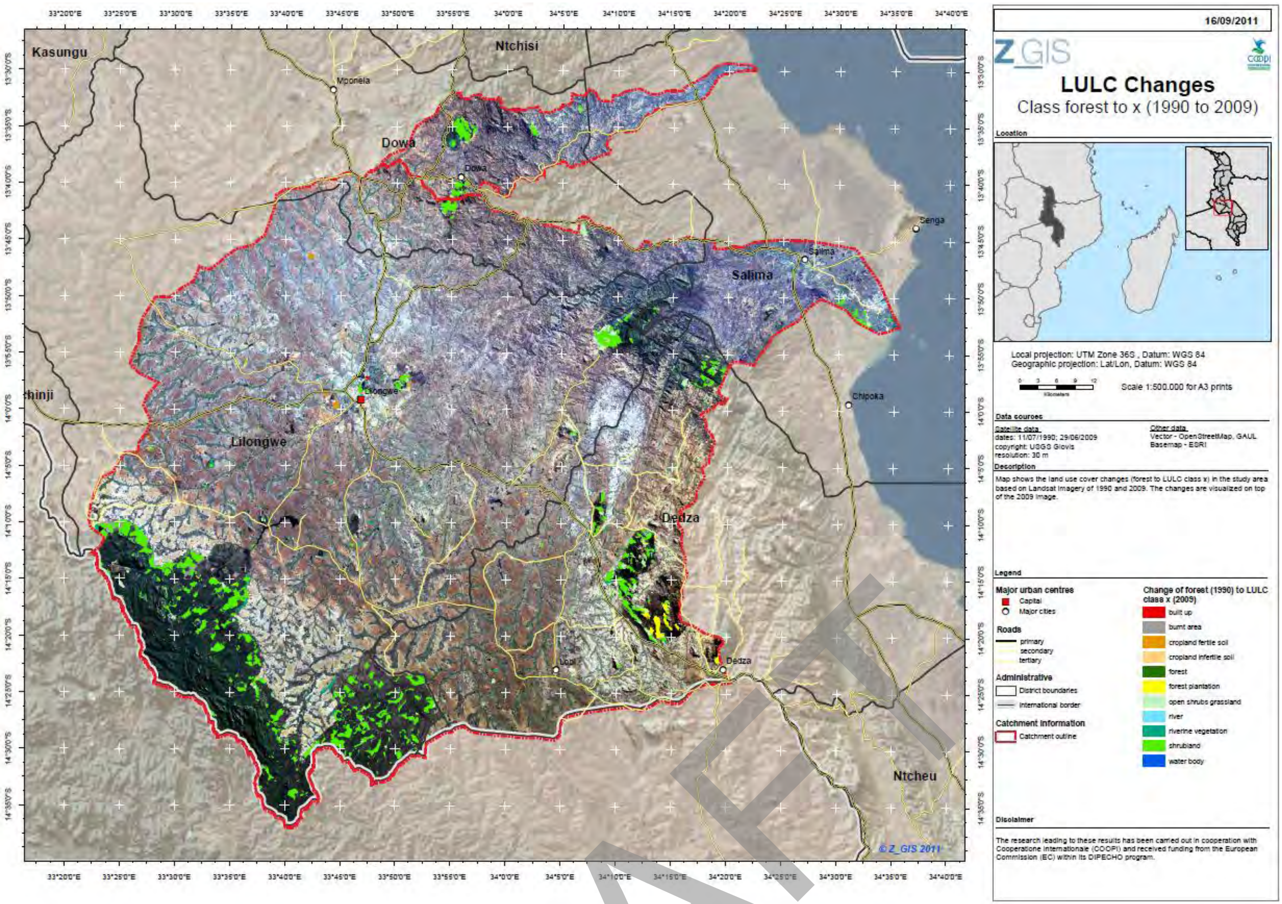


Figure 26: Change forest to class x (1990-2009)

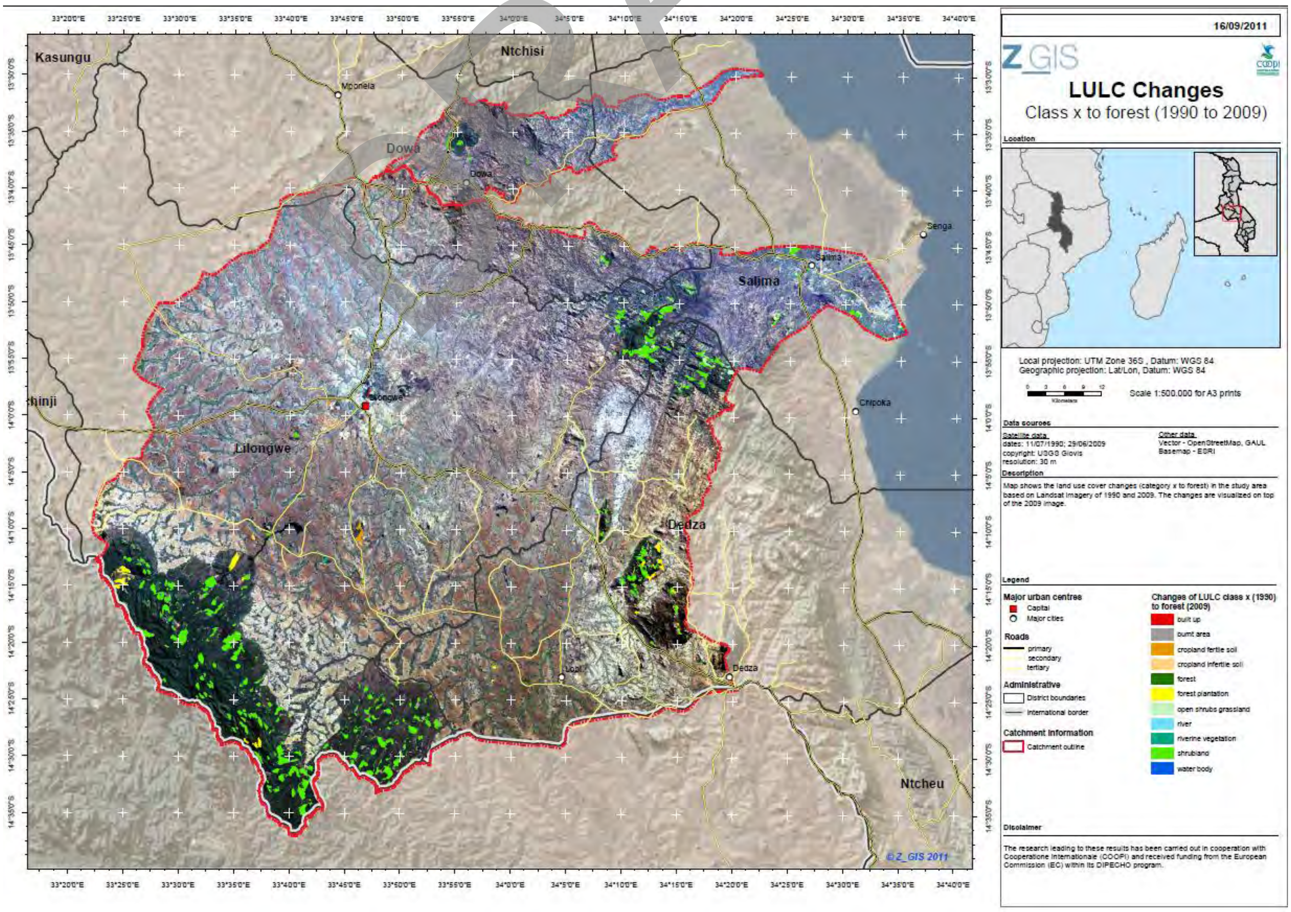


Figure 27: Change class x to forest (1990-2009)

Table 14 presents change of *forest* in 1990 to other LULC classes in 2009, while Table 15 gives an overview of the area per class, which transformed to forest in 2009. *Forest* mainly changed to *shrubland* and vice versa. Other LULC classes were only affected by minor changes. Similar tables are provided for the class *shrubland* as well as for *forest and shrubland* (i.e. *woody vegetation*) together. Concerning the changes of *shrubland* and *woody vegetation* one can observe that mainly the classes *cropland, open shrubs/grassland and riverine vegetation* were affected by certain changes. Anyway, the given numbers resulting from semi-automated image analysis represent rather an indication of the changes as the absolute truth as the result is highly dependent on the spatial resolution of the input Earth Observation data.

Class 1990 (in 2009 forest)	Area (km²)
Built-up	0.294
Burnt area	3.636
Cropland (fertile soil + infertile soil)	5.554
Forest Plantation	8.440
Open shrubs/grassland	7.727
Shrubland	108.861
River	0.006
Riverine vegetation	1.372
Water body	0.293
Total	**136.183**

Table 14: Change detection with focus on class *forest*: class x in 1990 changed to forest in 2009

Class 2009 (in 1990 forest)	Area (km²)
Built-up	0.900
Burnt area	4.760
Cropland (fertile soil + infertile soil)	11.461
Forest Plantation	7.529
Open shrubs/grassland	20.334
Shrubland	153.984
River	0.173
Riverine vegetation	14.995
Water body	0.067
Total	**214.201**

Table 15: Change detection with focus on class *forest*: forest in 1990 changed to class x in 2009

Class 1990 (in 2009 shrubland)	Area (km²)
Built-up	1.630
Burnt area	33.600
Cropland (fertile soil + infertile soil)	132.809
Forest	153.984
Forest Plantation	22.845
Open shrubs/grassland	234.326
River	0.475
Riverine vegetation	31.225
Water body	0.013
Total	**610.907**

Table 16: Change detection with focus on class *shrubland*: class x in 1990 changed to shrubland in 2009

Class 2009 (in 1990 shrubland)	Area (km²)
Built-up	4.804
Burnt area	20.521
Cropland (fertile soil + infertile soil)	147.584
Forest	108.861
Forest Plantation	15.695
Open shrubs/grassland	272.217
River	0.876
Riverine vegetation	102.740
Water body	0.153
Total	**673.450**

Table 17: Change detection with focus on class *shrubland*: shrubland in 1990 changed to class x in 2009

Class 1990 (in 2009 woody vegetation)	Area (km²)
Built-up	1.924
Burnt area	37.236
Cropland (= fertile soil + infertile soil)	138.363
Forest Plantation	31.285
Open shrubs/grassland	242.052
River	0.482
Riverine vegetation	32.597
Water body	0.305
Total	**484.244**

Table 18: Change detection with focus on class *woody vegetation*: class x in 1990 changed to woody vegetation in 2009

Class 2009 (in 1990 woody vegetation)	Area (km²)
Built-up	5.704
Burnt area	25.281
Cropland (= fertile soil + infertile soil)	159.044
Forest Plantation	23.224
Open shrubs/grassland	292.550
River	1.049
Riverine vegetation	117.734
Water body	0.220
Total	**624.806**

Table 19: Change detection with focus on class *woody vegetation*: woody vegetation in 1990 changed to class x in 2009

3.1.2.2 Population dynamics

This section presents and discusses the outcomes of the population mapping exercise. Thereby figure 28 shows the actual population counts for 2010 based on freely available global population data (cp. chapter 2.2), while figure 29 displays the change in population numbers from 1990 to 2010.

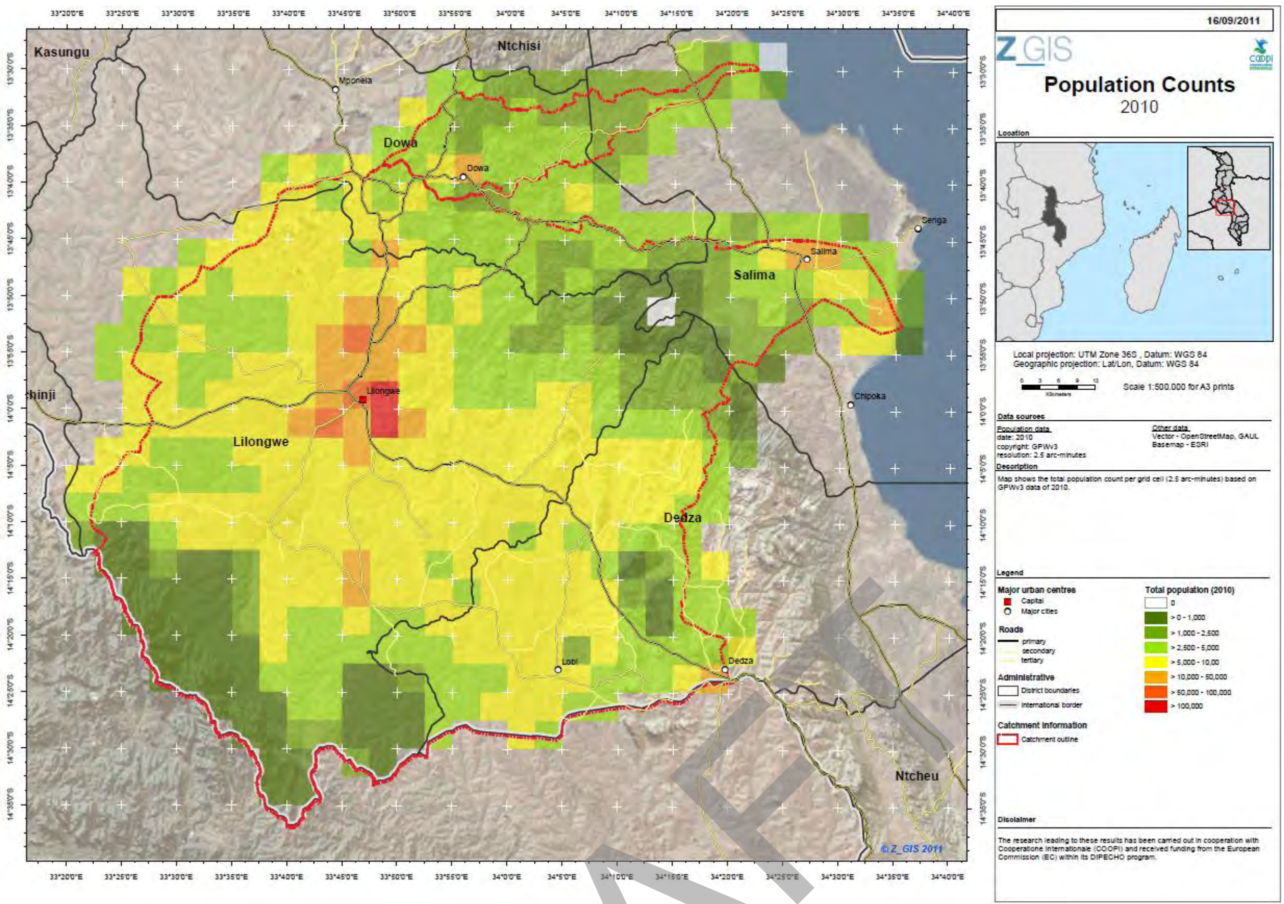


Figure 28: Population counts (2010)

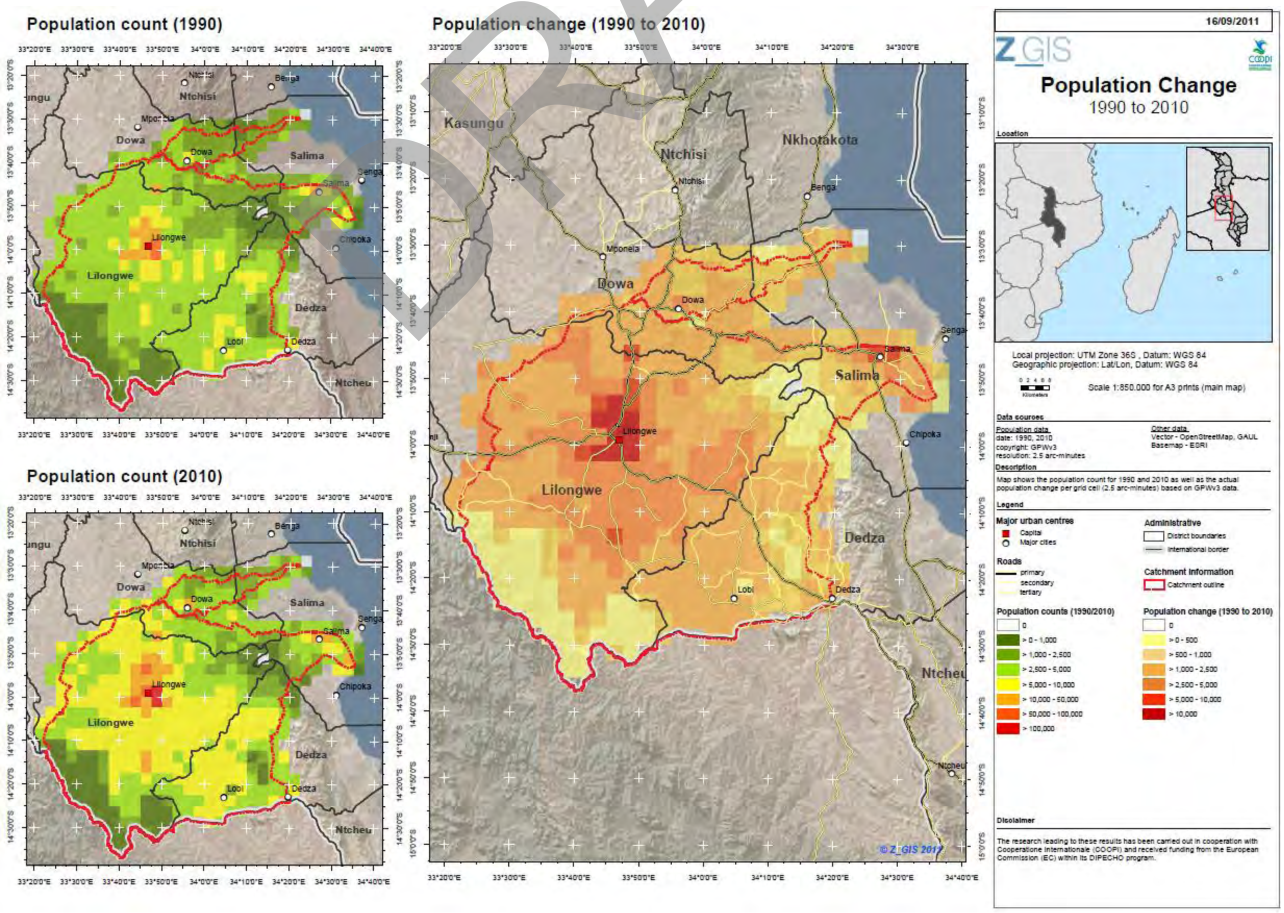


Figure 29: Population change (1990-2010)

It becomes obvious that the population had increased within the entire study area within these 20 years. However, a marked increase was observed especially in the surrounding of the capital of Malawi (i.e. Lilongwe) as well as in Salima city. In terms of vulnerability to flood hazards this increase results in a general increase of people at risk to flood hazards in the study area.

3.1.2.3 Anthropogenic impacts on increased flood risk and flood severity

With regard to objective 2 all relevant **anthropogenic impacts** (socio-economic factors, etc.) on increased **flood severity** and **risk** were assessed during the semi-structured interviews with the following local experts or stakeholders:

- Department of Disaster Management Affairs (DoDMA), Salima,
- Ministry of Irrigation and Water Development, Salima,
- Department of Forestry, Salima
- Cooperatione Internationale (COOPI), Salima.

Thereby, the following **factors** were identified by the experts:

- Environmental degradation (particularly deforestation; cf. Fig. 24),
- Poor agricultural practices,
- Population growth,
- Expansion of road networks and
- Brick making.

Table 20 gives an overview of the relative importance of these issues according to the interviewed experts.

Anthropogenic impact	DoDMA, Salima	Irrigation and Water Development, Salima	Dept. of Forestry, Salima	COOPI, Salima
Charcoal production	very high importance	high importance	very high importance	very high importance
Poor agricultural practices	very high importance	high importance	very high importance	high importance
Expansion of farmland	very high importance	high importance	high importance	high importance
Population growth	high importance	high importance	low importance	-
Expansion of road networks	-	-	low importance	-
Brick making	high importance	-	-	medium importance

Table 20: Rating of the importance of anthropogenic factors for increased flood risk in the study area

According to the experts (severe) **deforestation** (cf. Fig. 24) can be observed particularly along rivers and in upland areas due to a number of factors, including (i) firewood collection, (ii) charcoal production and (iii) the expansion of farmland. In combination with other forms of **environmental degradation** this results in a severe loss of ground cover and reduced infiltration, which again leads to increased surface run-off, gully erosion and thus flatter river beds in downstream areas where eroded materials are deposited.

These factors are reinforced by existing **poor agricultural practices**, such as unsustainable shifting cultivation practices and intensified cultivation along river streams. The latter results in increased deforestation, as trees are cut and land is cleared along the river beds, and thus in increased siltation trough instable river bank soils. According to the interviewed experts, the marked and widely observable extension of agricultural fields along river networks can be primarily traced back to small-scale irrigation practices, such as the widespread use of treadle-pumps.

The sharp **increase in population** in the country (according to the 2008 census report the population of Malawi increased by 32 per cent between 1998 and 2008, representing an annual growth rate of 2.8 per cent per annum) has resulted in increasing urbanization and opening (and clearing) of more land for farming purposes. Besides its impacts on the environment (i.e. environmental degradation, etc.) this also results in increased population at risk.

Finally, **brick making** was mentioned as another factor contributing to increased flood risk as it additionally reinforces deforestation in the region. According to the experts one large tree is needed to fire approximately 3,000 bricks.

Figure 30 displays the major root causes of deforestation in the study area according to the interviewed experts of the Forestry Department in Salima.

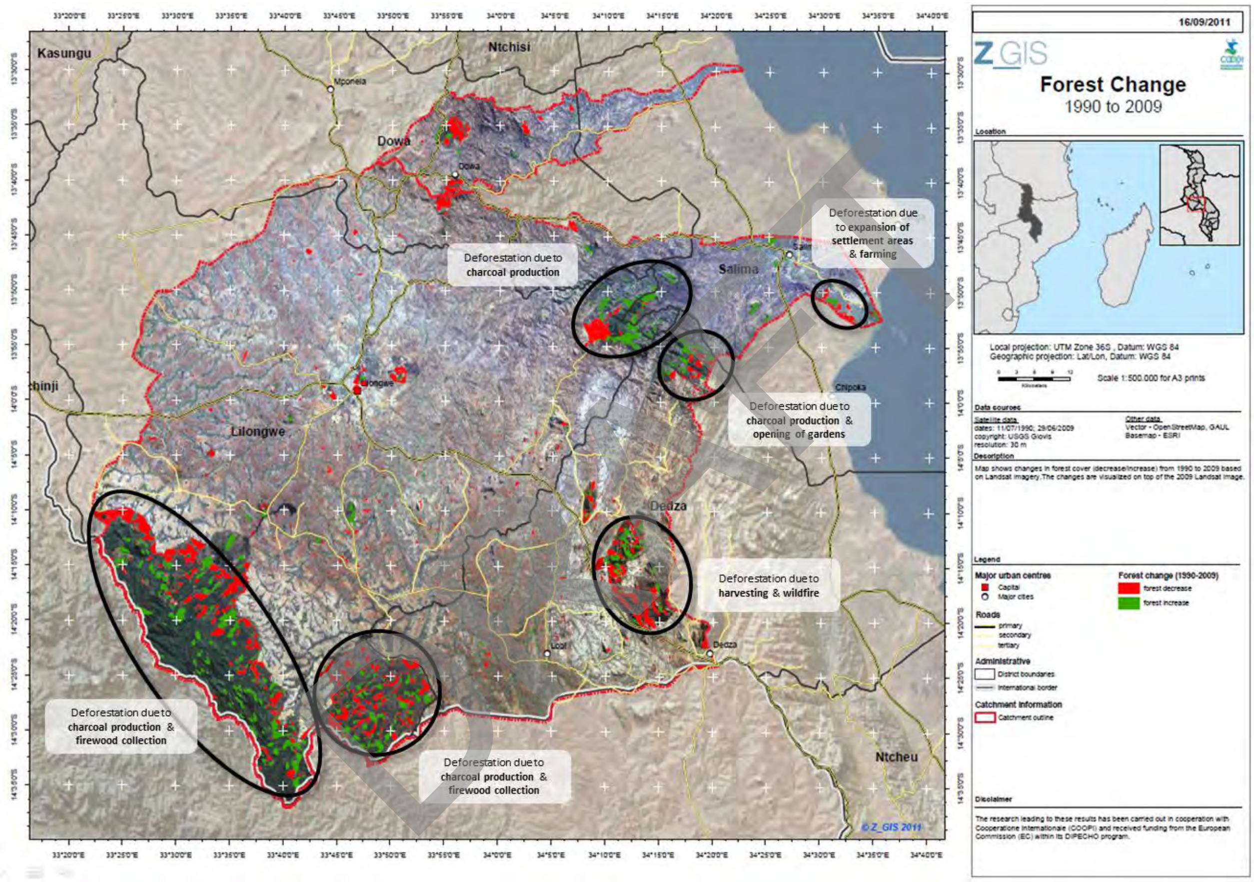


Figure 30: Root causes of deforestation (according to the Forestry Department, Salima)

3.2 DRR and recovery activities in the study area

In line with objective 3 existing **interventions** in (i) flood **disaster risk reduction (DRR),** (ii) **recovery** and (iii) **existing early warning systems (EWS)** in Salima district were assessed during the in-country assessment. This included an in-depth evaluation of their strengths, weaknesses, effectiveness and appropriateness.

3.2.1 Flood early warning systems (F- EWS)

3.2.1.1 National Flood Early Warning System (F-EWS)

The structure of the **national Flood Early Warning System** (F-EWS) which is maintained and operated jointly by the Department of Climate Change and Meteorological Services, the Ministry of Irrigation and Water Development and the Department of Disaster Management Affairs (DoDMA) is outlined in figure 31. The flash-points represent potential faults in the system according to the interviewees.

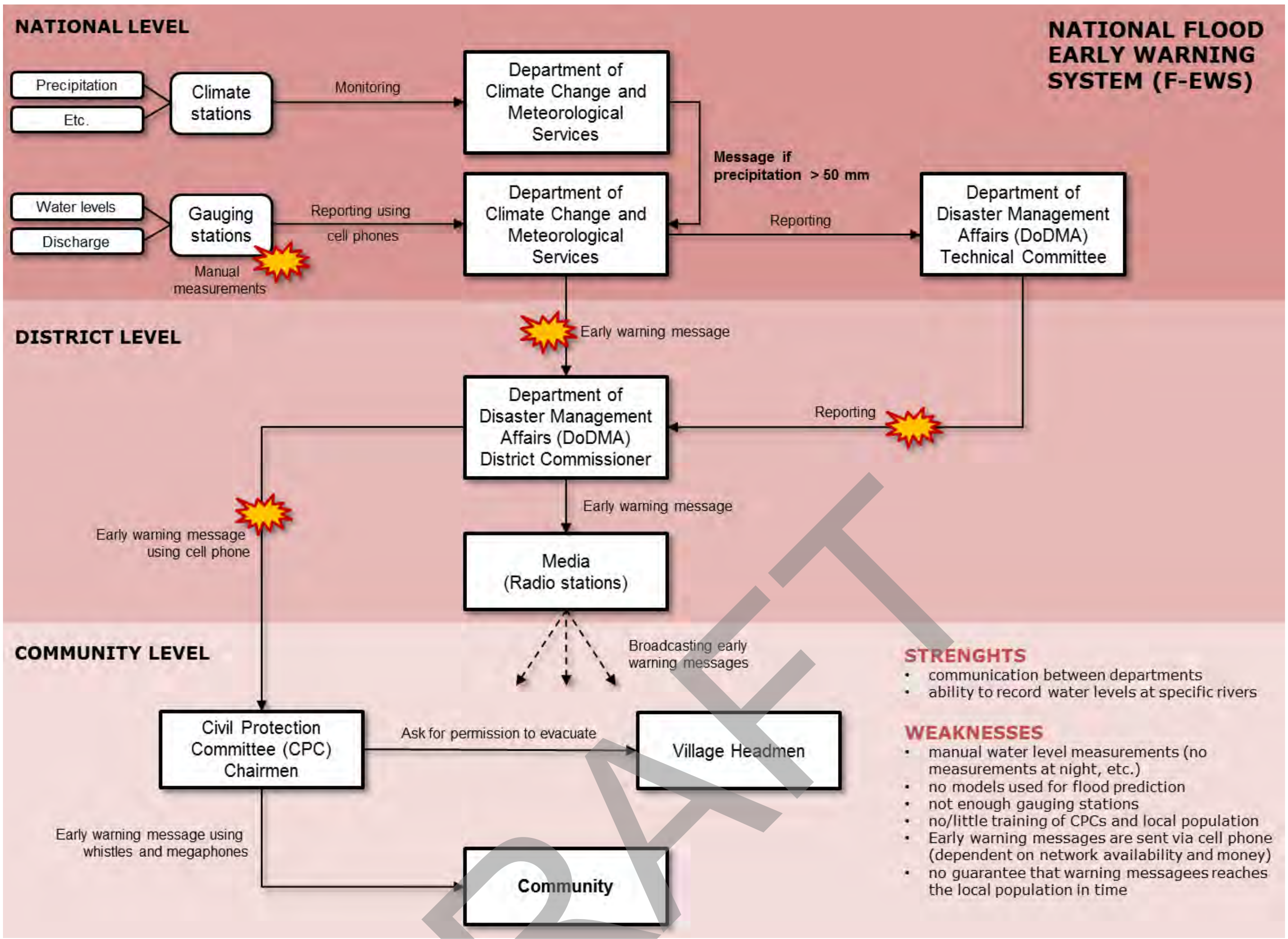


Figure 31: National flood early warning system (F-EWS)

The Department of Climate Change and Meteorological Services in Malawi operates a set of meteorological stations comprising 22 full meteorological stations, 21 subsidiary agro-meteorological stations and over 400 rainfall stations all over the country. Figure 32 shows the location of the main meteorological stations.

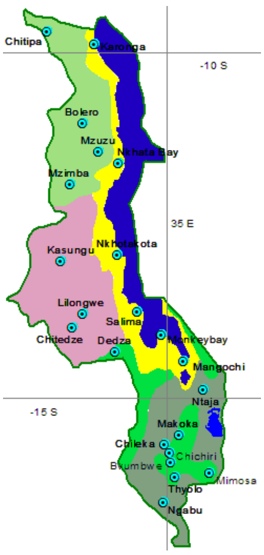


Figure 32: Main meteorological stations (Source: Department of Climate Change and Meteorological Services)

According to the Department of Climate Change and Meteorological Services observations at the 22 full meteorological stations are done by trained meteorological assistants regularly at 05:00, 06:00, 08:00, 09:00, 11:00, 14:00 and 17:00 local time. Thereby, the minimum number of observations per station is two at one-man stations and only on Saturdays and Sundays. Currently, two stations are doing observations 24 hours a day. As soon as precipitation values of more than 50 millimetres (mm) are observed at one of the meteorological stations, a warning message is sent to the Ministry of Irrigation and Water Development, which itself operates a number of gauging stations in some of the major rivers in the country providing information on water levels and water discharges in these rivers. A warning message is then sent from the Ministry of Irrigation and Water Development to both the Technical Committee of the Department of Disaster Management Affairs (DoDMA TC) and the DoDMA district commissioner in the respective district/s. The district commissioner forwards the message to the local media (i.e. primarily radio stations) and the chairmen of the Civil Protection Committees (CPCs) in flood-prone communities. Early warning messages are then broadcasted via radio and by the CPC members using whistles and megaphones. However, note that before villages at risk can be evacuated by the CPCs the local CPC chairman has to ask the village headman for his permission to evacuate.

Thus the F-EWS reveals the following **strengths** according to the interviewed experts:

- Strong institutional link between the departments involved in F-EW activities,
- The availability of gauging stations in some of the major rivers enables the monitoring of water levels and discharge in at least some rivers.

However, there are also distinct **weaknesses** that were mentioned by the experts:

- Although being conducted by trained personnel, the measurements at the gauging and rainfall stations are still manual, resulting in no measurements being taken during the night,
- To date no models are used for flood forecast and prediction,
- Many rivers in the country are still lacking gauging stations, disabling the provision of early warning messages by the responsible departments for wider regions,
- So far neither the CPCs nor the local population in flood-prone areas have been properly trained how to react when a EW-message is received (only selected communities have been trained by civil society organisations involved in DRR activities),
- Early warning messages are not sent automatically, there is no standardised approach as to when and how to send EW messages. Currently EW-messages are sent via cell-phone, making successful information dissemination dependent not only on network availability but also on the availability of credit on the respective phones. This means that there is no guarantee that the local population can be warned in time.
- In the southern part of the country (i.e. particularly in the lower Shire basin) flooding is sometimes caused by heavy rainfall in Mozambique. The existing F-EWS is not prepared to deal with these cases as there are currently no cross-border meetings of relevant stakeholders.
- Recently significant funds were disbursed by a donor to purchase new weather stations and water gauge stations, however, the interviewees gave the clear impression that there was little or no communication about this action with the DoDMA.

3.2.1.2 Flood Early Warning System (F-EWS) in Salima district

The assessment in **Salima district** has shown that, so far, only two **flood early warning systems (F-EWS)** based on river gauging stations along Linthipe and Lingadzi rivers are operational. The river gauges were installed by the Water Department in cooperation with the Red Cross and used by the communities to monitor the flow and quantity of water. As none of the gauging stations was operational as a result of vandalism, the international NGO Cooperatione Internationale (COOPI) has rehabilitated three stations (two along Linthipe river and one along Lingadzi river; cf. Fig. 33) and trained the local Civil Protection Committees (CPCs) in collaboration with a DODMA officer on

DRR and related DRR activities. Table 21 provides more specific information on the location of the three gauging stations that were rehabilitated by COOPI between 2010 and 2011. Moreover, figure 33 shows the actual location of the gauging stations on a map.

ID	EWS (named by the location)	x (WGS 84 – UTM 36S)	y (WGS 84 – UTM 36S)
01	Mwanza	8500420	632365
02	Katchisa	8474533	657838
03	Malapa	8472134	645585

Table 21: Existing gauging stations in Salima district

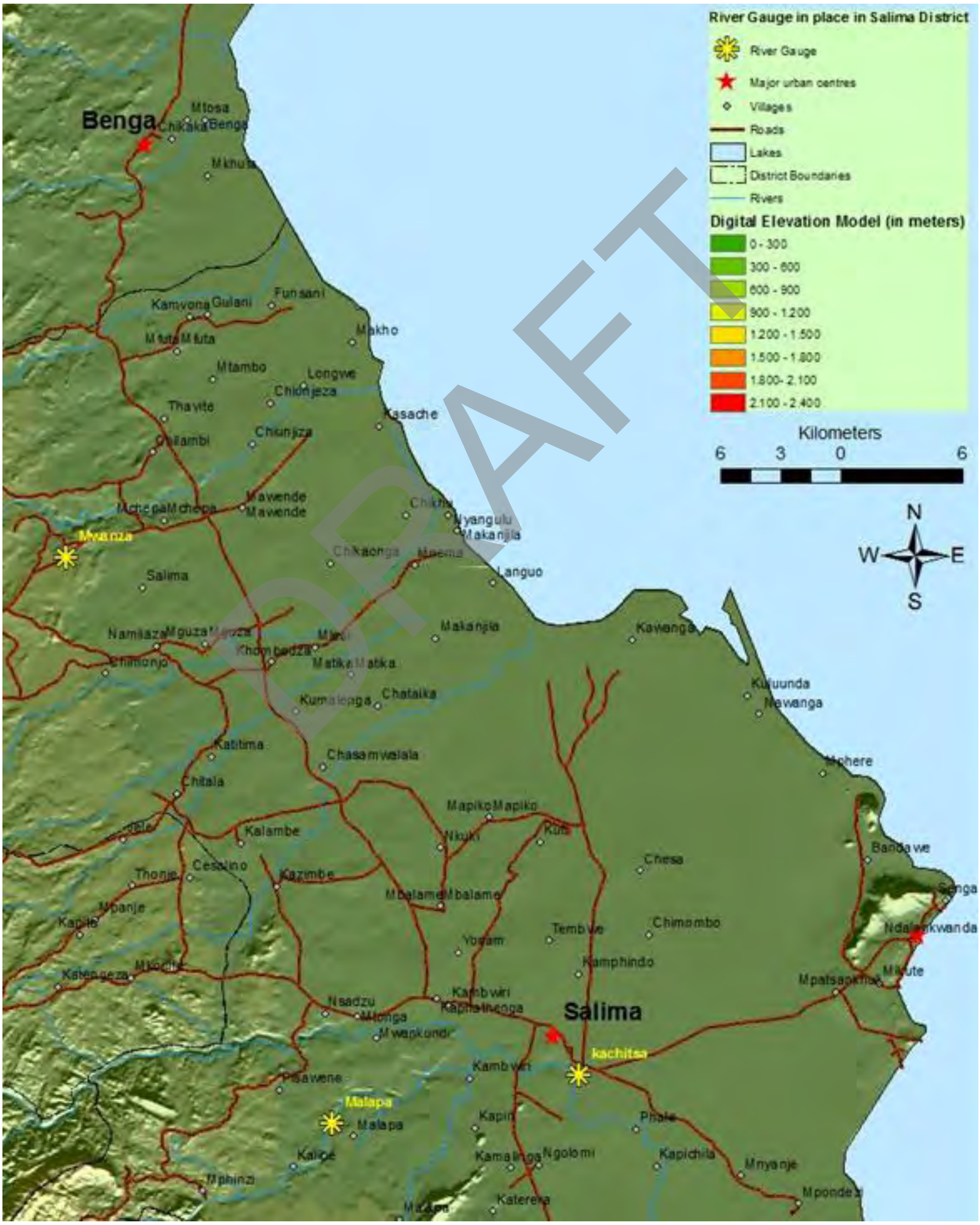


Figure 33: Location of the three gauging stations in Salima district

The measurements at the gauging stations are conducted by members of the local Civil Protection Committee (CPC). In case of increasing water levels, a warning message is transmitted to the CPCs of flood-prone villages in the downstream area. The transmission of the message is done using various methods depending on the distance and the local setting, comprising cell phones, megaphones as well as radio broadcasts. Once the message arrives at the endangered village, the CPC personnel in charge spread the alarm using whistles and megaphones. Moreover, the alert is transmitted to the local district and local rescue and first aid brigades are informed. However it became clear that the modalities of the horizontal transmission (from one CPC to another CPC), the modalities and the record of events between national and/or district offices and the CPC are less clear. During the in-country assessment, none of the CPC members could give clear indication of how and when they received some sort of vertical transmission; neither they could they report clearly the modalities of such warnings.

Based on that table 22 presents the results of a rating exercise as carried out with the interviewed experts concerning the **effectiveness of the flood EWS** in Salima district.

Effectiveness of the existing EWS	DoDMA, Salima	Irrigation and Water Development, Salima	Dept. of Forestry, Salima	COOPI, Salima
Very high	-	-	-	-
High	managed to save lives and property	-	-	communication in time
Low	-	human capacity/ personnel to collect gauging data	-	-
Very low	-	-	-	-

Table 22: Rating of the effectiveness of existing flood EWS in Salima district

Summarizing the mentioned aspects the F-EWS reveals the following **strengths** (according to the interviewed experts):

- The EWS managed to save lives and property in some communities,
- Communication in time,

However, there are also distinct **weaknesses** that were mentioned by the experts:

- The human capacity/personnel to collect gauging data is not sufficient which results in irregular measurements,
- Water levels are measured manually at the gauging stations which means that no measurements are taken at night,
- Early warning messages are communicated via cell phone which makes the success transmitting a warning message dependent on the availability of network and cell phone units,
- Currently, the system is supported by local NGOs (i.e. COOPI) which means that the system is not temporally sustainable (in case the NGOs stop operating in the area).

3.2.2 Overview of existing DRR and recovery activities and their weaknesses

Besides the existing flood EWS, the following **DRR** and **recovery interventions** were identified:

- Planting of trees in affected TAs (traditional authorities), particularly on bare lands in upland areas (large-scale) and along rivers (small-scale),
- Riverbank stabilization measures using sand bags or by planting elephant grass,
- Installation of latrines in evacuation sites,
- Rehabilitation of gauging stations in selected river systems.

According to the interviewed experts trees, however, were only planted and river banks were only stabilized in small, selected areas so far. Moreover, it became obvious that the office of the Department of Disaster Management Affairs (DoDMA) in Salima is not equipped with sufficient funds to effectively coordinate DRR and recovery activities in the district.

3.3 Participatory risk evaluation

The results of the study were presented during a **workshop** in Lilongwe on September 28 and 29 2011 at the Disaster Risk Reduction Centre of the Dep. of National Parks & Wildlife under the title 'River Modelling Study for the Central Region River Basin – Linthipe and Lingadzi River System'. The audience constituted a broad reflection of key stakeholders related to the Central River Basin. After the presentation of the project's objectives and an introduction of the conceptual framework for integrating Disaster Risk Reduction (DRR) and Climate Change Adaptation (CCA), the project partners gave an overview of the hazard (historic floods and hydrological modelling) and vulnerability assessment (land use/land cover change and population dynamics) that was conducted by the consultants. All assessment maps were placed in the room as hardcopies for the detailed inspection by participants.

Figure 34: Display of assessment results during workshop, Lilongwe 2011 (© Peter Zeil)

In a first round of feedback, the **key risk factors** for the Linthipe and Lingazi River catchments were compiled by the stakeholders. Those factors are grouped into **three clusters**:

Cluster 1 (technical issues)
Riverbed erosion, river bed cultivation, charcoal production, deforestation, inadequate sensitisation of population, extraction of construction material, poor land husbandry.

Cluster 2 (policy/governance issues)
Lack of stakeholder coordination, harmonisation of policy, water governance, biomass energy, integrated water resources management, charcoal from rural to urban, lack of local institution empowerment, inadequate network of met stations.

Cluster 3 (issues of general nature)
Poverty, high illiteracy, low income levels, population pressure.

The first two clusters served as headline topics for separate working groups with the aim to outline a strategy for action to reduce the risk from future floods.

Technical aspects:
On the issue of poor land husbandry, the local stakeholders noted that due to a change in policy by the local Government the LRC (Land Resource Centre) offices were abandoned at EPA (Extended Plan Area) levels, and therefore, there is no skills training provided by Land Husbandry staff. The insufficient number of extension workers creates a situation where no efforts are undertaken to encourage farmers to use good land husbandry practices and no new technologies for soil and water conservation are introduced. Poor agricultural practices cause river bank erosion and deforestation, which is additionally accelerated by the uncontrolled extraction of timber for construction. The spread of human settlements increases brick burning activities and charcoal production.

The **ideal situation** envisaged by the stakeholders would be characterized by the enforcement of land resources and conservation policies, holistic best agricultural practices, sensitivity and cooperation. The education sector integrates these issues in their curricula and trains more field workers in agricultural husbandry. This will cause the return of land husbandry staff to the field.
The challenges to overcome on the way to the ideal situation were identified as the lack of cooperation with best practice cases, resource constraints, conflicting policies at local level, ignorance and the high level of illiteracy.

The working group participants established a set of **first steps** in the right direction:

- Form river basin village management committees,
- Plant and conserve trees near river banks in all strategic areas,
- Explore proper solutions to deforestation, e.g. alternatives to wood energy,
- Develop and properly implement forest management plans,
- Re-enforce policies, acts and law,
- Request the harmonization of policies,
- Introduce small loans for local communities to reduce charcoal production for income generation,
- Abandon residual type of irrigation and promote motorized, small-scale T/pumps,
- Negotiate a long-term and sustainable solution for electricity supply especially to urban areas,
- Form VNRMC (village natural resource management committees) and catchment conservation committees, and ascertain the building of their capacity,
- Establish collaboration on risk management between the various stakeholders,
- Promote awareness,
- Ascertain adequate and competent personnel at all levels.

Policy and governance:
Three main **problematic aspects** were noted: a policy conflict regarding irrigation and forest management, lack of policy, and weak acts enforcing the law. In an **ideal situation**, policies are harmonised, acts are regularly updated and their enforcement ascertained. For this to happen the

challenges to address are the lack of knowledge for setting priorities for implementation, the insufficient coordination between departments and ministries, bureaucracy, and in adequate infrastructure development. As **first steps** in the right direction the group identified:

- Advocate the related policies,
- Request the review of policies,
- Stimulate knowledge sharing,
- Carry out sensitization campaigns,
- Institute the infrastructure in place.

4 GENERAL CONCLUSIONS AND RECOMMENDATIONS

4.1 Development scenarios, recommendations and interventions

Taking the assessment of hazard and vulnerabilities in the Central River Basin into account and recognizing the extensive input by the stakeholders of the catchments, **actions on three levels** are suggested as conclusions and recommendations. These suggestions are made to reduce the established vulnerabilities with the objective to mitigate the risk from future floods.

On a **district level**, the recommendations are defined as **development scenarios,** which require the concerted interaction of all branches of government.

1. Acts and extension work should encourage appropriate agricultural practices including soil and water protection measures, conservation agriculture and agro-forestry technology,
2. Integrated water resources management (IWRM) should be established at full scale to enforce river bank protection; appropriate land use plans need to include measures such as the planting of elephant grass and suitable tree species,
3. Measures need to be undertaken to improve the economic situation of the population, also including alternative forms of income.

A set of **recommendations** addresses issues, which require the involvement of actors outside of the group of stakeholders. These are:

1. Promote the use of energy-saving practices such as wood-saving stoves,
2. Incorporate ‘food-for-work’ schemes for community benefitting activities such as dredging of river beds,
3. Revamp natural resources management committees.

In the context of the cooperation between the stakeholders in the Linthipe and Lingazi River Basin and COOPI the following **interventions** are suggested:

1. To **strengthen the effectiveness of the observation system**, the number of meteorological stations, river gauging stations, and groundwater monitoring sites will be increased. From evidence gathered during the in-country assessment and input provided at the workshop by participants, the existing network of observation points is not sufficient to allow reliable information gathering for effective early warning. The emphasis is two-fold:

   a) DRR for floods (and drought) require time-series of precipitation, river flow and soil moisture for understanding the evolvement of flood events and to calibrate hydrological models for flood early warning. In the Salima River systems investigated in this assessment, the early warning times were seriously shortened to only two hours due to the fact that the upper part of the catchments is not covered sufficiently by (operational) gauging stations. In addition, the analysis of historic flood events shows that continuous data capture is required (24 hours) to increase warning times.

   b) CCA can only be planned based on long-term observations – of meteorological factors and the water cycle alike. A sufficiently dense observational network of met-stations covering the catchment areas will provide insight to the spatial variations of rainfall and associated recharge of groundwater aquifers as a pre-requisite to assess and identify appropriate coping strategies.

It is therefore suggested to install the following **observation stations**:

- **Met stations**
  3-4 stations, manual and automatic recording, data transmission, locations to be defined jointly with Climate Change and Meteorology Department,

- **Gauging stations**
  3 stations, preferably with automatic recording (at least 2 in strategic important locations - particularly in upstream areas - to improve the spatial coverage of the observation network and the efficiency of timely early warning), data transmission to river basin information system (see below),

- **Groundwater monitoring wells**
  2 existing groundwater boreholes to be pump-tested and to be equipped with loggers, regular observation campaigns.

The installation of the observational network has to be accompanied by an **awareness campaign** for communities in the river basin to (i) explain its function and role, and (ii) inform about the crucial importance of the collected data for DRR and CCA. Communities in the vicinity of the stations should assign custodians taking care of the stations. The network has to be seen as an asset by the communities and as a key factor for their sustainable livelihoods.

2. A **river basin information system** needs to be established which integrates the observational data from the above stations and enables the timely recognition of anomalous situations as a pre-condition for effective early warning. The information system will visualize, analyse and evaluate changes – at short-term (DRR), at long-term (CCA).

The following **components** need to be installed:

A computer workstation (server, internet connection) with the appropriate software fleet to handle the following operations:

- Baseline data base:
  - DEM - incl. detailed data for Salima and downstream area,
  - Land cover,
  - Land use,
  - Population – preferably on community level
  - Roads
  - Settlements
  - Additional critical infrastructure – schools, hospitals, dams, etc.

- Change analysis at:
  - *high temporal resolution*: information required for flood/drought warning, visualization and threshold detection based on:
    - Precipitation, temperature, water levels – transmitted data from observation network (hourly)
    - Groundwater levels – from observation boreholes (weekly)

  - *low temporal resolution*: information required for river basin status assessment and climate change adaptation planning:
    - Landcover change – woody cover, agriculture, settlements by RS analysis
    - Vulnerability monitoring – up-date of baseline assessment

and

- Early Warning

  The River Basin Information System provides the necessary indicators for the Flood EWS. Indicator thresholds should be calibrated by (i) using past events, (ii) knowledge from Civil Protection Committees on community and district levels, (iii) experts from Met-Dept. and the DoDMA. Effective warning messages and their transmission/ reception should be evaluated during emergency exercises.

- Planning

  The River Basin Information System provides the necessary data for regional planning and climate change adaptation. The key drivers for (i) development and (ii) climate change impact assessment should be visualized and analysed by vulnerability and risk maps.

3. **Dissemination and advocacy**: Specific dissemination campaigns informing district and community levels about the observation network and river basin information system should be carried out by Met-Dept./DoDMA/COOPI. Advocacy events by using presentations, outreach material, and media products target national policy levels and other stakeholders.

4. Existing documents and plans are evaluated. A **compendium of relevant documents** should be established and integrated into the River Basin Information System. To this end, documents should be scanned, tagged, and a short abstract be provided. The document database should be designed to allow the search by title, authors, key words, etc. The documents include:

   - Investment Framework on Water Resources,
   - Water laws and acts,
   - Studies,
   - Development plans.

4.2 General recommendations concerning further assessments

Building on the experiences of this study the consultants propose the following **recommendations for potential follow-up assessments**:

1. The **quality of the modelling results** depends predominantly on the **quality of the digital elevation model (DEM)**. Common problems are for example poor interpolation of DEMs derived from map contour lines, or DEMs representing the vegetation cover of an area rather than the surface itself. Such quality problems of the DEM will have an effect on the flood modelling process. So, the first requirement in both static and dynamic flood modelling is to have a good quality DEM which – in a hydraulic and hydrological sense – represents the terrain correctly. So, the modelling results presented in this study must clearly be seen as preliminary in nature. Using higher quality DEMs would result in an enormous increase in quality and accuracy of the achieved modelling results. Therefore it is strongly recommended to use alternative, high-quality DEM products for flood hazard assessments, such as the 10 m spatial resolution TerraSAR-X based DEM product which is based on TerraSAR-X StripMap stereo pairs.

2. The consultants strongly believe that the Government of Malawi and particularly the Climate Change Committee and all its members should be aware of the importance of **Spatial Data Infrastructure** (SDI) as a necessary framework enabling Malawi to properly manage its geoinformation resources and ease data availability for decision makers in the context of the Climate Change Adaptation program and DRR. This is the only way to ascertain the sustainability of any outcomes developed. Specifically this comprises the following issues:

a. **The Malawi Geoinformation Council (MAGIC) and the National Spatial Data Infrastructure are operational**
Participants of the final workshop explained that an initiative to establish an SDI in Malawi had already started some time ago, but due to a series of reasons, particularly the lack of resources, coordinating effort and support, it was abandoned in the past years. SDI is an essential framework to ensure data sharing and management at country level to the benefit of all development sectors. The former Malawi Geoinformation Council (MAGIC) and its implementing body, the National Spatial Data Infrastructure (NSDI) centre, should be reactivated and re-enforced according to the legal provision of the National Land Policy of 2002.

MAGIC should incorporate senior officers from the various government institutions and departments. The role of MAGIC would be to pull together the interest and commitments of various stakeholders towards the SDI and mandate the NSDI to put into operation the related activities. The NSD centre should have its operation core within the Survey Department since is the one having the official mandate to hold the geo data in Malawi.

Activities:
- Update the statutes of MAGIC and NSDI,
- Compile the membership,
- Develop an operational plan for MAGIC and the NSDI (for 2012),
- Organise and hold regular meetings (in 2012).

b. **SDI principles and guidelines are formulated for Malawi with the support of SDIAfrica**
Recognising that the Government of Malawi has undertaken several initiatives at a national (National Land Policy 2002) and international level (e.g. partner country to the UN GGIM 2011[2]), the establishment of a Malawi Spatial Data Infrastructure should be based on the existing building blocks. The experience from neighbouring countries in the region and Africa-wide initiatives, such as SDIAfrica coordinated by UNECA[3], provides support to the process. The main outcome should be a policy document outlining SDI principles for Malawi (e.g. institutional set-up, mandates, data sharing principles, data formats etc). The steering group of the Malawi SDI needs to convene regularly to resolve problems, create consensus, and advise on policy requirements. Members of the group should also attend respective African meetings, such as CODIST, AfricaGIS, AARSE, etc).

Activities:
- compile existing legal documents and update inventory of implementation papers & studies,
- draft principles on data sharing by exploring the Implementation Guide provided by SDIAfrica,
- organise workshops with government experts and experts from SDIAfrica
- adopt policy document on SDI principles in Malawi,
- attend meetings on regional and international level (CODIST, AfricaGIS, AARSE, etc).

c. **Advocacy on SDI principles carried out**
The concept of Spatial Data Infrastructure is geared to building together, as data users and producers, a common data resource, a collective data asset, including management tools and rules. An operational SDI facilitated by a clearinghouse mechanism enables potential users at country level to find out what data exists,

[2] See http://ggim.un.org/
[3] http://geoinfo.uneca.org/sdiafrica/default1.htm

where and how to access it and under what conditions it can be used with the objective to derive from the analysis of such data meaningful information for decision making. Seen from a country perspective, the various data sets do not need to be centralised in one location. They will be kept accessible over distributed computer networks in as many locations as there are data contributors. The possibilities to query the corresponding meta-database and to perform analytical operations and transactions on the actual data over the network are part of the facilities offered by the SDI. This is according to the agreed rules and procedures and of course entails a form of organisation. The target audience of an SDI is so large and the potential uses so diverse that consensus building through a participatory approach is essential for its design, involving both Government agencies and institutions from civil society. This approach leads to a consensus-based definition of goals, objectives and outputs. To this end, continuous outreach and advocacy is required to keep decision makers informed and the technical level on the right track (e.g. by external and independent evaluation).

Activities:

- create information products for awareness building on SDI (folders, brochures, slide shows, posters),
- hold awareness events (seminars, workshops) for government institutions,
- produce a series of newspaper articles, radio features and TV interviews on SDI,
- organise a regional conference jointly with SDIAfrica in Lilongwe,
- ascertain compliance with SDI standards and principles for government and donor projects (e.g. external evaluation).

d. **An inventory of existing spatial data is established compliant to SDI standards**

The putting into operation of the SDI requires some technical measures to address the following issues: (a) what data/information is available (meta-database) (b) in which format (c) how can the data/information be accessed. This is the technical infrastructure to make data/information, (primarily baseline data) flow between providers and users.

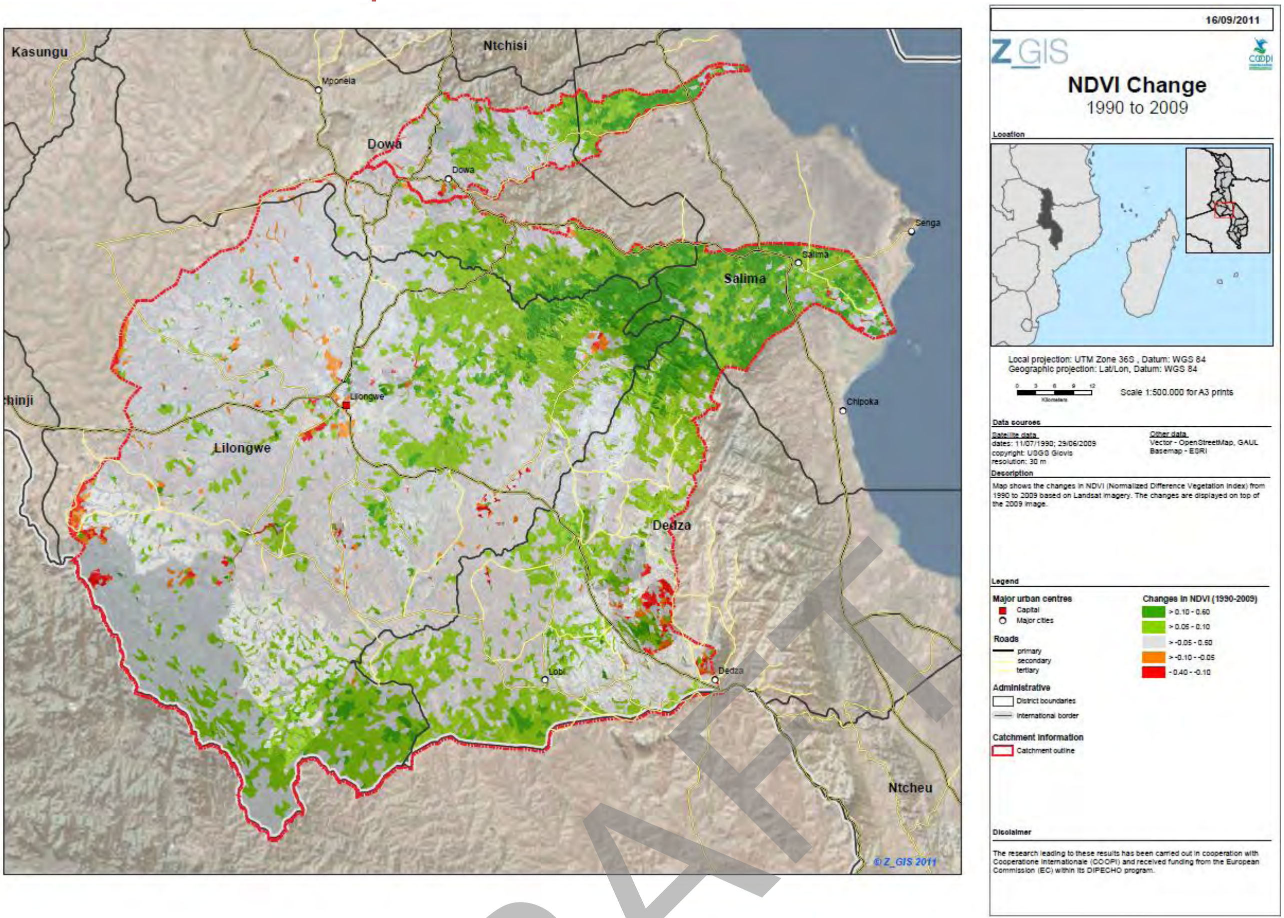
Activities:

- design web-based meta-data form and database,
- inform all relevant departments about use of form and specifications required,
- implement data transfer policy (e.g. web-server),
- upgrade the technical infrastructure to provide geospatial baseline data at Land Survey Department and DODMA (e.g. DEM, roads, settlements, etc.),
- design and establish a national web-GIS platform as a service delivery point (a suggested location could be the DRR Resource Centre, inaugurated in 2011 in Lilongwe city centre since already used as an information centre).

5 ANNEX

- Annex 1 Additional maps
- Annex 2 References
- Annex 3 Semi-structured questionnaire
- Annex 4 Presentation at the expert workshop in Salima, Malawi

Annex 1 Additional maps



Map 1: NDVI change (1990-2009)

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Annex 3 Semi-structured questionnaire

DATE: ________________

Malawi Central River Basin Study

semi-structured interviews at national level (Malawi)

1) General information

1. What is the name/address/website of your agency/institution/department/unit?
2. What is the mission of your agency/institution/department/unit?
3. Contact details of person interviewed (name, position, email, etc.)

2) Natural hazards/historic hazard events (focus on flood hazards)

Which/where have been the most severe (flood) hazard events in the past decades (specify location on the base map)

4. When do these hazards (flood events) usually occur? Are there geo-climatic patterns that are linked to extreme events (such as El Nino/La Nina years, tropical cyclones, etc.)
    - Yes → details
    - No

5. Is there a link between global climate change and increased hazard frequency/hazard risk/hazard severity (particularly concerning floods)
    - Yes
    - No

6. Are there areas/regions/districts/communities which are frequently affected by natural hazards (particularly flood events)? Which areas are particularly vulnerable to flooding (locate on the base map)?

3) Early warning systems (EWS)

7. Is there/are there EWS in place in Malawi?
    - If yes,
        - Where exactly? (can you locate it on the map)
        - Is it a single or a multi-hazard EWS?
        - Who installed the EWS?
        - Who paid for it (funding)?
        - When has the EWS been set up?
        - Who is operating/maintaining the EWS?
        - Who is coordinating the warning activities?
        - Which are the most important institutions involved in early warning in Malawi?
        - Is your agency/institution/department/unit also involved in early warning activities?
            - Yes → details:
            - No
        - Are the existing cooperation's between/with relevant institutions

    - How does the existing EWS work?
        - Who is monitoring which indicators and how?

        - Which indicators/models are utilised for hazard (flood) prediction?

- How are early warning messages communicated to the district/local level? Is there a centralised or a decentralised EW-structure in Malawi?

- Has the local population/local experts been trained (community-based early warning)?
  - Yes → by whom and when?
  - No → why not; is this planned?

- How would you rate the effectiveness of the existing EWS? Explain.
  - Very high
  - High
  - Low
  - Very low

- What are the major strengths/weaknesses of the existing EWS?

- What could/should be improved to reduce hazard (flood) risk?

- If no,
  - Are there plans to install an EWS in the future?
    - Yes
    - No

  - Who is coordinating the planning efforts?

  - Who is paying for the EWS (funding, partnerships)?

  - Who will be responsible/in charge of the operation/coordination of the EWS?

  - Are there any plans how to communicate early warning messages to the local level?

  - Will there be a training of the local population (community-based EWS)?

4) Anthropogenic impacts on flood severity/flood risk

8. Which are the main drivers having an impact on flood risk in Malawi

9. How would you rate the importance of land use changes, population growth, etc. for increased flood risk in Malawi? Explain:
   - Very high
   - High
   - Low
   - Very low

10. Do you have any reports/documents/etc. justifying these suggestions/statements (with regard to the importance of land use changes, etc.)? Is it possible to get a copy?

5) Disaster risk reduction (DRR) and recovery activities

11. Who/which institution has the official mandate for interventions in the field of DRR in Malawi?
    - Name/contact details

    - Is your agency/institution/department/unit also involved in DRR and recovery activities?
        - Yes → details

        - No

    - Are there existing cooperation's with other relevant institutions?
        - Yes → with whom (contact details), since when?

        - No → is this planned for the future?

12. Which are the most important policies regulating DRR and DRR-related planning activities and responsibilities in the field of DRR?

13. Have there been any interventions in flood DRR in the past (river management, dams, etc.)?
    - Yes
        - → Which interventions have been made by whom (government, donors, NGOs, communities, etc.), where and when?

        - Did the interventions result in reduced flood risk? Experiences?!

        - What are the strengths/weaknesses of the existing interventions?

        - What could/should be done to improve the effectiveness of existing interventions?

        - Are there plans for further investments in this field?
            - Yes → details
            - No

    - No (there have been no interventions so far),
        - Are there any plans for investments in interventions in the field of disaster risk reduction in the next years? Details?!

14. What is currently done and could/should be done to:
    - Reduce risk from natural hazards (particularly flood risk)

    - Mitigate the consequences of natural hazards (particularly flood risk)

15. Are there any plans for investments (who, with whom, where, what, when, funding)?

6) Additional comments

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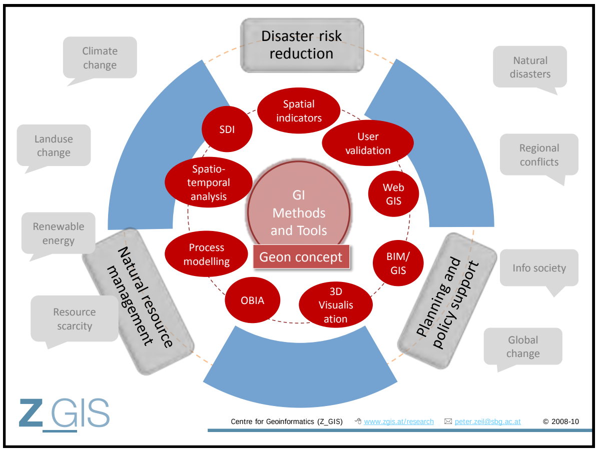
UNIVERSITÄT SALZBURG Z_GIS COOPI COOPERAZIONE INTERNAZIONALE

River Basin Study for the Linthipe and Lingadzi River Catchments

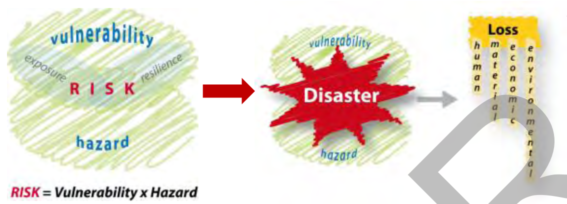
Summary of Results

Stefan KIENBERGER | Michael HAGENLOCHER | Peter ZEIL

Centre for Geoinformatics – Salzburg University, Austria



Approach and concept



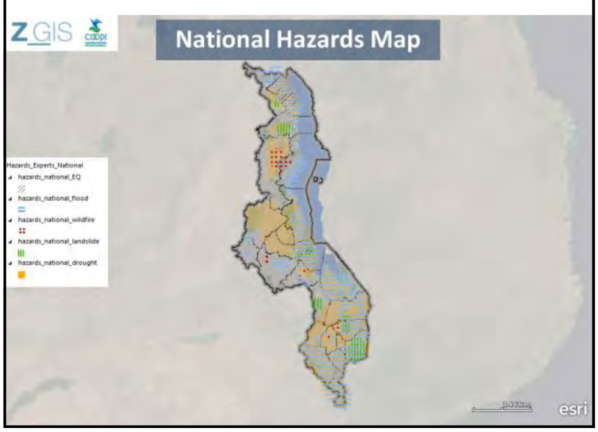
Z_GIS COOPI

Approach and concept

- **Hazard**
  - Historic floods
  - Scenario based hazard modelling
- **„Vulnerability"**
  - Identification of changes in land use/land cover
    - Deforestation issue
  - Population dynamics

Z_GIS COOPI

National Hazards Map



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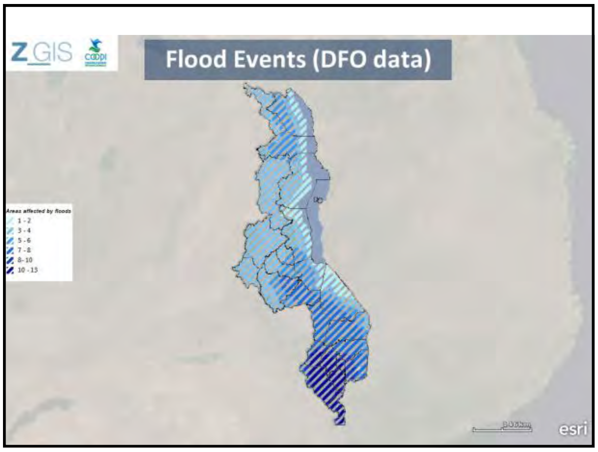

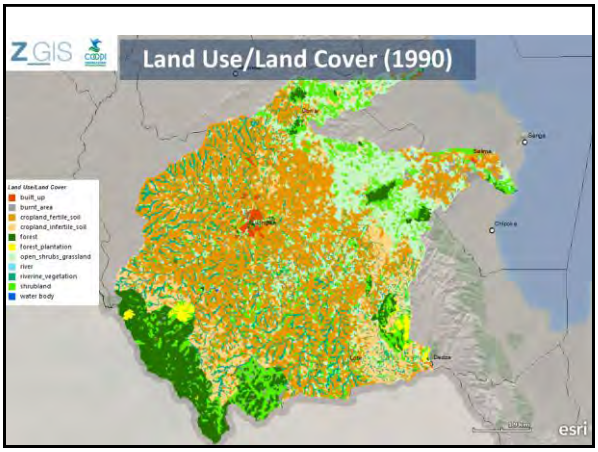

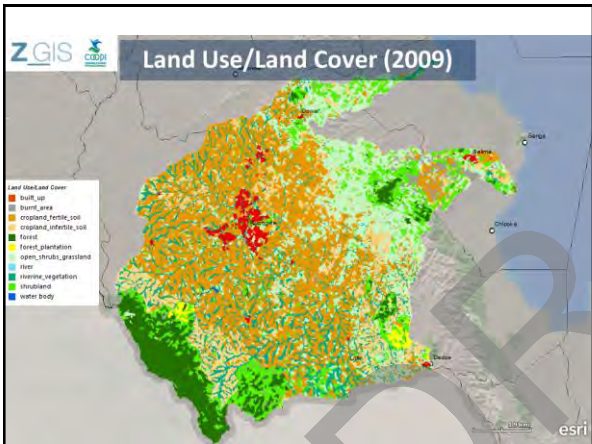

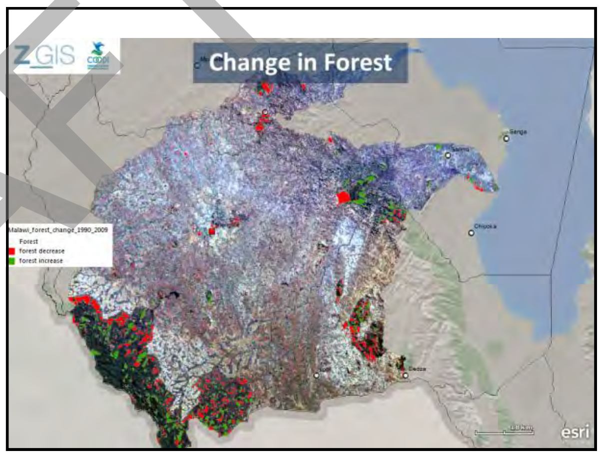

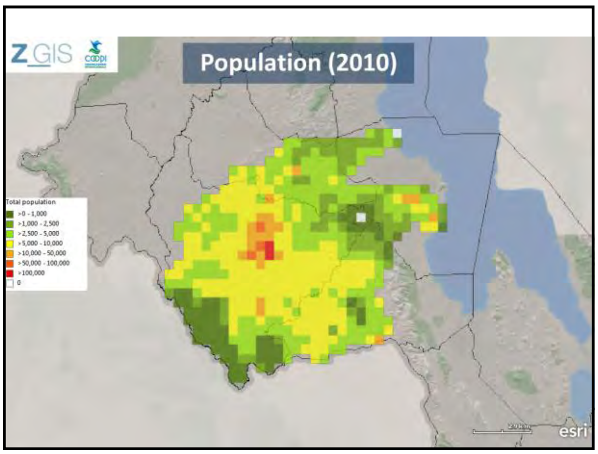

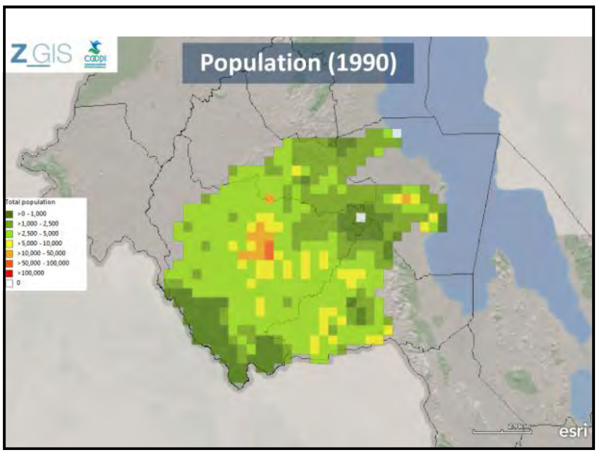

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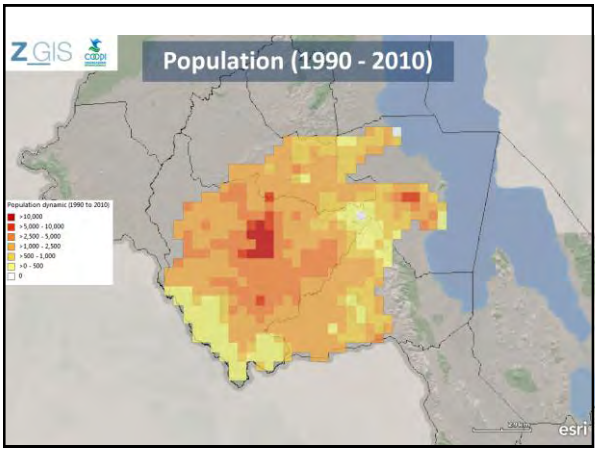

Achievements

- **Downstream area most flood prone**
- **Changes in time and space**
  - Identification and quantification of ***forest changes***
  - Identification and quantification of ***population dynamics***

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Challenges

- **For flood modelling quality of elevation data**
- **Long-term time series**
- **Validation through observational data**
- **Detailed population statistics**

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Hazard Assessment

Historic Floods | Flood Modelling

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Hazard Assessment

Historic Floods | Flood Modelling

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Historic flood assessment
(National and Downstream)

→ **To provide an overview of the floods in the past 30 years**

- **Integration of global datasets**
  - Dartmouth Flood Observatory
- **In-country assessment**
  - Statistics from DoDMA
  - Statistics from COOPI
  - Integration of expert knowledge

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Historic Flood Events
Dartmouth Flood Observatory (DFO), 1985-2010

Profile of flood disasters in the study area (catchments)

Date	Duration	District
September, 1989	11 days	Chikwawa, Nsanje, Machinga, Mango Chi, **Salima**, Balaka, Zomba, Mulanje, Nwanza, Chiradzulu
December, 1997	6 days	Nkhotakota
January, 1998	17 days	Karonga, Nkhotakota, Phalombe
January, 2003	48 days	**Salima**, Balaka, Dedza, Machinga, Ntcheu, Dowa, Phalombe, Lilongwe, Mwanza, Rumphi, Nsanje, Shire, Chikwawa, Nyungwe-Wovwe
March, 2006	8 days	Mangochi, **Salima**
December, 2007	82 days	No information on affected districts

Profile of flood disasters in the catchment (source: DFO Flood Archive)

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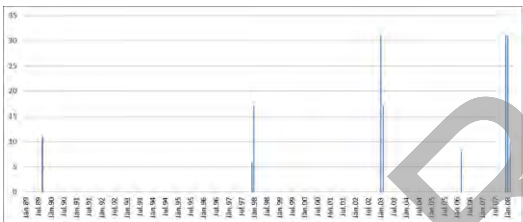
Historic Flood Events
Dartmouth Flood Observatory (DFO), 1985-2010

Profile of flood disasters in the study area (catchments)



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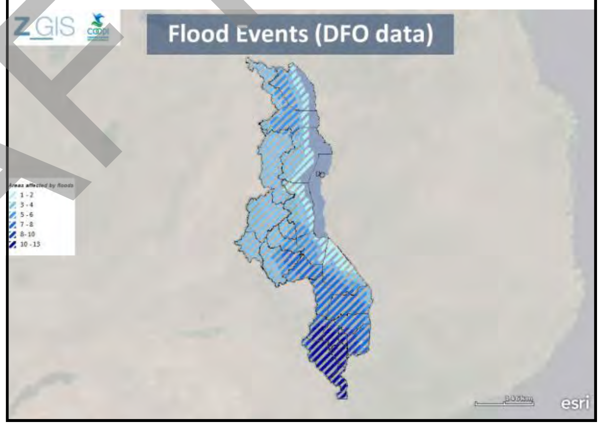

Historic Flood Events
Department of Disaster Management Affairs (DoDMA) - Malawi, 1980-2010

Profile of flood disasters in Salima district

Date	District	Location (TAs, GVHs, etc)	[illegible]
December, 1980	Salima	Boma & Maganga areas	334 families affected (ca. 1,326 people), 112 houses damaged
March, 1983	Salima		7 villages affected, 180 houses damaged
January, 1996	Salima		12.5 hectares of maize crop damaged
March, 1997	Salima	59 villages in TAs Ndindi, Pemba, Maganga, Kalonga	5,226 households lost their maize gardens (i.e. 1,894 ha)
April, 1997	Salima	38 villages in TAs Kalonga, Maganga, Pemba	3,842 households lost their maize gardens (i.e. 1,096 ha)
March, 1999	Salima	Villages in TA Kalonga and GVH Mphunga	500 households: houses damaged, 720 households: gardens damaged, 334 ha of maize affected
February, 2001	Salima	23 villages in TAs Khombedza, Chikombe, Kuluunda, Sub Chief Ndindi and STA Msosa	9,000 households (45,000 people) affected; 6,048.4 ha of maize, 962 ha of rice and 762,6 ha of cotton affected. 3 people lost their lives.
January, 2002	Salima	GVH Nkhwidzi and Ngodzi areas	185 households affected: crops and livestock washed away
January, 2003	Salima	TAs Ndindi and Maganga	3,000 households: houses damaged; 24,568 families: gardens washed away
March, 2006	Salima	TAs Ndindi, Maganga, Pemba	250 households affected; 367 ha of crops flooded
November, 2006	Salima	3 villages in TA Pemba and Ndindi	85 households displaced
February, 2007	Salima	5 GVH in TA Ndindi and Khombedza	41 households: houses damaged; 100 ha of crops and livestock washed away
March, 2010	Salima	TAs Karonga, Kambwiri, Maganga and Pemba	6 households had their houses and property destroyed

Profile of flood disasters in Salima district (source: DoDMA – National Profile of Disasters in Malawi)

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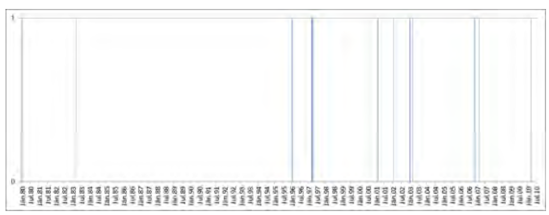
Historic Flood Events
Department of Disaster Management Affairs (DoDMA) - Malawi, 1980-2010

Profile of flood disasters in Salima district (affected GVHs)



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Historic Flood Events
COOPI, 1979-2011

1979	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2000	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2001	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2003	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2004	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2005	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2006	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2007	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2008	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2009	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2010	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho
2011	Chimphanga, Chionjeza, Mkhanje, Kabumbu, Kandulu, Sanimaganga, Mphunga, Kasache, Mwanjowa, Makho

Profile of flood disasters in Salima district (source: COOPI)

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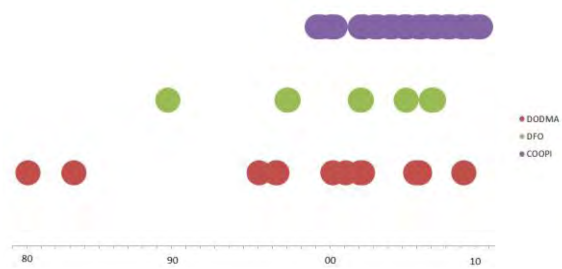
Comparison of historic flood events



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National Hazard Map Expert based approach

- **Interviews and participatory mapping exercise with experts on national (and district level)**
- **Institutions consulted:**
  - Department of Climate Change and Meteorological Services
  - Department of Forestry
  - Department of Land Surveys
  - FEWSNET
  - Geological Survey Department
  - Ministry of Irrigation and Water Development
  - Ministry of Local Government and Rural Development
  - Ministry of Natural Resources, Energy and the Environment
  - National Statistical Office
  - UNICEF
  - Worldbank
  - World Food Programme

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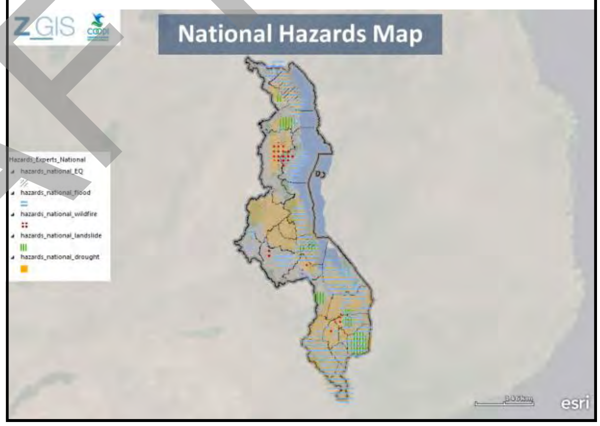

Observations

- **Increase of floods in recent years**
  - „Climate Change“, „Exposure“, „Suscpetibility“,... ?
- **No common statistics on observed flood events**
  - Criteria for floods not clear
  - General picture seems to be similar
  - COOPI observed floods every year in the past
- **According to expert knowledge floods in downstream area**
- **National scale, severest floods in the Shire**

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Hazard Assessment

Historic Floods | **Flood Modelling**

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Modelling floods

- **Hazard: Flood**
  - *"The temporary covering by water, from any source, of land not normally covered by water but does not include a flood solely from a sewerage system."*
  - Intensity: Area covered, water levels
  - Frequency: how often does it occur?

  → HQ100 (Flood extent with a frequency of every 100yrs)

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Example of flood map

- **City of Salzburg**
  - HQ30 + HQ100

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Modelling of floods in Malawi

- **Available data**
  - Digital Elevation Model (DEM) with 25m resolution
    - Derived from topographic maps
    - Digitised contour lines
  - Precipitation data
    - For 6 meteorological stations

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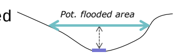
Approaches identified

- **Static modelling**
  - Identify the areas potentially (!!!) flooded
  - Assumed water level during high flow



- **Dynamic modelling**
  - Inclusion of time component
  - Scenario based approach
  - Based on a similar precipitation/flood event as in March, 2006

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Static modelling - Method

- **Calculation of catchment area**
- **Improvement of digital elevation model**
  - Takes 80-90% of the time
  - Identify proper river network (based on topographic maps and satellite imagery)
  - Fill sinks
  - Improve ‚step' effect; filtering of elevation model, recalculations
- **Calculation of vertical distance to river**
  - Shows the flooded areas if the a potential (!!!) inundation would be e.g. 2m above the normal water level of the river

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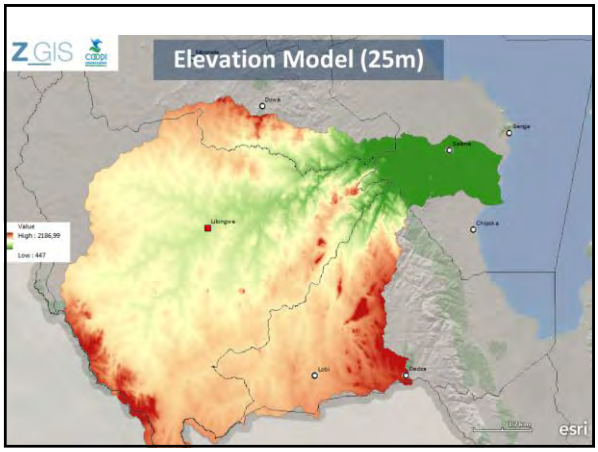

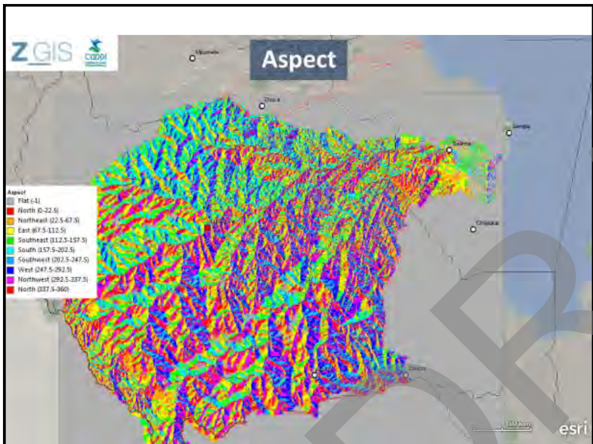

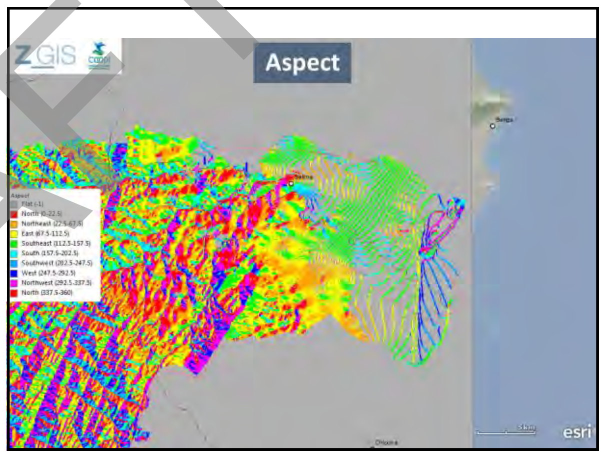

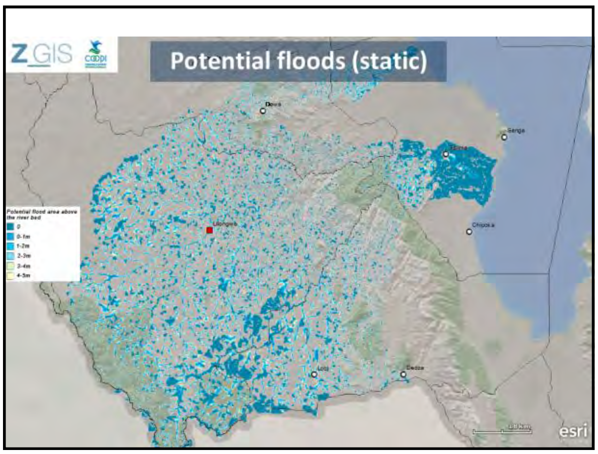

Dynamic modelling - Method

- **Apply corrected DEM**
- **Identify precipitations values for a significant flood event**
  - From station data in Malawi (6)
  - From satallite data (Radar data; TRMM)
- **Apply FloodArea tool of GEOMER**

→ **Scenario based modelling of potential inundated areas**
  - → Time animation
  - → As maximum flood mask

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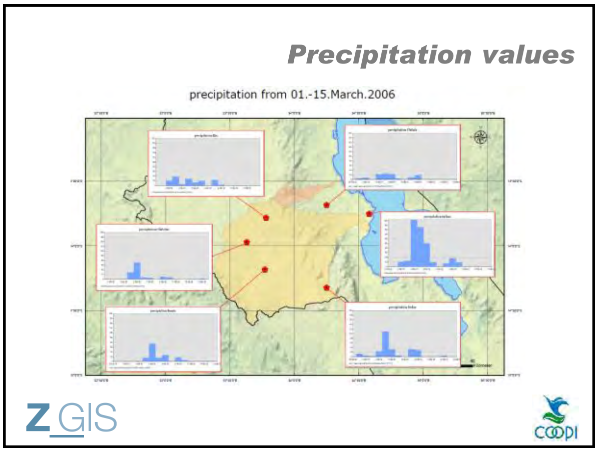

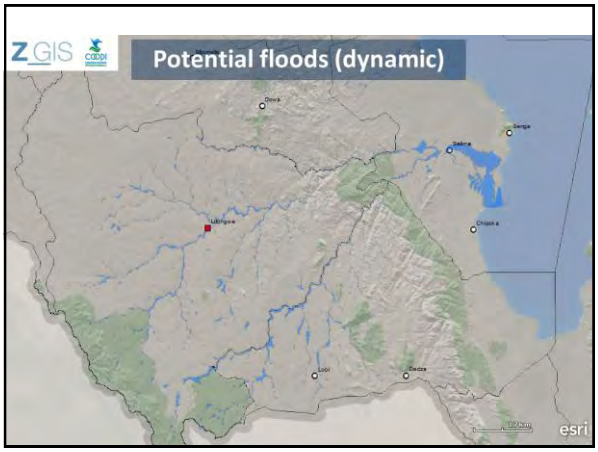

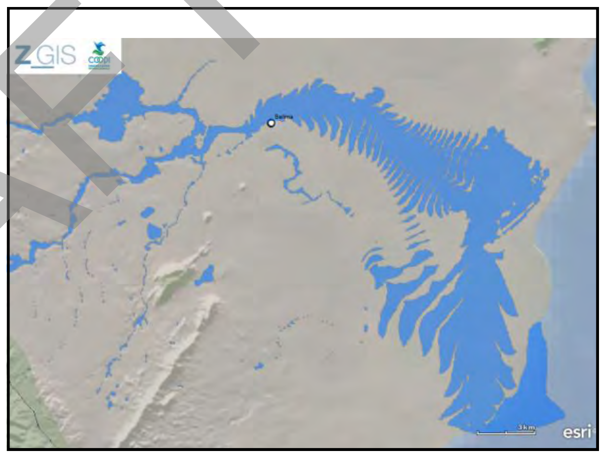

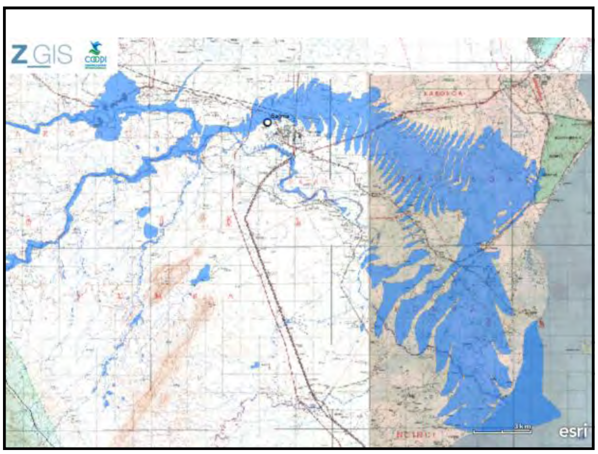

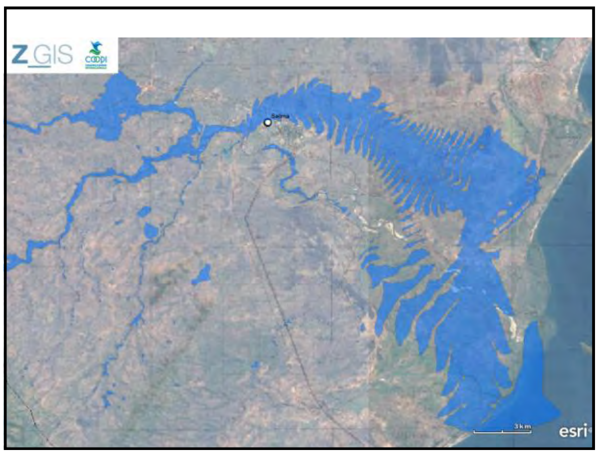

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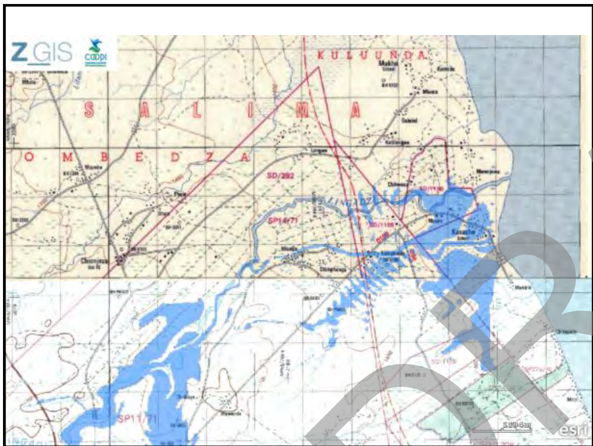

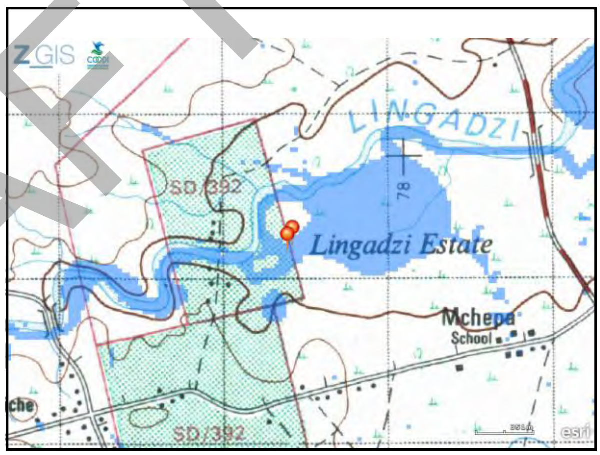

Observations

- **Downstream area most flood prone**
- **Validation has shown different challenges:**
  - Major obstacle is the quality of the DEM
  - Deepened river bed, small-scale feature which determines flooded area
  - Dynamic river course not reflected in topographic data
- **Precipitation data is available, but has to be validated**
  - However long term time series also needed
- **Gauging data also needed as time series**

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Vulnerability Assessment

Deforestation | Population Dynamics

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Vulnerability Assessment

Deforestation | Population Dynamics

Land Use/Land Cover

- **Data**
  - Landsat 5
    - Operational since March 1, 1984
    - Resolution of 30m
    - Vis + NIR
  - Ancillary data (roads, settlement areas)
- **Method**
  - Object-based approach
  - Establish appropriate classification scheme
    - Aim to identify deforestation
  - Identify changes between two time points
    - July 11, 1990
    - June 29, 2003
  - Quantify changes in forest and shrubland (=woody vegetation)

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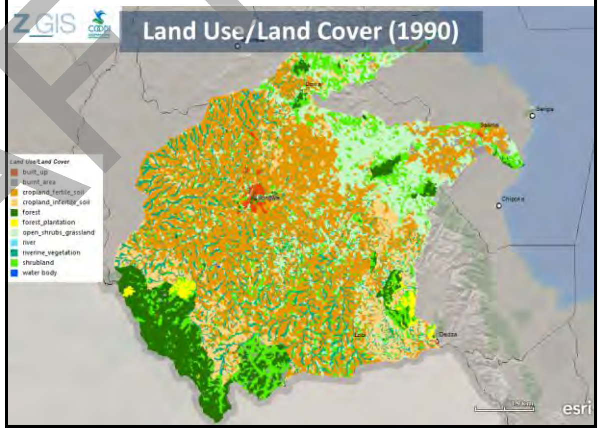

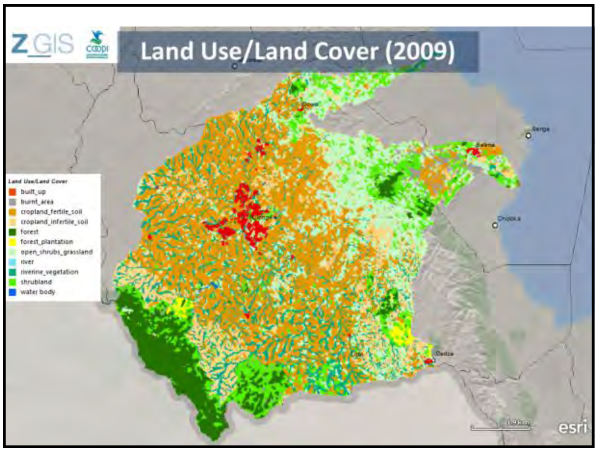

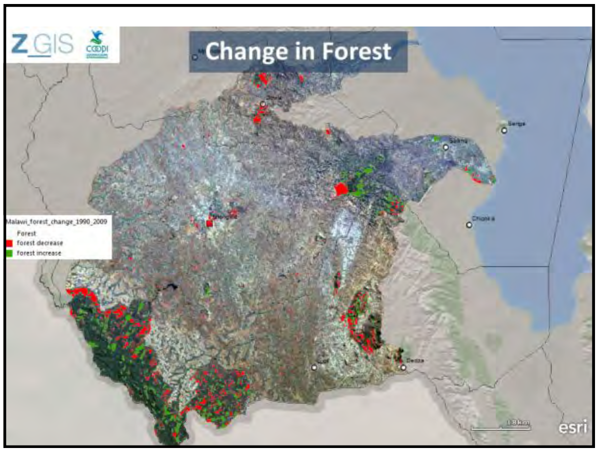

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Results Change Detection

Decrease of forest/shrubland

	1990	2009	change (1990 to 2009)	%
Forest (total in sqkm²)	812,38	734,22	**-78,16**	**-9,62**
Shrubland (total in sqkm²)	1028,01	965,39	**-62,61**	**-6,09**

Change from forest to…

Change detection (forest 1990 to class x in 2009)	
Class 2009 (in 1990 forest)	***Area (sqkm²)***
Built up	0,900
Burnt area	4,760
Cropland	11,461
Forest plantation	7,529
Open shrubs/grassland	20,334
River	0,173
Riverine Vegetation	14,995
Shrubland	153,984
Water body	0,067

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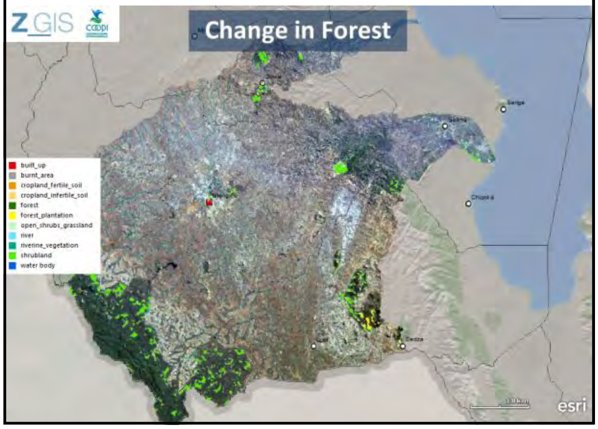

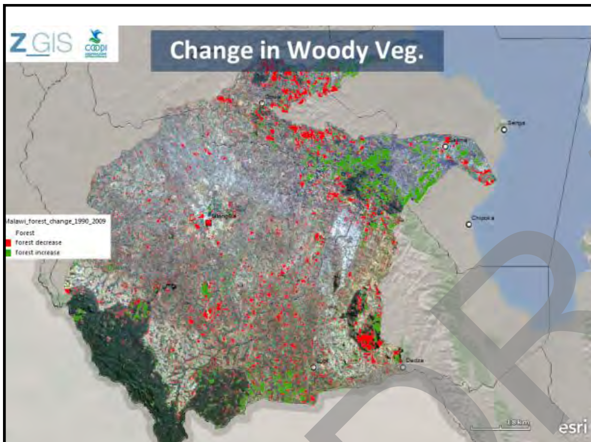

Observations

- **Free data used to model LULC change**
- **Methodology available**
- **Major shifts in forest class and shrubland**
  - Especially in established ‚forest areas'
  - Main part of the catchment has been deforested before \`90s
- **Human impact through various resource needs**

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Vulnerability Assessment

Deforestation | **Population Dynamics**

Population data in Malawi

Malawi Population Census - 1998, 2008

- **Population census (1998)**
  - available as shapefile (.shp) for the entire country
  - number of households (HH) per EA; total population per EA not available
  - average household occupancy scenarios per district available (e.g. 4.2 persons/HH in Salima*)
- **Population census (2008)**
  - available as shapefile (.shp) only for Salima district
  - total population per EA
  - spatial delineation (and ID) of EAs different to 1998

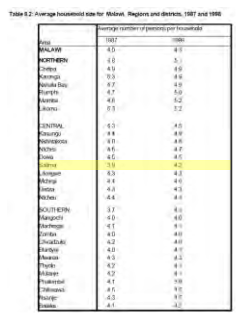

Table 8.2: Average household size for Malawi, Regions and districts, 1987 and 1998

Area	Average number of persons per household 1987	1998
MALAWI	4.5	4.3
NORTHERN	4.8	5.1
Chitipa	4.9	4.9
Karonga	5.3	4.9
Nkhata Bay	4.7	4.9
Rumphi	4.7	5.0
Mzimba	4.8	5.2
Likoma	5.3	5.2
CENTRAL	4.3	4.5
Kasungu	4.8	4.9
Nkhotakota	4.0	4.6
Ntchisi	4.6	4.7
Dowa	4.5	4.5
Salima	3.9	4.2
Lilongwe	4.3	4.3
Mchinji	4.4	4.6
Dedza	4.3	4.3
Ntcheu	4.4	4.4
SOUTHERN	3.7	4.0
Mangochi	4.0	4.0
Machinga	4.1	4.1
Zomba	4.0	4.0
Chiradzulu	4.2	4.0
Blantyre	4.0	4.1
Mwanza	4.3	4.3
Thyolo	4.2	4.1
Mulanje	4.2	4.1
Phalombe	4.1	3.9
Chikwawa	4.6	4.5
Nsanje	4.3	4.5
Balaka	4.1	4.2

*1998 Census - Analytical Report
www.nso.malawi.net/images/stories/data_on_line/demography/census_98/analytical_report.pdf

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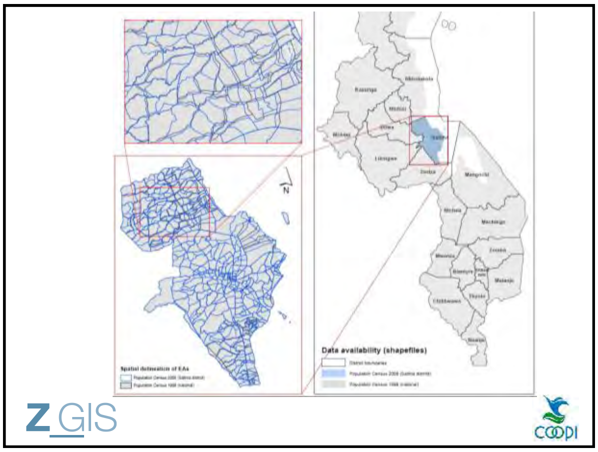

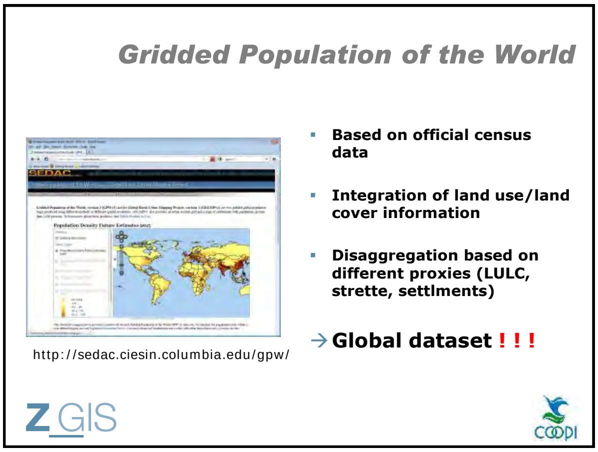

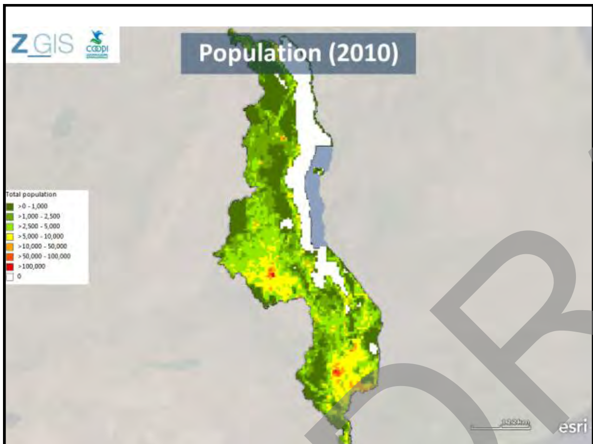

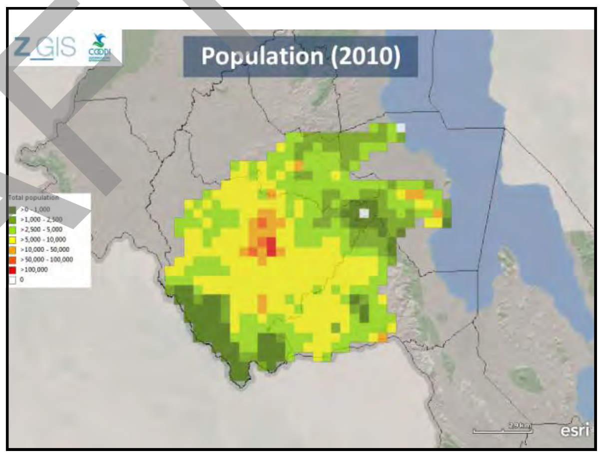

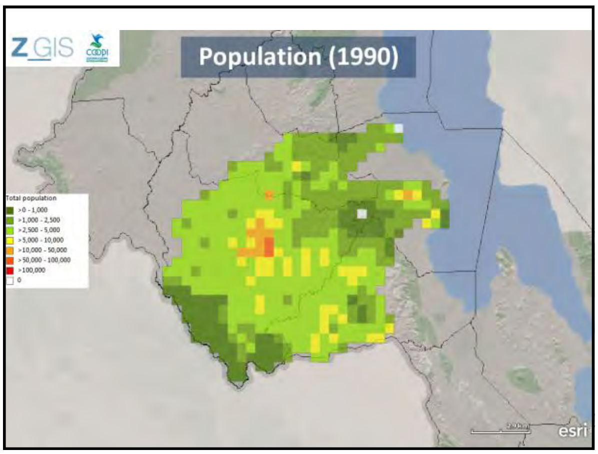

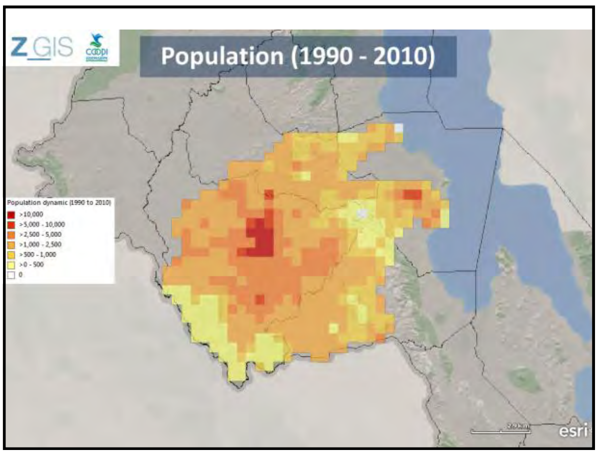

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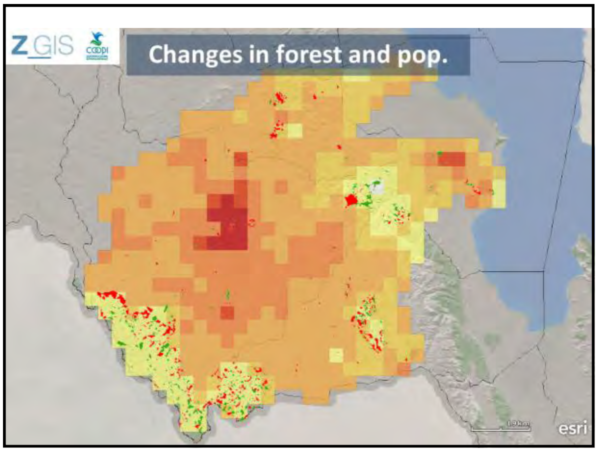

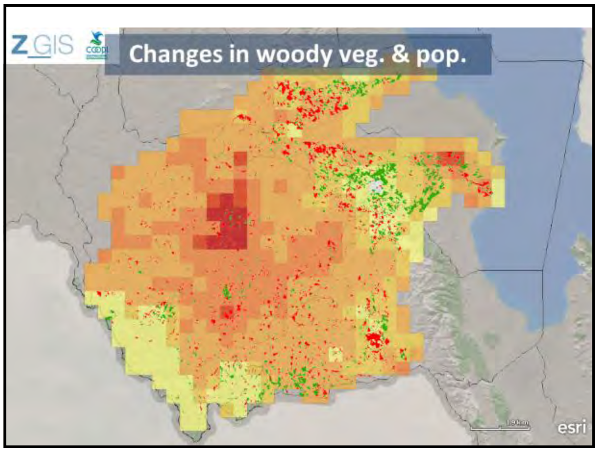

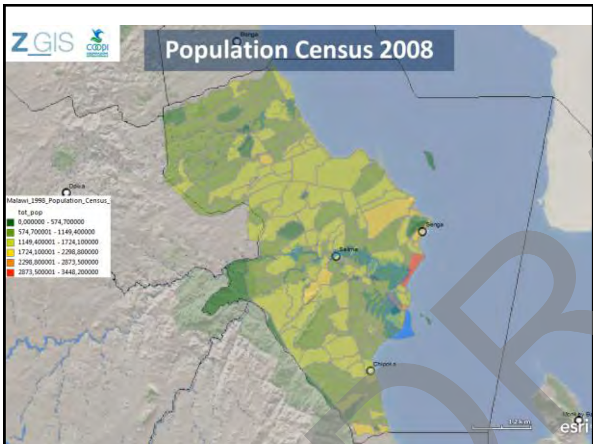

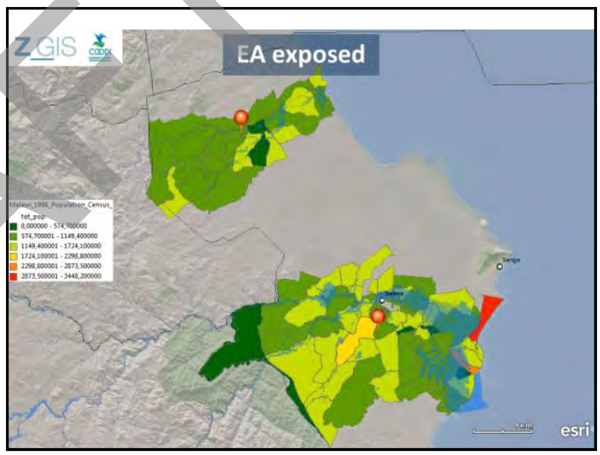

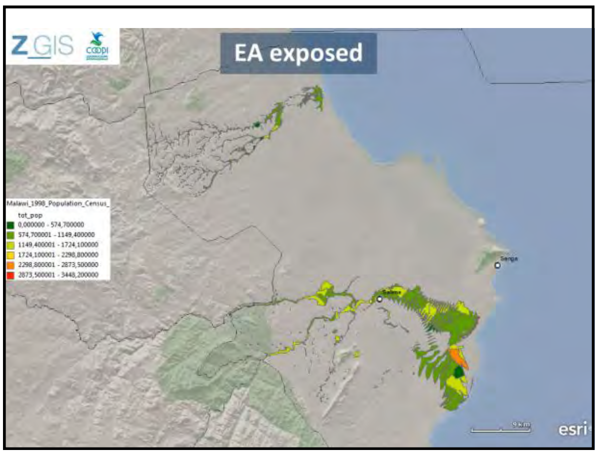

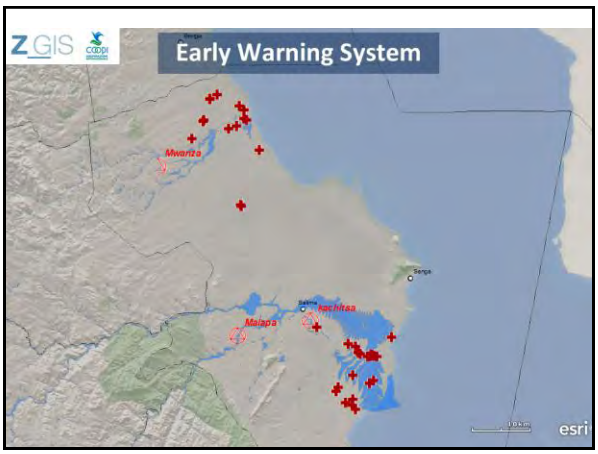

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Observations

- **Highly dynamic around Lilongwe and close to Salima with increase in population**
- **Challenges in applying census data; especially for time series analysis**
  - Quantification of exposure

Z_GIS

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