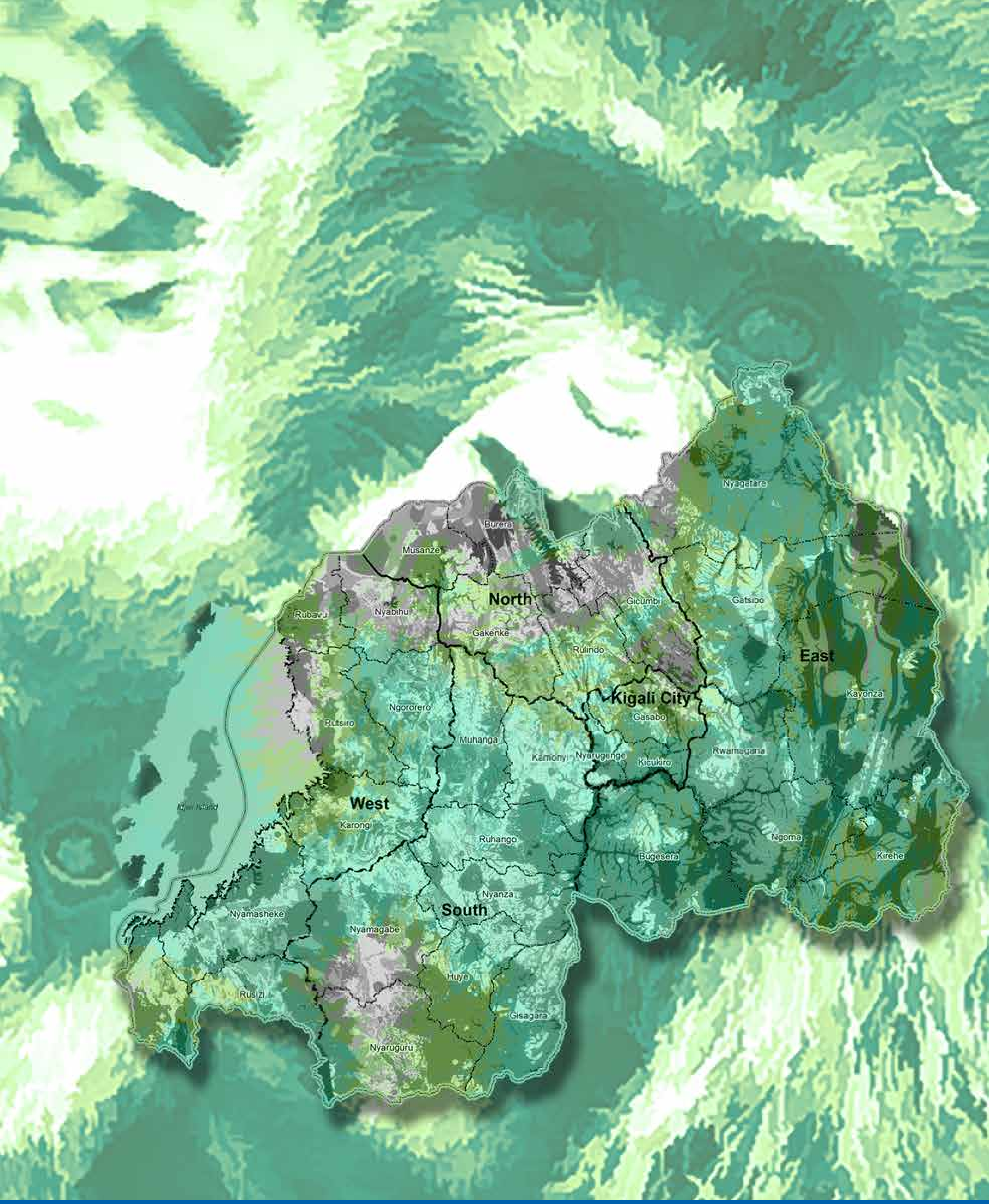

The National Risk Atlas of Rwanda

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ACP-EU Natural Disaster Risk Reduction Program
An initiative of the African, Caribbean and Pacific Group, funded by the European Union and managed by GFDRR

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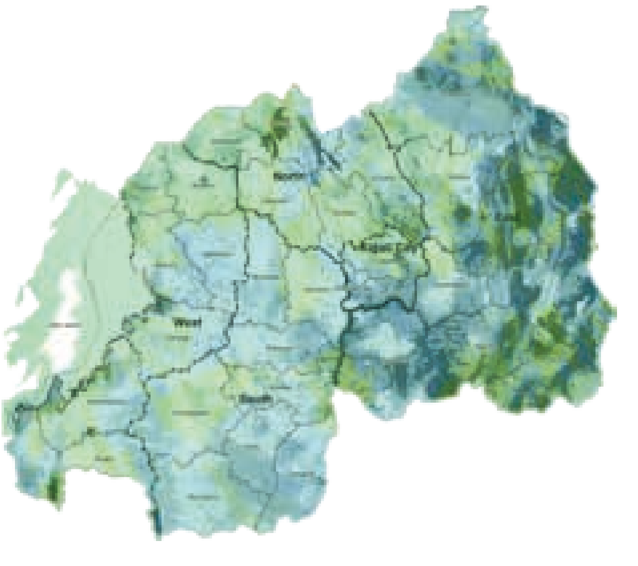

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Foreword

In 2012, the Government of Rwanda through the Ministry of Disaster Management and Refugee Affairs started an assessment of hazards and development of a comprehensive disaster risk profiles of the Country. With a technical and financial support of UNDP Rwanda, the European Union-Africa-Caribbean and Pacific Programme (EU-ACP) through the Global facility for Disaster Risk Reduction of World Bank, MIDIMAR launched in 2013 a project entitled "Development of comprehensive disaster risk profiles for enhancing disaster management in Rwanda".

The objective of the project was to assist the Government of Rwanda to conduct a comprehensive and nationwide assessment of the existing risks with the view of developing a comprehensive disaster risk profiles for Rwanda.

The project covered five (5) main hazards mostly impacting Rwanda namely: droughts, floods, landslides, earthquakes and windstorms, which were selected basing on their economic and social negative impacts on the development of our country. This report constitutes the first phase on national risk assessment process. The remaining hazards, both natural and man-made, will be assessed as soon as the requirements will be gathered.

The project was largely implemented by a team of consultants in collaboration with different departments, governmental, civil society and private, UN agencies, which intervene in disaster risk management and related fields. The findings highlight main prone areas, and the potential losses in case of hazard occurring. The project produced robust information useful for the planning and necessary preparedness to those hazards and to mitigate the risks our country is facing.

It is now very interesting that the decision makers are aware of National Disaster Risk Atlas as tools that must be applied during planning and programming for preparedness and response to disasters. Given that the disaster management is a cross cutting issue, the Atlas will serve to identify and prioritize hazard prone areas during planning and programming for development activities in various sectors, such as transport, health and education, essential service, as well as in urban and rural land use planning and in the development of building codes.

The risk profile is to form a basis for decision making and mainstreaming disaster risk reduction in the government´s sectorial planning process. It provides recommendations to different institutions on revision or formulation of national policies, laws and regulations for disaster risk reduction and management.

I thank all Ministries and agencies for their helpful participation in the assessment, and particularly the European Union, the World Bank and the United Nations Development Program for continuous support in disaster risk reduction.

I urge all Ministries, public institutions and other development partner agencies to consider and apply the National Comprehensive Disaster Risk Profile in their plans and programs. We trust all these efforts will help the Government of Rwanda in its long way to become more resilient to disasters.

Seraphine MUKANTABANA
Minister of Disaster Management and Refugee Affairs

Acknowledgements

The Ministry of Disaster Management and Refugee Affairs takes the opportunity to acknowledge and recognize all the support and assistance (both financial and technical), contributions, technical guidance and advice provided by a range of organizations, institutions and individuals at the international, regional, national and local levels which made possible the successful completion of the National Risk Atlas of Rwanda.

Foremost, deepest gratitude and appreciation to the Government of Rwanda for taking the full ownership and leadership in embarking on this first-ever nationally-led comprehensive disaster risk assessment made possible through its support to the MIDIMAR, the project's main implementing agency.

The same deep gratitude and recognition is accorded to our partners – the European Union (EU), the African, Caribbean and Pacific (ACP) Group of States, the World Bank and the United Nations Development Programme (UNDP), with specific mention of the ACP-EU Natural Disaster Risk Reduction (NDRR) Program and the Global Facility for Disaster Risk Reduction (GFDRR), for the financial support and technical guidance provided which made this project possible.

Warm thanks and appreciation also goes to the members of the National Technical Advisory Group (NTAG) comprised of the focal points from different institutions. Their contribution and participation to several consultations and technical validation workshops enabled the risk assessment process to proceed smoothly and successfully. Their valuable inputs drawing from country experiences, mandates and functions allowed for the risk assessment to be undertaken with much ease and grounded on the country context.

The same appreciation and gratitude are also accorded to all the stakeholders and partners from different public, private, academic and research institutions in the country and at regional level for providing technical and administrative support needed to complete the project, specifically for the different datasets shared, reports and including technical expertise provided without which this risk assessment would have not been possible.

Special thanks and appreciation is given to the technical experts, advisors and consultants who have provided their invaluable technical guidance and advice which made this first risk assessment in Rwanda at par with international best practice and standards. Specific mention of Dr. Jianping Yan – the Disaster Risk Assessment Expert of UNDP at Headquarters in New York for his untiring expert guidance provided to the project team from start to finish. Also to Dr. Jean Paul Dushimumuremyi –National Programme Officer, Vulnerability Assessment and Mapping of WFP in Rwanda, and Dr. Georges Tuluka Mavonga – former Head of Seismology at OVG.

Appreciation and recognition to the team behind the preparation of this National Risk Atlas led by the Project Manager, Erasme Ntazinda and the Vulnerability-Loss and Impact Analyst, Herve Villard Habonimana. Acknowledgement is also due to Maria Gemma Dalena, the DRR Technical Advisor for her help in the analysis and writing of this report. Also appreciation to the other members of the team: Camille Nyamihana, Gregoire Nsengiyumva and Flora Umutoni with special mention of Jutta Dijkstra who assisted in the writing of the report. Special thanks to Patrice Izerimana, the MIDIMAR SPIU Coordinator for overseeing and managing the project implementation.

Finally, acknowledgment to all those who have contributed either directly or indirectly to the successful conduct and completion of this comprehensive risk assessment project.

Acronyms

ACP:	Africa, Caribbean and Pacific
AHP:	Analytical Hierarchy Process
ARV:	Africa Risk View
CFSVA:	Comprehensive Food Security and Vulnerability Analysis
CRED:	Centre for Research on the Epidemiology of Disasters
DEM:	Digital Elevation Model
DHS:	Demographic Health Survey
DRAMS:	Disaster Risk Assessment and Monitoring Systems
DRC:	Democratic Republic of the Congo
DRM:	Disaster Risk Management
DRR:	Disaster Risk Reduction
EARS:	East African Risk System
EDPRS:	Economic Development and Poverty Reduction Strategy
EICV:	Enquête Intégrale des Conditions de Vie des Ménages
EM-DAT:	Emergency Events Database
ENSO:	El Niño Southern Oscillation
EOS:	End Of Season
ET:	Evapo-Transpiration
EU:	European Union
FAO:	Food and Agriculture Organization
FEMA:	Federal Emergency Management Agency
FEWSNET:	Famine Early Warning System Network
GFDRR:	Global Facility for Disaster Reduction and Recovery
GFT:	GIS Flood Tool
GIS:	Geographic Information System
GMD:	Geology and Mines Department
GPS:	Geographic Positioning System
GoR:	Government of Rwanda
ILWIS:	Integrated Land and Water Information System
ISO:	International Office for Standardization
MIDIMAR:	Ministry of Disaster Management and Refugee Affairs
MINAGRI:	Ministry of Agriculture and Animal Resources
MINALOC:	Ministry of Local Government
MINECOFIN:	Ministry of Finance and Economic Planning
MINIRENA:	Ministry of Natural Resources

Acronyms

MoH:	Ministry of Health
NELSAP:	Nile Equatorial Subsidiary Action Program
NGO:	Non-Government Organization
NISR:	National Institute of Statistics of Rwanda
NNE:	North-North East
N-S:	North-South
NW-SW:	North West – South West
OFDA:	Office of U.S. Foreign Disaster Assistance
OGMR:	Office of Geology and Mines of Rwanda
OVG:	Volcanology Observatory of Goma
PCE:	Population Casualty Estimate
PGA:	Peak Ground Acceleration
PGNRE:	Projet de Gestion National des Ressources en eau du Rwanda
PSHA:	Probabilistic Seismic Hazard Analysis
RCMRD:	Regional Center for Mapping of Resources for Development
REMA:	Rwanda Environmental Management Authority
RMCA:	Royal Museum of Central Africa
RNRA:	Rwanda National Resources Authority
RRCS:	Rwanda Red Cross Society
RTDA:	Rwanda Transportation Development Agency
SADC:	South African Development Community
SMCE:	Spatial Multi Criteria Evaluation
UNCCD:	United Nations Convention to Combat Desertification
UNDAF:	United Nations Development Assistance Framework
UNDP:	United Nations Development Program
UNISDR:	United Nations Office for Disaster Risk Reduction
UR:	University of Rwanda
USGS:	United States Geological Survey
VCT:	Voluntary Counselling and Testing
VRAM:	Vulnerability, Risk Analysis and Mapping
WFP:	United Nations World Food Program
WHO:	World Health Organization
WR:	Water Requirement
VRA:	Vulnerability and Risk Assessment
WRSI:	Water Requirement Satisfactory Index
WRVA:	Western Rift Valley of Africa

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Executive Summary

Background

Rwanda experienced a growing number of disasters in recent decades, causing physical, social and economic damages and losses. The best known amongst these disasters are droughts that occurred in 1989, 2000, 2005-2006 and 2014; the devastating landslides that occurred in 1988, 2006, 2010 and 2011 mainly in the northern and western provinces; the ever increasing floods across the country, the earthquake of 2008; and the windstorms that constantly hit different parts of the country.

It is in this context that the Ministry of Disaster Management and Refugee Affairs has prepared the project "Development of comprehensive disaster risk profiles for enhancing disaster risk management in Rwanda" in order to analyze and assess the disaster risks of the country and by this risk knowledge development decisions, policies and strategies are appropriately risk-informed to make development sustainable.

The project was financially supported by European Union-Africa Caribbean Pacific (EU-ACP) Program through the WB-Global Facility for Disaster Risk Reduction and the UNDP Rwanda. It was implemented by MIDIMAR through its Single Project Implementation Unit (SPIU). The project was implemented by a team of consultants in collaboration with different government ministries and institutions, UN agencies, international non-government organizations including civil society and the private sector. A National Technical Advisory Group (NTAG) comprised of these stakeholders was formed mainly to provide support and guidance in the risk assessment process.

Project objective and scope

The project aims to assist the GoR to conduct a nationwide risk assessment with the view of developing a comprehensive disaster risk profiles for Rwanda. The risk profiles report is called the National Risk Atlas. The National Risk Atlas covers five major natural hazards prevailing in Rwanda namely; droughts, floods, landslides, earthquakes and windstorms. The elements at risk considered in the assessment are: population, agriculture, health, education, housing (building) and transportation (roads). The risk profile is analyzed and presented at national and local scale i.e. district level.

Methodology

The methodology used to prepare this report has been compartmentalized in several sections. It consists of: (i) the baseline data compilation that allowed for a basic understanding of the country situation. It entailed data collection from different institutions such as demographics, infrastructure and other socio-economic data including an inventory and analysis of historical data of disasters in Rwanda; (ii) the methodology for hazard assessment and mapping; (iii) the methodology for exposure assessment; (iv) the vulnerability assessment and loss estimation methodologies.

The hazard assessment and mapping of selected hazards (drought, landslides, floods, earthquakes and windstorms) used well-established scientific assessment tools and modeling techniques based on international best practices and standards. The methodologies, tools and modeling techniques were chosen based on available data and what is applicable to the Rwanda context.

Drought Hazard Assessment. The drought hazard assessment was done using the Water Requirement Satisfactory Index (WRSI). The analysis was made for two scenarios i.e. Season A and Season B, the main cropping seasons in Rwanda.

Landslide Hazard Assessment. For the landslide hazard assessment and mapping, the Spatial Multi Criteria Evaluation (SMCE) process was used. Seven factors were identified for the analysis considering their respective influence to landslide. These are slope, lithology, rainfall, soil type, soil depth, land cover and distance to roads.

Flood Hazard Assessment. For the flood hazard assessment, the GIS Flood Tool (GFT) was used to estimate inundation. The data used as input is the available digital elevation models (10 m spatial resolution), in a simple geographic information system (GIS) based on the implementation of the Manning equation. The GFT was used to produce inundation patterns in various catchments around the country just by specifying a discharge value at a location of interest. Due to the scale of the analysis, only a return period of 25 years was taken into consideration.

Earthquake Hazard Assessment. The earthquake hazard assessment used the OpenQuake modeling engine. The analysis was done for two scenarios i.e. 2475-year and 475-year return periods.

Windstorm Hazard Assessment. For the windstorm hazard assessment, a wind speed analysis has been carried out using the available data from the ten weather stations in the country. The analysis of windstorm hazard was made for two scenarios i.e. 5-year and 10-year return periods.

The identified elements at risk in the study are: population, houses (residential buildings), agriculture sector (cultivated area and crop production per crop), education facilities, health facilities and transportation (roads). It is also noted that the exposure, vulnerability assessments and estimation of economic cost were only analyzed for droughts, landslide, earthquake and windstorm with the exception of flood hazard. The later was not included in the analysis due to inadequate data.

Exposure Assessment. The exposure assessment was done by overlaying geo-referenced inventory maps of elements at risk with hazard maps in a GIS setting. The spatial interaction between the elements at risk and the hazard footprints was depicted in GIS by simple map overlaying of the hazard map with the elements at risk map. The element at risk dataset are aggregated at district level.

Vulnerability Assessment. The methodology for vulnerability assessments differ per hazard. For drought, vulnerability of population and crops were assessed. In the assessment of vulnerability of the population, the study adopted the methodology used by WFP in which the vulnerable households per district were identified. This information on vulnerable households was used to assess the total number of population that might be affected by different levels of severe drought. On the other hand, the analysis of vulnerability of major crops followed the methodology used by the FAO study on the estimate of harvest loss due to the occurrence of severe drought.

The assessment of vulnerability to landslide followed the methodology proposed by Michael-Leiba, et al. (2000). They performed an analysis of the vulnerability of residents, buildings and roads to landslides. It used the average vulnerability values of the elements at risks from 0 up to 1.

The assessment of vulnerability to earthquake relied on the use of probability damage matrix (PDM) for physical vulnerability assessment and lethality ratio for Population Casualty Estimation (PCE). The vulnerability function of the different element at risks relied on the filed survey done by MIDIMAR and literature reviews.

A simple methodology for the assessment of vulnerability to windstorms was developed. The study used an analysis of the different categories of elements at risk (e.g. residential buildings or houses) in combination with the damages expected from typical wind on the Beaufort scale. Meanwhile, the number of population vulnerable to windstorms was calculated using the methodology proposed by Coburn and Spence (2002).

Estimation of Economic Cost. The methodology used for the estimation of economic cost is simple considering the parameters such as the element at risk, the economic value of each element and its vulnerability or damage state. The estimation of economic cost is a function of the total exposure, the damage state of each element at risk, and their replacement or repair cost. For this study, only the replacement cost was considered hence the assumption of assets having suffered total damage.

Summary of findings

The comprehensive risk assessment generated significant findings that pertains to the five hazards that are currently or may potentially affect Rwanda as well as to the exposure and vulnerability of the country to these hazards including some estimates of potential economic cost. Below is a summary of the key findings of the study.

- The hazard assessment revealed that the country is highly prone to drought, landslide, flood, earthquake and windstorm. Drought hazard assessment revealed that the districts of Kayonza, Gatsibo, Kirehe, Nyagatare, Rwamagana, Ngoma and Bugesera in the eastern province are very likely to experience severe drought from moderate to very high susceptibility. Meanwhile, the highlands of the Congo-Nile Ridge in the Western, Southern and Northern provinces are prone to landslide due to their moderate to very high slope susceptibility.

- The flood hazard assessment revealed that floods are prone in areas around the five catchments analyzed namely Nyabarongo, Sebeya, Nyabisindu, Mukungwa, and Kagitumba based on a 25-year return period. In addition, based on historical flood events data, it also indicated that flood hazards are likely to occur in many different locations in the country, however, due to data limitations only analysis by catchment was possible for this study.

- For earthquake hazard, the study revealed that the country could have potential intensity varying from MMI V to MMI VII based on two scenarios of 2475-year and 475-year return periods. MMI VII is the highest earthquake intensity recorded in the western part of the country.

- The windstorm hazard assessment analyzed for two return periods (5 and 10 years) showed that the areas which are prone to windstorms are those constituting a belt of the southwest through the extreme northwest up the east.

- In terms of exposure, the study revealed a very high level of exposure to different hazards. Drought exposure is high specifically during Season B, both in terms of cultivated area and volume of crop production. Agricultural exposure to drought is apparent mostly in the eastern province and crops like banana, cassava and Irish potato are the main crops which have higher volumes of production exposed.

- Rwanda is also highly exposed to landslide. The high level of population exposure to landslides is evident in the highlands of the western, southern and northern provinces. About 40 percent of the country's population is exposed to landslide at moderate to very high slope susceptibility. Fourteen percent of the exposed population are children aged <20 years and elderly aged >64 years. Over 1.6 million poor Rwandans (about fifteen percent of the total population) are exposed to landslides with majority coming from the Districts of Nyamagabe, Ngororero, Rutsiro, Nyabihu and Kamonyi. The housing exposure to landslides is highest in Nyabihu, Burera and Ngororero at very high slope susceptibility; and it is highest in the 3 Districts in Kigali City at high and moderate slope susceptibility. The exposure of health facilities to landslides is high at forty-three percent or a total of 234 health facilities. A total of 1,478 schools are exposed to landslides at varying slope susceptibility levels. This is about 25% of the total schools in the country. The transportation sector, specifically national roads which connects districts together for purposes of domestic and international trade, service delivery, tourism, manufacturing and processing and general access are also exposed to landslides at different slope susceptibility levels. A total of 553 kilometers of paved national roads and 691 kilometers of unpaved national roads are exposed to landslides. These figures represent respectively forty-five percent and thirty-nine percent of total [classified] national paved and unpaved roads in the country. The total district roads exposed to landslides is 2,003 kilometers. This represents about seventy-four percent of the total length of the [classified] district roads in the country.

- Rwanda's exposure to earthquake at intensity scale of MMI VI and VII is also very high. The entire population is exposed with about 3.2 million people exposed to earthquake at intensity MMI VII and approximately 7.3 million Rwandans are exposed to earthquake at intensity MMI VI. The population in all the districts in the western province are exposed to earthquake intensity VII including some districts in the southern and northern provinces. The rest of the country is also exposed to earthquake at intensity MMI VI. About 1.3 million poor Rwandans are exposed to earthquake of MMI VII and another 2.5 million people are exposed to earthquake of MMI VI. Majority of the poor Rwandans exposed are from the districts of Rubavu, Rutsiro, Rusizi, Ngororero, Nyabihu, Nyamagabe and Nyamasheke including Gatsibo and Nyagatare. The housing exposure to earthquake of a 2475-year return period is very high in Rwanda at 100% given that the entire country is located in a seismic zone with a maximum intensity of MMI VI and VII. The exposure of the health sector to earthquake is also very high comprising of 52% of the total health facilities in the country exposed. The exposure of the education sector to earthquake of 2475-year return period is also at 100% given the entire country is prone to seismic hazard at intensities VI and VII. Thirty percent of the schools georeferenced are exposed to earthquake at intensity VII and the rest of the 70% are exposed to earthquake at intensity MMI VI. A total of 1,211 kilometers of national paved roads, approximately 1,539 kilometers of unpaved national roads, and about 3,899 kilometers of district roads are exposed to earthquake.

- Approximately 2.8 million Rwandans are exposed to windstorms at intensities of moderate gale to strong gale across 13 districts. Amongst the exposed population, about 1 million are poor Rwandans and 0.4 million are children and elderly. More than half a million houses are exposed to windstorms. Out of the total health facilities considered in the analysis, 148 (or twenty-four percent) are exposed to windstorms and a total of 882 schools (about eighty-nine percent) are exposed.

- The vulnerability assessment also indicates Rwanda's high vulnerability to these natural hazards. Rwanda's drought vulnerability is high. About 28,500 and 157,700 people are vulnerable to severe drought in Seasons A and B respectively. These vulnerable population comprises the districts in the eastern province. A total of about 62,000 tons and 157,700 tons of major crops are vulnerable to severe drought in Season A and Season B respectively. Banana and cassava are the most vulnerable crops including Irish potato. It has been observed that agriculture vulnerability to drought decreases from the eastern to the western part of the country.

- The country's vulnerability to landslide is also relatively high. About 7,500 people countrywide are potential casualties from landslides and mostly from Nyarugenge, Gasabo and Kicukiro districts in the capital Kigali City, and about twenty-five and twenty-one percent respectively are from the districts in the western province and northern province. About 30,000 houses are vulnerable to landslides in the abovementioned locations. Sixty-two health facilities and 360 schools countrywide are vulnerable to landslide. The transportation sector is also highly vulnerable to landslide where 165 km of national paved roads, 207 km of national unpaved roads, and 604 km of district roads are vulnerable.

- The earthquake vulnerability of Rwanda is also significant. The number of casualties due to earthquake varies from about 7,000 people on a nighttime scenario to only about 3,000 people on a daytime scenario. Most of the districts in the western province could have more casualties with Rubavu, Rusizi, and Nyamasheke topping the list. The least casualties would be in the eastern province. In total, there are about 0.4 million houses vulnerable to earthquake. Most of these houses could experience a D2 damage state accounting for more than with 70% of the vulnerable houses. A total of 52 health facilities and 304 schools are vulnerable to earthquake.

- The study revealed a low to moderate vulnerability to windstorms. Only about 692 people are vulnerable to strong gale windstorms where D3 damage state is expected causing houses to collapse and impact on the occupants resulting to deaths and injuries. These vulnerable people are located in Nyamasheke and Rusizi Districts as these are the areas where a strong gale is likely to occur. More are vulnerable to a nighttime scenario than daytime scenario. About five thousand houses are vulnerable to windstorms at a scale ranging from moderate gale to strong gale.

- Considering the high levels of exposure to natural hazards of some assets such as crops, houses (residential buildings), health facilities and roads, according to the risk assessment scenarios evaluated during this study, the country could incur in huge economic losses from disasters triggered by drought, landslide, earthquake and windstorm. For instance, the total economic cost of vulnerable crops in the drought-prone areas could be estimated approximately at 8.8 billion Rwandan francs according to both drought hazard scenarios for Season A and Season B. These crop failure-related losses are concentrated mainly in the eastern province, in particular, Kayonza, Kirehe and Gatsibo where the highest losses are predicted under Season B.

- The total economic cost of the damaged houses due to landslide is estimated to be approximately over 9.2 billion Rwandan francs. The loss is highest in the most densely populated districts of Nyarugenge, Kicukiro and Gasabo. The total economic impact of the damaged health facilities from landslides is estimated at about 2.7 billion Rwandan francs. Ninety-nine percent of damage costs are incurred from damaged health centers and only about one percent are incurred from damaged health posts. There is no predicted damage resulting from landslides to district hospitals as there are no such hospitals exposed to landslide hazard. The districts of Gakenke, Nyamagabe and Rulindo are predicted to have the highest damage costs resulting from damage to health facilities from landslides. Landslide could also cause a total economic impact of approximately 54.5 billion Rwandan francs nationwide due to damages of paved national roads. The losses are high in Nyamasheke, Nyamagabe and Ngororero where there are many paved national roads vulnerable to landslide.

- Earthquake with an intensity of MMI VII could also result to a potential losses of 10.3 billion Rwandan francs due to damaged houses. The highlands of Rubavu, Rusizi, Nyamasheke, Nyamagabe, Karongi and Rutsiro could incur high losses. About 11.3 billion Rwandan francs is the estimated economic losses nationwide from damaged health facilities which could be incurred due to an earthquake of intensity MMI VII. Karongi could incur the highest losses of about 1.9 billion Rwandan francs. The other districts which could also expect high losses are Nyamagabe, Rusizi, Rutsiro and Nyamasheke. Meanwhile, damaged houses resulting from windstorms in Rwanda could incur an economic cost of about 1.6 billion Rwandan francs. The districts of Rusizi and Nyagatare could incur high losses.

Conclusions

The study revealed that Rwanda is prone to drought, landslide, flood, earthquake and windstorms. Considering some assets such as houses, crops, health facilities, schools and roads, the country has a very high exposure to these hazards. Meanwhile, the [physical] vulnerability of the different assets vary across hazards with high vulnerability to drought and landslide and moderate vulnerability to earthquake and windstorms. The economic cost of the assets vulnerable to landslide and earthquake is estimated to be 100.3 billion Rwandan francs.

Chapter I

Introduction

1.1 Background

Hazards prevailing in Rwanda include droughts, floods, earthquakes, landslides, various storms (i.e. windstorms, rainstorms and thunderstorms), forest fire, traffic accidents, diseases and epidemics that disrupt people's lives and livelihoods, destroy infrastructure, interrupt economic activities and retard development (MIDIMAR, 2013). Over the last decade, the frequency and severity of natural disasters, particularly caused by floods and droughts, have significantly increased, with increasing toll of human casualties as well as economic and environmental losses.

However, few studies have been undertaken on characterizing disaster risk profiles in Rwanda, which can provide critical inputs and evidence to public policy and decision making in disaster management and development processes. In this regard, the Government of Rwanda (GoR) requested the Ministry of Disaster Management and Refugee Affairs (MIDIMAR) in 2012 to lead an assessment of hazards and risks in Rwanda and develop a comprehensive disaster risk profile of the country. In 2013, with technical and financial support from United Nations Development Programme (UNDP) Rwanda and the GFDRR-managed EU-ACP programme, MIDIMAR successfully launched a project entitled "Development of comprehensive disaster risk profiles for enhancing disaster management in Rwanda".

The project is also one of the components of the overall UNDP-supported programme "Building National and Local Capacities for Disaster Risk Management in Rwanda", which aims to assist the GoR in building national capacities for disaster risk management through advisory, policy and technical support to render fully operational an effective disaster risk management system at the national and local levels.

The capacity building programme has five output areas.[1] Output Area 3 aims to establish a functioning national disaster risk assessment and monitoring system and including the following key activities:

- Develop a National Risk Assessment Framework;
- Develop evidence-based national hazard risk profile by conducting national risk assessment;
- Establish national damage and loss accounting system (i.e. National Disaster Observatory);
- Enhance national capacities for undertaking risk assessments and;
- Establish a national coordination and governance mechanisms for effective functioning of the integrated national disaster assessment and monitoring system in Rwanda.

Furthermore, the project is in line with Outcome 3 of the United Nations Development Action Plan 2013 – 2018 (UNDAP)[2]: "Rwanda has in place improved systems for: sustainable management of the environment, natural resources and renewable energy resources, energy access and security, for environmental and climate change resilience, in line with rio+20 recommendations for sustainable development."

The project was jointly funded by the European Union under the African Caribbean and Pacific European Union (ACP-EU) Natural Disaster Risk Reduction Program, the World Bank, GFDRR and UNDP Rwanda. The request submission was done by MIDIMAR through UNDP.

1 The five distinctive but mutually reinforcing outputs of the "Building National and Local Capacities for Disaster Risk Management in Rwanda" are: 1) Enhanced capacities of national and local institutions to manage disaster risk and recover from disaster events; including improved national and local coordination mechanisms; 2) DRR mainstreamed into national/district/sectorial plans and policies; and capacities on DRM planning enhanced; 3) A functioning national disaster risk assessment and monitoring system (DRAMS) established; 4) End-to-end early warning systems established and operational and 5) Reduced community vulnerabilities and increased household resilience in selected high-risk districts and increased public awareness on DRR.

2 UNDAP is the business plan of all the UN agencies funds and programmes in Rwanda for the period July 2013 to June 2018. UNDAP Rwanda supports the realization of the Millennium Declaration, the related Millennium Development Goals (MDGs) and the other international development aspirations, the transition from the MDGs to the post-2015 framework, the country's medium-term national development priorities as set out in the Economic Development and Poverty Reduction Strategy (EDPRS 2) for the period 2013-2018, as well as the Rwanda Vision 2020. UNDAP replaced the UNDAF which is formerly the common strategic framework of the United Nations system at country level. This project on 'developing comprehensive disaster risk profiles in Rwanda' contributes to Output 3.3, Key Action 3.3.2 of the UNDAP.

1.2 Objectives of the project

The project seeks to assist the GoR to conduct a comprehensive and nationwide assessment of the existing risks with the view of developing a comprehensive disaster risk profile for Rwanda. The risk profile covers five previous mentioned major hazards prevailing in Rwanda and are related to six sectors (population, agriculture, health, education, housing and transportation). Ultimately, these profiles will be presented as a National Risk Atlas of Rwanda that detail the risk profile per district, the expected losses/damages per hazard and the mitigation measures required per hazard.

The project has three outputs:

- Output 1: To develop a disaster risk assessment methodology and associated tools (at least one country-specific methodology for comprehensive hazard and one associated tool)
- Output 2: To enhance the national capacity for implementing risk assessment (at least two training modules are developed; 30 DDMC members are trained; and training on technical risk assessments are conducted)
- Output 3: To conduct a national risk assessment including hazard identification, exposure mapping and vulnerability assessment

1.3 Scope of the project

The risk analysis was done at the extent of both the national and local levels. It will focus on five main hazards namely flood, landslide, earthquake, drought and windstorm. The project was initially planned to last twelve months however, an extra six-month period extension has been granted to allow completion of the study.

1.4 Constraints and challenges

One of the challenges the project faced was the delay in the execution of project implementation plan resulting in the delay of planned activities. One of the reasons for this delay has to be found in the (initial) lack of expertise especially in the fields of hydrology, structural engineering, geology and geophysics. Another reason is the methodology that has been modified during the project implementation. A methodology based on primary data (proposed by the project document) was changed to adopt the methodology based on modelling (which is an internationally used model).

The collection of raw data from different institutions was also a challenge for the project. As no other study in the field of risk assessment had been conducted in the country prior to this project, the data collection system was not established. The use of proxy data and/or data from regional and international sources were the solutions taken to address the data constraints.

1.5 About the national risk atlas

The main deliverable of the project is the National Risk Atlas. As a result of the achievements of the three project outputs above, a National Risk Atlas was developed. The National Risk Atlas contains general information about Rwanda's demographic, socio-economic and other characteristics. It describes the main elements at risk and the hazard profile of the country. It contains an analysis of the exposure and vulnerability and describes the level of exposure and vulnerability of the country. It also provides an overview of the potential economic cost the country could incur given certain hazard scenarios and the levels of exposure and vulnerabilities.

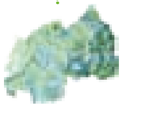
The National Risk Atlas of Rwanda is a tool to enhance decision-making to reduce the economic and social impacts of natural hazards in the country. It is intended to provide a wide range of decision makers and policy makers with appropriate risk information in order to strengthen the capacity of Rwanda to develop strategic risk management strategies. It provides an excellent tool in identifying, showcasing and disseminating important information needed to make timely and sound technical decisions to enhance the development process. The atlas serves as a catalyst for the holistic approach of building resilient communities.

1.6 Expected benefits to the nation

At the end of this project, the GoR will possess a lot of information on hazards and risks and is able to define the disaster profile of Rwanda. Such disaster risk profile will help MIDIMAR to better coordinate all disaster management related initiatives in a proactive manner at national and local levels, leading to the reduction of disaster risk for all Rwandan citizens.

1.7 Beneficiaries and users

The National Risk Atlas is intended to benefit a range of stakeholders and potential users. Mainly, the key decision/policy-makers will be able to ensure policy making and decisions are based on robust risk information. The atlas will benefit donors and development partners by informing their respective project formulation and design and risk-proofing development interventions. It will also ensure a risk-



informed planning by Planners in the government institutions, non-government organizations and the private sector. In addition, the academe is one of the expected beneficiary and user of the atlas specifically as basis or reference for further researches and academic papers. Moreover, the private sector will also benefit from the atlas as its findings could guide them in disaster risk-proofing their investments. The humanitarian actors could also utilize the atlas as guide in identifying hazard-safe areas where humanitarian interventions are placed and implemented. The Districts and the local communities will by and large be the main beneficiaries and users of the atlas.

1.8 Stakeholders

A whole range of stakeholders has been involved in the project. As herein listed, these stakeholders were grouped into ministries, governmental institutions, regional organizations, and international organizations (including UN Agencies and NGOs).

All these stakeholders have contributed to the risk assessment process by sharing expertise, providing technical advice and data. The Ministry of Disaster Management and Refugee Affairs (MIDIMAR) is the lead ministry implementing the risk assessment project. It is the ministry with the disaster management mandate. As the lead agency, MIDIMAR has commissioned a team of consultants to undertake the risk assessment process.

The project also formed the National Technical Advisory Group (NTAG) providing technical inputs, reviews and recommendations to the project team during the course of the assessment. The NTAG meets regularly on a bi-monthly basis. Most of the stakeholders listed here are members of the NTAG.

Some of the other stakeholders, particularly the regional organizations, participated in the project by providing data required in the assessment including thematic inputs in the use of software, and modeling, including the development of the methodology and analysis.

In particular, the UNDP, aside from providing funding support to the project, have extensively provided technical guidance and assistance to the risk assessment process through its in-house disaster risk assessment expertise.

1.8.1 Ministries

- Ministry of Disaster Management and Refugee affairs (MIDIMAR);
- Ministry of Agriculture and Animal Resources (MINAGRI);
- Ministry of Local Government (MINALOC);
- Ministry of Finance and Economic Planning (MINECOFIN);
- Ministry of Natural Resource (MINIRENA);
- Ministry of Infrastructure (MININFRA)
- Ministry of Health (MoH)
- Ministry of Education (MINEDUC)

1.8.2 Governmental institutions

- National Institute of Statistics of Rwanda (NISR);
- Center for Geographical Information System and Remote Sensing (CGIS/UR);
- Rwanda Environmental Management Authority (REMA);
- Rwanda Natural Resource Authority (RNRA);
- Rwanda Meteorology Agency (Rwanda METEO);
- Institute of Applied Sciences of Ruhengeri (INES-Ruhengeri);
- Rwanda Biomedical Centre (RBC);
- Rwanda Education Board (REB);
- Rwanda Transportation Development Authority (RTDA);
- Rwanda Housing Authority (RHA).

1.8.3 Regional organizations

- Nile Basin Initiative/Nile Equatorial Subsidiary Action Program (NBI/NELSAP);
- Famine Early Warning System Network (FEWSNET-Rwanda);

- Volcanology Observatory of Goma (OVG);
- Regional Center for Mapping of Resources for Development (RCMRD);
- Royal Museum of Central Africa (RMCA).

1.8.4 United Nations agencies

- United Nations Development Program (UNDP);
- Food and Agricultural Organization (FAO);
- United Nations World Food Program (WFP).

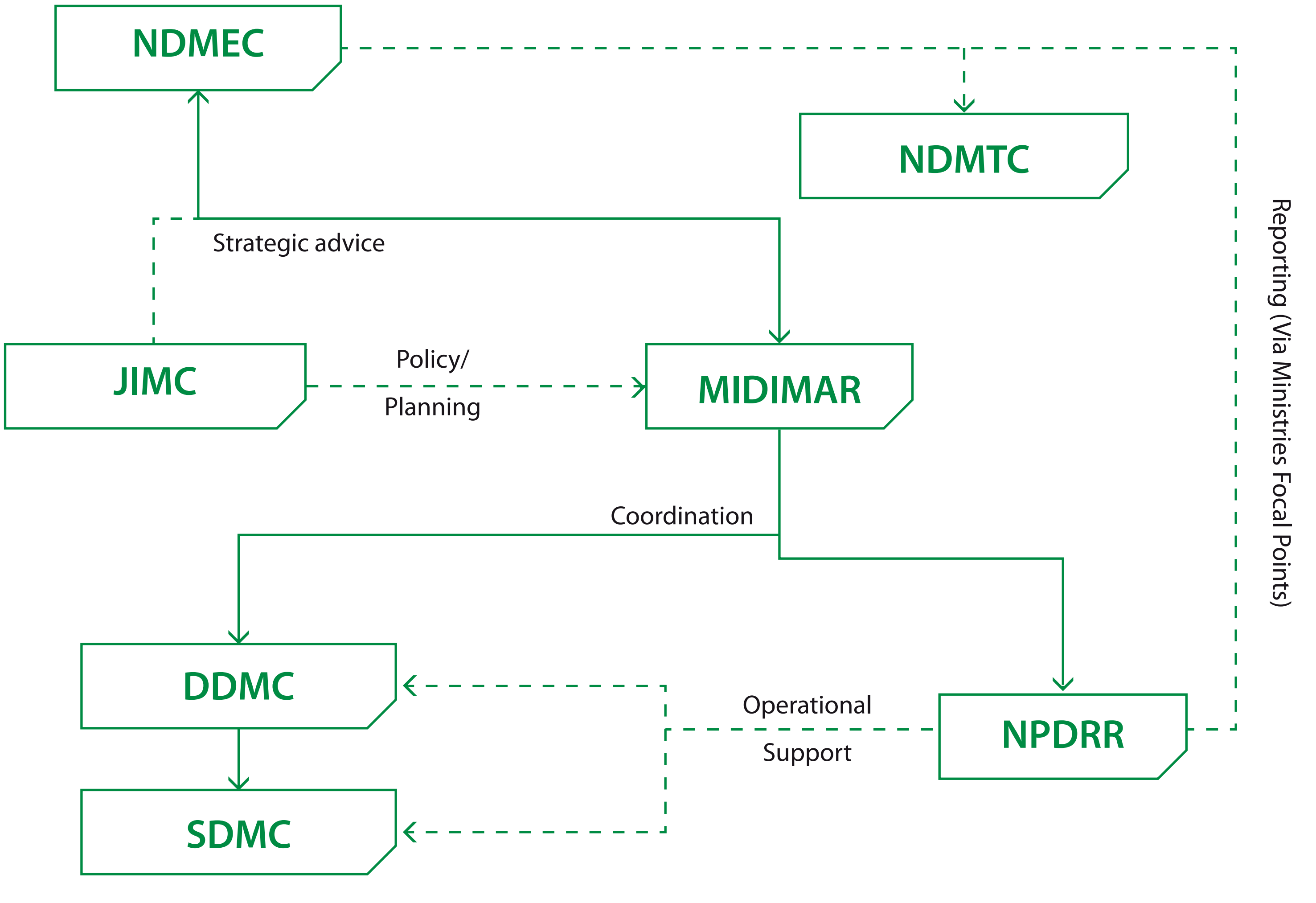
1.9 Rwanda DRM context

In the past, disasters occurring in Rwanda were managed on an ad hoc basis and the country was heavily dependent on international assistance in the occurrence of a disaster (MIDIMAR, 2012). Some particular events and international agreements related to disaster management changed the mind-set of the Rwandan Government regarding DRR. The Hyogo Framework for Action 2005-2015 (HFA) is a consensus strategy adopted by 168 member countries in Japan in 2005 at the UN World Conference on Disaster Reduction. The negotiated outcome of this conference on disaster risk reduction was building the resilience of nations and communities to disasters, and since then the HFA became the blueprint for DRR in many member states.

The HFA aims at the "substantial reduction of disaster losses, in lives and in the social, economic and environmental assets of communities and countries" (UNISDR, 2007). Ever since Rwanda made its commitment to the HFA goals in 2005 some divergent and important strides in the area of DRM policy and institutional framework were made. The establishment of the Ministry of Disaster Management and Refugee Affairs (MIDIMAR) in 2010 demonstrated the government's commitment to disaster management. Subsequently, the country formulated a National Disaster Management Policy in 2012 which serves as a guidepost for all DRM initiatives, activities, programs and projects being designed, implemented and planned in the country. It details the coherent functioning of different organs and stakeholders intervening in disaster management and its structure" (UNISDR, 2007).

Now Rwanda has established a wide range of disaster management institutions. The institutional framework seeks to ensure coherence among the different institutions and stakeholders. Figure 1 below shows

Figure 1. Institutional framework for disaster management in Rwanda[3]



3 The National Disaster Management Policy details the functions of different stakeholders of the institutional framework. These are: the National Disaster Management Executive Committee (NDMEC); the National Disaster Management Technical Committee (NDMTC); the MIDIMAR/UN Joint Intervention Management Committee (JIMC); the District Disaster Management Committee (DDMC); and the Sector Disaster Management Committee (SDMC).

the current institutional framework of Rwanda. Legal frameworks are an important tool for governments to regulate processes aimed at reducing human impact of natural hazards as well as assigning responsibilities and mandates to different actors (UNDP, 2007). Accordingly, various rules and legislation containing elements of DRM have been drafted in order to address disaster risk management. The National Disaster Management Policy (NDMP) demonstrates the legal and institutional frameworks. MIDIMAR is the national coordinator for disaster risk reduction (DRR). It has the mission to develop a highly proficient mechanism for preventing, mitigating, securing, monitoring, recovering, and responding to disasters in a timely manner in order to promote management of natural and man-made disasters (MIDIMAR, 2013).

1.10 Key definition of terms

The terminology in disaster risk management is comprehensive and broad. This section explains the terms that are important to understand the content of the report. If not referenced otherwise, all definitions have been retrieved from (UNISDR, 2009) Terminology on Disaster Risk Reduction.

- **Disaster**
  A serious disruption of the functioning of a community or a society involving widespread human, material, economic or environmental losses and impacts, which exceeds the ability of the affected community or society to cope using its own resources. Disasters are often described as a result of the combination of: the exposure to a hazard; the conditions of vulnerability that are present; and insufficient capacity or measures to reduce or cope with the potential negative consequences. Disaster impacts may include loss of life, injury, disease and other negative effects on human physical, mental and social well-being, together with damage to property, destruction of assets, loss of services, social and economic disruption and environmental degradation.

- **Disaster risk**
  The potential disaster losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period. The definition of disaster risk reflects the concept of disasters as the outcome of continuously present conditions of risk. Disaster risk comprises different types of potential losses which are often difficult to quantify. Nevertheless, with knowledge of the prevailing hazards and the patterns of population and socio-economic development, disaster risks can be assessed and mapped, in broad terms at least.

- Dis**aster risk redu**ction
  The concept and practice of reducing disaster risks through systematic efforts to analyse and manage the causal factors of disasters, including through reduced exposure to hazards, lessened vulnerability of people and property, wise management of land and the environment, and improved preparedness for adverse events. A comprehensive approach to reduce disaster risks is set out in the United Nations-endorsed Hyogo Framework for Action, adopted in 2005, whose expected outcome is "The substantial reduction of disaster losses, in lives and the social, economic and environmental assets of communities and countries." The International Strategy for Disaster Reduction (ISDR) system provides a vehicle for cooperation among Governments, organizations and civil society actors to assist in the implementation of the Framework. Note that while the term "disaster reduction" is sometimes used, the term "disaster risk reduction" provides a better recognition of the ongoing nature of disaster risks and the ongoing potential to reduce these risks.

- **Early warning system**
  The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately and in sufficient time to reduce the possibility of harm or loss. This definition encompasses the range of factors necessary to achieve effective responses to warnings. A people-centered early warning system necessarily comprises four key elements: knowledge of the risks; monitoring, analysis and forecasting of the hazards; communication or dissemination of alerts and warnings; and local capabilities to respond to the warnings received. The expression "end-to-end warning system" is also used to emphasize that warning systems need to span all steps from hazard detection through to community response.

- **Exposure**
  People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. Measures of exposure can include the number of people or types of assets in an area. These can be combined with the specific vulnerability of the exposed elements to any particular hazard to estimate the quantitative risks associated with that hazard in the area of interest.

- **Hazard**
  A dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other

health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. There are hazards of natural origin and related environmental and technical hazard and risks. Such hazards arise from a variety of geological, meteorological, hydrological, oceanic, biological and technical sources, sometimes acting in combination. In technical settings, hazards are described quantitatively by the likely frequency of occurrence of different intensities for different areas, as determined from historical data or scientific analysis.

- **Natural hazard**
  Natural process or phenomenon that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. Natural hazards are a sub-set of all hazards. The term is used to describe actual hazard events as well as the latent hazard conditions that may give rise to future events. Natural hazard events can be characterized by their magnitude or intensity, speed of onset, duration, and area of extent. For example, earthquakes have short durations and usually affect a relatively small region, whereas droughts are slow to develop and fade away and often affect large regions. In some cases hazards may be coupled, as in the flood caused by a hurricane or the tsunami that is created by an earthquake.

- **Susceptibility**
  Refers to the propensity (i.e. a natural tendency that you have to behave in a particular way.) of a particular receptor to experience harm. It reflects an intrinsic property of an object.

- **Resilience**
  The ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions. The resilience of a community in respect to potential hazard events is determined by the degree to which the community has the necessary resources and is capable of organizing itself both prior to and during times of need.

- **Return period**
  A return period, also known as a recurrence interval or repeat interval, is an estimate of the likelihood of an event to occur. It is a statistical measurement typically based on historical data denoting the average recurrence interval over an extended period of time. The theoretical period is the inverse of the probability that the event will be exceeded in any other year. For example, a 25 year flood has a 1/25 = 0.25 or 25% chance of being exceeded in any one year. Despite the connotations of the name "return period", it does not mean that a 25 year flood will happen regularly every 25 years or only once in 25 years (Wikipedia, 2015)

- **Risk**
  The combination of the probability of an event and its negative consequences.

- **Risk analysis**
  The process to comprehend the nature of risk and to determine the level of risk (ISO 31010).

- **Risk assessment**
  A methodology to determine the nature and extent of risk by analyzing potential hazards and evaluating existing conditions of vulnerability that together could potentially harm exposed people, property, services, livelihoods and the environment on which they depend. Risk assessments (and associated risk mapping) include: a review of the technical characteristics of hazards such as their location, intensity, frequency and probability; the analysis of exposure and vulnerability including the physical social, health, economic and environmental dimensions; and the evaluation of the effectiveness of prevailing and alternative coping capacities in respect to likely risk scenarios. This series of activities is sometimes known as a risk analysis process.

- **Single-risk assessments and multi-risk assessments**
  Single-risk assessments determine the singular risk (i.e. likelihood and consequences) of one particular hazard (e.g. flood) or one particular type of hazard (e.g. flooding) occurring in a particular geographic area during a given period of time. Multi-risk assessments determine the total risk from several hazards either occurring at the same time or shortly following each other, because they are dependent from one another or because they are caused by the same triggering event or hazard; or merely threatening the same elements at risk (vulnerable/ exposed elements) without chronological coincidence.

- **Vulnerability**
  The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. There are many aspects of vulnerability, arising from various physical, social, economic, and environmental factors. Examples may include poor design and construction of buildings, inadequate protection of assets, lack of public information and awareness, limited official recognition of risks and preparedness measures, and disregard for

wise environmental management. Vulnerability varies significantly within a community and over time. This definition identifies vulnerability as a characteristic of the element of interest (community, system or asset) which is independent of its exposure.

1.11 Structure of the report

This report on the National Risk Atlas of Rwanda consists of nine chapters as follows:

Chapter I is devoted to the introductory information on the project. The project background, objectives and outcomes are discussed in this chapter. The challenges and the context of Rwanda in terms of disaster risk management are also detailed.

Chapter II demonstrates the basic data and base maps. The social, economic and physical environments are discussed. All secondary data collected from different institutions are analysed and presented in maps, figures or tables.

Chapter III is the methodological framework. In this chapter, an overall methodology for risk assessment in Rwandan context is presented.

Chapter IV discusses the hazard assessment and mapping. For each hazard, the following information is presented: detailed methodology, data and source, hazard maps and analysis, the application in disaster risk management including limitations and recommendations.

Chapter V is dedicated to the exposure assessment. A detailed methodology and data on all elements exposed to a certain hazard are mapped and discussed and findings presented.

Chapter VI covers the vulnerability assessment. It contains the methodology used for the assessment and the vulnerability profiles and findings per hazard.

Chapter VII presents the estimation of economic cost. It contains the methodology used to calculate the economic cost and presents the cost profiles for selected assets or elements at risk.

Chapter VIII contains the information needs analysis for application of the National Risk Atlas in decision making and policy. It presents some concrete forward actions and recommendations on how the National Risk Atlas is applied in three sectors or application areas i.e. disaster management, food security and urban development, settlement planning, land use and relocation programme.

Chapter IX covers some of the recommendations to further enhance disaster risk assessment in Rwanda.

Appendix contains the national and district hazard, exposure and vulnerability profiles.

Chapter II

Basic Data and Base Maps

The development of a comprehensive disaster risk profile requires foremost a good understanding of the general context and background of the country. Accordingly, many country data has been gathered during the project. These data were organized in a dataset and converted into GIS formats. This chapter will provide an overview of the basic data and base maps gathered and analyzed. Specifically, it includes data on administrative entities, population, infrastructure, buildings and settlement, livelihood, health, education, elevation and topography and land use countrywide. It is important to note that the data availability constitutes a main challenge and constraint for this project and it has been described in Chapter I, section 1.4.

The ensuing page demonstrates a table detailing data collected from different institutions, governmental, international organization and UN Agencies.

Table 1. Database inventory

S/N	Source/Owner	Type of data	Format	Content	Observation
1	RNRA/ Department of Lands and Mapping	DEM	Image	Digital Elevation Model of 10 meters	This image contains errors in west northern (volcano area)
		Ortho-Photos	Image	Images covering the whole country taken in 2008	
		Topographic Maps	Image	Images covering the whole country produced in 1988	
		Land Cover Map	Shapefiles	The shapefiles cover the whole country, they were prepared by RCMRD in 2010	
		Land use	Shapefiles	Information about existing and planned infrastructure	
		Education facilities location	Excel spreadsheet	Georeferenced spreadsheet	No detailed information about education sector
		Health facilities location	Excel spreadsheet	Georeferenced spreadsheet	No detailed information about health
2	RNRA/ Geology and Mines Department	Geology	Printed sheets	Different sheets of geological map of Rwanda	
3	RNRA/ Department of Water Resource Management	Rwanda National water Resources master plan	Report	Different report about National water resources master plan	
4	Rwanda Meteorological Agency	Meteorological data	Excel Spreadsheet	Daily rainfall, maxima and minima temperatures, longitudes, latitudes and elevation from 14 meteorological stations located in all four provinces and Kigali City for 14 years (from 2000 to 2013)	

contd...

S/N	Source/Owner	Type of data	Format	Content	Observation
5	National Institute of Statistics for Rwanda (NISR)	Socioeconomic data	Excel spread sheets	Population and housing data	Data contain information from Rwanda Census of 2012
		Reports	Printed report	EICV 3, DHS 2010	Information on livelihood
6	FEWSNET Rwanda	Rainfall data	Excel Spreadsheet	Daily rainfall for the period from as early as 1930 to 2011. Available data are broken down by station and over 130 stations spread all over the country are listed.	
7	Rwanda Ministry of Education (MINEDUC)	School statistics	Excel Spreadsheet	List of school per province, district, sector, cell, village and number of assets per school and per school type until 2013	Data not georeferenced
8	Rwanda Ministry of Health (MoH)	Statistics on health facilities	Excel Spreadsheet	Number and type of health facilities per location and number of assets and equipment per type of health facility.	
9	Rwanda Housing Authority (RHA)	Information on Rwanda Building codes and Regulation	Hard copy printed booklet	Basic housing construction guidelines for protection against natural and manmade disasters in rural areas.	The information contained in the booklet could be utilized in evaluation infrastructure risk and exposure.
		Housing and urbanization	Shapefile	Built up area Informal settlement in districts Urban delineation District Development plans Commercial centres	
		Information on building inspection guidelines	Hard copy printed booklet	Some information on building codes and regulations	
10	RNRA , CGIS/UR	Rwanda basemap	Shapefile	Boundaries Elevation (Contour lines Hydrography Physical Infrastructure (Power line, road network	
11	REMA	Wetland, land cover and rivers	Shape file	Wetland boundaries and protected areas	
12	MINAGRI	Soil Data	Shape file	Soil types Soil depth Geology	Data extracted from the Soil Map of Rwanda (2003)
13	MINALOC	Settlement and "high risk zone " data	Shape file	Imidugudu planned sites Existing imidugudu Model village location High risk zone in Kigali	
14	RTDA	Road infrastructure	Shapefiles	Road categorization	
15	MINAGRI	Data on crop assessment	Excel Spreadsheet	Information on crop yield, crop production and harvested area from 2002-2013.	Data not georeferenced
16	World Food Program (WFP)	Data on rainfall and evapotranspiration	Shapefiles	Information on rainfall and evapotranspiration	Data used in drought hazard mapping
17	UN HABITAT	Urban delineated areas	Shapefiles	Information on urban and trading centres	

2.1 Geography and administrative division

Geographically located in Central Africa between 1°04′ and 2°51′ south latitude, and between 28°45′ and 31°15′ East longitude, Rwanda is a land-locked country, bordered by Burundi in the South; Tanzania in the East; Uganda in the North, and the Democratic Republic of Congo in the West. The borders of Rwanda stretched up to 900 kilometers.

The country's administrative division counts for five provinces: Northern Province, Western Province, Southern Province, Eastern Province and the City of Kigali. Rwanda is divided into 30 districts (Uturere) which are further subdivided into 416 sectors (Imirenge), 2,148 cells (Utugari) and 14,837 villages (Imidugudu) (NISR, 2014). The village is the smallest politico-administrative entity of the country (MINALOC, 2014).

Table 2. Borders of Rwanda

Region	Borders	Length of Borders (in km)*
South	Burundi	290
North	Uganda	169
East	Tanzania	217
West	DR Congo	217

Table 3. Rwanda administrative entities

Province	Districts	Number of Sectors	Number of Cells	Number of Villages
Kigali City	Gasabo	15	73	494
	Kicukiro	10	41	355
	Nyarugenge	10	47	327
Rutsiro	Bugesera	15	72	581
	Gatsibo	14	69	603
	Kayonza	12	50	421
	Kirehe	12	60	612
	Ngoma	14	64	473
	Nyagatare	14	106	628
	Rwamagana	14	82	474
Northern	Burera	17	69	571
	Gakenke	19	97	617
	Gicumbi	21	109	630
	Musanze	15	68	432
	Rulindo	17	71	494
Southern	Gisagara	13	59	524
	Huye	13	77	508
	Kamonyi	12	59	317
	Muhanga	12	63	331
	Nyamagabe	17	92	536
	Nyanza	10	51	420
	Nyaruguru	14	72	332
	Ruhango	9	59	533
Western	Karongi	14	88	538
	Ngororero	13	73	419
	Nyabihu	12	73	473
	Nyamasheke	15	68	588
	Rubavu	12	80	525
	Rusizi	18	94	596
	Rutsiro	13	62	485
TOTAL	**30**	**416**	**2,148**	**14,837**

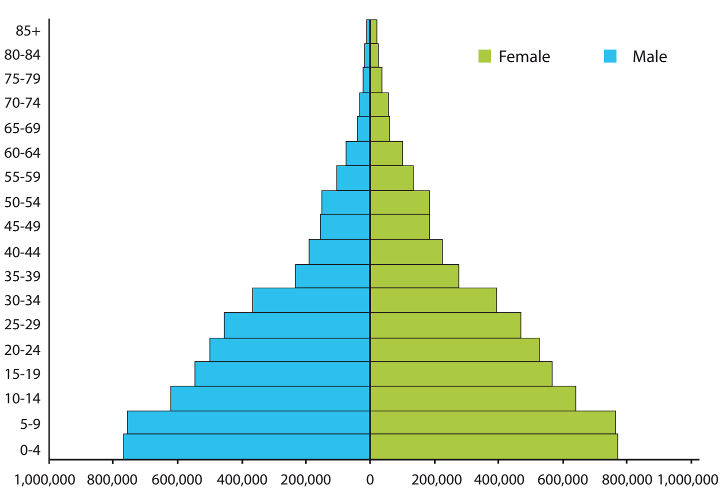
Source: Rwanda Statistical Yearbook, 2014

Figure 2. Administrative boundaries of Rwanda

2.2 Population

The population of Rwanda is 10,515,973 residents, of which 52% are women and 48% men based on the 2012 Census. Since the 2002 Census, the population has increased by 2.4 million, which represents an average annual growth rate of 2.6%. The age pyramid of Rwanda has a large base, implying that the majority of the population is young. Around 50% (5.4 million) of the population is under 20. People aged 65 and above account for only 3% of the resident population. The mean age of the population of Rwanda is 22.7 years. The mean age of females is higher than that of males (23.5 vs. 21.9). As a consequence the demographic dependency ratio, measuring the number of potential dependent persons per 100 persons of productive age, is 93 at national level. In other words, in Rwanda every 100 persons of an economically active age are theoretically expected to be responsible for 93 persons of inactive age. Urban areas have more young adults than rural ones, and thus the dependency ratio is only 67 compared to 100 in rural areas (NISR, 2014).

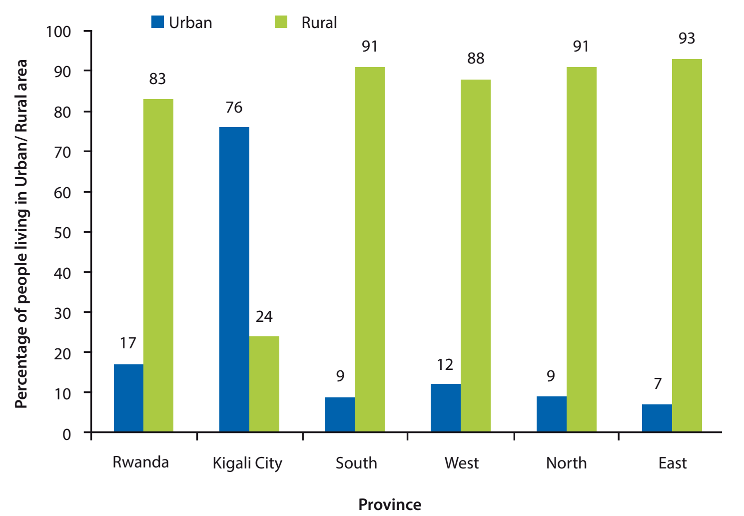
Figure 3. Population pyramid of Rwanda, 2012



Source: Rwanda 4th Population and Housing Census, 2012 (NISR)

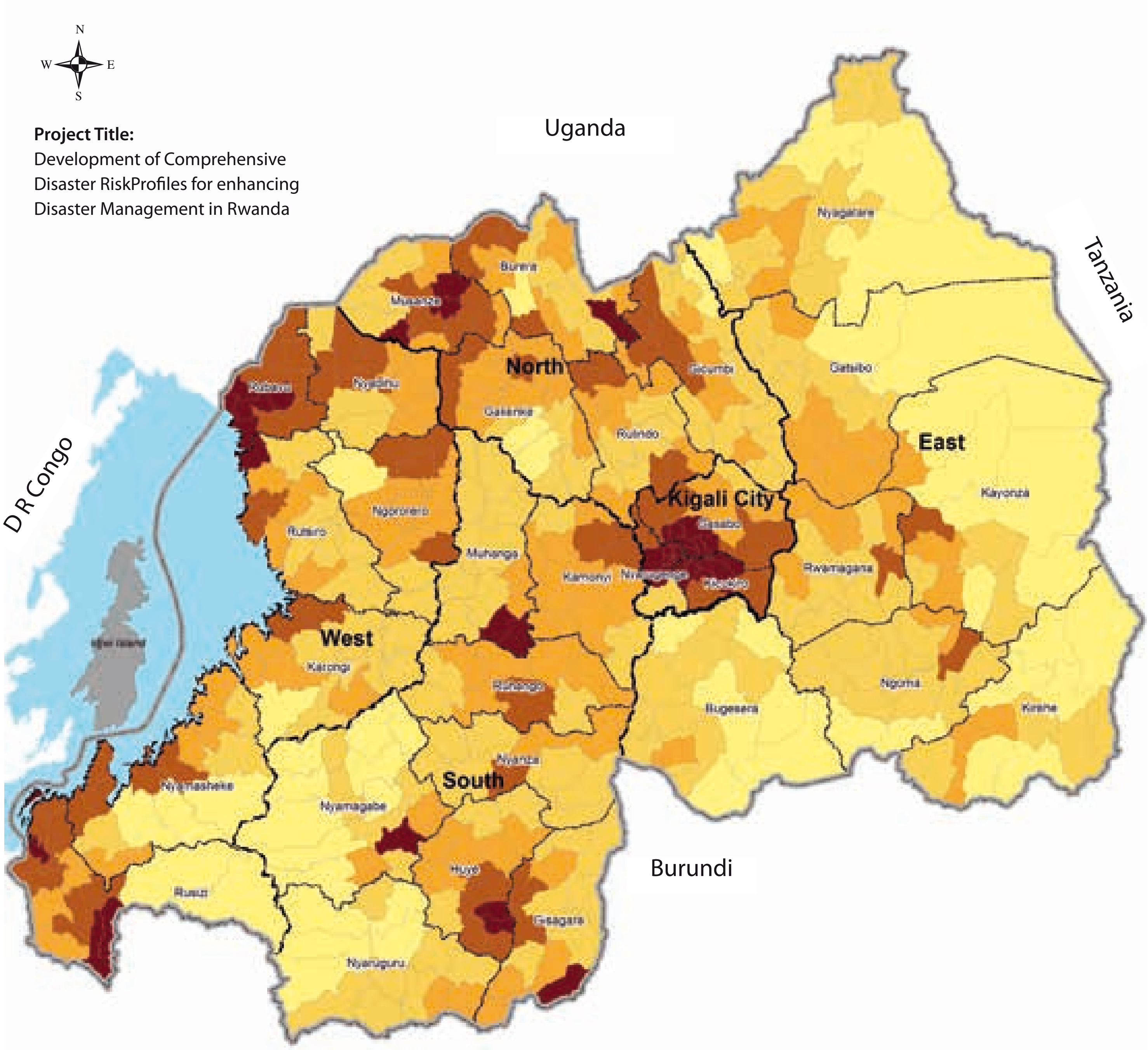
The population of Rwanda is still largely rural, with 83% living in rural areas. There are some clear differences among the provinces. The Eastern Province is the most populated with 2,595,703 inhabitants, followed by the Southern Province with 2,589,975 inhabitants. The Northern Province has 1,726,370 residents and the Western Province 2,471,239, while Kigali City has the smallest population with 1,132,686 inhabitants. Gasabo district is the most populated with more than 500,000 inhabitants and the least populated is Nyarugenge district, which has less than 300,000 inhabitants. Figure 4 below shows the percentage of people living in urban and rural area per province (NISR, 2014). Furthermore, the spatial distribution of urban and rural population of Rwanda are illustrated in respectively Figure 5 and Figure 6. These figures show that the country is comprised largely of rural inhabitants.

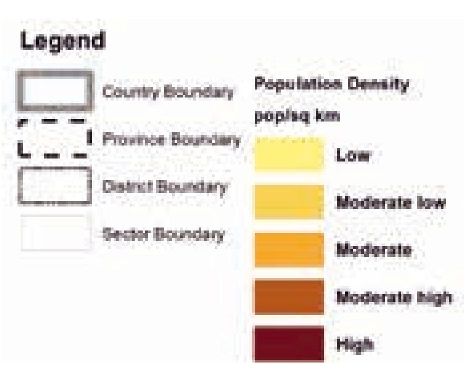
Figure 4. Population by area of residence



Source: Fourth Rwanda Population and Housing Census

Figure 5. Urban population map of Rwanda





Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:

0 10 20 30 40 Km

Date:
16 December 2014

Source:
National Institute of Statistics
2012 Population and Housing
Census

Figure 6. Rural population map of Rwanda

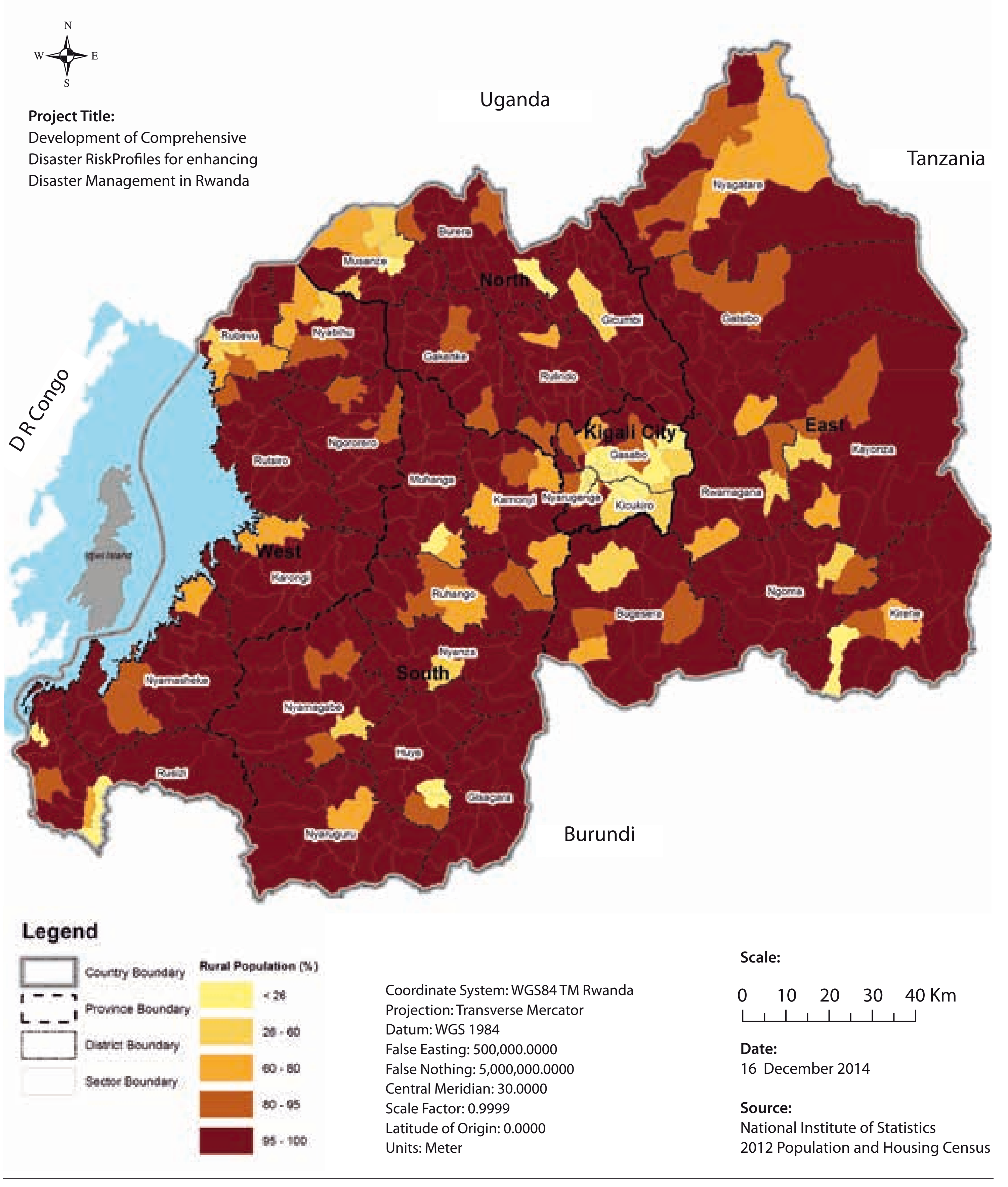


Figure 7 shows the population density of Rwanda at sector level. The population density is divided into five classes ranging from ≤ 300 inhabitants/km2 to ≥ 1001 inhabitants/km2 and above. In defining the classes of population density, the lower limit ≤ 300 inhabitants/km2 and the upper limit ≥ 1001 inhabitants/km2 were adopted from the classification used by (NISR, 2014) which classify districts 'with low population density' and 'with high population density' respectively. Meanwhile, in order to distribute the middle values of the districts with 301-1000 inhabitants/km2, the standard deviation of 150 was used. Hence, the population density classes are as follows:

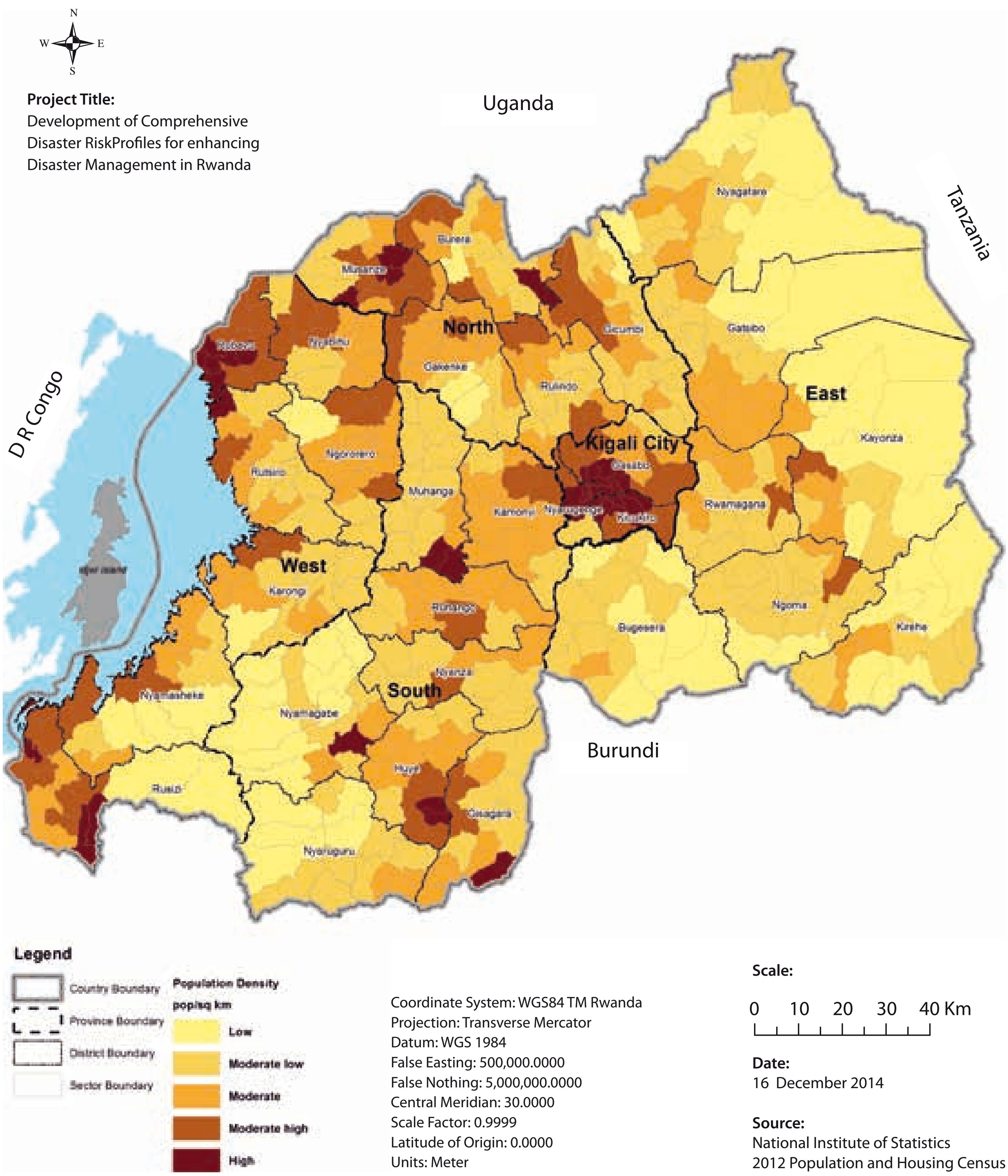
The population density in 2012 was 415 inhabitants per square kilometer for the country. Compared to neighboring countries: Burundi (333), Uganda (173), Kenya (73) or Tanzania (48), Rwanda is the highest densely populated country in the region. In general, urban districts have the highest densities of population, in particular the districts of Nyarugenge (2,124 inhabitants/km2), Gasabo (1,234 inhabitants/km2), Kicukiro (1,911 inhabitants/ km2) in the capital city Kigali, and Rubavu (1,039 inhabitants/ km2) in the west. The districts with the low population density are: Kirehe (287 inhabitants/ km2), Bugesera (280 inhabitants/ km2), Gatsibo (274 inhabitants/

km2), Nyagatare (242 inhabitants/km2), Kayonza (178 inhabitants/km2) from the eastern province, Rutsiro (281 inhabitants/km2) from the west, and Nyaruguru (291 inhabitants/km2) from the south. The population density of 19 districts is above the average density of the country (NISR, 2014). The following map gives more details.

Table 4 Classification of population density

≤ 300 inhabitants/km²	Low population density
301 – 450 inhabitants/km²	Moderate low population density
451 – 600 inhabitants/km²	Moderate population density
600 – 1000 inhabitants/km²	Moderate high population density
≥ 1001 inhabitants/km²	High population density

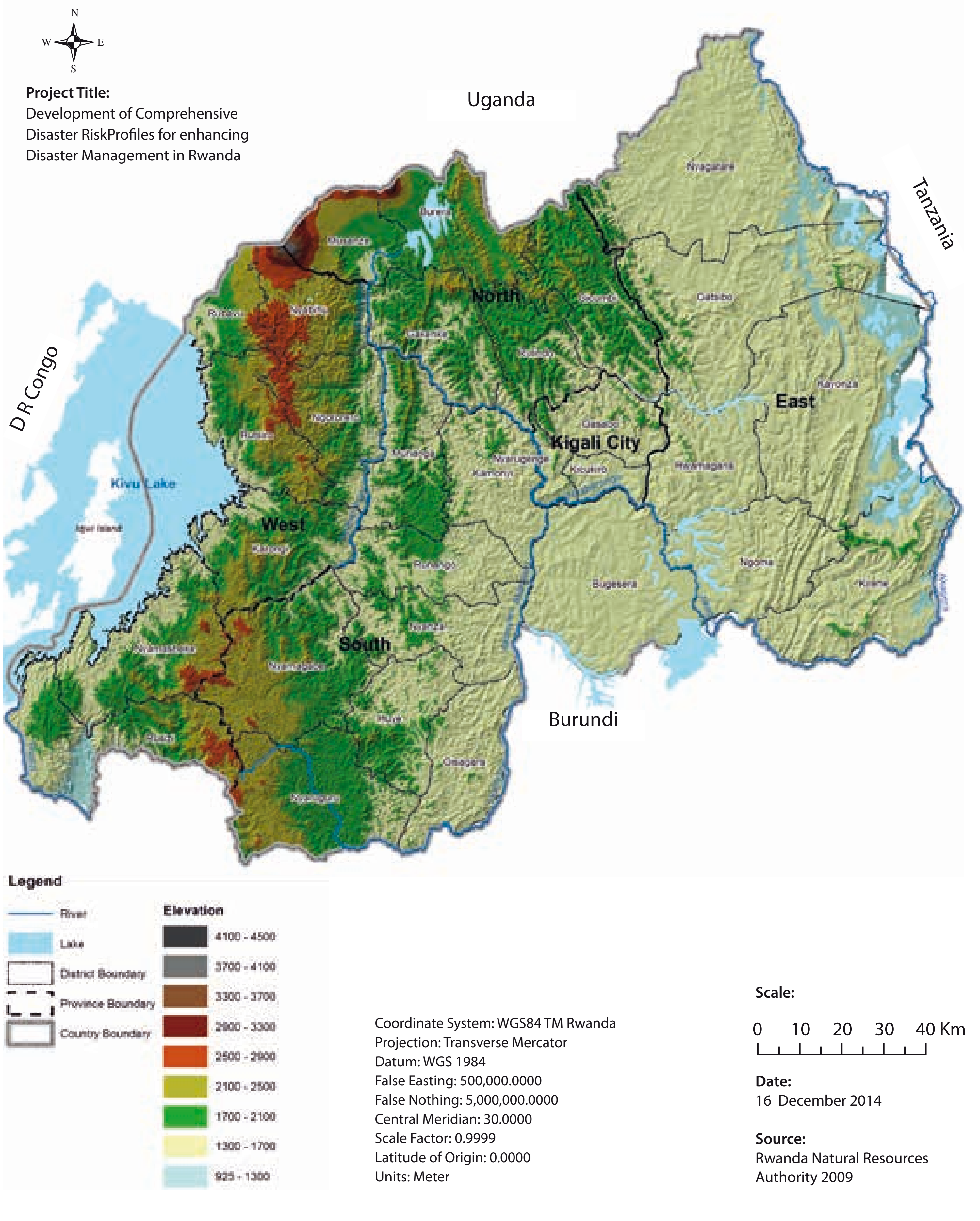
Figure 7. Population density of Rwanda



2.3 Climate and topography

Rwanda topography is considered hilly and mountainous with altitude ranging between 900 meters and 4,707 meters (with an average of 1,700 meters) and has a tropical temperate climate due to this high altitude. The highest point is on Mount Karisimbi at 4,507 meters above sea level. Rwanda has volcanic mountains at the northern fringe and undulating hills in most of the central plateau. However, the eastern part of the country is relatively flat with altitudes well below 1,500 meters. This relief pattern gives Rwanda a mild and cool climate that is predominantly influenced by altitude. Average annual temperature is 18.5˚C and average rainfall is about 1,250 mm per annum. The lowlands of the southwest in Bugarama plain with an altitude of 900m are part of the tectonic depression of the African Rift Valley (REMA, 2009). The altitudes of the country are shown in Figure 8.

Figure 8. Elevation map of Rwanda



Geomorphologically, Rwanda can be divided into five regions from west to east: 1) the Congo-Nile Ridge, 2) the volcanic Virunga Mountains and high lava plains of northwestern Rwanda, 3) the narrow Great Rift Valley region along or near Lake Kivu, 4) the rolling hills and valleys of the Central Plateau, which slope eastward from the Congo-Nile Ridge, and 5) the savannahs and marshlands of the eastern and southeastern border areas, which are lower, warmer, and drier than the central upland plateaus (Encyclopedia of Nations, 2014).

The Congo-Nile Ridge divides two of Africa's great watersheds; the Congo and the Nile basins. It extends from north to south through Western Rwanda at an average elevation of almost 2,743 meters (9,000 feet). The altitude of this range of mountains ranges between 2,500 and 3,000 meters and overhangs Lake Kivu. The Congo-Nile Ridge is dominated in the northwest by the volcanoes range which consists of five massifs, the highest of which is the previous mentioned Karisimbi. On the western slopes of this Congo-Nile Ridgeline, the land slopes abruptly toward Lake Kivu in the Great Rift Valley at the border of the country. The eastern slopes of the Central Plateau are more moderate, with rolling hills extending across the central uplands at gradually reducing altitudes to the plains, swamps, and lakes of the eastern border region. With an altitude ranging between 1,500 and 2,000 meters, the central plateau's relief is made of hills with tops that are sometimes stretched, sometimes round, separated by deep valleys of 15 to 50 meters, often filled up with alluvial deposits. The lowlands in the East of the country are dominated by a depression of the relief, generally undulating between 1,100 and 1,500 meters of altitude. The lowlands of the South West in the plain of Bugarama are part of a tectonic depression of the African Rift, and they have an altitude of 900 meters.

2.4 Land cover

Rwanda's total area is 26,338 km^2, of which 3% is covered by water. The country's land cover is classified into eight categories (Table 5). The largest cover type is 'open agriculture' which covers 55% of the total area followed by 'open land' covering 12% of the total area and 'closed agriculture' covering 7%. The rest of the areas are classified as 'forest plantation' and 'natural forest' each at 5% of the total area, and 'irrigation" covering 3% of the total area. The smallest cover is classified as 'built-up area' which is 1% of the total area and is concentrated in Kigali City. Results of the land cover dataset developed for the 1990, 2000 and 2010 time periods show a steady increase in cropland as sparse forest coverage decreases over the years (RCMRD - Servir Africa, 2013). The land cover map is shown in Figure 9.

Table 5. Types of land cover and distribution of area in km^2

Cover type	Area km^2	% of the Total Area
Built-up area	282	1
Closed agriculture	1868	7
Forest plantation	1276	5
Irrigation	810	3
Natural forest	1423	5
Open agriculture	14468	55
Open land	3049	12
Runway	0	0

Source: RCMRD and REMA, 2008

2.5 Education

In Rwanda, the education and training system is structured into four main levels. A pre-primary level, which lasts three years, precedes the primary level of a six-year duration. After primary school, two levels exist. One level is technical or vocational education, which aims to prepare students to enter the labour market once they complete primary education. The other level is secondary education, preparing students who wish to pursue a college or university degree before entering the labour market. Each of these levels is a six-year programme, with the first three years being a general cycle. The fourth level is higher learning or tertiary education and takes place in colleges and universities. The duration is maximum seven years (NISR, 2014).

As of 2012, the total number of education institutes in Rwanda was 5,968, comprising of 1,870 pre-primary schools (2 public; 1868 private), 2,594 primary schools with 28,914 classrooms, 1,466 secondary schools with 13,490 classrooms and 38 higher learning institutions (18 of which are private and 20 public). Figure 10 below shows the spatial distribution of the education facilities of Rwanda. The student classroom ratio for primary and secondary levels is 83 and 40 respectively (NISR, 2014).

Literacy rate in Rwanda as revealed by the 2012 Census indicates about 68% of the population aged 15 and above is able to read, write and understand in at least one language. About 49% is literate in Kinyarwanda only. 7% of this population is literate in both Kinyarwanda and English while about 6% is literate in Kinyarwanda, English and French. Overall, adult literacy rates are higher among urban residents (about 82% in urban areas versus 65% in rural areas) as well as among males (about 72% among males versus 65% among females). Meanwhile, the Net Attendance Rate (NRA) in primary school is 88% at national level while only 22% in secondary schools (NISR, 2014).

Figure 9. Land cover map of Rwanda

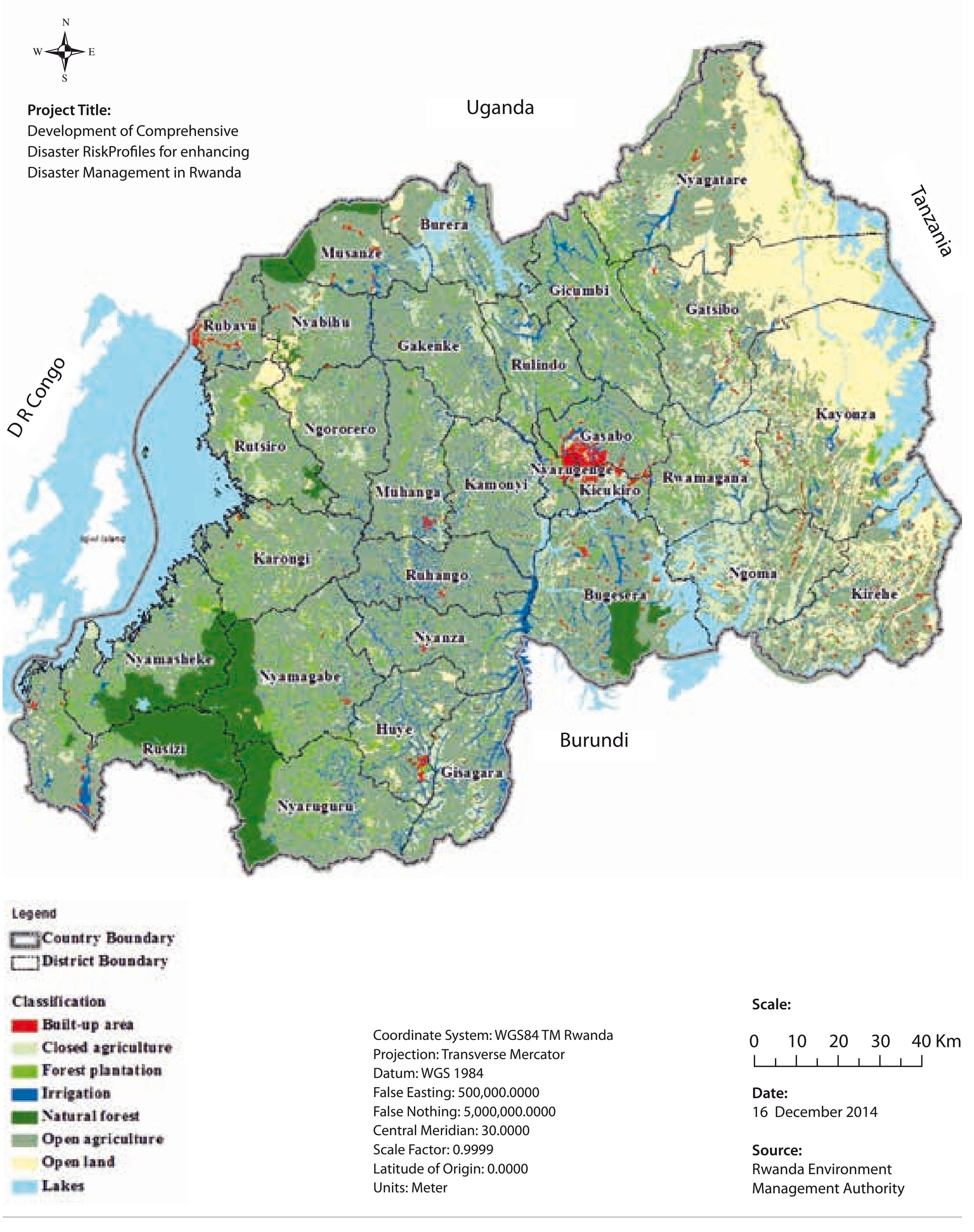
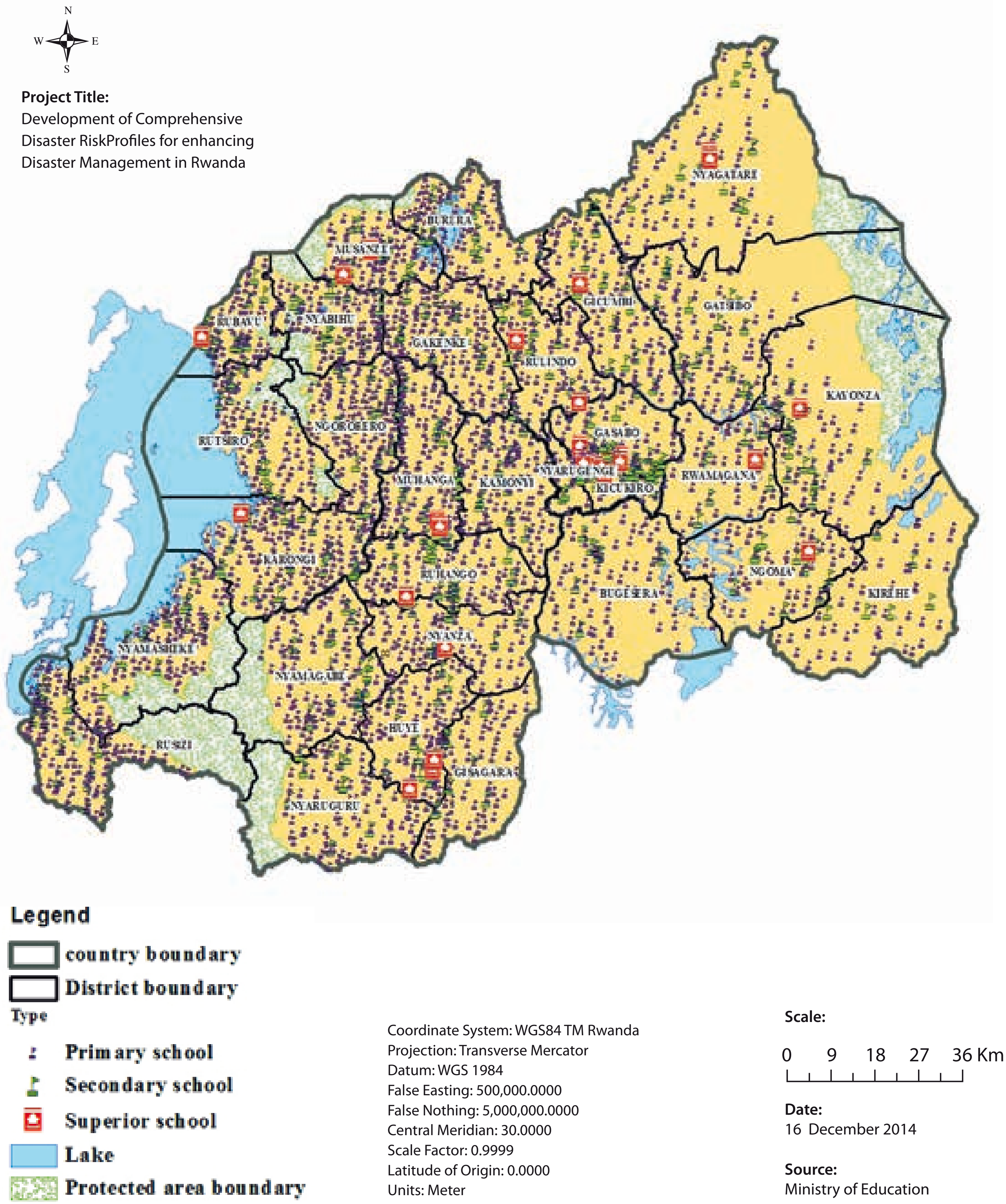


Figure 10. Education facilities map of Rwanda



2.6 Health facilities

According to the Health Management Information System (HMIS) of the Ministry of Health (MoH), there are 1,036 health facilities in Rwanda. Figure 13 shows the spatial distribution of these health facilities across the country. These include the national referral hospitals, district hospitals, police/military hospital, health centers, prison dispensaries, health posts, private dispensaries, private clinics, community-owned health facility and VCT centers as shown in Table 6 below.

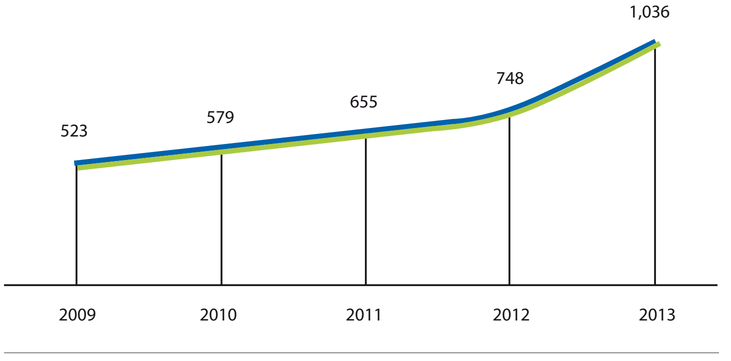
Table 6. Type and number of health facilities (as of 2013)

Type of Health Facility	No. of Facilities
National Referral Hospitals	5
District Hospitals	42
Police/Military Hospital	1
Health Centers	465
Prison Dispensaries	15
Health Posts	252
Private Dispensaries	137
Private Clinics	84
Community-owned health facility	15
VCT Center	20
TOTAL	**1036**

Source: Ministry of Health, Health Facilities Database, HMIS Unit

There has been a steady increase in the number of health facilities in the country during 2009-2013. In 2012 alone there has been an increase of 39% as shown by the Figure 11 below.

Figure 11. Number of health facilities from 2009-2013

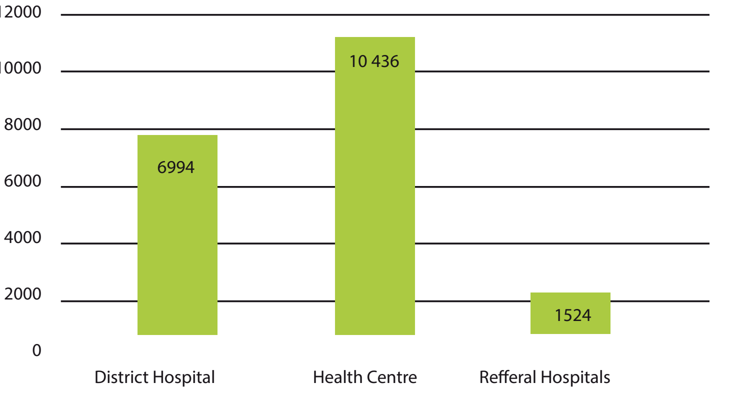


Source: Rwanda Statistical Yearbook 2014

The total number of beds in these health facilities is 18,954 and are shown in Figure 12. The Figure includes beds in district hospitals, health centers and referral hospitals, being all public hospitals.

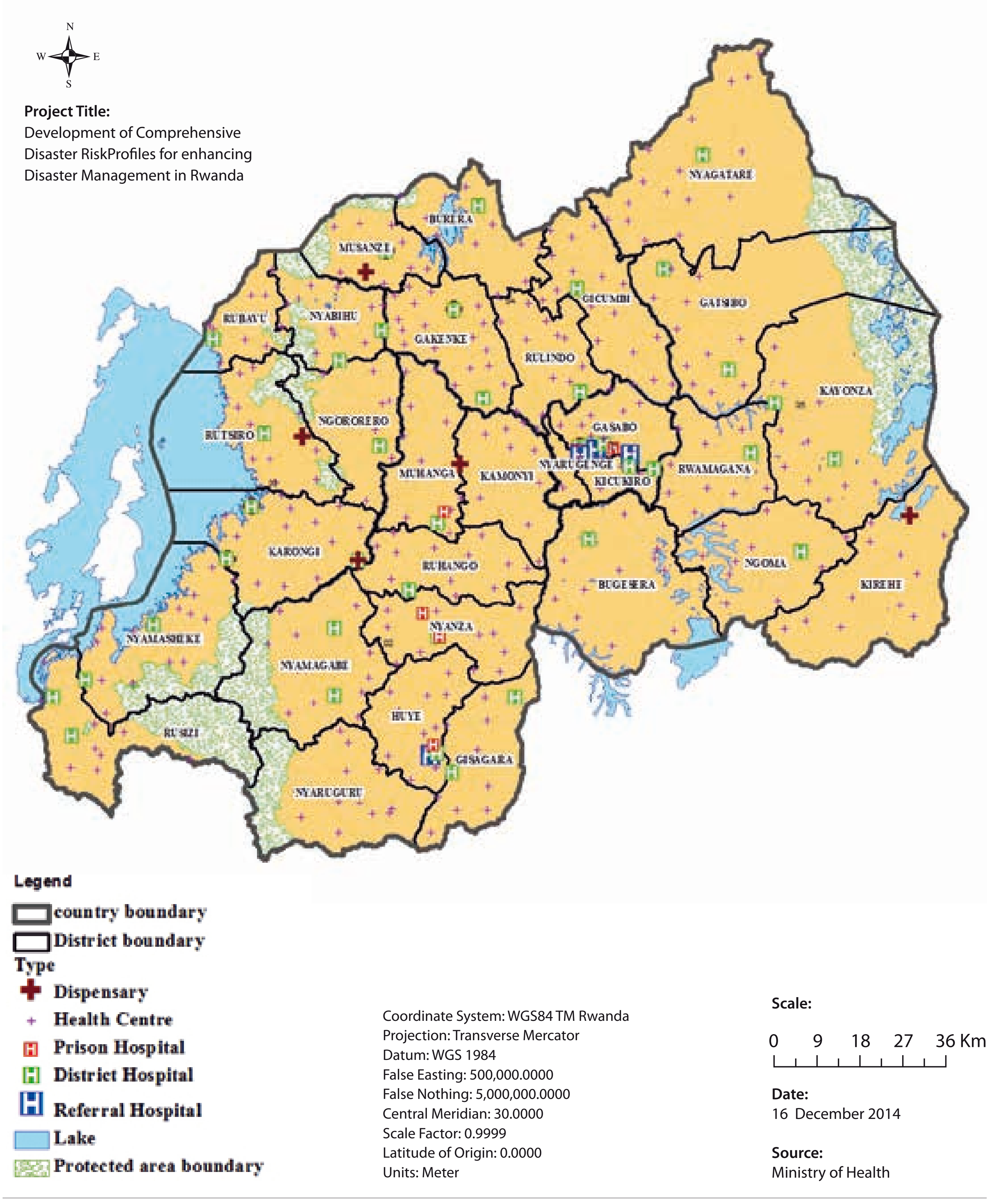
The 2012 data on the ratio of public health workers to the population shows that the ratio is very high. The ratio doctor: population is 1:15428 people. The dentist per population ratio is much higher at 1:91628. There is one nurse for 1,200 people and one midwife for about 23,364 people (NISR, 2014).

Figure 12. Number of beds by public health facility



Source: Rwanda Statistical Yearbook 2014

Figure 13. Health facilities map of Rwanda



2.7 Transportation

The main transportation system in Rwanda is land transportation. Being a landlocked country, roads are the primary links between the different districts, the capital Kigali and neighbouring countries. Road transport is the dominant mode of travel in Rwanda, catering for the bulk of domestic passenger travel and freight traffic demands (AfDB, 2013).

Table 7. Total length of roads in Rwanda

Type of Roads		Length (km)
Classified	Paved National Roads	1,075
	Unpaved National Roads	1,785
	Unpaved District Roads	1,838
Total length of classified roads		**4,698**
City of Kigali Roads	Paved Roads	153
	Unpaved Roads	864
Total length of roads in Kigali		**1,017**
Unpaved Roads		8,285
Grand total road length in Rwanda		**14,000**

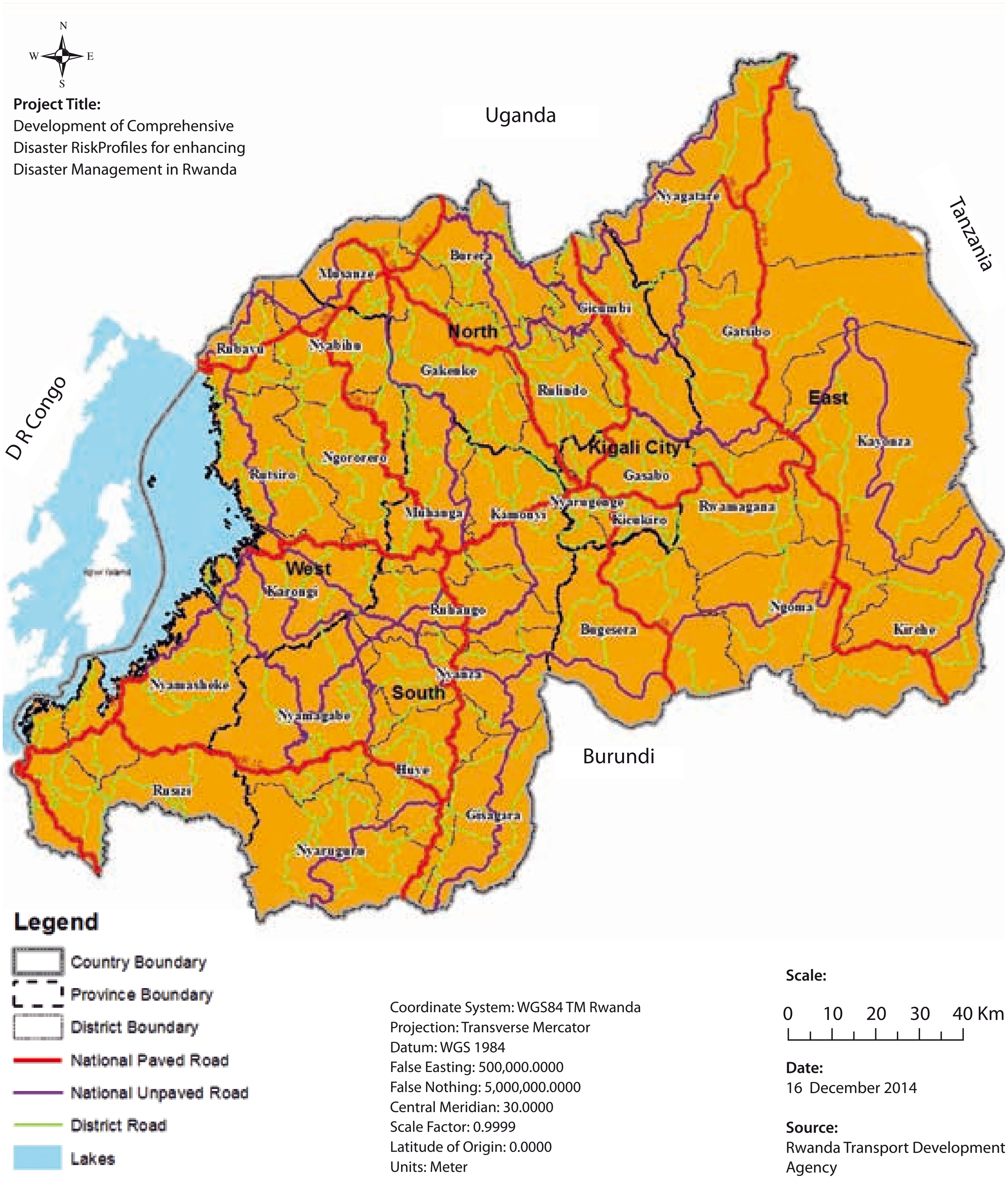
Source: Transport Sector Strategic Plan for EDPRS II, Draft Report, MININFRA, (2012)

According to the Law number 55/2011, dated 14/12/2011, containing provisions on roads in Rwanda, roads are defined into four categories: (1) National roads, (2) Districts and City of Kigali roads and that of other urban areas Class I, (3) Districts and City of Kigali roads and that of other urban areas Class II, and (4) Specific roads. The National roads are comprised of the international roads that link Rwanda with neighbouring countries; the roads that link Districts or that link a District and the City of Kigali, roads that link areas of tourist significance and facilities of national or international importance such as ports and airports. The Districts and City of Kigali roads and other urban areas Class I are roads linking different Sectors' headquarters within the same District, or those roads that are used within the same Sector. Districts and City of Kigali roads and other urban areas Class II are the arterial roads that connect Districts roads to rural community centres that are inhabited as an agglomeration. Specific roads are those specifically constructed to connect national roads or District roads to Kigali City and other urban areas to the centres for private sector's activities such agricultural production, natural resources processing or to tourist sites (MININFRA, 2014). Figure 14 shows the road network map of Rwanda.

The total road length in Rwanda is 14,000 kilometers. According to a survey conducted by RTDA in 2011, a total of 1,201 km of roads were paved and about 8% were in good condition. Another 32% of the unpaved national and 15% of the district road networks were in good condition (AfDB, 2013).

Rwanda has a high road density of 0.53 km/km^2, which almost matches the weighted average for Africa of 0.57 km/km^2. However, this high road density may be a consequence of the mountainous terrain, which requires long, meandering roads. Another factor is the dispersed human settlement pattern in the ridges. The roads with the highest passenger volumes of 2,000 – 4,000 per day are RN1 between Kigali, Muhanga and Ruhango and RN3 between Kigali and Rwamagana. Many roads have passenger traffic volumes of 1,000-2,000 per day including those between Kigali, Gicumbi and Rubavu; Rwamagana and Kibungo; Ruhango, Huye and Karongi; and Kayonza and Ryabega. The high-volume roads are the cross-border highways, which provide links to the country's major production and economically active regions (AfDB, 2013).

Figure 14. Road network map of Rwanda

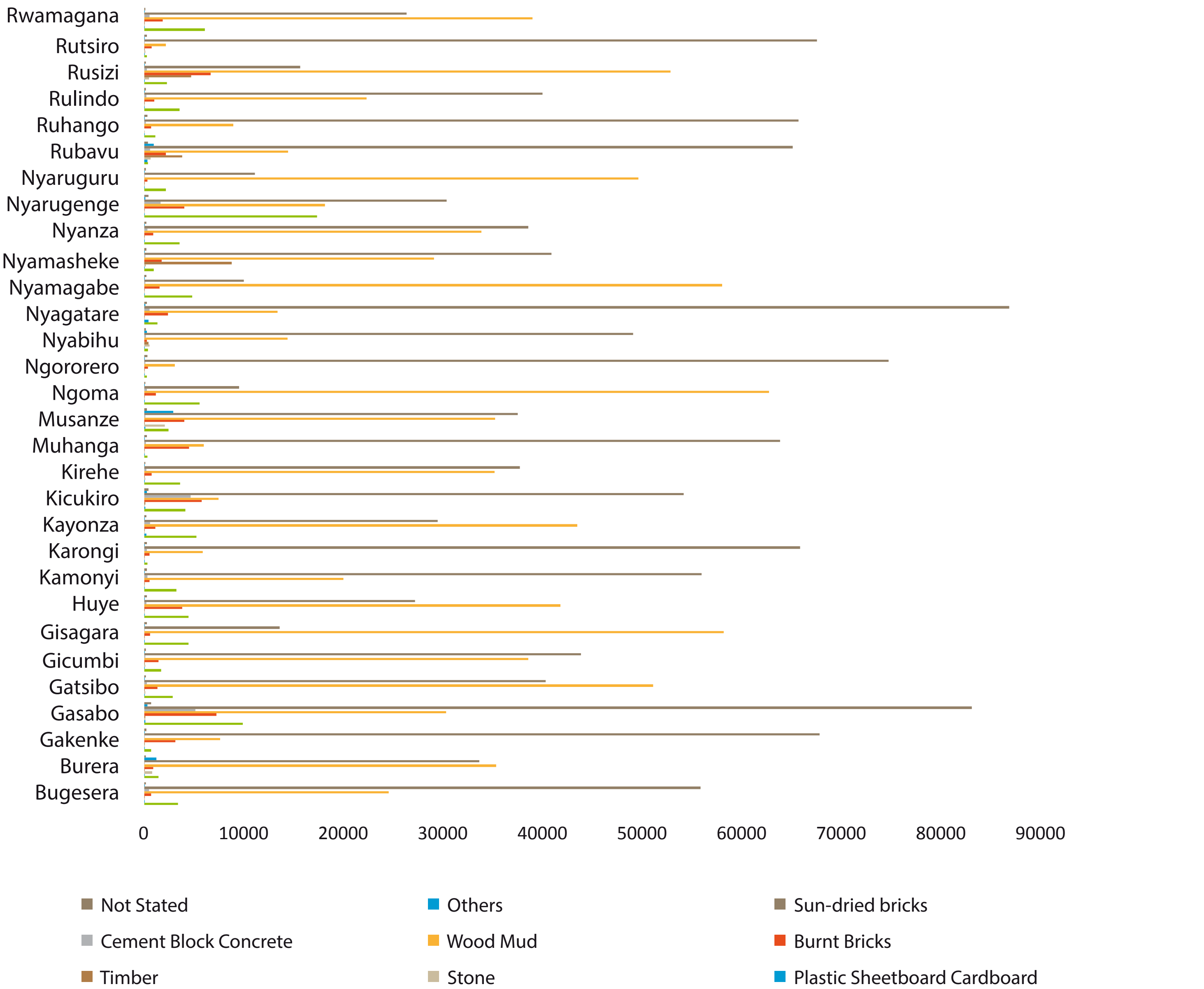


2.8 Residential buildings

Residential buildings in Rwanda are classified according to the physical characteristics of private households. The classification focuses on the materials used to build walls, roof and floor. With regards to materials used for walls, Rwandan households use a variety of wall types such as sun-dried bricks, wood and mud, wood, mud and cement, and others such as cement blocks/concrete, burnt bricks, stone and timber. Across all Rwanda, 91% of the private households are built with walls made of sun-dried bricks (55%) or wood/mud (36%). The remaining are built with wood/cement mud and other durable materials such as cement blocks (NISR, 2012).

In terms of roofing, about 99% of Rwanda's private households use either iron sheets (about 60%) or local tiles (about 39%) as the main material of their roof. In urban areas, about 87% of the households use iron sheet roofs compared to 54% in rural areas. Local tiles are mostly used in the Southern, Northern and Western provinces, while grass roofs have been almost eradicated (NISR, 2012).

Figure 15. Number of houses by wall types in Rwanda per District



Earth or sand is still the most commonly used material for floors, accounting for the flooring of about 78% of all households. In urban areas, about 64% of households have concrete floors compared to 11% in rural areas. The percentage of households with concrete floors has doubled from about 10% in 1991 to about 20% in 2012 (NISR, 2012).

There are four (4) types of habitat or settlements in Rwanda. These are: (i) clustered or grouped rural settlements, also referred to as *Imidugudu*; (ii) dispersed/isolated housing, also referred to as scattered settlements; (iii) planned urban housing; and (iv) squatter housing or informal settlements also referred to as *akajagari*. About 49% of the Rwandan households are in clustered rural settlements *(Imidugudu)*, 34% are in dispersed areas, 14% are in *akajagari* or squatter housing and only 2% are in planned urban housing. This distribution of settlements varies significantly between rural and urban areas (NISR, 2012). Figure 17 shows the spatial distribution of the *Imidugudu* settlements in the country. Imidugudu are located all over the country.

Figure 16. Number of houses by roof types in Rwanda per District

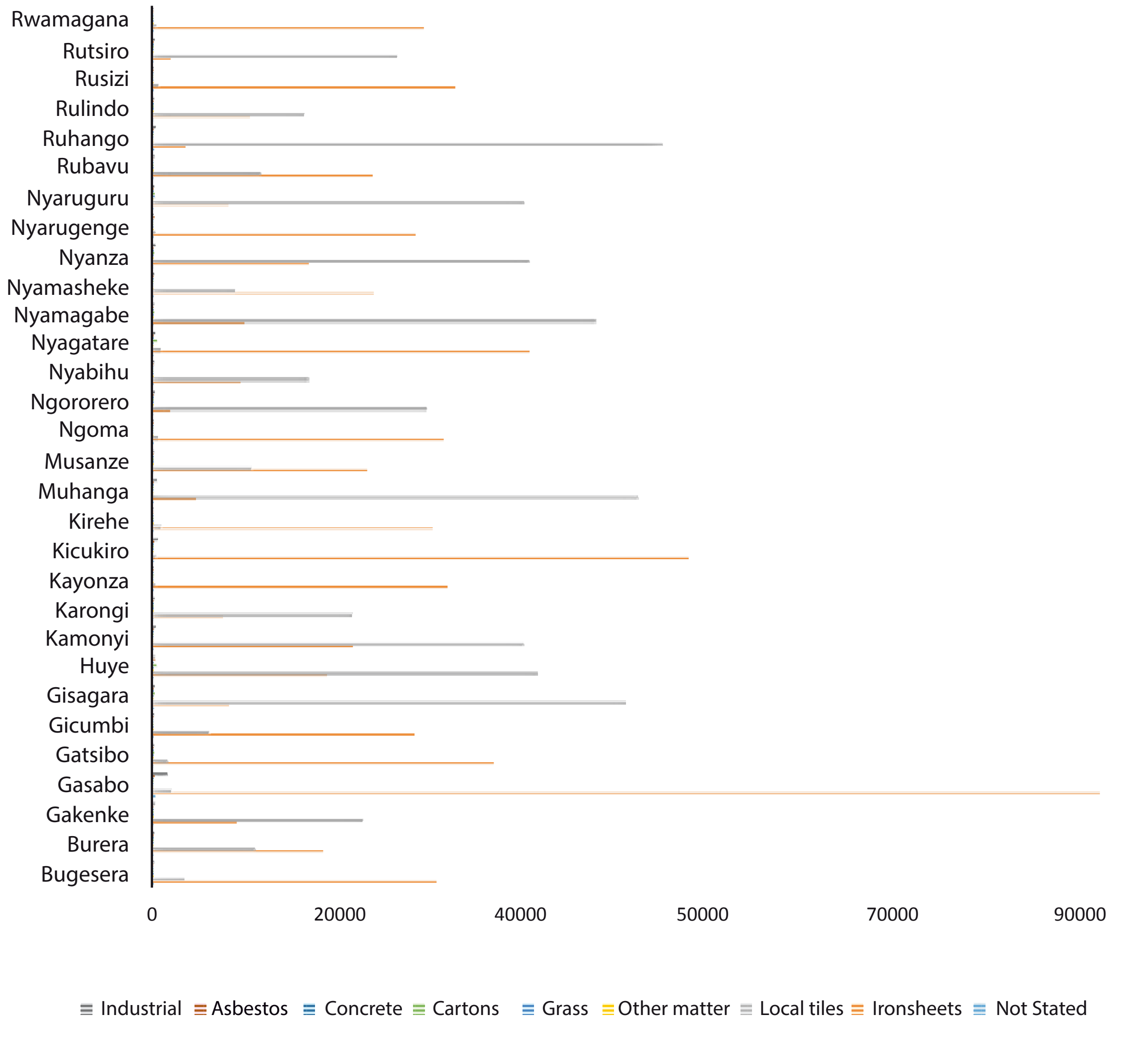
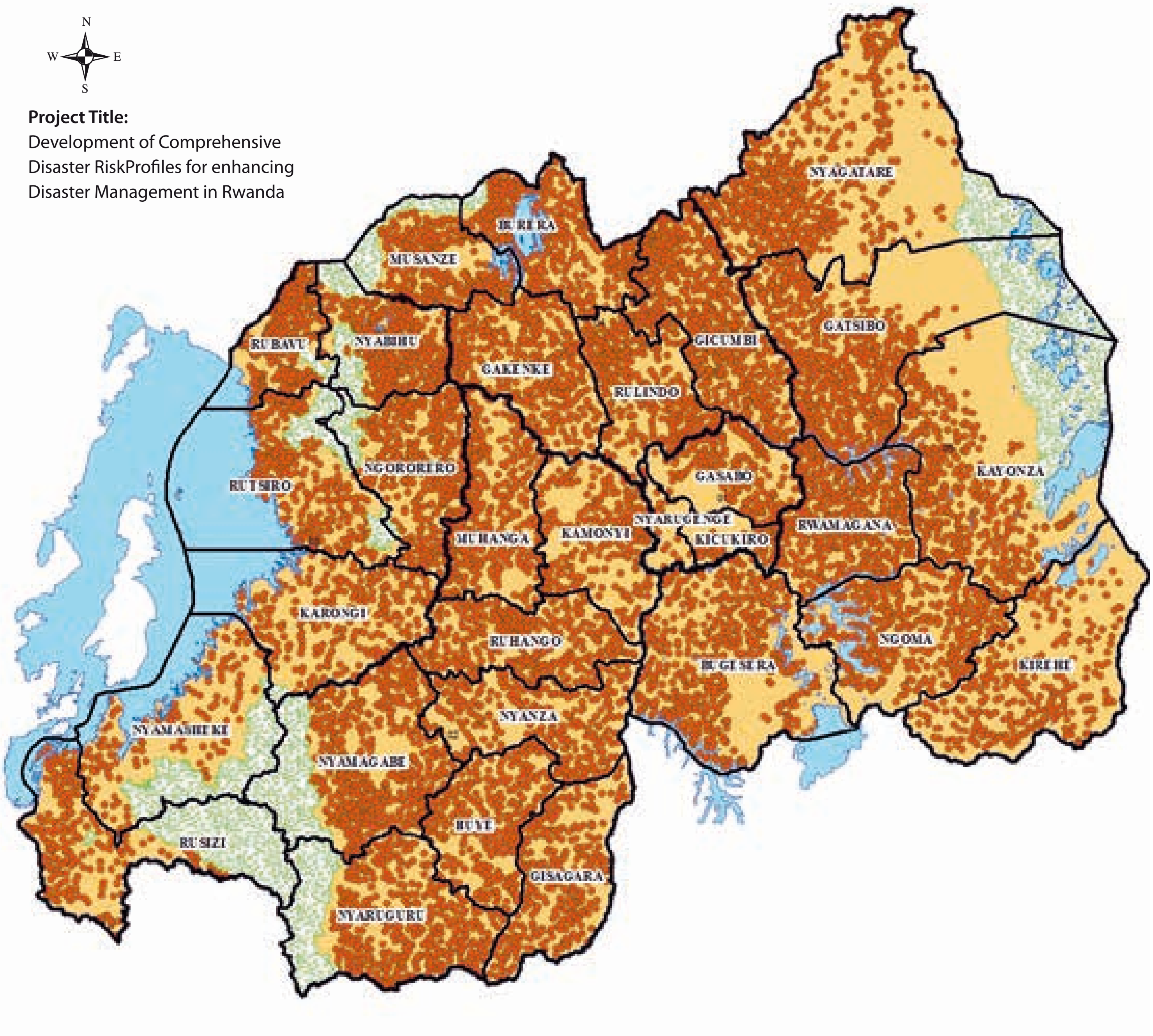


Figure 17. Settlements (imidugudu) map



Legend

- District boundary
- Settlement(umudugudu)
- Lake
- Protected area boundary

Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 9 18 27 36 Km

Date:
16 December 2014

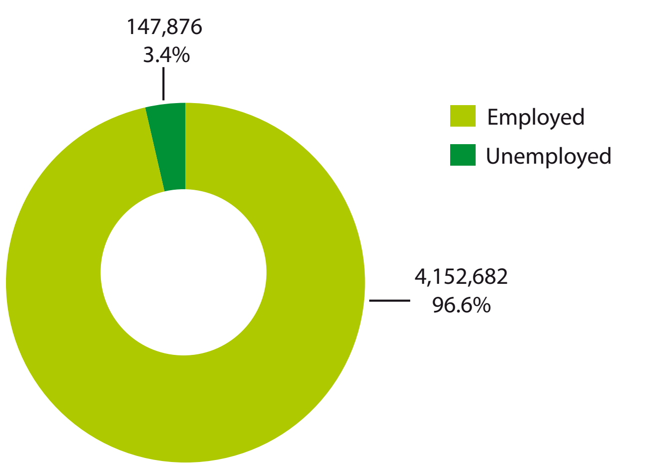
Source:
Ministry of Local Government

2.9 Employment and income

About 96.6% of the economically active population of Rwanda are employed, which equals 4,300,558 persons. The active population is shown in Figure 18. The economically active population has been defined as the population of 16 years and above. Of these employed persons, 52% are females. The highest percentage of employed population can be found in rural areas which account for 84%. The employed population in urban areas is dominated by males, contrary to rural areas where the majority of the working population is female. In a disaster context, it is important to note employment ratio man:women. Women, in general, are particularly vulnerable to natural hazards. The resilience of employed women is usually enhanced which makes it easier for them to cope with and recover from disasters compared to unemployed women. Furthermore, most disasters place an undue burden on women and girls who are often responsible for unpaid work such as providing care, water and food for households (UNDP, 2010).

The overall majority of the unemployed population are females (61.4%). The 2012 Census results show that six out of ten unemployed persons are females. Kigali City registers the highest percentage of unemployed persons in Rwanda (31%) and the lowest percentage is in the Northern Province (10%) (NISR, 2014).

Figure 18. Composition of active population in Rwanda



Source: Fourth Rwanda Population and Housing Census

The predominant occupation in Rwanda is agricultural forestry and fishery work, which accounts for 73% of the employed population. The other occupations with high prevalence are service and sales workers (9%), craft and related trade workers (6%) and elementary occupations (5%). Employment occupations were dominated by agriculture. The occupational structure is different in urban areas compared to rural areas. While 83% of the employed population is involved in agriculture in the rural areas, this percentage is only 21% in urban areas (NISR, 2014).

Figure 19 below shows the spatial distribution of employment to the population ratio in Rwanda. The highest employment to population ratio (51-58%) is registered in the districts of Gakenke, Muhanga, Rulindo, Rwamagana, Ngoma, Kirehe, Ruhango and Huye. The districts of Rubavu, Nyabihu and Nyamagabe have lowest employment to population ratio (23-35%).

Consequently in terms of income, almost half of all income in Rwanda is derived mainly from agriculture and about a quarter from salaried labour (or wage income). The income in the poorest households almost exclusively comes from agriculture. The wealthier households on the other hand generates their income most significantly from wages. At the national level, agriculture contributes the largest share of income, followed by wage income, business income (e.g. self-employment), transfers and rents. Table 8 below shows the shares of different income sources in Rwanda (NISR, 2014).

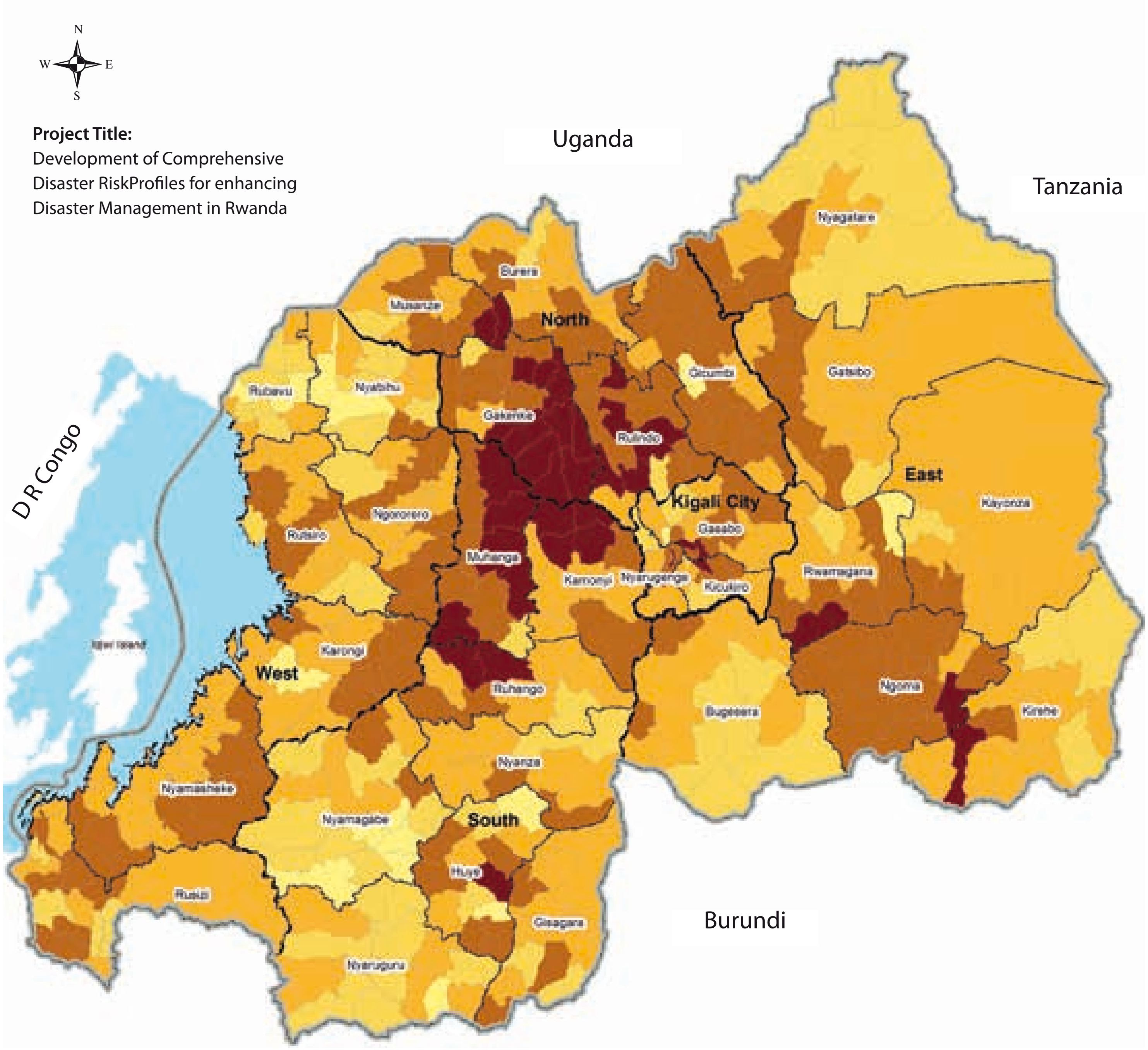
As Rwanda is largely dependent on agriculture for employment and income, this is an important consideration when assessing disaster risks on the agriculture sector. As noted in various studies, often the impact of disasters on agriculture is enormous. Every year natural disasters, such as hurricanes, floods, fires, and earthquakes, challenge agricultural production. Because agriculture relies on the weather, climate, and water availability to thrive, it is easily impacted by natural events and disasters. Agricultural impacts from natural events and disasters most commonly include: contamination of water bodies, loss of harvest or livestock, increased susceptibility to disease, and destruction of irrigation systems and other agricultural infrastructure. These impacts can have long lasting effects on agricultural production including crops, forest growth, and arable lands, which require time to mature (US Environmental Protection Agency, 2012).

Table 8. Share of income sources (%)

	Agriculture	Wage	Business	Public Transfers	Private Transfers	Rents
All Rwanda	45.7	25.3	10.5	3.2	6.9	8.4
Kigali City	11.8	44.0	21.5	2.4	10.0	10.4
Southern Province	51.4	22.5	6.7	3.5	6.9	9.0
Western Province	44.7	24.2	12.1	4.4	7.4	7.2
Northern Province	49.6	24.5	9.1	3.8	5.7	7.3
Eastern Province	51.9	22.0	9.4	1.5	6.1	9.1

Source: NISR, 2012

Figure 19. Employment to population ratio of Rwanda



Legend

- Country Boundary
- Province Boundary
- District Boundary
- Sector Boundary

Ratio (%)
23 - 35
35 - 43
43 - 47
47 - 51
51 - 58

Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:

0 10 20 30 40 Km

Date:
16 December 2014

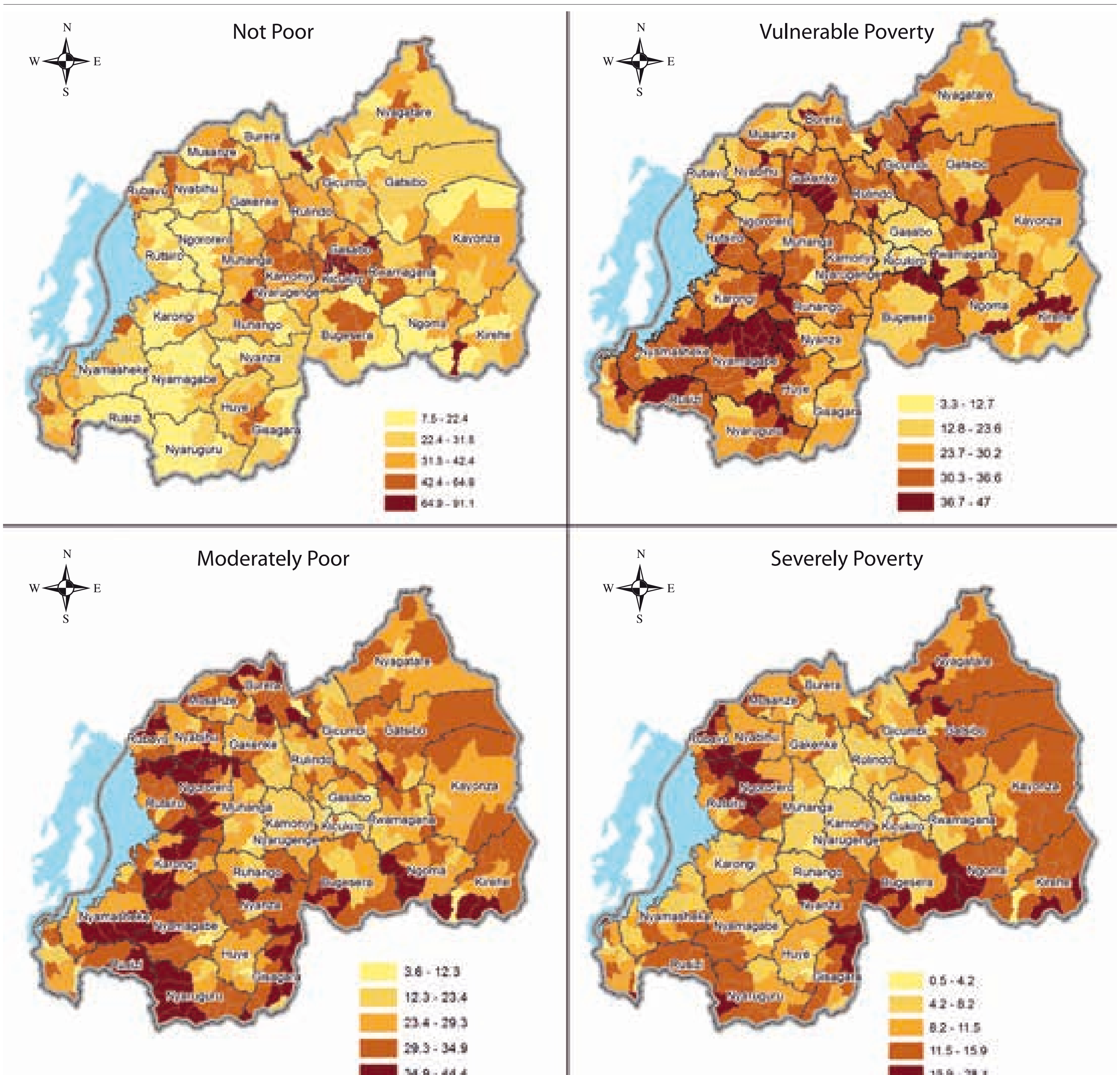
Source:
National Institute of Statistics
2012 Population and Housing Census

2.10 Poverty status

Poverty in Rwanda is classified into four groups: severely poor, moderately poor, slightly poor, and non-poor. These groups are spatially presented in Figure 20 below. Census data indicates that 10% of the total resident population are severely poor and 27% are moderately poor. This makes up for 37% of the population classified as poor. Of this figure, percentages of the poor are higher in rural (45%) than in urban areas (15%). Western and Eastern provinces are poorer than other provinces both with 42% of individuals living in poverty, whereas Kigali City has the lowest percentage of poor people at 15% of the population. Generally, the rural areas are poorer than the urban areas.

In terms of poverty status by district, the better-off districts are those in Kigali. Districts with relatively large cities, such as Muhanga, Huye, Gicumbi, Rwamagana and Musanze, as well as Rulindo and Gakenke, which have more rural settlements, show an overall poverty level around or below 35%. However, Gisagara, Ngororero, Rutsiro, Nyaruguru, Kirehe and Burera have more than 45% poor people. Eastern province is the poorest, however, there are districts with high concentrations of poverty both in the west and south of the country.

Figure 20. Poverty status map of Rwanda



Project Title:
Development of Comprehensive Disaster RiskProfiles for enhancing Disaster Management in Rwanda

Legend
Country Boundary
District Boundary
Sector Boundary

Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 20 40 60 80 Km

Date:
16 December 2014

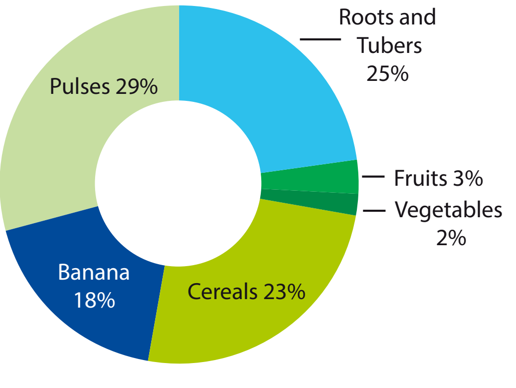
Source:
National Institute of Statistics 2012 Population and Housing Census

2.11 Agriculture and livestock

Agriculture is among major engines of growth of Rwanda, representing more than 43% of the Gross Domestic Product or GDP (Rwanda Vision 2020, 2000). Agriculture is currently the backbone of Rwanda's economy. One of the major inputs of agricultural production is land. It is a small country with a total arable land of 1.4 million hectares. About 90% of the Rwandese households cultivate at least one parcel of land. At the national level, 84% of these cultivating households cultivate less than 0.9 hectares of land. Only around 3% of cultivated land is irrigated (NISR, 2014).

Crop production constitutes the major part of agricultural production for the majority of the Rwandese households. These households produce a wide variety of crops. All cultivating households produce at least one main crop and the majority also produces fruits and vegetables. Rwanda has two agricultural seasons: September to February (Season A) and March to July (Season B). Countrywide, in average, the share of land area per major crop for two seasons are as follows: Pulses (29.5%[4]), Roots and Tubers (25%[5]), Cereals (22.5%[6]), and Banana (18%[7]), fruits (3%) and vegetables (2%) (MINAGRI, 2014). Figure 21 shows the share of land in percentage by category of crops cultivated in 2014 Season A.

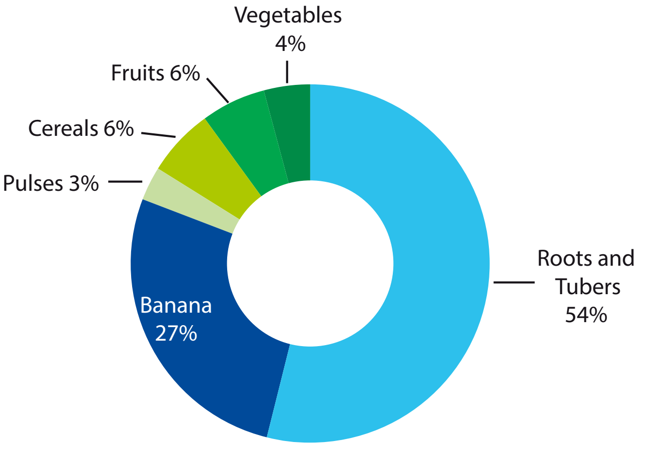
Figure 21. Share of land by category of crop (Season A 2014)



Source: Crop Assessment Season A (MINAGRI, 2014)

The major crops in terms of crop production as per 2014 Season B data, indicates Roots and Tubers (54%), Banana (27%), Cereals (6%), Fruits (6%), Vegetables (4%), and Pulses (3%). Figure 22 provides the graphical distribution of crop produced in Season B 2014.

Figure 22. Crop production by group of crops (Season B 2014)



Source: Crop Assessment Season B (MINAGRI, 2014)

In addition to crops, livestock is another important source of income and food for agricultural households in the country. About 68% of all households in Rwanda raise some type of livestock (Table 9). Goats, cattle and chicken are the most commonly raised types of livestock. According to the Integrated Housing Living Conditions Survey (EICV3)[8], the Northern Province has the highest percentage of households raising cattle and sheep while the Southern Province has the highest percentage of households raising goats, pigs and rabbits. Eastern Province had the highest percentage of households raising chickens, followed by Kigali City. The Western Province accounts for the highest percentage of households raising other types of livestock and poultry. Table 10 below shows these distributions.

Table 9. Percentage of households (HHs) raising livestock

	HHs raising livestock (%)
All Rwanda	68.2
Kigali City	34.5
Southern Province	73.1
Western Province	69.2
Northern Province	76.1
Eastern Province	70.1

Source: EICV3 (NISR, 2014)

4 30% for Season A and 29% for Season B
5 25% for both Season A and B
6 22% for Season A and 23% for Season B
7 18% for both Season A and B
8 EICV3 is the 2010/11 Integrated Housing Living Conditions Survey otherwise known as "Enquête Intégrales sur les Conditions des Vies des Ménages"

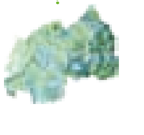


Table 10. Percentage of households raising livestock, by type

	% of HHs raising livestock, by type						
	Cattle	Sheep	Goats	Pigs	Rabbits	Chicken	Others
All Rwanda	47.3	15.7	53.0	24.1	22.9	45.5	10.2
Kigali City	41.2	5.4	46.2	4.5	17.2	53.4	4.9
Southern Province	47.1	7.2	56.4	37.6	29.7	45.6	10.8
Western Province	42.5	19.9	50.4	25.1	23.2	36.5	15.5
Northern Province	57.8	35.8	39.3	20.3	25.9	39.7	10.6
Eastern Province	44.6	6.2	64.5	15.8	14.1	57.3	5.1

Source: EICV3 (NISR, 2014)

Chapter III

Methodological Framework for Hazard and Risk Assessment

This chapter describes the overall methodology that is used to conduct the national risk assessment. Furthermore it demonstrates the structure of the report. Specific methodologies for hazard assessments and exposure mapping, vulnerability assessments and estimation of economic cost are detailed in the subsequent chapters dedicated to these specific subjects.

3.1 Methodology

The methodology used to carry out this study is basically divided in four main parts:

- Understanding country situation and baseline data compilation
- Hazard assessment and mapping
- Exposure assessment
- Vulnerability assessment and estimation of economic cost

3.1.1 Understanding country situation and baseline data compilation

A preliminary step of the Rwanda risk assessment process was an extensive inventory and compilation of existing data and information related to hazards and elements at risk. It involves an understanding of the country's disaster risk management framework, practices and institutional set-up. It entails collection of baseline data of the country such as administrative boundaries, infrastructure, socio-economic data (e.g. demographics, poverty index, employment, agriculture, etc.), spatial data (e.g. Digital Elevation Model, geology, soil, land cover, land use, road network, etc.) and meteorological data (e.g. rainfall, temperature, etc.). This process also include collection of historical disaster events and the damage and losses they caused. The collected data are compiled and structured in different datasets according to its nature, format and contents. Subsequently, the datasets are integrated in the Geographical Information System (GIS) platform and processed into maps and spatial formats. Some of the baseline data are presented in figures and tables. These maps, figures and tables are presented in chapter 2.

3.1.2 Hazard assessment and mapping

Hazard assessment and mapping is the first step of the risk assessment process. It involves characterizing the hazards in terms of its spatial distribution, frequency and intensity. It covers five major hazards that are prevalent in Rwanda namely, drought, landslide, flood, earthquake and windstorms. Specific hazard intensity maps are produced per hazard. The hazard maps identify the hazard-prone areas, describe the physical characteristics of the hazards and characterize the hazards in terms of magnitude, frequency, duration, extent, intensity and probability. The hazard assessment and mapping phase also entails building of plausible scenarios for each hazard and developing hazard intensity maps.

3.1.3 Exposure assessment

Identifying and assessing the elements at risk is the next step in the risk assessment process. Exposure assessment is an intermediate stage of risk assessment which links the hazard assessment with the targeted elements under consideration for the risk assessment (ADPC, 2013). The elements at risks in this study, also labelled as sectors of activity, are population, building, critical facilities such as health and education facilities, infrastructure (e.g. roads) and agriculture (Table 11). Exposure will be quantified and expressed as the number of population (or human lives) and the value of properties and assets that can potentially be affected by a specific hazard.

Table 11. Elements considered in the assessment per hazard

Hazard\Sector	Population	Building	Crop	Healthcare facilities	Education facilities	Transportation facilities
Drought	x		x			
Earthquake	x	x		x	x	x
Flood	x	x	x	x	x	x
Landslide	x	x	x	x	x	x
Windstorms	x	x	x	x	x	

The exposure assessment is aimed at creating a national database of elements at risks. It qualifies the elements located in hazard-prone areas. The goal is to develop a comprehensive profile of elements at risk and analysis of their exposure to various natural hazards. The analysis is carried out based on available data.

3.1.4 Vulnerability assessment and estimation of economic cost

In multi-hazard risk assessment, the vulnerability assessment is the most challenging part as the concept of risk assessment and is defined in many different ways. According to Leon's literature review (2006), vulnerability is generally characterized as the susceptibility of a society of being affected by disasters and their capacity to cope with them. Risk is the possibility of harmful consequences, or expected losses due to interactions between hazards and vulnerable conditions. For this atlas, the vulnerability assessment of the population, building, education, agriculture, transportation, and healthcare sector is conducted. A hazard intensity-damage relationship is to be developed for landslide, earthquake, windstorm and drought.

Vulnerability is defined as the degree of damage of a specific element-at-risk and will be determined by the intensity of the hazard event and the characteristics of the elements-at-risk. As shown in Figure 23, the vulnerability will be hazard specific and physical forces like ground acceleration (earthquake), wind speed (windstorms) and water deficiency (droughts) will determine the level of vulnerability of different elements exposed. Table 12 below details criteria which were considered to assess vulnerability.

The methodology used for estimation economic cost is simple considering the parameters in Table 54. The estimation of economic cost is a function of the total exposure, the damage state of each element at risk, and their replacement or repair cost. The calculation of potential economic cost due to different hazards were done using the formula as demonstrated below:

Loss = total exposure of the element at risk x vulnerability (damage state) x the replacement cost

3.2 Limitations

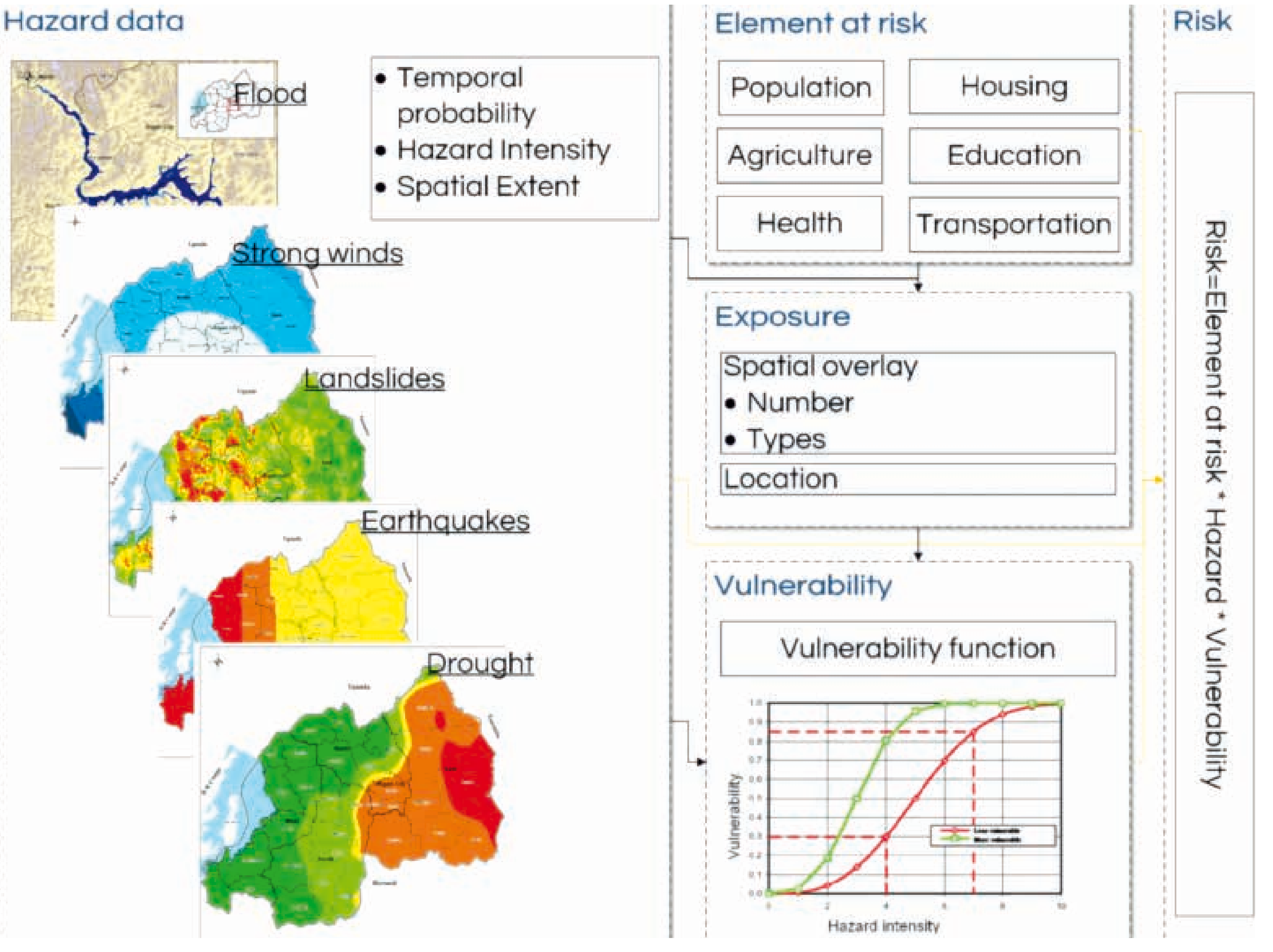
A national risk assessment is heavily dependent on data availability, accessibility and applicability to specific use. A project like this atlas has never been conducted before in Rwanda and never such huge amount of data related to disaster risk in Rwanda had been gathered. The main challenge has been the availability and quality of required data. Most risk assessment models require data recorded for a long period and should be disaggregated to the spatial level of analysis. The challenge was the short period of data recording because many data collection systems in the country were established just very recently. In addition, the data recording systems that already existed before 1994 were halted during the genocide and reopened years later.

In order to do the analysis, the study used proxy data and/or data which are aggregated at District level to fill in the data gaps and used data which are recorded for a limited duration. For this reason, the level of analysis is limited to District level and for some return periods selected based on data availability. Moreover, the flood hazard assessment was only made for river flooding as the data available only allows the assessment by catchments. Since the hazard assessment was made by catchment, the flood hazard assessment for the whole country was not possible. Furthermore, due to this limitation, the flood-prone areas as revealed in the flood hazard maps were mostly uninhabited or no settlement or no development activities present. Hence, the exposure, vulnerability assessment and estimation of economic cost for floods were not undertaken.

Table 12. Criteria considered for vulnerability assessment

Hazard\Sector	Criteria to be considered for Vulnerability assessment
Flood	A 25 years return period with 1m and above of water depth
Windstorms	Areas with gale and strong gale on Beaufort scale
Landslides	Areas with a susceptibility class of high and very high
Earthquakes	MMI scale of 10% probability of exceedance in 50 years which divide the country into three zones
Drought	Areas with drought index of high to very high.

Figure 23. Framework of the methodology



Chapter IV

Hazard Assessment and Mapping

Hazard assessment and mapping aims to characterize major hazards prevailing in Rwanda and map out all hazard-prone areas within the territory of the country. This chapter presents the results of the hazard assessment and mapping of five major hazards that prevail in Rwanda i.e. drought, landslide, flood, earthquake and windstorm. Each of the hazard assessments is discussed in separate sections and presented with a background of the hazard, a discussion of historical disasters per hazard and the vulnerable groups to the hazard. The methodology for the assessment and mapping vary per hazard and is explained in the respective hazard assessment and mapping section. The data requirements and sources of data for each hazard are discussed in sub section 3 of each main section. Each paragraph on hazard mapping also includes hazard intensity maps or susceptibility maps (sub section 4), hazard analysis (sub section 5) and a section on the application of the analysis in disaster management and development planning (sub section 6). Limitations (sub section 7) and corresponding recommendations (sub section 8) are provided at the end of each hazard analysis.

4.1 Drought hazard assessment and mapping

4.1.1 Background

All droughts originate from a deficiency of precipitation. In contrast to aridity, which is a permanent feature of regional climate, drought is a temporal aberration, relative to some long-term average condition of balance between precipitation and evapotranspiration in a particular area, a condition often perceived as "normal". The United Nations Convention to Combat Desertification (UNCCD), defines drought as "the naturally occurring phenomenon that exists when precipitation has been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems."

There are different methodologies for measuring droughts because the characteristics of drought differ from region to region. The impact of drought also vary significantly from location to location, due to differences in economic, social, and environmental settings. Therefore, methods and models for measuring drought should be impact or application-specific and region-specific.

In addition to precipitation, a number of other factors play a significant role in the occurrence of drought. These are evaporation (affected by temperature and wind), soil types and their ability to store water, the depth and presence of ground water supplies and vegetation. Taking this into account three types of droughts are commonly noted: meteorological, agricultural, and hydrological.

- Meteorological drought is defined "solely on the basis of the degree of dryness (often in comparison to the average amount) and the duration of the dry period" and must be region-specific. For example, in the dry lands of sub-Saharan Africa there are differences between bimodal rainfall areas and areas of mono-modal rainfall. Bi-modal rainfall means that there are two peaks of rainfall during the year e.g. seen in the pastoral areas of East Africa. Mono-modal rainfall means that there is one peak of rainfall and occurs in the Sahel. For some areas in these dry lands, it has been suggested that meteorological drought is defined in terms of rainfall failure in two successive years.

- Agricultural drought focuses on differences between actual and potential evapotranspiration and soil-water deficits. They are crop-specific and heavily dependent on the timing of rain and dry periods related to crop-cycles. Agricultural droughts can therefore occur in the absence of meteorological drought, and vice versa.

- Hydrological drought or water supply drought, is best defined by deficiencies in surface and sub-surface water supplies, which lead to a lack of water availability that is needed to meet water demands. Hydrological drought occurs less frequently than agricultural drought because considerable time elapses between precipitation deficiencies and declines in ground water and reservoir levels. Likewise, these components of the hydrologic system are usually the last to recover from longer term droughts.

There are clearly strong relationships between the three types of drought especially during prolonged periods of rainfall deficiency, although with leads and lags in terms of their respective onsets and departures.

In this atlas, solely agricultural drought will be analyzed for two reasons. Firstly, agricultural drought links various characteristics of meteorological (or hydrological) drought to agricultural impacts, focusing on precipitation shortages, differences between actual and potential evapotranspiration, soil water deficits, reduced groundwater or reservoir levels, and so forth. Secondly, the Rwandan labor market is predominated by agriculture with 73% of Rwandan population classified as farmers (NISR, 2014). The agricultural drought is one of the challenges that they face.

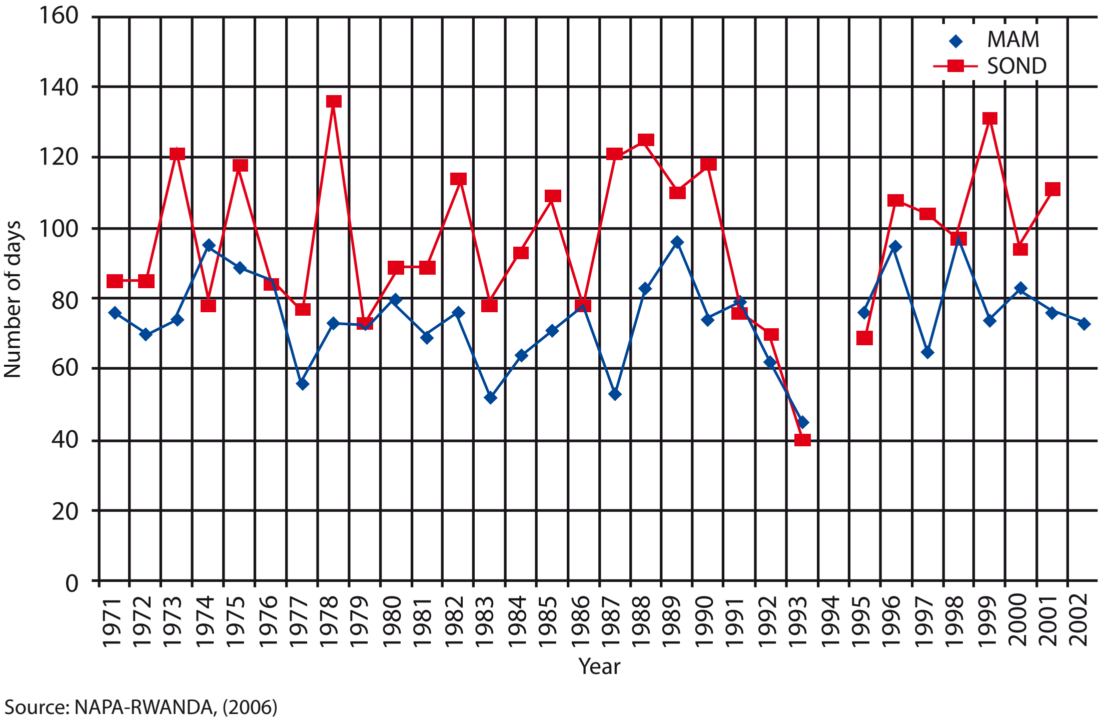
The drought hazard is a function of rainfall, evapotranspiration and moisture. Rwanda is characterized by a cyclic irregularity of rainfall across the country due to different factors. El Nino phenomenon has been identified as the most influencing the irregularities of rainfall (MINIRENA, 2006). El Nino years were characterized by a pluviometry which tends to be excessive. However, some years of El Nino registered pluviometric deficits. These years are also associated to the delay of the start of rainy seasons and some years are characterized by significant frequency of short droughts (dry spells). In the years immediately after the El Nino phenomenon, deficits of rainfall were registered during the rainy season and a significant frequency of (short period) drought were marked.

The exposed districts to rainfall deficit are Bugesera, Nyagatare, Gatsibo, Kayonza, Ngoma and Kirehe in the Eastern Province and the eastern parts of Nyanza and Gisagara districts in Southern Province. These districts are characterized by high frequency of rainfall deficit, late rainfall onsets, early rainfall cessations, and a significant number of dry spells and are prone to drought.

The rainfall distribution across the country is not homogeneous. The spatial and temporal patterns of rainfall are influenced by the morphology and topography of a given region. The average rainfall in western highlands is above the national average. Meanwhile rainfall in the eastern part of the country is below the national average. Elevation is one of the main factors that influences rainfall distribution. The rainy season's length is also influenced by elevation.

In terms of season, Rwanda has two rainy seasons corresponding with agricultural seasons: Season A from September until the end of December and season B that starts in March and ends in May. Figure 24 below shows the length of the rainy period by season. The red line in the Figure indicates season A (September – October – November – December) and shows heavy peaks of rainfall in 1978 and 1999. The blue line shows the length of days

Figure 24. Length (days) of rainy season at Kigali station (1971-2002)[9]



Source: NAPA-RWANDA, (2006)

[9] MAM: March-April-May and SOND: September-October-November-December

of season B (March – April – May). Most of the time, season A registers more days of rain than season B.

According to CRED/EM-DAT and various sources as cited by the Royal Museum for Central Africa (RMCA, 2014), different periods of droughts occurred in past years. The years of the droughts and the affected (former) provinces are summarised in Table 13 below.[10] Between 1910 and 2010, eleven main drought events have been recorded, causing crop failure or shortage that further caused famines. The worst situation was recorded in December 1989 where 237 people died due to famine. This happened in Southern Province (Gitarama, Butare and Gikongoro) and 60,000 people were affected. Other main droughts occurred in in March-May 2000 and September 2005 - February 2006. An important low rainfall was registered followed by a prolonged drought, which devastated many regions in Central and Eastern Africa including Rwanda. During these farming seasons, practically no harvest was recorded in the Eastern and Southern Province (1. Umutara, 2. Kibungo, 3. Bugesera, 4. Mayaga, and 5. Butare)[11] leading to a famine and an emergency intervention from the government to the most vulnerable population of these regions (MINIRENA, 2006).

Since the establishment of MIDIMAR in 2010, Rwanda has its own system of data collection on hazard events occurring in the country. For drought, one important event is recorded in March-May 2014. A prolonged delay of rainy season resulted in destroyed crops and soil dehydration. It impacted the eastern province mainly in Bugesera and Kayonza districts (MIDIMAR, 2014).

Table 13. List of drought events in Rwanda

Event date	Affected zone	Secondary hazards	Chained events	Death	Affected Pop	Source info	Comments
1910	Kibungo/Zaza (EP)			0	1,700,000	Scaetta, 1932	
1976-1977	National	Famine/ Crop failure	Famine/ Crop failure	0	420,000	CRED	
October 1984	National	Famine/ Food shortage	Famine/ Food shortage	0	60, 000	CRED; Reliefweb	
December 1989	Gikongoro, Gitarama and Butare (SP)	Famine/ Crop failure	Famine/ Crop failure	237	82,000	CRED	
1996	Gikongoro	Famine/ Food shortage	Famine/ Food shortage	0	894,545	CRED	
November 1999 - Early 2000	Umutara, Kibungo (EP), Kigali (Central), Gitarama, Butare and Gikongoro (SP)	Famine/ Food shortage	Famine/ Food shortage	0	267,000	CRED; Glidenumber; Reliefweb	
March 2003	Kigali Rural (Gashora and Bugesera), Kibungo, Umutara (EP), Butare, Gikongoro and Gitarama (SP)			0	1,000,000	CRED	
February 2005	National	Famine/ Crop failure	Famine/ Crop failure			CATNAT; OCHA; Reliefweb	6.5 million people affected in eastern Africa; also in Burundi
March - September 2006	Kibungo, Umutara, Bugesera (EP), Butare, Gikongoro and Gitarama (SP)	Famine/ Food shortage	Famine/ Food shortage	0	1,011,200	IFRC	202239 households affected
June 2014	Bugesera and Kayonza Districts (EP)					MIDIMAR	

Source: Royal Museum of Central Africa combined with MIDIMAR data (from 2010).

[10] Table 13 displays the areas, data and affected people by drought. As the data is gathered before the administrative rearrangement of 2006, the names of these former provinces do not exist anymore. Therefore, behind the names of the provinces, the names of the current province is written between brackets (e.g. SP = Southern Province; EP = Eastern Province).

[11] 1, 2 and 5 are former Rwandan provinces and 3 and 4 are geographical areas in Rwanda. After the administrative rearrangement in 2006, these names disappeared from the administrative boundary map.

Drought hazard is one of the major hazards severely affecting Rwandan farmers. Family farms are in general small (0.5ha in average) and farmers are rainfall-dependent due to the lack of irrigation systems. Besides the use of artisanal farming tools increases the vulnerability of small farmers to any climate hazard.

4.1.2 Methodology for drought mapping

The methodology for drought mapping used in this study is Water Requirement Satisfactory Index (WRSI) developed by FEWSNET. It is based on soil water demand and analyzes the soil moisture according to a given crop (FAO, 1998). The method indicates the crop performance based on the availability of water during a growing season. It has been applied in several countries including Africa with similarities of Rwanda (SADC country members) and it is also useful to Rwandan context.

Within this approach, the water supply from rainfall (or irrigation) is compared to the water demand of a target crop. Both factors vary throughout the season. It runs a simple water balance model with a 10-day time step. Rainfall is monitored from the beginning of the season and at each time step, the rainfall (plus any water stored in the soil) is compared to the water requirements of the crop. If this exceeds the crop requirement, the excess is added to the soil; if it is below the crop requirements, a deficit is registered.

The lengths of crop seasons A and B are considered for key crops normally grown in Rwanda. At the end of the season (EOS), a numerical index is computed, the previously mentioned WRSI. The scale of this index is 0 to 100. The WRSI is 100 in case the crop water requirements are fully satisfied throughout the season. The more the value of the index goes below this value the more the rainfall is unable to satisfy water needs of the crop.

The onset of Season A was considered to be the first decade of August while the EOS was taken as the last decade of February. For Season B, the start of the season was set on the first decade of March up to last decade of June.

The end of season WRSI (EOS WRSI) output has been selected as the agricultural drought hazard index. In its simplest form it represents the ratio of seasonal actual crop evapotranspiration to the seasonal crop water requirement.

To run the model, maize was used as a proxy crop because it is potentially cultivated across the country and it demands more water (500-800mm) for its vegetative cycle (125-180 days) longer than other seasonal crops (FAO, 1998). In addition to the fact that maize requires a lot of water, maize is also far more sensitive to water stress than most other (cereal and tuber) crops, particularly during its flowering and grain filling stages. This means that for the same degree of water supply deficit, maize will suffer a larger decrease in final yield than another cereal crop growing under similar circumstances.

WRSI for a season is based on the water supply and water demand of a crop during a growing season. It is calculated as the ratio of seasonal actual evapotranspiration (ETa) to the seasonal crop water requirement (WR):

$$WRSI = \frac{(Eta)}{WR} * 100 \qquad \text{Equation 1}$$

WR is calculated from the FAO Penman-Monteith (FAO, 1998) reference evapotranspiration (ETo) using the LSP-based crop coefficient (Kcp) to adjust for the growth stage and land cover condition.

The Penman-Monteith form of the combination equation is:

$$\lambda ET = \frac{\Delta(R_n - G) + \rho c_p (e_s - e_a)/r_a}{\Delta + \gamma(1 + r_s/r_a)} \qquad \text{Equation 2}$$

Where R_n is the net radiation, G is the soil heat flux, $(e_s - e_a)$ represents the Vapor Pressure Deficit (VPD) of air at the reference height (kPa), ρ is the mean air density (kg m-3), pc is the specific heat of air at a constant pressure (MJkg-1°C-1), Δ is the slope of the saturation vapor pressure-temperature relationship at mean air temperature (kPa°C-1), γ is the psychrometric constant (kPa°C-1), r_s is the (bulk) surface resistance (s m-1), and r_a is the aerodynamic resistance (s m-1)

$$WR = ETo * Kcp \qquad \text{Equation 3}$$

From WRSI equation, ETa represents the actual (as opposed to the potential) amount of water withdrawn from the soil water reservoir ("bucket").

In practice, WRSI explains simply the crop performance within its growing period according to its requirement in terms of water and is calculated as follows: 100 – (Total Deficit / Total Crop Requirement). It varies between 0 and 100 with values below 50 generally considered as complete crop failure. The model is tuned to specific crops by using tables of seasonal water requirements published by FAO for specific crops. The behaviour of crops with higher water requirements (maize in this case) or longer development cycles is accounted for and differentiated from those of less water demanding crops (such as millet).

The crop water requirements vary throughout the season reflecting the crop development stages: they are lowest at planting time, increase steadily to reach a peak in the approach to maturity (during the crop flowering and grain filling period for cereals) and decrease again as the crop ends its development. They are specified by means of so called *crop coefficients* which are determined for a given crop and apply irrespective of where the crop is grown.

The occurrence of significant impacts on crop production is evaluated by deriving the magnitude and frequency of deviations of the WRSI from a reference value, its medium term average value. Deviations from the average are related to qualitative drought levels as such:

Mild drought	WRSI within 80-90% of the median
Moderate drought	WRSI within 70-80% of the median
Severe drought	WRSI below 70% of the median

The severe drought (with WRSI below 70% of the median) was retained[12] and the WRSI model was run for each season in the record (2001-2002 to 2013-2014). From the set of seasonal outputs, the long term average was derived and the ratios of the average derived for each season. This set was then converted into frequencies of occurrence and then in drought index. Five classes are identified: very low corresponding to below 5% of probability of occurrence, 5-10% (low), 10-20% for moderate, 20-30% corresponding to high and very high corresponding to more than 30% of probability of occurrence. Note that the highest probability of having severe drought in the country is 42%.

Table 14. Severe drought probability in percentage across the country

Susceptibility Levels	Severe drought probability in %
Very High	>30
High	20 -30
Moderate	10-20
Low	5-10
Very Low	<=5

4.1.3 Data requirements and data sources

The required data for the application of WRSI are rainfall and evapotranspiration. For this study, the data have been retrieved from United States Geological Survey (USGS), with a spatial resolution of 10x10 km of pixel, and were organized in decadal for the period of March 2001 to February 2014. The Africa Risk View (ARC, 2013) was used to process the data. From the ARV model, mean total seasonal water deficit and seasonal WRSI were computed and respective drought hazard maps were produced.

4.1.4 Drought hazard zonation maps

The drought hazard zonation maps show the probability of an area to be affected by a severe drought or a complete crop failure as explained in the methodology. The probability for having a severe drought varies from 0% in the Western part of the country to 42% in the East. Note that, in general the chance for having severe drought are below 50% across the country and almost zero in the west in both seasons A and B. The probability was used to produce a drought susceptibility classes as shown in Figure 25 (season A) and Figure 26 (season B).

Normally, the eastern part of the country records more rainfall anomalies than the western part. Kayonza and Kirehe districts receive the lowest precipitation while higher precipitations are recorded in mountainous part of the country especially in volcano's park and the south west (Rusizi district) and all along the Cong-Nile crest.

For EOS-WRSI results for both seasons (A & B), there was a high correlation between rain distribution and crop performance. For the season A, the area with low rainfall are those with less crop performance (Kayonza and Kirehe districts eastern parts). However, the average of 13 years decadal rain doesn't show any severe crop failure. Much of the country knows an average crop performance (between 80 and 95). Therefore, the season B, extended from March to June, is the one which experiences crop failures. Nevertheless, the season B receive most of precipitation but for a short period (end of March and April) which leads to a poor crop performance as the rainfall is not well distributed along the season.

[12] Severe drought is only retained for analysis because it is more difficult to mitigate than other categories of drought (mild and moderate). In case of severe drought, the crop performance is failure and the food security starts to be a problem. For other categories, situation is still possible to control to secure harvest.

Figure 25. Drought hazard map of Rwanda (Season A)

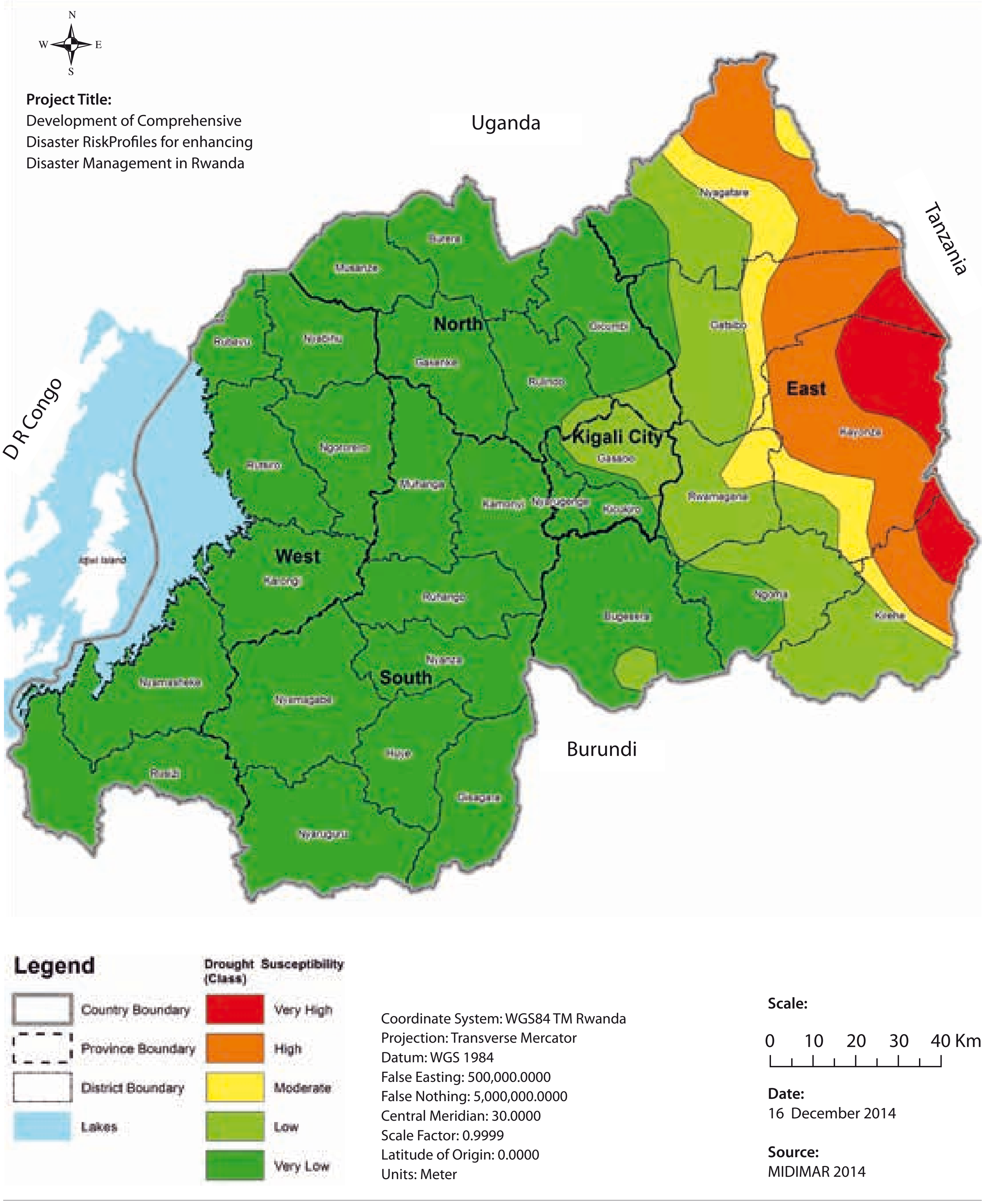
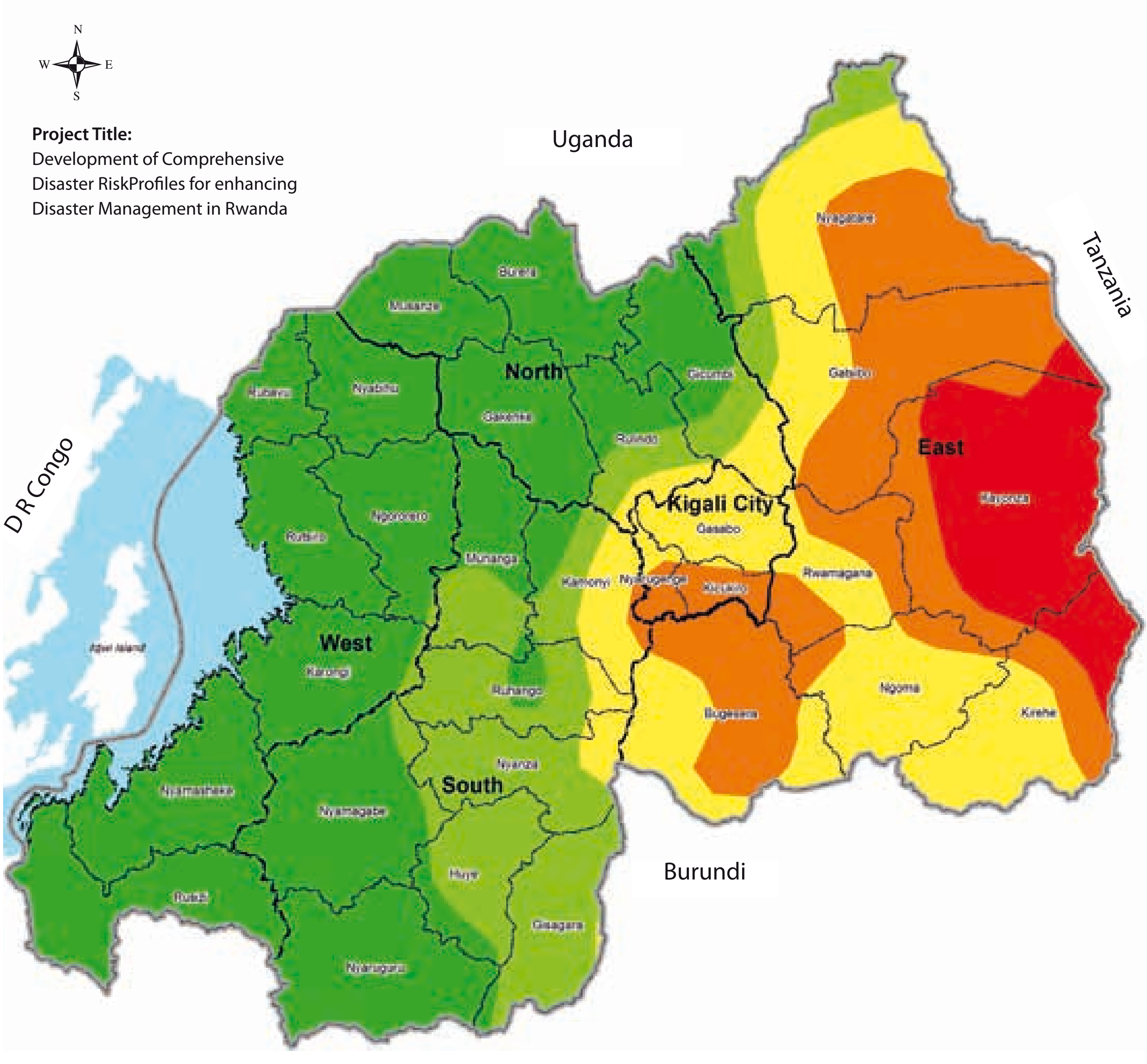
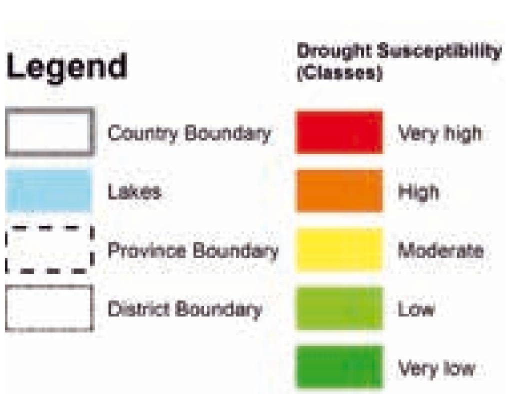


Figure 26. Drought hazard map of Rwanda (Season B)





Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:

0 10 20 30 40 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

4.1.5 Drought hazard analysis

The agriculture drought was analyzed for this study for two different cropping seasons, A and B. The districts of Gatsibo, Kayonza, and Kirehe are highly susceptible for being affected by severe drought compared to other districts in Season A. Table 15 shows that 26% and 24% of the total area of Kayonza district are exposed to severe drought with high to very high respectively. Note that all districts of the northern, southern, and western provinces are low in drought susceptibility except for a small part of Kigali city, Gasabo district (29% of its area), is exposed to low probability of having a severe drought.

Table 15. Percentage of the areas exposed to different level of drought susceptibility in Season A

District	Very high	High	Moderate	Low	Very low
Bugesera	0	0	0	0	100
Burera	0	0	0	0	100
Gakenke	0	0	0	0	100
Gasabo	0	0	0	29	71
Gatsibo	8	15	23	29	24
Gicumbi	0	0	0	0	96
Gisagara	0	0	0	0	100
Huye	0	0	0	0	100
Kamonyi	0	0	0	0	100
Karongi	0	0	0	0	100
Kayonza	24	26	37	12	0
Kicukiro	0	0	0	0	100
Kirehe	13	10	19	53	5
Muhanga	0	0	0	0	100
Musanze	0	0	0	0	100
Ngoma	0	0	0	31	68
Ngororero	0	0	0	0	100
Nyabihu	0	0	0	0	100
Nyagatare	0	2	55	23	19
Nyamagabe	0	0	0	0	100
Nyamasheke	0	0	0	0	100
Nyanza	0	0	0	0	100
Nyarugenge	0	0	0	0	100
Nyaruguru	0	0	0	0	100
Rubavu	0	0	0	0	100
Ruhango	0	0	0	0	100
Rulindo	0	0	0	0	100
Rusizi	0	0	0	0	100
Rutsiro	0	0	0	0	100
Rwamagana	0	0	5	81	15
National Level	**3**	**4**	**10**	**11**	**72**

In season B, there is an increase in probability of having a severe drought. The total area, country wide, exposed to high and very high susceptibility increases from 3% and 4% in season A to 7% and 17% in season B respectively. Kayonza district is still the most exposed to high probability of being affected by severe droughts, where 75% and 25% of its total area are in high and very high drought susceptibility classes (Table 15). Other districts that have high susceptibility to severe drought are Kirehe, Gatsibo, Kicukiro, Nyagatare, Nyarugenge, and Rwamagana where more than 40% of their total area are in high or very high drought susceptibility classes.

In general, the findings of this study are in line with those of NAPA (2006) and REMA (2010). NAPA and REMA highlighted that the eastern and southern provinces of Rwanda are the most affected areas by droughts. The droughts tend to be cyclical and can be persistent. Kigali city was not among the areas reported by NAPA and REMA mainly due to the fact that agriculture sector is less developed.

Table 16. Percentage of the areas exposed to different level of drought susceptibility in Season B

District	Very high	High	Moderate	Low	Very low
Bugesera	0	56	44	0	0
Burera	0	0	0	0	100
Gakenke	0	0	0	0	100
Gasabo	0	1	99	0	0
Gatsibo	4	67	22	7	0
Gicumbi	0	0	19	19	62
Gisagara	0	0	1	95	4
Huye	0	0	0	79	21
Kamonyi	0	5	44	31	21
Karongi	0	0	0	4	96
Kayonza	75	25			0
Kicukiro	0	92	8	0	0
Kirehe	24	22	54	0	0
Muhanga	0	0	0	39	61
Musanze	0	0	0	0	100
Ngoma	0	20	80	0	0
Ngororero	0	0	0	2	98
Nyabihu	0	0	0	0	100
Nyagatare	0	42	36	18	5
Nyamagabe	0	0	0	8	92
Nyamasheke	0	0	0	0	100
Nyanza	0	0	15	85	0
Nyarugenge	0	62	38	0	0
Nyaruguru	0	0	0	0	100
Rubavu	0	0	0	0	100
Ruhango	0	0	11	78	12
Rulindo	0	0	16	33	51
Rusizi	0	0	0	0	100
Rutsiro	0	0	0	0	100
Rwamagana	0	0			0
National Level	**7**	**17**	**18**	**15**	**43**

4.1.6 Application in disaster management and development planning

The main purpose of the drought hazard mapping exercise is to produce drought hazard zonation maps that can be used by governmental institutions, NGOs, decision makers and other stakeholders towards the management of rainfall unpredictability and the early warning of the population living in drought-prone areas for emergency preparedness and resilience development. In the past, droughts have frequently resulted in a reduction in plant and animal species, displacement of people in search of food and pasture, food shortages and famine which have further led to conflicts over different land uses, in particular in the protected areas. Drought hazard maps will be useful in promoting drought tolerant varieties and prioritization of research in the development of drought-resistant varieties especially for dry season crops. Emerging threats to food security also escalates the need to build irrigation infrastructure in highly productive but drought susceptible areas.

4.1.7 Limitations

Drought is a slow-onset hazard since it is a creeping phenomenon. Droughts typically unfold on a timescale of months to years. This makes it difficult to determine its onset and end. The impact of drought goes beyond the spatial area directly affected by the shortfall of precipitation and varies in space and time. This is because the shortfall of precipitation has both direct and indirect impacts.

The second limitation met during this study was the recording of data. The data recording in the country is still a problem mainly for continuous data. The use of SPI model was not possible due to the fact that it requires at least 30 recorded years and without interruption. The use of WRSI was the appropriate possibility to analyse droughts in this context.

4.1.8 Recommendations

The unpredictable rainfall patterns in the country compounded by non-comprehensive rainfall observations from climate meteorologists, requires policymakers to establish early warning for drought and tracking systems to minimize damage and create resilience in the event of drought events.

As climate change and climate variability impacts keep worsening, droughts could cause much suffering on Rwandan communities destroying crops, animals and livelihoods, especially in the eastern province of the country. Thus long-term monitoring of climate is highly recommended.

Since Rwanda has two agricultural seasons (A & B), and Season B with low crop performance, farmers should plant crops that demand less water. Special attention should be paid to the eastern province since it has less rainfall than the other parts of the country. This could be done by putting in place certain mitigation measures such as irrigation, water retention, etc.

Finally, it is recommended to conduct further study on soil types and their ability to store water, the depth and presence of ground water supplies. All these factors play important roles in the occurrence of drought.

4.2 Landslide hazard mapping

4.2.1 Background

The Rwandan relief is hilly and mountainous with an average altitude of 1,700 meters. The highest point, on Mt Karisimbi, is 4,507 meters above sea level. Rwanda has volcanic mountains at the northern fringe and the western province extends over an unstable mountainous area while the central plateau is dominated by undulating hills. This topography is characterized by steep slope often affected by landslides. However, the eastern part of the country is relatively flat with altitudes well below 1,500 meters. The lowest point is located in the Bugarama area at 900 m, corresponding to the rift valley where Kivu Lake is situated (REMA, 2010).

Landslides affected different areas of Rwanda in the past. Landslides have led to loss of lives, injuries, and left many homeless and without livelihood. However, little research or literature exists about landslide hazards in Rwanda till date. In addition, there are significant data gaps on historical landslide events. A systematic recording of disasters started in 2010 by MIDIMAR. Prior to this period, international centres of data collection such as CRED (EM-DAT) and the Royal Museum for Central Africa (RMCA) were the only sources of disaster data. Most often the recorded events are not well georeferenced and the inventory is challenging.

From RMCA data, around eight thousand people were affected since 1963 up to 2010, among them 45 died and a few houses were destroyed. The details of the events that are available are presented in Table 17.

Table 17. Historical landslide events

Date	Province/ District	Death	Affected people	Damages	Source info	Comments
1963	Ruhengeri	-	-	-	Byers A. C., 1992	Multiple landslides
1987	Gitarama	-	-	fields destroyed	Byers A. C., 1992	-
May 1988	Ruhengeri	-	15	3 houses destroyed	Byers A. C., 1992	debris avalanche at Nyagitaba
Nov. 2006	Kigali	24	2000	-	CRED; Afrol	-
2010		21	5937	-	em-dat	-
2011	Nyabihu	17		3 Houses destroyed or damaged	MIDIMAR	2 people injured
	Burera	7			MIDIMAR	1 people injured
	Rutsiro	1		14 Houses destroyed or damaged	MIDIMAR	
2012	Ngororero	2		19 Houses destroyed or damaged and 54 ha of Crop lands affected	MIDIMAR	
	Nyabihu	5		147 Houses destroyed or damaged and 305 ha of Crop lands affected	MIDIMAR	
	Gasabo	2		6 Houses destroyed or damaged	MIDIMAR	
	Nyamagabe			2 Houses destroyed or damaged	MIDIMAR	
	Rulindo			1 house damaged and 40 ha crop lands affected	MIDIMAR	
	Nyamasheke	3		1 house damaged	MIDIMAR	
	Nyarugenge	-		1 house damaged	MIDIMAR	
	Burera	2		-	MIDIMAR	1 people injured
2013	Gasabo	2		47 Houses destroyed or damaged	MIDIMAR	3 people injured
	Nyarugenge	4		87 Houses destroyed or damaged	MIDIMAR	4 people injured
	Kicukiro	-		22 Houses destroyed or damaged	MIDIMAR	
	Rutsiro	3		18 Houses destroyed or damaged	MIDIMAR	1 people injured
	Rulindo	12		79 Houses destroyed or damaged and 257 ha crop lands affected	MIDIMAR	7 people injured
	Gakenke	2		41 Houses destroyed or damaged	MIDIMAR	people injured
	Gicumbi	3		52 Houses destroyed or damaged	MIDIMAR	people injured
	Nyamagabe	-		8 Houses destroyed or damaged	MIDIMAR	people injured
	Burera	2		19 Houses destroyed or damaged	MIDIMAR	people injured
	Ngororero	-		4 Houses destroyed or damaged	MIDIMAR	people injured
	Rubavu	2			MIDIMAR	3 people injured
	Karongi	5		2 houses damaged	MIDIMAR	

Since the establishment of MIDIMAR, a systematic recording system was installed and from 2011 to 2013, 74 deaths, 22 injuries, 573 houses destroyed or damaged, and 656 ha of affected land were recorded due to landslide. The most impacted is the western province with more than half of the total deaths records (51%), followed by the northern province (38%) of the total cases. Districts Nyabihu, Rulindo, Burera and Karongi experienced more deaths than others. See Table 17 for more details.

During the last decades, it is noted that the most vulnerable category of Rwandan is composed of households who are located in sloppy area of western and northern provinces. These people stay often in houses of areas classified as "high risk zones" and are characterized by a very fragile settlement and modest income.

4.2.2 Methodology for landslide hazard mapping

There are four different approaches to the assessment of landslide hazard: landslide inventory-based probabilistic, heuristic, statistical and deterministic. Landslide risk assessment methods are classified into three groups, as qualitative (probability and losses based on quality or characteristic terms), semi-quantitative (indicative probability, qualitative terms) and quantitative (probability and losses are both numerical). The heuristic approach is considered to be useful for obtaining qualitative landslide hazard maps for large areas in a relatively short time. It does not require the collection of lots of data.

Given time limitations and scarce data, it was decided to use a semi-quantitative slope susceptibility index approach by adopting a Spatial Multi-Criteria Evaluation (SMCE) method on the Integrated Land and Water Information System (ILWIS-GIS). The slope susceptibility index should use indicator maps collected from reliable secondary sources (Boerboom, et al., 2009). The semi-quantitative index approach is considered useful in the following two situations: 1) as an initial screening process to identify landslide hazards and 2) when the possibility of obtaining numerical data is limited. Semi-quantitative approaches consider explicitly a number of factors influencing the slope stability. For this study, the following seven factors were used: lithology, soil type, soil depth, rainfall, slope, land cover, and distance to roads. A range of scores and settings for each factor are used to assess the extent to which that factor is favorable or unfavorable to the occurrence of instability (slope).

The slope susceptibility index method started with the selection of indicator maps, the way the criteria are going to be structured and the selection of standardization and weighting methods following the example of Abella (2007). To implement the model, the SMCE module of ILWIS-GIS was used. SMCE application assists and guides users in doing multi-criteria evaluation in a spatial manner. The input is a set of maps that are the spatial representation of the criteria. They are grouped, standardized and weighted in a criteria tree. The output is one or more composite index map, which indicates the realization of the model implemented. The theoretical background for the multi-criteria evaluation is based on the analytical hierarchical process (AHP) developed by Saaty (Saaty, 1980). The AHP has been extensively applied on decision-making problems, and only recently, some research has been carried out to apply AHP to slope susceptibility mapping.

To make spatial multi-criteria analysis possible, the input layers need to be standardized from their original values to the value range of 0–1. There was provided different standardization in the SMCE module of ILWIS. For standardizing value maps, a set of equations can be used to convert the actual map values to a range between 0 and 1. The class maps use an associated table for standardization where a column must be filled with values between 0 and 1. In the section of Indicator Analysis, a detailed description of the indicator maps and their standardization is given. The next step is to determine the weight of each indicator whether it influence or not the overall objective. The influence of a given indicator can be evaluated through its weight when compared to other indicators.

a) Scoring and weighting process

This study adopted the classification of soil as proposed by the Food and Agriculture Organization (FAO) manual of methods and materials in soil conservation. A score between 0 and 10 is assigned to each factor. After classification of the selected factors, each factor is assigned a weight according to its level of potential influence to cause slope failures. Through experts' opinion and depending on observed physical characteristics of landslide sites, the levels of influencing factors were determined. Table 18 below details the weights assigned to each of the factors. It is assumed that once a landslide occurs, factors will contribute at different levels according to their nature. A score of 1 is considered as landslide event and each factor contributes to the score ranging between 0.1 and 1. A weight of 1 in a single factor, therefore means that is the only factor contributing to the event. Otherwise, a weight of 0 is given in case of the absence of influence of a factor to the event. The slope classification map in Figure 28 is generated considering the combined scores of all factors used in the assessment. Meanwhile, the Integrated Land and Water Information System (ILWIS), a GIS-based software was used to compute the SMCE.

Table 18. Assigned weights to factors

Factor	Weight
Lithology	0.15
Soil type	0.14
Slope	0.3
Rainfall	0.2
Land cover	0.09
Soil depth	0.07
Distance to roads	0.05

b) Field survey in the selected landslide-prone areas

The main objective of the field survey was to identify landslide-prone areas based on historical records and testimonies from local communities and indigenous knowledge. The field visits allowed to identify, pinpoint the locations where landslide occurred, take the geographical coordinates, the period of occurrence, and to evaluate different characteristics that might have led to instability. Simple observation and experts' opinions helped to visualize the extent of landslides, to know the type of historical landslides and to identify the possible and potential triggers. A physical landslides 'Hazard Mapping Field Survey' was conducted in the 14 districts that are most affected by landslides (Rusizi, Nyamasheke, Karongi, Rutsiro, Muhanga, Nyaruguru, Nyamagabe, Rulindo, Gakenke, Musanze, Ngororero, Nyabihu, Burera and Gicumbi). For the remaining districts, the survey was conducted by phone and other historical events recorded by MIDIMAR were consulted. All evidence of the past landslide events was used to validate the slope susceptibility map. The knowledge of past landslide events leads to ascertain that future slope failure could occur as a result of the same geologic, geomorphologic, and hydrologic situations that occasioned past and the present failures.

To validate the methodology, among the 35 visited sites, it was found that 65% of the sites (23 sites) were classified high and very high susceptibility, 30% moderate susceptibility and 5% low susceptibility.

4.2.3 Data requirements and data sources

Different data were collected on the seven factors (i.e. lithology, soil type, soil depth, rainfall, slope, land cover and distance to roads). These are compiled in datasets which are demonstrated in Table 19.

The following sections discuss the selected factors and the classification of contents.

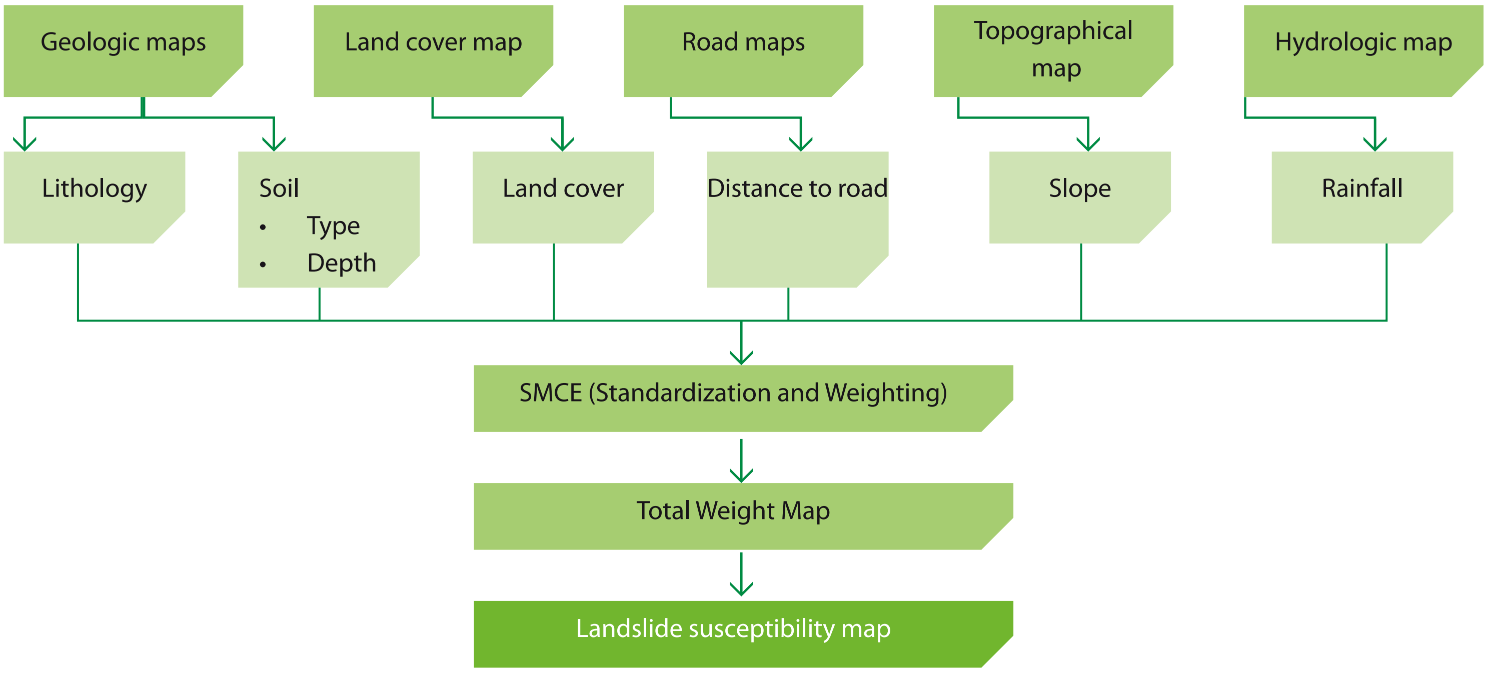
Table 19. Data required for slope susceptibility mapping and their sources

Data type	Data type
Administrative boundaries	RNRA
Lithology	GMD/RNRA
DEM (10m resolution)	RNRA
Slope	RNRA
Soil (type and depth)	RNRA
Land cover	RCMRD
Road network	RNRA
Rainfall (annual average)	RNRA

a) Slope in percentage

As reported by Goretti (2010) relief is a principal factor in the determination of the intensity and character of landslides. It has both direct and indirect influences. Direct influences encompass slope, steepness, river valley morphology, and thalweg gradients. The most important relief characteristic is the steepness, which affects the mechanism as well as the intensity of the landslides. The greater the height, steepness and convexity of slopes, the greater the volumes of landslides. The stability of the slope against sliding is defined by the relationship between the shear forces and the resistance to shear. The main force responsible for mass wasting is gravity. Gravity is the force that acts everywhere on the earth's surface, pulling everything in a direction toward the centre of the earth. On a flat surface, the force of gravity acts downward and so long as the material remains on the flat surface it will not move under the force of gravity. On a slope, the force of gravity can be resolved into two components, one acting perpendicular to the slope and another acting tangential to the slope.

Figure 27. A contextual framework for slope susceptibility mapping



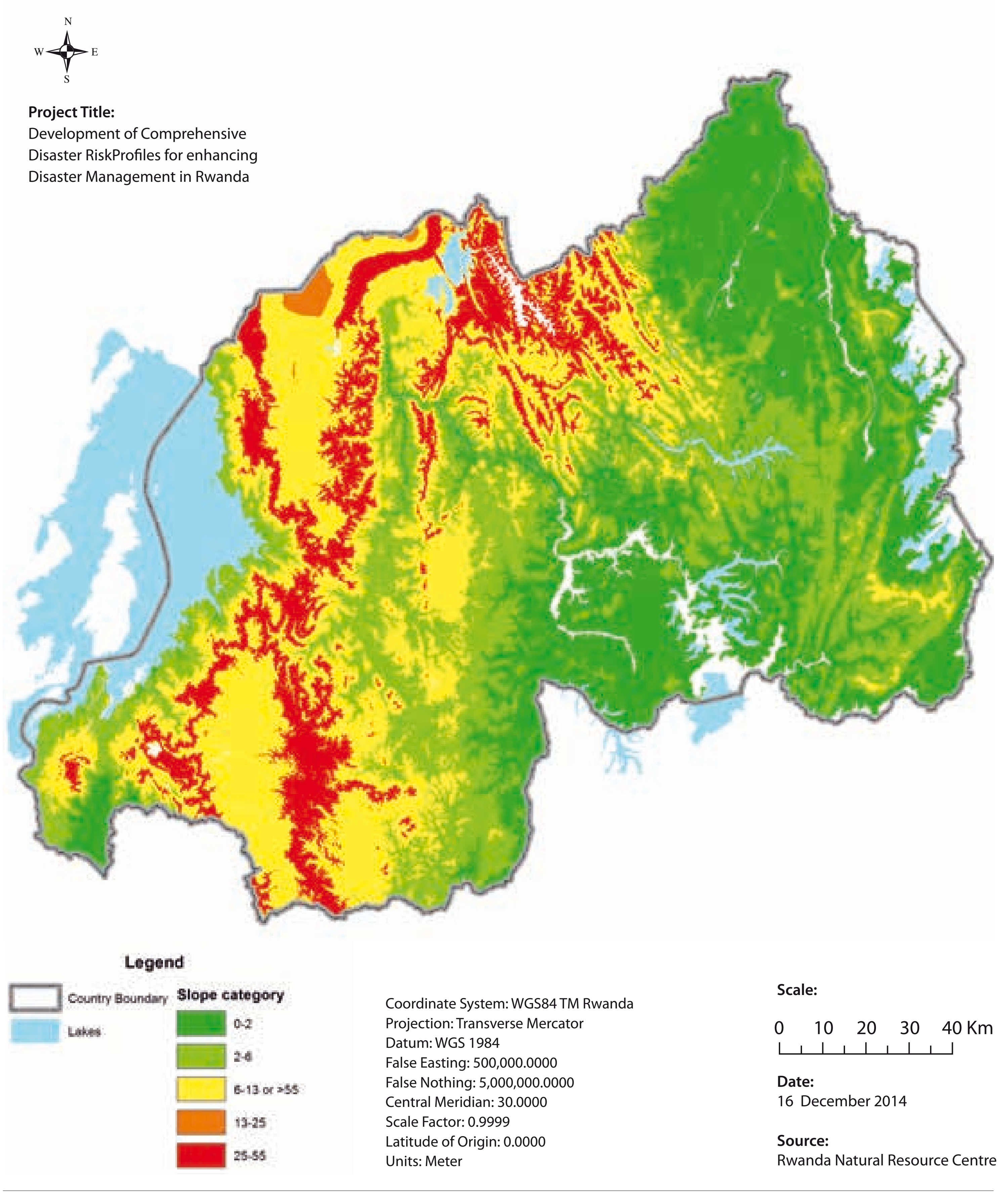
The perpendicular component of gravity helps to hold the object in place on the slope. The tangential component of gravity causes a shear stress parallel to the slope that pulls the object in the down-slope direction parallel to the slope. On a steeper slope, the shear stress or tangential component of gravity increases and the perpendicular component of gravity decreases. The forces resisting movement down the slope are grouped under the term shear strength which includes frictional resistance and cohesion among the particles that make up the object. When the shear stress becomes greater than the shear strength then the slope fails.

For most of the studies on landslides, the orientation of the slope or aspect is taken into account. However, the slope aspect does not cause large differences in soil temperature in the tropics because of the low latitude (Knapen, et al., 2006). Accordingly, the aspect was not taken into account in the analysis of Rwandan landslides. In this study, slope has been extracted from the Digital Elevation Model of 30 meters and is expressed in percentage. The classification of slope as recommended by FAO in land conservation was standardized. The classification (or score) ranges from 0 to 10, where 10 means high susceptible area and 0 none susceptible. Figure 28 shows the slope angle of all areas in Rwanda.

Table 20. Slope classification by angle

	Slope Angle	Score
1	0-2	0
2	2-6	1
3	6-13	4
4	13-25	6
5	25-55	10
6	>55	4

Figure 28. Slope classification map for Rwanda



b) Lithology

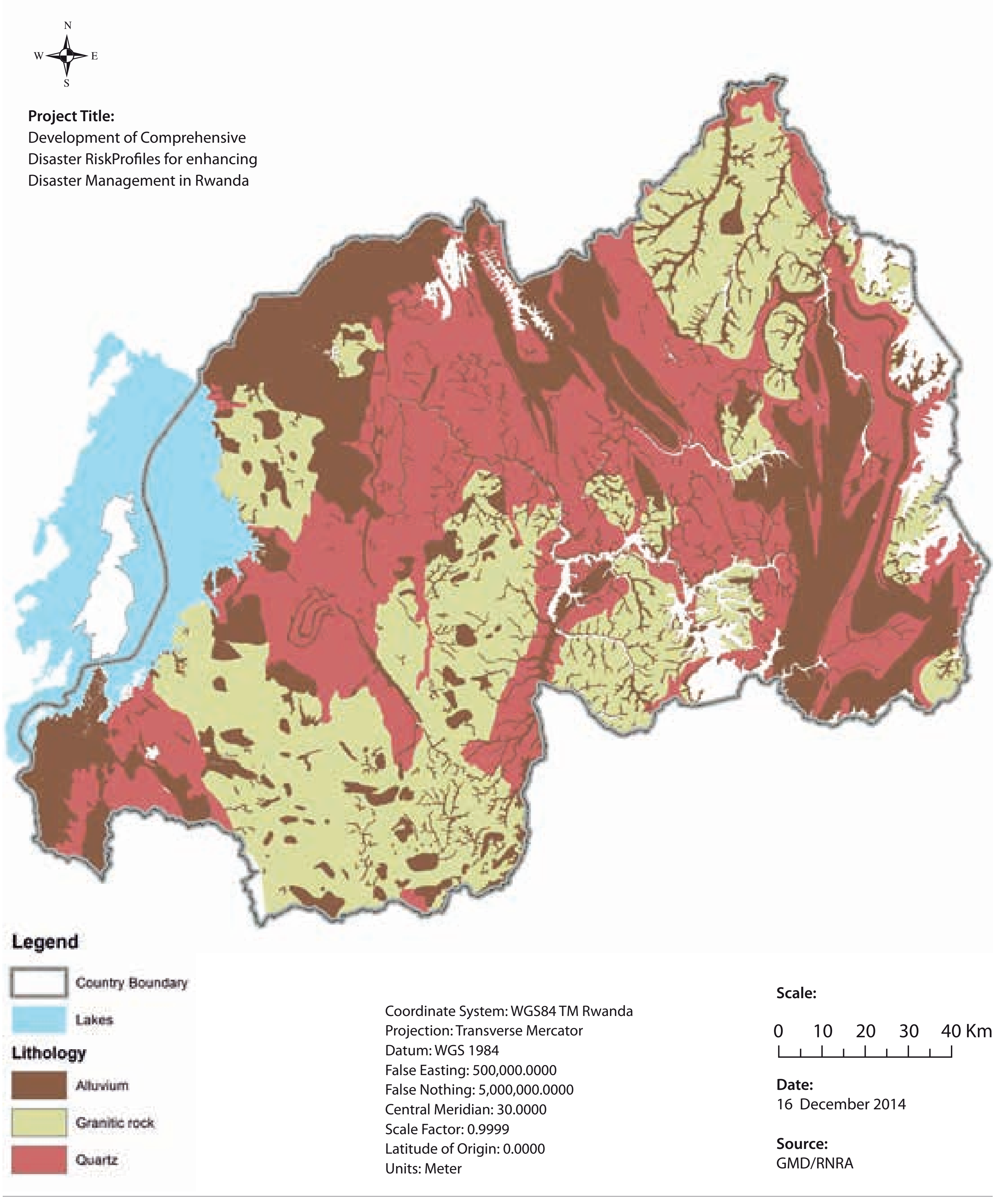
Landslide is largely controlled by the lithology properties of land surface. In case of Rwanda, the lithology is composed of three main types as shown in Table 21.

Rwanda's lithology is graphically presented in the map in Figure 29.

Table 21. Classification of lithology in Rwanda

	Lithology type	Score (FAO classification)	Standardized Score
1	Alluvions de fonds de vallées et des terrasses, épandages récents/Lacs/Non déterminé/ Quartzites dominant sur les niveaux schisteux	1	1
2	Roches granitiques et gneissiques (Granitic and gneissic rocks)	2	5
3	Schistes, Micaschites quartzeux. Quelques niveaux quarzitiques/Schistes, Micaschites, Quarztites peu importants	4	10

Figure 29. Lithology classification map for Rwanda



c) Soil

The role of soil in mass movement is also decisive. Soil plays a dual role. It is a by-product of the landslide process and at the same time it is an important causal factor. The most important properties in soil stability are those that influence the rate of water movement in the soils and the capacity of the soil to hold water (Sidele, et al., 1985). In the context of this study, two components of soil have been taken in account separately: soil type and soil depth.

- **Soil type**
  Soil data were extracted from the Rwanda soil map (1/250,000, 1981). The soil type classification was based on the percentage of concentration in material. Four classes have been retained: gravel, sand, silt, and clay.

Figure 30. Soil type classification map for Rwanda

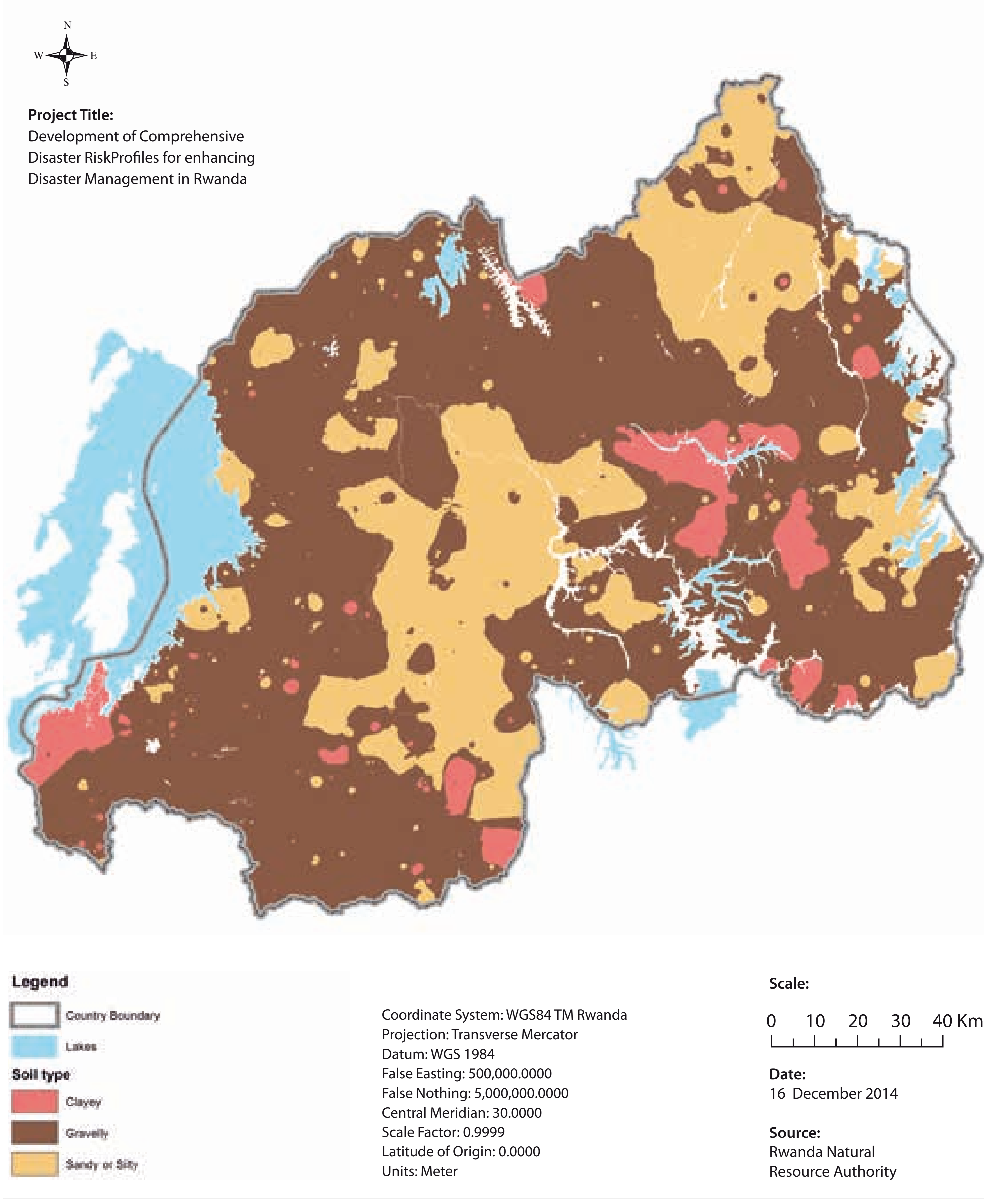


Table 22. Soil type classification

	Soil type	Score (FAO classification)	Standardized Score
1	Gravel	1	1
2	Clay	2	5
3	Sand	3	7.5
4	Silt	3	7.5

- **Soil depth**

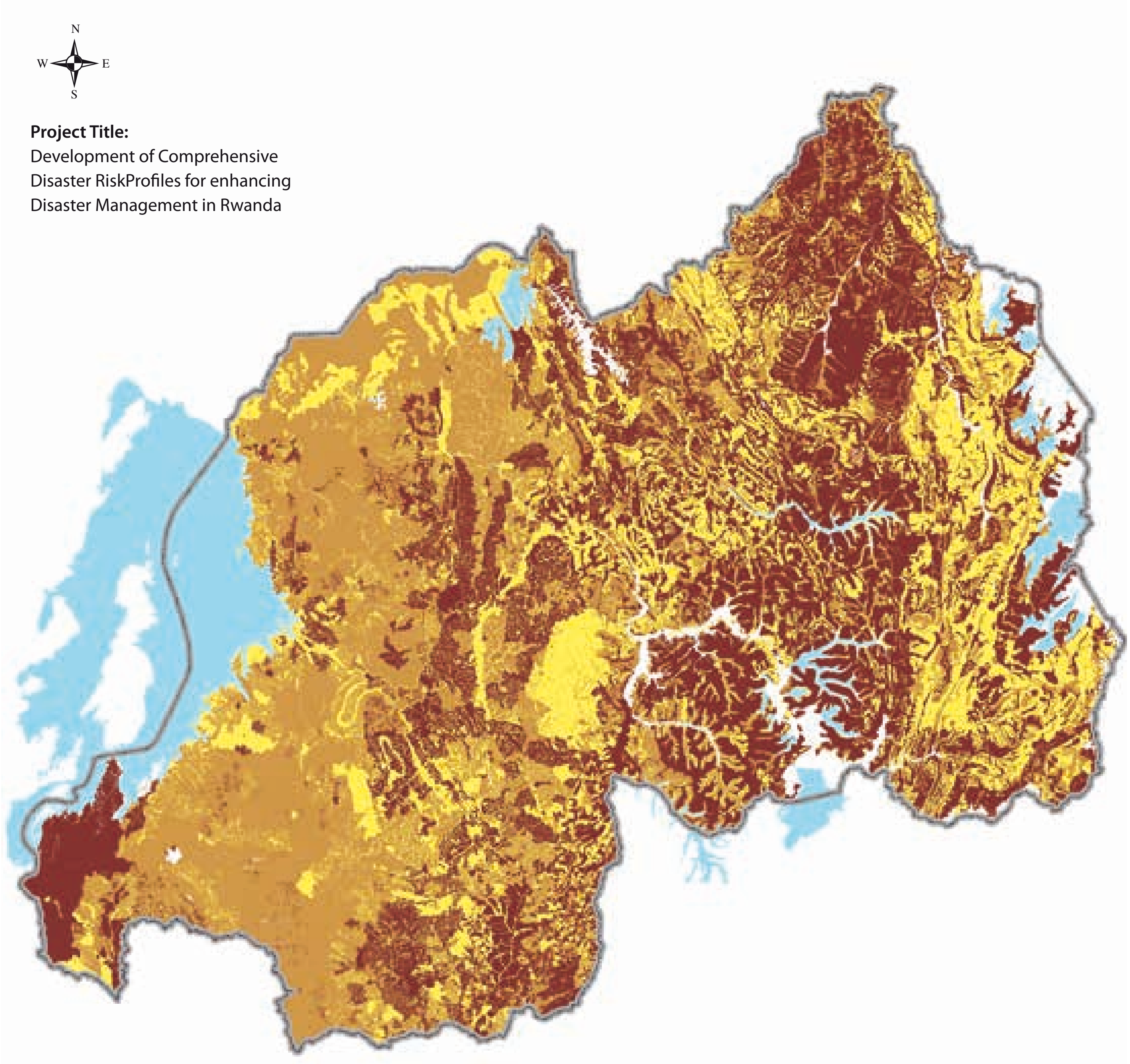
  Soil depth was also taken into account in the analysis. Soil depth alone can be a source of landslide. Landslide could occur in areas where soil is really deep.

The capacity of the soil to retain water contributes to rock alteration and gives place to instability of land. Three classes of soil depth were used as shown on the Table 23 and Figure 31:

Table 23. Soil depth classification

	Soil depth (cm)	Score (FAO classification)	Standardized Score
1	< 50	1	1
2	50-100	2	4
3	> 100	3	10

Figure 31. Soil depth classification map for Rwanda



Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 10 20 30 40 Km

Date:
16 December 2014

Source:
Rwanda Natural Resource Authority

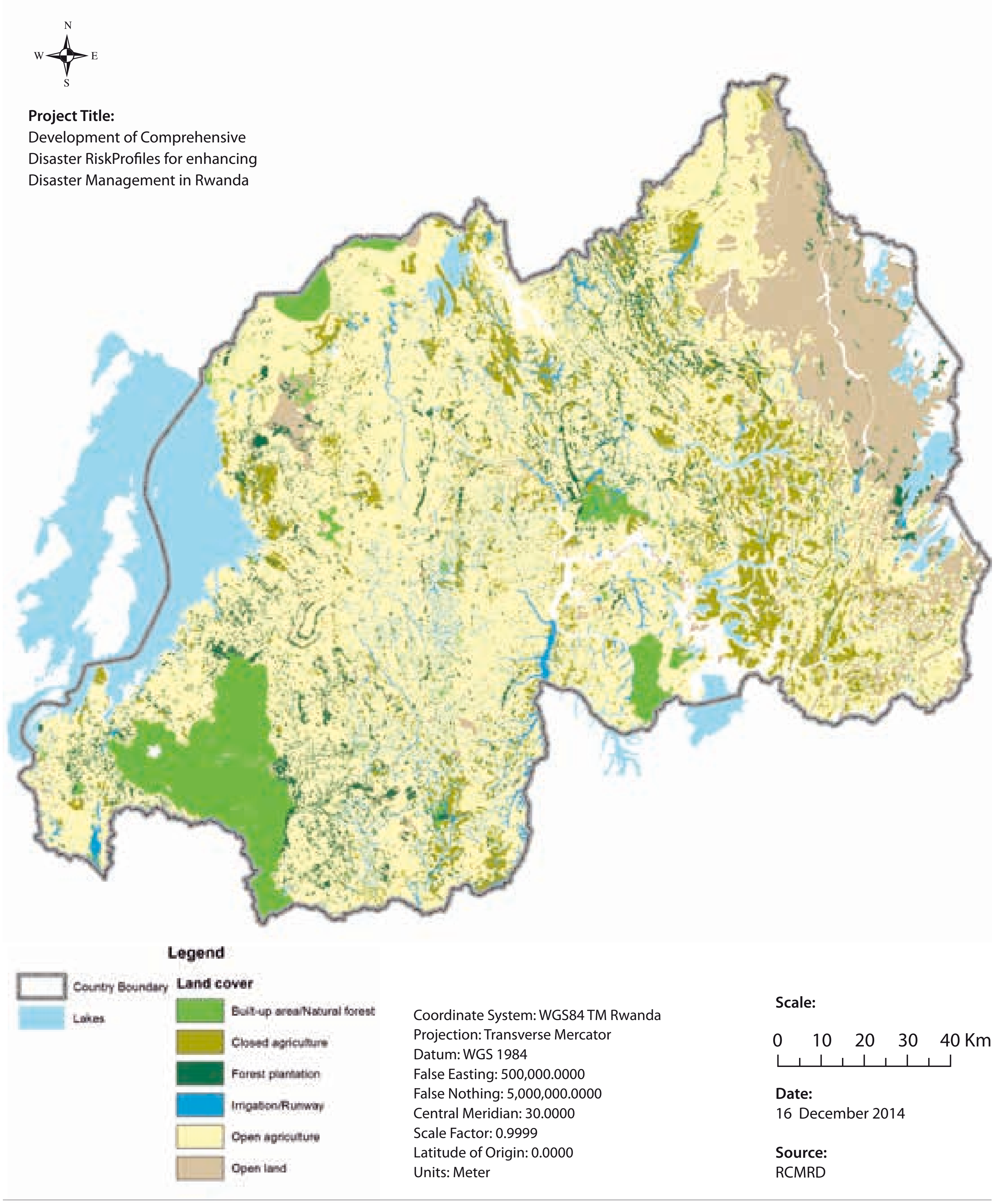
d) Land cover

The more an area is permanently covered, the less it is exposed to landslide. Several researches emphasize on the importance of vegetation cover or land use characteristics on the stability of slopes, and they consider vegetation cover to assess the conditioning factors of landslides. For the slope susceptibility, we used the land cover map to show the relationship between land use factor and landslide occurrence. Six main types of vegetation were identified and were classified according to their potential influence. Table 24 and Figure 32 below show the different classes of land cover in Rwanda.

Table 24. Land cover classification

	Land cover	Score
1	Irrigation/runway	1
2	Built up and natural forest	2
3	Forest plantation	3
4	Closed agriculture	7
5	Open agriculture	8
6	Open land	10

Figure 32. Land cover classification map for Rwanda



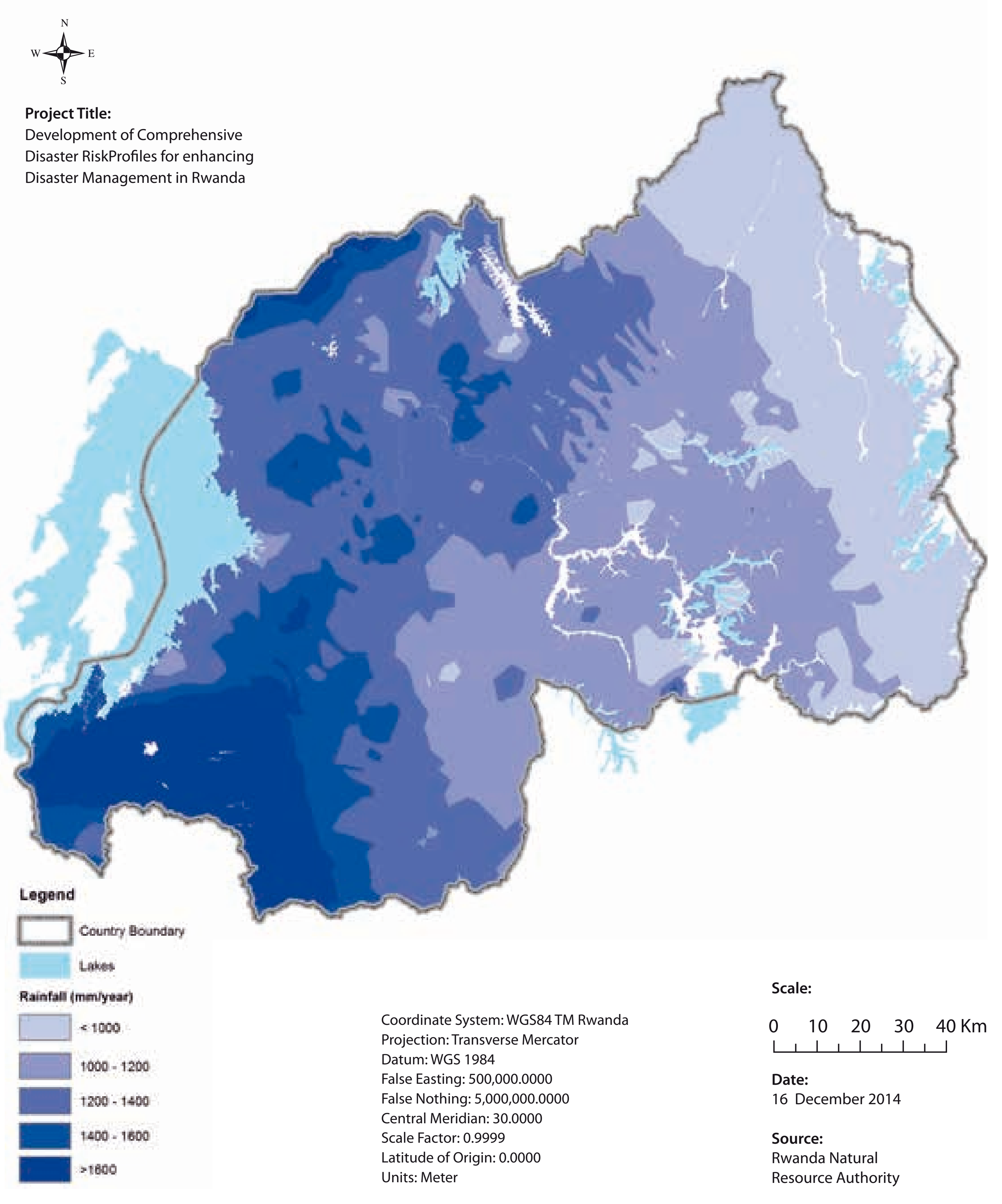
e) Rainfall

Rainfall is considered as a trigger of landslide. A triggering factor is an external stimulus that triggers the movement and one of the renowned triggering factor is rainfall. Its influence on landslide process is considerable. Data provided by Rwanda Meteorology Centre were classified as follows:

Table 25. Rainfall classification

	Rainfall (mm/year)	Classification and score
1	<1000	1
2	1000 -1200	4
3	1200 -1400	6
4	1400 -1600	8
5	>1600	10

Figure 33. Rainfall classification map for Rwanda

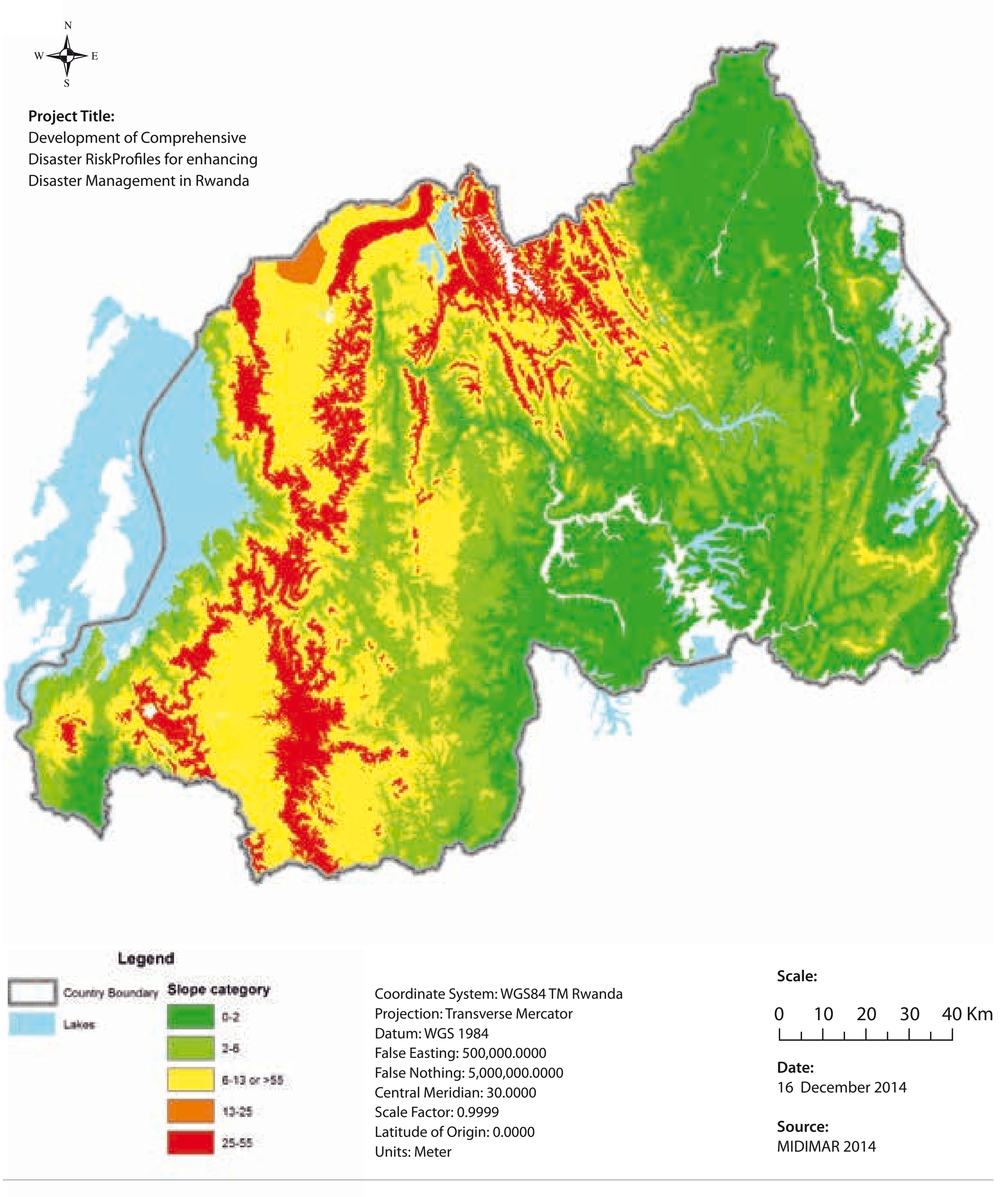


f) Distance to road network

Among human activities that can lead to landslide, the distance to road was taken in account. A road segment may constitute a barrier or a corridor for water flow, a break in slope gradient or, in any case, may induce instability and slope failure mechanisms. The distance from roads is computed as the minimum distance between each of the cells and the nearest road represented in vector format. Buffer areas were created on the path of the road in the identified landslide location to determine the effect of the road on the stability.

Two kinds of roads were considered: national and district roads. A buffer of 20 meters to national roads and 10 meters to district roads were created to get data on distance to roads. The assigned scores are 0 and 10 representing none susceptible and highly susceptible to landslide respectively.

Figure 34. Slope susceptibility map of Rwanda



4.2.4 Slope susceptibility maps

The map above shows the slope susceptibility produced using SMCE in ILWIS. Colors from green to red indicate the susceptibility classes from very low to very high.

4.2.5 Landslide hazard analysis

The Rwanda slope susceptibility map (Figure 34) shows the spatial distribution of the susceptibility classes for the entire country. The western high lands are more prone to landslide while the eastern lowlands are of low susceptibility. The different susceptibility classes per district are shown in Table 25. Due to its hilly topography, Rwanda shows high susceptibility to landslide, 42% of the country's area is classified with moderate to very high susceptibility. It was further validated by the results of the field surveys and historical records.

Districts with high to very high susceptibility are Gakenke, Karongi, Muhanga, Ngororero, Nyabihu, Nyamagabe, Nyamasheke, Nyaruguru, Rusizi, Rubavu, and Rutsiro.

Nyabihu has the highest percentage (58%) of area exposed to high and very high slope susceptibility and accounts for the highest number of people killed by landslide and the highest number of houses destroyed or damaged by landslide.

Table 26. Percentage of the areas exposed to different slope susceptibility classes per district

District	Very high	High	Moderate	Low	Very low
Bugesera	0	3	11	66	19
Burera	5	25	24	45	1
Gakenke	10	30	38	21	1
Gasabo	1	9	22	59	8
Gatsibo	0	1	20	63	15
Gicumbi	0	5	21	66	7
Gisagara	0	6	22	68	4
Huye	0	5	28	65	2
Kamonyi	3	17	53	27	1
Karongi	9	28	34	26	3
Kayonza	0	0	5	59	36
Kicukiro	0	1	5	83	11
Kirehe	0	0	3	58	39
Muhanga	12	22	35	30	1
Musanze	3	21	21	52	2
Ngoma	0	0	4	71	25
Ngororero	14	38	27	21	0
Nyabihu	8	50	24	18	0
Nyagatare	0	1	11	78	10
Nyamagabe	27	26	32	15	0
Nyamasheke	11	21	32	36	1
Nyanza	1	7	38	49	5
Nyarugenge	3	9	27	53	8
Nyaruguru	20	14	26	41	0
Rubavu	8	23	17	48	4
Ruhango	1	11	37	49	3
Rulindo	0	13	34	50	3
Rusizi	16	16	34	32	3
Rutsiro	15	26	29	29	1
Rwamagana	0	1	26	61	13
National Level	**6**	**13**	**23**	**49**	**10**

4.2.6 Application in disaster management and development planning

The map could serve as basis for sustainable physical settlement planning that will help in the reduction of the impact of landslides on the population, houses, crops, other properties and infrastructures. The results of this study can also be used as baseline for future quantitative research that can be done at small scale targeting areas with high susceptibility. The map could also inform land use planning.

4.2.7 Limitations

The objective of the study was to assess slope susceptibility nationwide. However, there were some issues with data availability, accuracy and detail. The data available did not allow the application of deterministic landslide hazard assessment methods, which are required to derive quantitative landslide hazard maps. Furthermore, the application of statistical or probabilistic methods is not possible because of the lack of a sufficiently complete national landslide inventory. The lack of landslide inventory dataset made the weighting of factors dependent on experts' opinion. The digital elevation model available was not complete in places bordering Congo in the North. This made the landslide analysis for those areas less accurate.

4.2.8 Recommendations

It has been proven that landslides' frequency and extent can be estimated by the use of seven factors. These are lithology, soil type, soil depth, rainfall, slope, land cover and distance to roads. However, despite these factors landslides remain difficult to predict. It is therefore recommended to conduct a quantitative research on landslide in areas identified as highly susceptible to landslide hazard. This Landslide Hazard Assessment revealed that areas with higher likelihood of hazard are mostly located in the Western and Northern Province. It is therefore recommended that local authorities and communities in these provinces give particular attention to land use and land planning rules including improving settlement regulations in order to keep people and settlements away from landslide-prone areas. In so doing, it directly contributes to reduction of soil erosion and vegetative cover removal and thereby help in the stabilization of the slopes.

4.3 Flood hazard mapping

4.3.1 Background

Floods are the most common natural hazards that affect societies around the world, affecting 80% percent of the world's population. It is estimated that more than one third of the world's land area is flood-prone (Dilley, et al., 2005). Floods alone killed 100,000 persons and affected over 1.4 billion people during the 20th century worldwide (Jonkman, 2005).

There are different types of floods. However, the most frequent flood types are riverine floods and flash floods. According to Jonkman (2005), riverine floods are those caused by flooding of the river outside its regular boundaries. The flood can be caused by various sources:

high precipitation levels, not necessarily in the flooded area, or other causes such as melting snow, blockage of the flow. Flash floods occur after local rainfall with high intensity, which leads to a quick raise of water levels causing a threat to lives of the inhabitants. The time available to predict flash floods in advance is limited. Severe rainfall on the flood location may be used as indicator for this type of flood. This generally occurs in mountainous and urban areas.

Because of its geographical features and climatic profile, Rwanda is prone to various hazards but especially localized floods and landslides (Douglas et al, 2008). Due to its dense river network and large wetlands, the country is threatened mainly by riverine floods. According to Stockholm Environment Institute (2009) and REMA (2010), major flood events occurred in 1997, 2006, 2007, 2008, and 2009, resulting in infrastructure damage, fatalities and injuries, landslides, loss and damage to agricultural crops, soil erosion and environmental degradation.

Available information from USGS indicates that since 1974, floods caused a lot of damages in terms of human lives, houses, crops and infrastructure. The Table 27 below details these events with date and type of damage recorded.

Flood hazards affect people and activities located in flood prone areas across the country. The effects of flood hazards have worsen with recent increase of the population accompanied with the scarcity of land that have pushed people to settle in marginal land and flood prone areas. In general, the agriculture sector is the most affected by flood hazards. Between 2011 and 2013, a recording system of flood hazard events and its impacts has been installed. It showed that 38 people have been killed, 40 injured, 878 houses were damaged or completely destroyed and 746 ha of land were affected.

Table 27. Historical flood events

Date	Province	District	Death	Affected	Damages	Source info	Comments
June 1974	National	National	0	1 900 000		CRED	
6-9 May 1988	Ruhengeri, Kibuye, Gisenyi, Gitarama and Gikongoro		48	21 678	1 225 houses & 19 bridges destroyed, 7 roads cut off	CRED; Reliefweb; Byers A. C., 1992	Nyakinama & Nyamutera Communes in Ruhengeri Prefecture most affected
21 Nov 2000	Gisenyi	Karambo and Nyundo	0	1 000	>200 houses destroyed; crops & roads damaged	IRIN	
22 Sept 2001	Gikongoro	Nshili, Nyaruguru and Mushubi	10			CRED; Glidenumber	
30 Oct. - 2 Nov. 2001	Gisenyi, Kibuye, Ruhengeri, Byumba, and Gikongoro		2	3 000	>100 houses, 60 schools & crops destroyed	CRED; Glidenumber; IRIN	
26 April - 28 May 2002	Kibuye, Cyangugu, Byumba and Kigali	Rusenyi	69	20 000		CRED; Reliefweb; Earth observatory; IRIN	
30 Oct 2003	Umutara and Byumba		0	7 016		CRED	
16 Aug 2005	Kigali	Kigali	2	3		CATNAT; Reliefweb	
16 Aug 2005	Ruhengeri and Byumba		25	25 000	5 000 houses & 3 000 plantations flooded	CATNAT; OCHA; Reuters	

Contd...

Date	Province	District	Death	Affected	Damages	Source info	Comments
12-20 September 2007	Western	Rubavu and Nyabihu	20	4 000	678 partially & 342 houses completely destroyed	CRED; Reliefweb; Moeyersons et al. 2007	1,020 households displaced
3-16 February 2007	Western	Rubavu and Nyabihu	10	500		CRED; Reliefweb	
12 Sept 2007	Western and Northern	Nyabihu and Gicumbi	15	2 810	37 houses destroyed, 562 families homeless	Moeyersons et al. 2008; allAfrica.com	
Oct 2008	Western and Southern		0	500	2 000 Ha crops damaged	Reliefweb	
2 Oct 2008	Western and Northern				numerous houses and crops destroyed	Glidenumber; IRIN	Extensive torrential rains
6 Oct 2008	Western and Northern		0	2 500	>500 homes submerged; 2000 ha crops destroyed, as well as bridges, roads, pylons & schools	IRIN; Reliefweb	
Sep 2009	Western	Rubavu			houses and crops destroyed	Personal Communication Paul Nshimyimana	
23-24 February 2010	City of Kigali	Kigali	3		Industrial sites submerged (around Rwandexco factory), damage to constructions and crops	Vincent Manirakiza, Kigali Institute of Education	
2011	Western	Nyabihu	1		19 houses and 87 ha of land affected	MIDIMAR	
	Northern	Burera	1			MIDIMAR	
	Eastern	Nyagatare			65 ha of land affected	MIDIMAR	
2012	Northern	Bugesera	2			MIDIMAR	
		Burera	1			MIDIMAR	
		Gicumbi	2			MIDIMAR	
		Musanze	1				
	Western	Rubavu	7		252 houses and 58 ha of land affected	MIDIMAR	
		Rusizi	3		341 houses and 125 ha of land affected	MIDIMAR	
	City of Kigali	Gasabo			6 people injured	MIDIMAR	
		Kicukiro	3			MIDIMAR	
	Southern	Nyamagabe	1			MIDIMAR	

Contd...

Date	Province	District	Death	Affected	Damages	Source info	Comments
2013	Western	Karongi	5		2 houses affected	MIDIMAR	
		Nyabihu	2		35 houses and 4 ha of land affected	MIDIMAR	
		Rubavu	3	65 houses affected	MIDIMAR	MIDIMAR	
	Southern	Nyaruguru	2			MIDIMAR	
		Ruhango			48 houses and 12 ha of land affected	MIDIMAR	
	City of Kigali	Gasabo			49 houses affected	MIDIMAR	
		Kicukiro			8 houses affected	MIDIMAR	
		Nyarugenge	3		20 houses affected	MIDIMAR	
	Northern	Musanze			39 houses and 395 ha of land affected	MIDIMAR	

4.3.2 Methodology for flood hazard mapping

Floodplain management and, in particular, floodplain mapping often require the estimation of the flood's main parameters, i.e. the discharge value corresponding to a given recurrence interval or return period[13] of an extreme rainfall event, flood depth, duration and extent. This requires data on infiltration or water availability for runoff, topography of an area, drainage systems or cross sections, and land cover (Padi, et al., 2011; Winsemius, et al., 2013). This hydrological information is not always available, which makes the flood estimation complicated. The lack of data makes the analysis challenging and in some of the cases impossible (Habonimana, 2014).

Except for topography data, Rwanda lacks most of the hydrological and hydraulic data needed for flood hazard analysis. In addition, there is little existing flood literature that could serve as reference. In a situation where there is lack of field surveys and hydraulic modelling studies required for detailed flood hazard mapping, the GIS Flood Tool (GFT) is very useful (RCMRD, 2012). The GFT, developed by USGS and extended by SERVIR Africa, is a tool that can be used in inundation estimation (RCMRD, 2012; Verdin, 2012). GFT produces a flood inundation hazard map when a discharge value (in m3) and stage (m) is specified at a location of interest. Translation of discharge to stage is done using the "Manning equation" for flow in an open channel where it is done using a "Relative Digital Elevation Model (DEM)" (Verdin, 2012). The Manning equation is explained as follows (RCMRD, 2012; Pappenberger, 2005):

$$V=\frac{1}{n}R^{2/3}\sqrt{S}$$ Equation 4

$$Q = V * A$$ Equation 5

Where;

- V = mean velocity in meters/second
- R = hydraulic radius in meters
- S = slope of the energy line
- n = coefficient of roughness ("Manning's n")
- Q = discharge (m3/sec)

The data used as input, the available digital elevation models (10 m spatial resolution) as shown in the elevation map in Figure 8, in a simple geographic information system (GIS) based on the implementation of the Manning equation. Thus, the GFT is used to produce inundation patterns in various catchments around the country just by specifying a discharge value at a location of interest. The discharge value was assumed to occur at an outlet location of a watershed as measured by different river gauges installed across the country. River gauges are located in catchments highly affected by riverine floods. Table 27 shows the input data uses as measured by river gauges. The analysis used the default "Manning's n" as there are no existing estimations of this coefficient across

[13] The concept of 'return period' is explained in paragraph 3.1.4

the country. For a better vulnerability and risk analysis, overland water depth of 0.2m or more above the ground is defined as flood and grouped in the following classes: below 0.5 m, 0.5-1, 1-1.5, 1.5-2, above 2m. In addition, due to the scale of the analysis, only a return period of 25 years was taken into consideration.

Due to limited data, this study conducted flood mapping for five catchments of flood plains that have records on discharge and water level. These flood plains are: Mukungwa, Nyabugogo, Kagitumba, Nyabisindu, and Sebeya. The only riverine flood considered was overbank flood. The flood frequency analysis was done for each hydrometric station corresponding to the identified flood plain for selected return periods. After identifying the plausible water levels recorded for each hydrometric station, contour lines were generated according to the predicted extent. The flood plain was then delineated following the corresponding contour line. This was repeated for all identified flood plains (Table 28). The values were used in GFT modeling.

To validate the accuracy of the method, an additional detailed field survey was conducted for two of the flood plains, namely for the Sebeya and the Nyabugogo catchment. These flood plains were chosen because of the high density of population and economic activities around the flood plains.

4.3.3 Data requirements and data sources

The data required for this method are: slope distribution, river network, wetland, contour lines and flood frequencies. The main source of data was the Digital Elevation Model (DEM) of ten meters resolution while flood frequencies are regularly collected through the automatic hydrometric stations disseminated across the country. The database used was constructed by PGNRE (MINERENA) in 2004 but records were collected from as early as 1968 until 2000. However, records were not consistent for all stated twelve main catchments as indicated on Rwanda Master plan. In total, six hydrometric stations have been selected according to the proximity to the flood plain and available data of the stations. These flood frequencies allowed to calculate water levels according to different return periods. The return period considered in this study is only 25 years as shown in Table 28.

4.3.4 Flood hazard zonation maps

Five flood plain areas have been mapped across the country. These are Nyabarongo covering districts of Kamonyi, Bugesera, Kicukiro, Nyarugenge, Rwamagana and Ngoma; Nyabisindu in districts of Nyanza, Sebeya in the districts of Rubavu, Ngororero and Rutsiro; Mukungwa in districts of Musanze, Nyabihu, Muhanga, Gakenke; and Kagitumba in Nyagatare district.

Table 28. Water level for selected hydrometric stations for 25 years return period

Flood plain	Hydrometric station	Return period	Water level (m)	River	Maximum Discharge (m3/s)
Mukungwa	Mukungwa –Nyakinama and Mukungwa -Ngaru	25	3.3	Mukungwa	57,6
Rukarara	Nyabisindu-Rukarara	25	2.0	Mwogo	15,41
Nyabarongo	Nyabarongo-Ruliba	25	5.5	Nyabarongo	338
Sebeya	Sebeya - Kanama	25	2.2	Sebeya	5,77
Kagitumba	Kagitumba	25	4.2	Muvumba	44,1

Figure 35. National flood hazard map of Rwanda

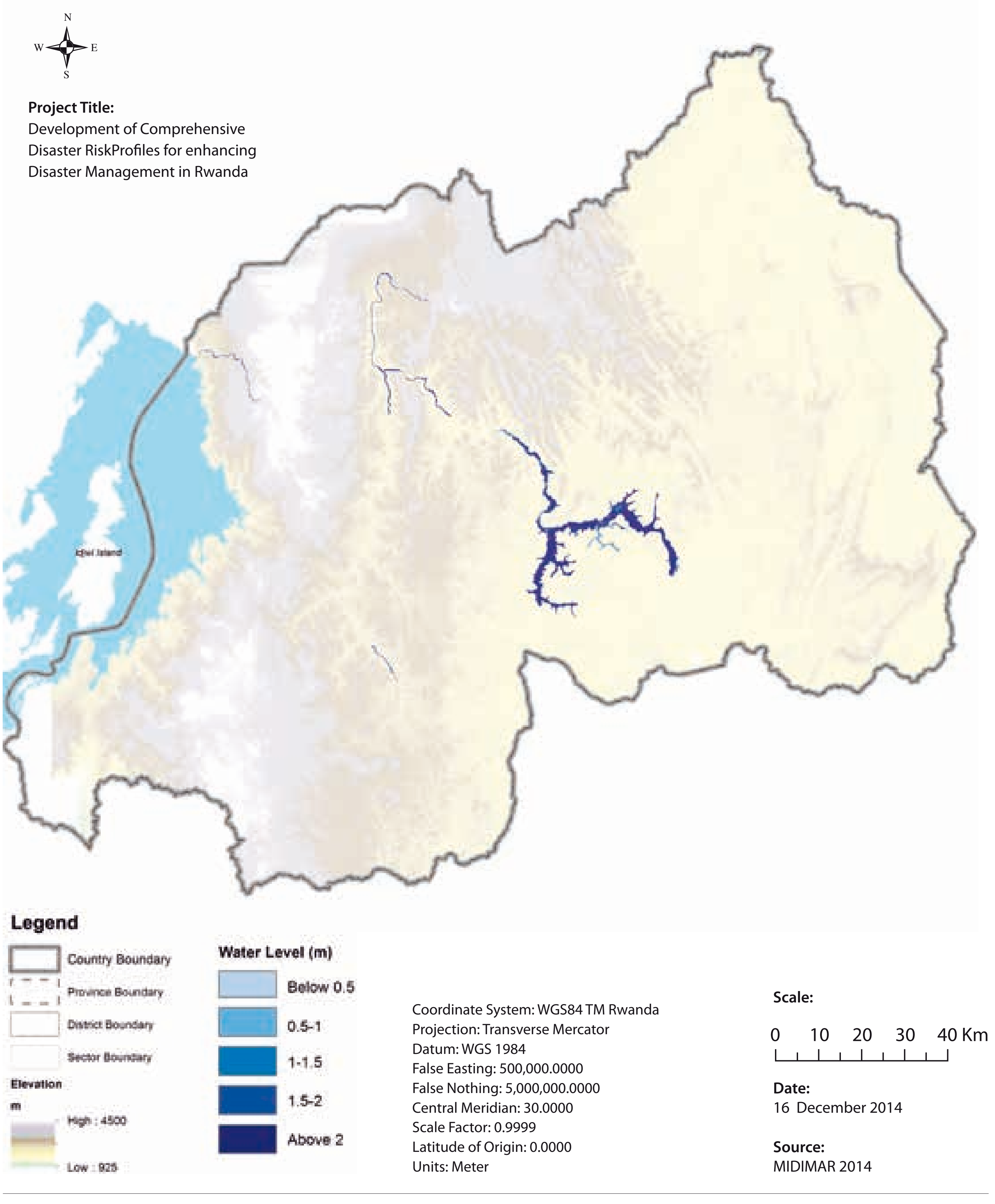
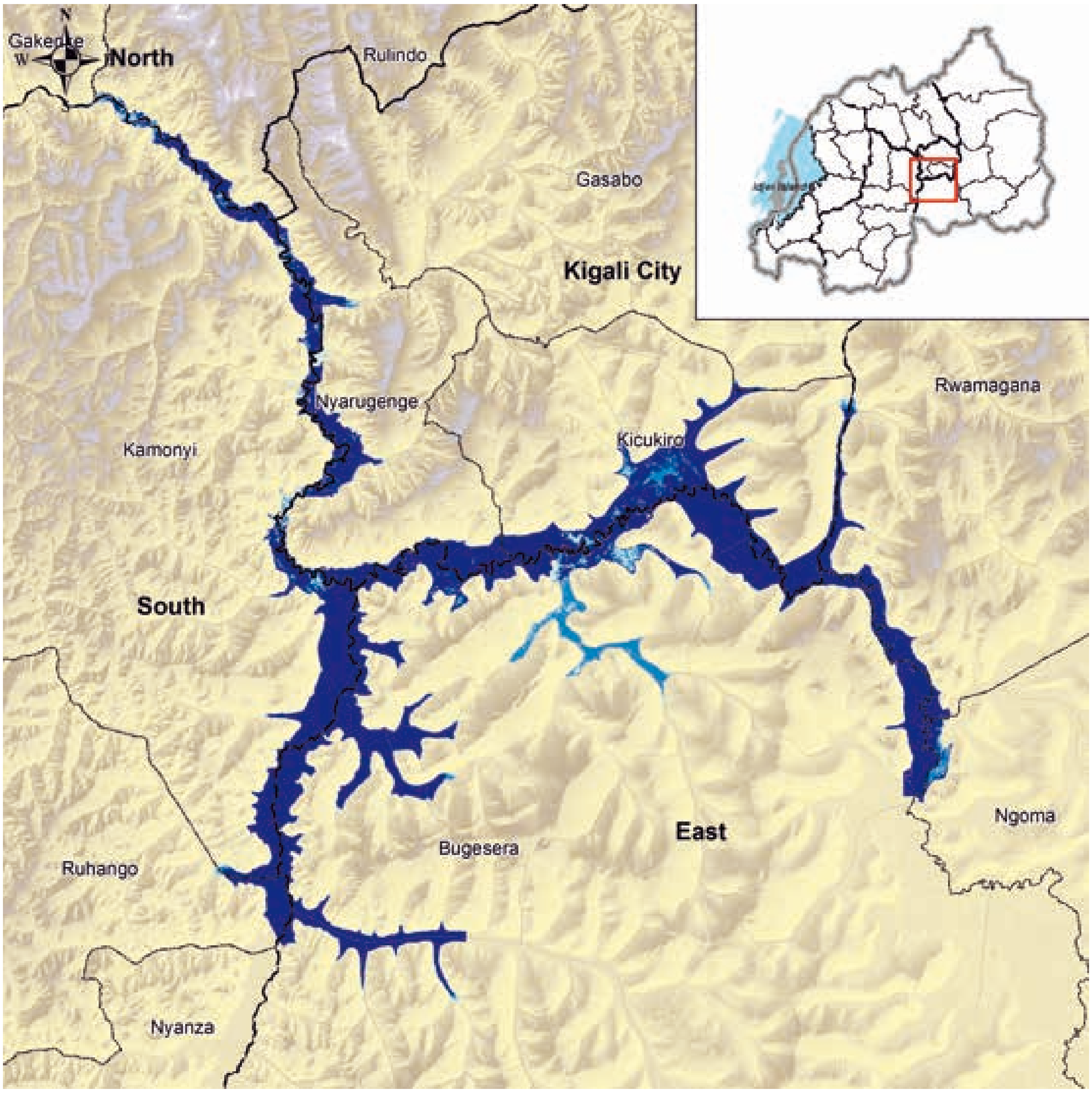
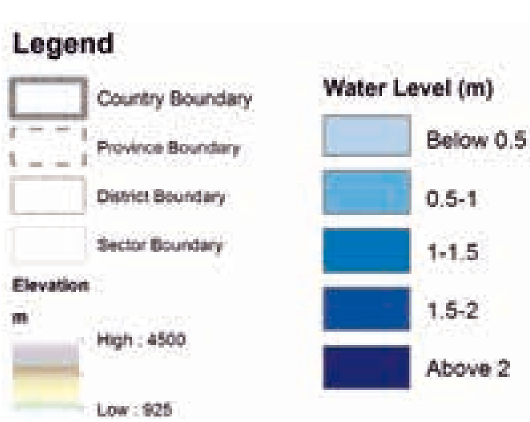


Figure 36. **Nyabarongo flood hazard map**



Project Title:
Development of Comprehensive
Disaster RiskProfiles for enhancing
Disaster Management in Rwanda



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Projection: Transverse Mercator
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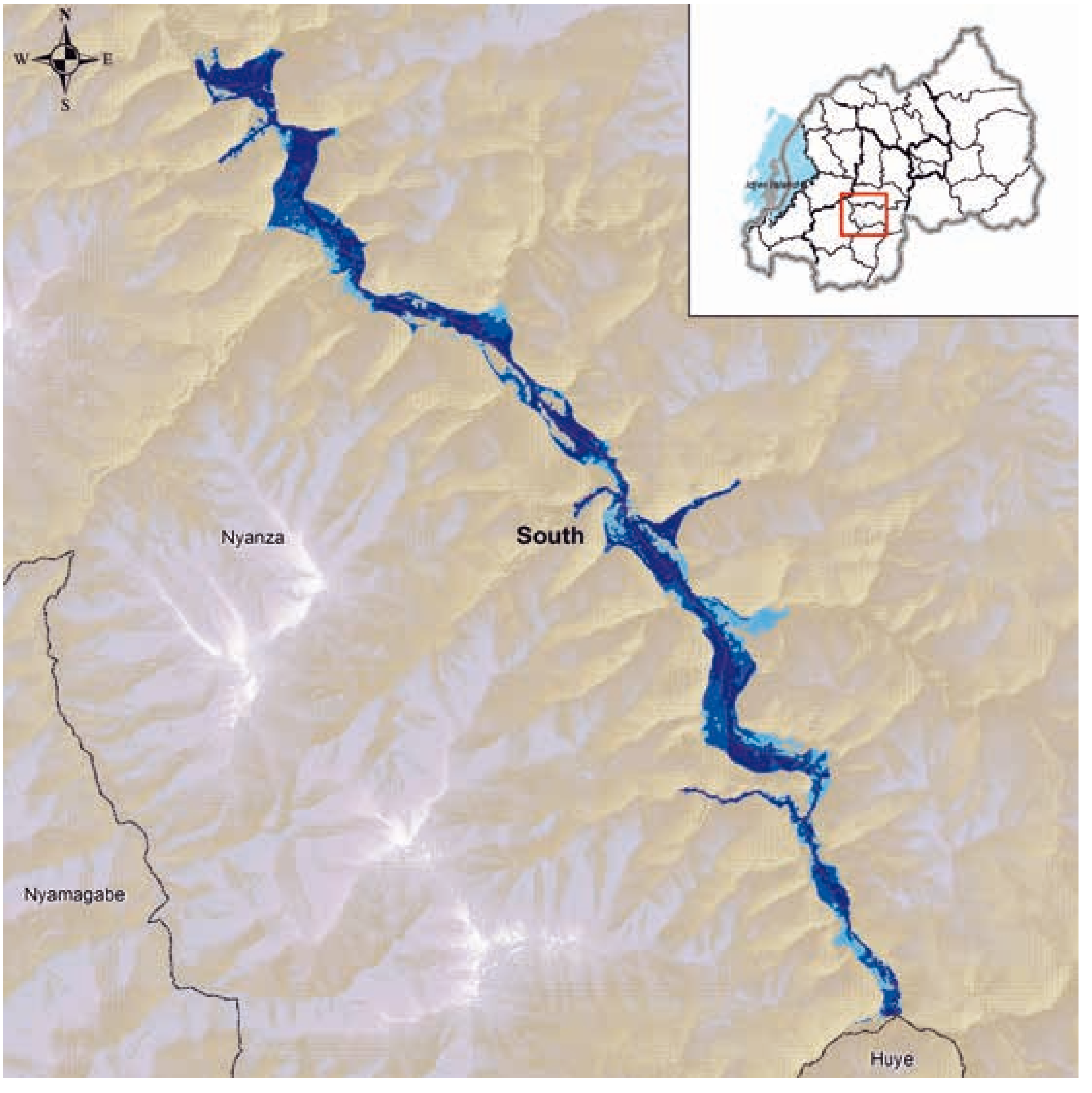
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 2 4 6 8 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

Figure 37. Nyabisindu flood hazard map



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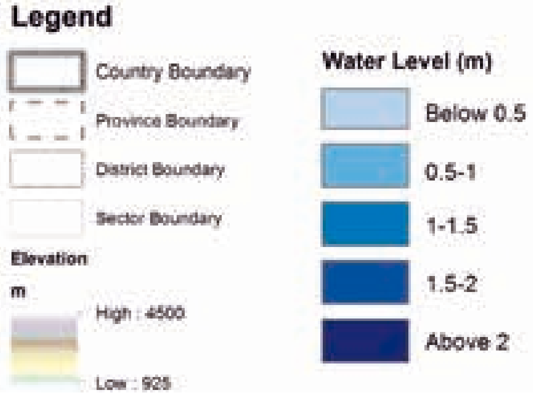
Disaster Management in Rwanda



Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 0.4 0.8 1.2 1.6 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

Figure 38. Sebeya flood hazard map

Project Title:
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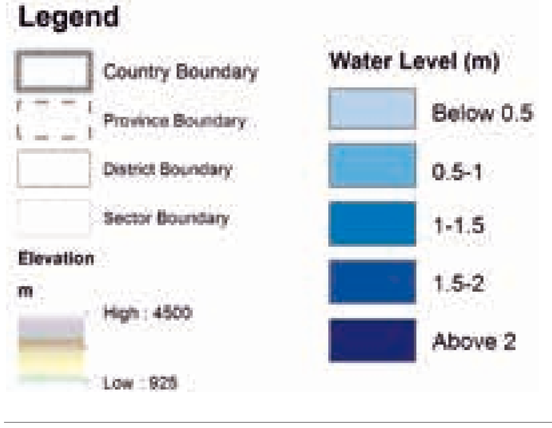


Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

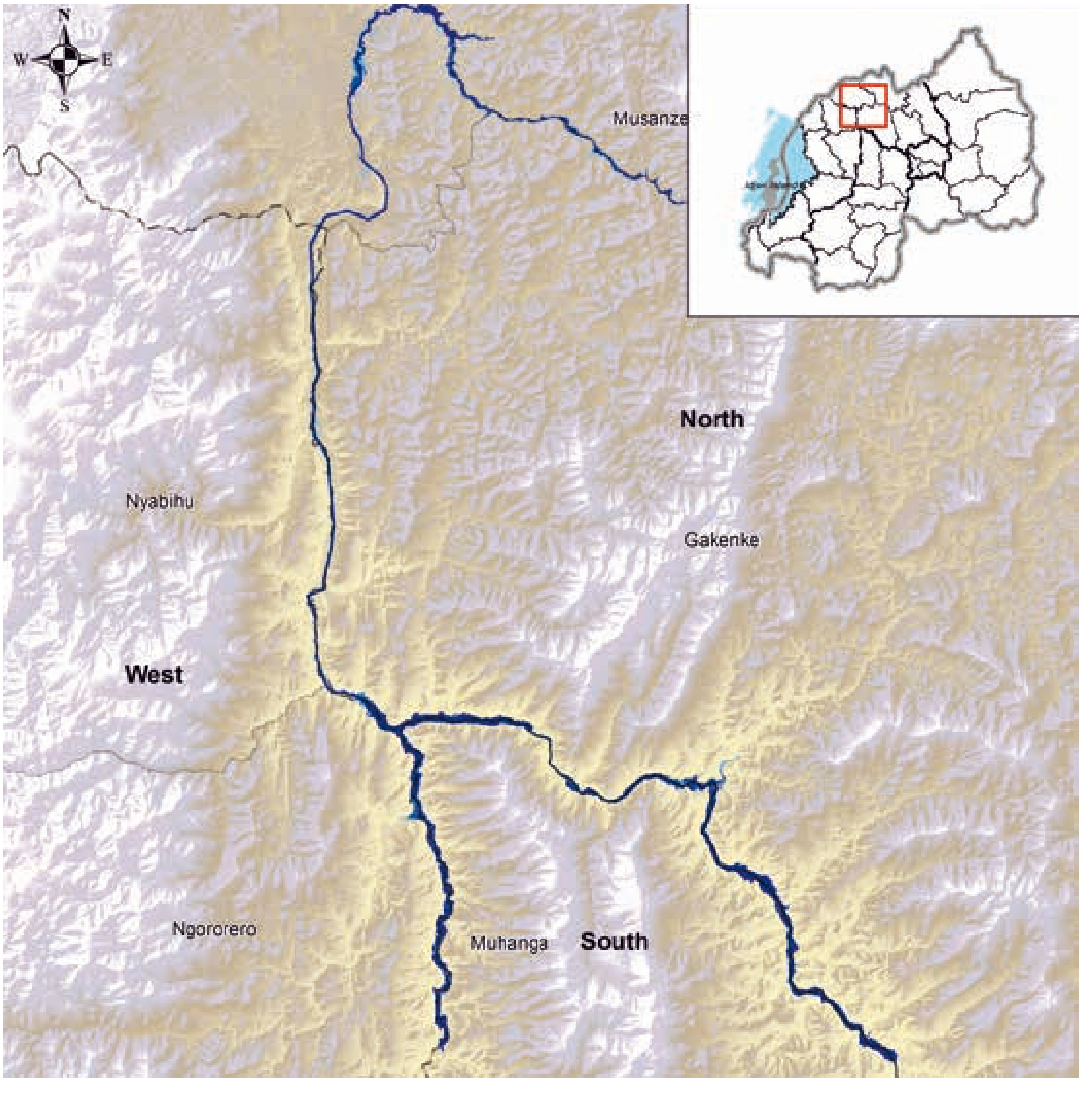
Scale:

0 0.75 1.5 2.25 3 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

Figure 39. Mukungwa flood hazard map



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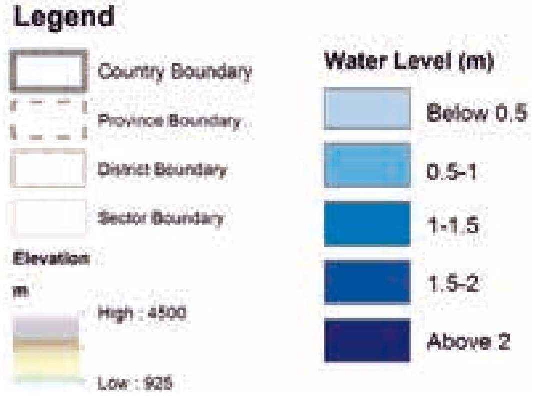


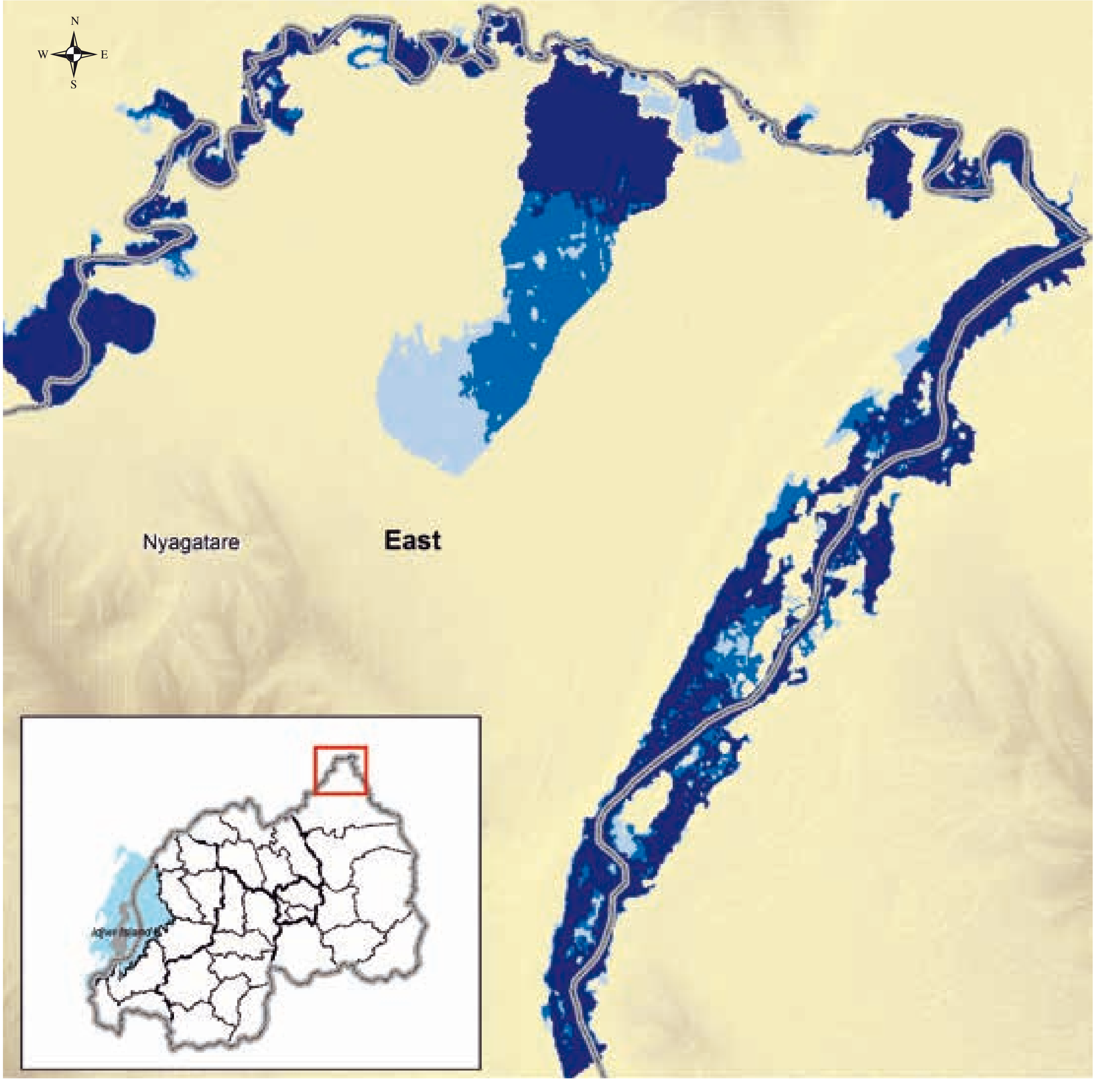
Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 1.5 3 4.5 6 Km

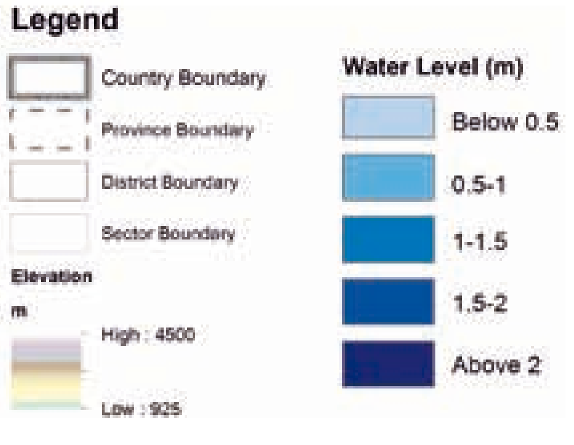
Date:
16 December 2014

Source:
MIDIMAR 2014

Figure 40. Kagitumba flood hazard map



Project Title:
Development of Comprehensive Disaster RiskProfiles for enhancing Disaster Management in Rwanda



Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 0.25 0.5 0.75 1 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

4.3.5 Flood hazard analysis

Flood hazard affects people and activities generally located near major rivers. The flood analysis of the selected catchments show that the total area affected by flood is around 0.7% (197 km2) of the country. This area is smaller compared to the flood affected area as registered in historical records. The methodology explained that areas without hydrometric stations were not included in this study. Neither were those areas affected by flash flood like Kigali City or unreported flood cases around the country. As shown in Table 28, Nyabarongo River affected more districts than any other river analyzed. In addition, historical records show that numerous flooding events happen in the districts in which Nyabarongo River runs.

Water depth of above 2m is the most dominant for the 25 years return period flood. Bugesera district is the most affected in total area according to the model. The historical records show that Bugesera is among the most affected areas in terms of location/area, but not on population. In eighteen districts affected by river flood, the district of Gasabo is the least affected where only 39 ha of area is predicted to be flooded.

4.3.6 Application in disaster management and development planning

The flood hazard maps are useful for policy makers, decision makers and planners as they can serve as basis to complement developed master plans (in rural and urban areas) for safe development. The maps can be useful in planning and implementing flood hazard mitigation measures for the sustainability of different economic sectors such as agriculture, housing, tourism and production. The flood hazard maps will help the local authorities in prone areas to undertake necessary measures to cope with the identified flood hazard severity and extent and accordingly develop preparedness plans. The flood hazard maps can help decision-makers, economic operators and other occupants to determine the areas that may potentially be impacted. They can then adapt their activities, and or safeguard their equipment, houses, schools, market and other tools against the potential hazard. The flood hazard maps will allow the government including humanitarian organizations to prioritize disaster preparedness and mitigation interventions.

4.3.7 Limitations

The main limitation for this flood hazard assessment has been the lack of sufficient data. For carrying out a complete flood hazard assessment, detailed data on rainfall events, river profiles or drainage systems, soils' hydraulic properties, and land cover information are required. These should allow the use of more robust 1D, 2D or 1D2D models like HEC-RAS, OpenLISEM, SOBEK, MIKE-SHE, etc.

In addition, the lack of hydrometric stations in different floodplain locations was a barrier in the estimation of total flood affected area across the country. The lack of detailed data was also the reason why flash floods were not analyzed especially in the city of Kigali.

Table 29. Water level area (ha) per District

	District	Above 2	1.5-2	1-1.5	0.5-1 Below 0.5	Below 0.5	Total Flooded Area
1	Bugesera	6285	0	875	0	405	7565
2	Gakenke	355	56	3	44	4	462
3	Gasabo	28	0	6	0	5	39
4	Kamonyi	2671	0	246	0	134	3051
5	Kicukiro	2282	0	264	0	107	2652
6	Muhanga	274	29	0	16	0	320
7	Musanze	234	55	0	62	0	350
8	Ngoma	139	0	92	0	10	241
9	Ngororero	154	27	0	16	0	197
10	Nyabihu	67	10	0	15	0	92
11	Nyagatare	186	0	61	0	52	299
12	Nyanza	118	97	0	66	0	281
13	Nyarugenge	1711	0	150	0	100	1961
14	Rubavu	204	0	63	0	82	349
15	Ruhango	390	0	12	0	13	415
16	Rulindo	267	0	54	0	39	360
17	Rutsiro	78	0	3	0	3	84
18	Rwamagana	926	0	38	0	27	990
	Total Area	**16368**	**274**	**1867**	**219**	**981**	**19709**

4.3.8 Recommendations

- GFT does not give information on some intensity parameters of flood events such as duration and speed. Therefore, it is recommended that the future studies remove various assumptions as introduced in this research. In addition, the calibration and validation can be done by taking into account discharge, flood depth and duration in different locations of floodplain. Note that, the extent of information currently can only be provided using a participation approach which is sometimes uncertain and inaccurate. It is recommended that relevant monitoring system (i.e. hydrometric stations) can be put in floodplains that are reported to be affected by flood.

- A detailed assessment on local level is needed to help policy makers, planners, decision makers and related actors to better plan and implement an effective flood management system. The detailed local assessment can be done by removing assumptions introduced by this research. High temporal rainfall and river discharge datasets are highly needed for sustainable flood management.

4.4 Earthquake hazard mapping

4.4.1 Background

Rwandan territory and the Western Rift Valley of Africa (WRA) in general, have experienced severe destructive shallow earthquakes. Seismic hazards and its impacts to Rwandan population are steadily increasing as urbanization and development is expanding to earthquake prone areas. Moderate and even small earthquakes may turn out to be catastrophic in the earthquake prone regions with poor construction practices.

The western rift system remains the main source of seismic movements impacting the region and Rwandan territory. This part of the Rift Valley has experienced several severe earthquakes of magnitude exceeding 6 in the recent historical times. Since 2002 two earthquakes of magnitude (Mw) 6+ occurred: (1) in Kalehe (DRC) on 24 October 2002 with Mw=6.1 and (2) in Bukavu –Rusizi (DRC-RWANDA) on 3 February 2008 with Mw=6.0.

According to different sources USGS (2008) and MIDIMAR (2013), the most impacted by seismic hazard is the western province. Between 2002 and 2008, five earthquake events struck Western Province causing deaths and many other damages as demonstrated in Table 29 below.[14] The most impacted districts are Rubavu, Rusizi and Nyamasheke. 85 people were killed, several people got injured and various houses, schools and hospitals were totally or partially destroyed.

The last earthquake event that severely affected the Rwandan territory occurred on 3 February 2008. According to USGS, 37 people were killed, 643 injured, 1,201 houses destroyed and 24 buildings damaged in Rusizi and Nyamasheke districts. Intensity IV was felt in Butare and Kigali, including Bujumbura and Kirundo in Burundi, Kabanga and Rulenge in Tanzania, and Kabale in Uganda (USGS, 2008).

The most vulnerable groups to earthquakes are poor people living in fragile houses. Even a small earthquake can cause damage to them. Also people who are gathered in one place such as schools, markets, hospitals are more vulnerable to earthquakes.

Table 30. Historical earthquake hazard events in Rwanda

Date	Province	District	Deaths	Affected	Damages	Source	Remarks
17/01/2002	Gisenyi	Rubavu	45	1643		CRED; Glidenumber	
20/03/ 2003	Western	Rubavu					Epicenter in southern lake Kivu; depth of 10 km
03/2/ 2008	Cyangugu	Cyangugu	36	643	Structural damage	CRED; CATNAT; Earth observatory; USGS; Africa Global Media; AFP	3 subsequent earthquakes, epicenter at a depth of 33 km
14/2/ 2008	Western	Rusizi, Nyamasheke	1	21		Reliefweb	
15/2/ 2008	Western	Rusizi, Nyamasheke	3	240	45 homes damaged	IRIN	

[14] The former district of Cyangugu (earthquake of 2008) was located in and around the current district Rusizi, Eastern Province.

4.4.2 Methodology for earthquake hazard mapping

Conceptual model

To assess the earthquake hazard, the probabilistic seismic hazard analysis (PSHA) as formulated by McGuire (1993) was applied. The PSHA is identified to be the most appropriate analysis in the context of insufficiency of records and data in the region. The approach assumes that earthquake occurrence in time is random and follows the "Poisson process". This implies that earthquakes occurrences are statistically independent and they occur at a constant rate. Statistical independence means that occurrence of future earthquakes does not depend on the occurrence of the past earthquakes.

The computation of a seismic hazard curve is based on the total probability theorem (Benjamin, 1970). It assumes that seismic hazard is characterized by a ground motion parameter Y. The probability of exceeding a specified value y, $P[Y \geq y]$, is calculated for an earthquake of a given magnitude located at a possible source. Then it is multiplied by the probability of a particular earthquake to occur. The computations are repeated and summed for the whole range of possible magnitudes and earthquake locations. The resulting probability $P[Y \geq y]$ is calculated by utilizing the total probability theorem which is:

$$P[Y \geq y] = \sum P[Y \geq y \mid E_i] \cdot P[E_i], \qquad \text{Equation 6}$$

$P[Y \geq y \mid E_i]$ denotes the probability of ground motion parameter $Y \geq y$, at the site of interest, when an earthquake occurs within the seismic source i.

After assuming that in every seismic source, earthquake occurrence in time follow a Poissonian distribution, the probability r that a specified level of ground motion y at a given site will be exceeded at least once within any time interval t is:

$$P[Y > y, t] = r(y) = 1 - \exp(-TH(y)) \qquad \text{Equation 7}$$

Where;

- T is the time period of exposure;
- H(y) is the annual rate of exceedance of ground motion y, and
- 1/H (y) is the return period
- r(y) is the hazard curve

Mapping process

The deductive method that was used allows the incorporation of geological and geophysical data and requires the following steps:

- Build a catalogue from instrumental seismic data with a unified magnitude that provides information on the location and frequency of earthquake occurrence during the past years.
- Delineate seismic source zones based on geological and seismological evidence. These source zones describe the potential locations of future earthquakes within the study area.
- Evaluate, for each seismic source zone, earthquake seismic parameters (such as maximum expected magnitude), activity rate and b-value of the Gutenberg-Richter relation.
- Predict future ground motion for the study area using an appropriate regional attenuation relationship for the strong motion between magnitude, distance and site conditions
- Compute seismic hazard (the probability that a specified ground motion level at a given site will be exceeded during a particular time period), using the above parameters as input, to characterize each seismic source zone.
- The ultimate result of a PSHA is a seismic hazard curve: the annual probability of exceeding a specified ground motion at least once. An alternative definition of hazard curve is the frequency of exceedance versus the ground amplitude (Mc Guire, 2004).

Tool

The model runs with the "OpenQuake" software to prepare the seismic hazard maps for 2% and 10% probability of exceedance in 50 years equivalent to the annual probability of exceedance equal to 0.04% and 0.2%, respectively. Developed by Global Earthquake Model (GEM), the OpenQuake engine is an open-source software written in the Python programming language for calculating seismic hazard and risk at variable scales (from single sites to large regions). The engine relies on two scientific Python libraries for hazard and risk computations, respectively, oq-hazardlib and oq-risklib. Since 2013, OpenQuake includes also the Hazard Modeler's Tools Kit (HMTK) which is useful to create the seismogenic input models that go into Earthquake Hazard Assessment engine.

The tools are broken down into separate libraries: i) Declustering, ii) Completeness, iii) Calculation of Gutenberg-Richter a- and b-value and iv) Statistical estimators of maximum magnitude from seismicity.

4.4.3 Data requirements, sources and processing of the catalogue

All seismic data used in this report are instrumental data and were compiled from various sources covering the region 1°S to 3°S and 28°E to 32°E for the period 1954 to 2013. All the territory of Rwanda is included, together with parts of South Kivu Province in DRC, Uganda and Tanzania. The main source of data since 1954 is the seismological bulletins published by the Institut pour la Recherche en Afrique Centrale (IRSAC) from 1953 to 1977, and by its successor, the Centre de Recherche en Sciences Naturelles (CRSN).

The IRSAC-CRSN seismograph network in the eastern DRC is operational since May 1953 when the station at Lwiro (LWI) was installed. This network operated initially with three stations: Lwiro (LWI), Butare (BTR) in Rwanda, and Uvira (UVI) (Sutton and Berg, 1958). It was later extended by setting up the Rumangabo (RMG) and Butembo (BTC) stations in the North Kivu province.

However, most of these seismic stations in the DRC were closed from 1964 to 1970 due to the political instability. Current seismograph stations in DRC are operated by the Centre de Recherche en Sciences Naturelles (CRSN) and Goma Volcanic Observatory (GVO). At the moment, seven stations, mostly concentrated in the Virunga volcanic and Lwiro areas are operational.

Data for the period prior to the establishment of the IRSAC/CRSN network were obtained from the catalogue of the International Seismological Centre (ISC), the former International Seismological Summary (ISS); the catalogues published by the United States Geological Survey, which include the NEIS, NEIC, USCGS and CGS catalogues; the Zimbabwe Meteorological Service Seismological Bulletin, particularly the station at Bulawayo (BUL); and Gutenberg and Richter (1949 and 1954).

A homogenized catalogue for Rwanda was compiled listing the source of the data; the date, origin time, coordinates of the earthquake[15]; and a magnitude homogenized according to the moment magnitude scale.

From the original catalogue, a seismicity dissemination was retrieved according to the recorded magnitude. Around 150 seismic events were analyzed. To identify the Poissonian rate of seismicity, it is necessary to remove foreshocks/aftershocks/swarms from the original catalogue. We used library in HMTK which task is to decluster the catalogue. After declustering the catalogue, a seismicity map (Figure 41) was prepared for the purpose of assigning seismotectonic regions. The number of events filtered with the magnitude above 3.5 within the area is 123. The map below shows the spatial distribution of the seismic events with a minimum magnitude of Mw = 3.5 and the maximum magnitude recorded is Mw = 6.1. The most recent significant earthquake with maximum magnitude of 6.0 in Lake Kivu had affected Rwandan territory. It occurred on 3 February 2008 at approximately 20 km north of Bukavu City (DRC) and Rusizi District in the south of Rwanda.

Based on the distribution of epicentres and tectonic setting of the region, two zones with seismic sources were delineated (Figure 41). From the point of view of Tectonic earthquake, the first zone (orange points) is tightly related to the Lake Kivu zone. The second zone (green points) is more related to MesoProterozoic North Eastern Kibaran Belt (a tectonic shear zone). According to the seismicity distribution, some gaps of seismicity are observed between these two zones.

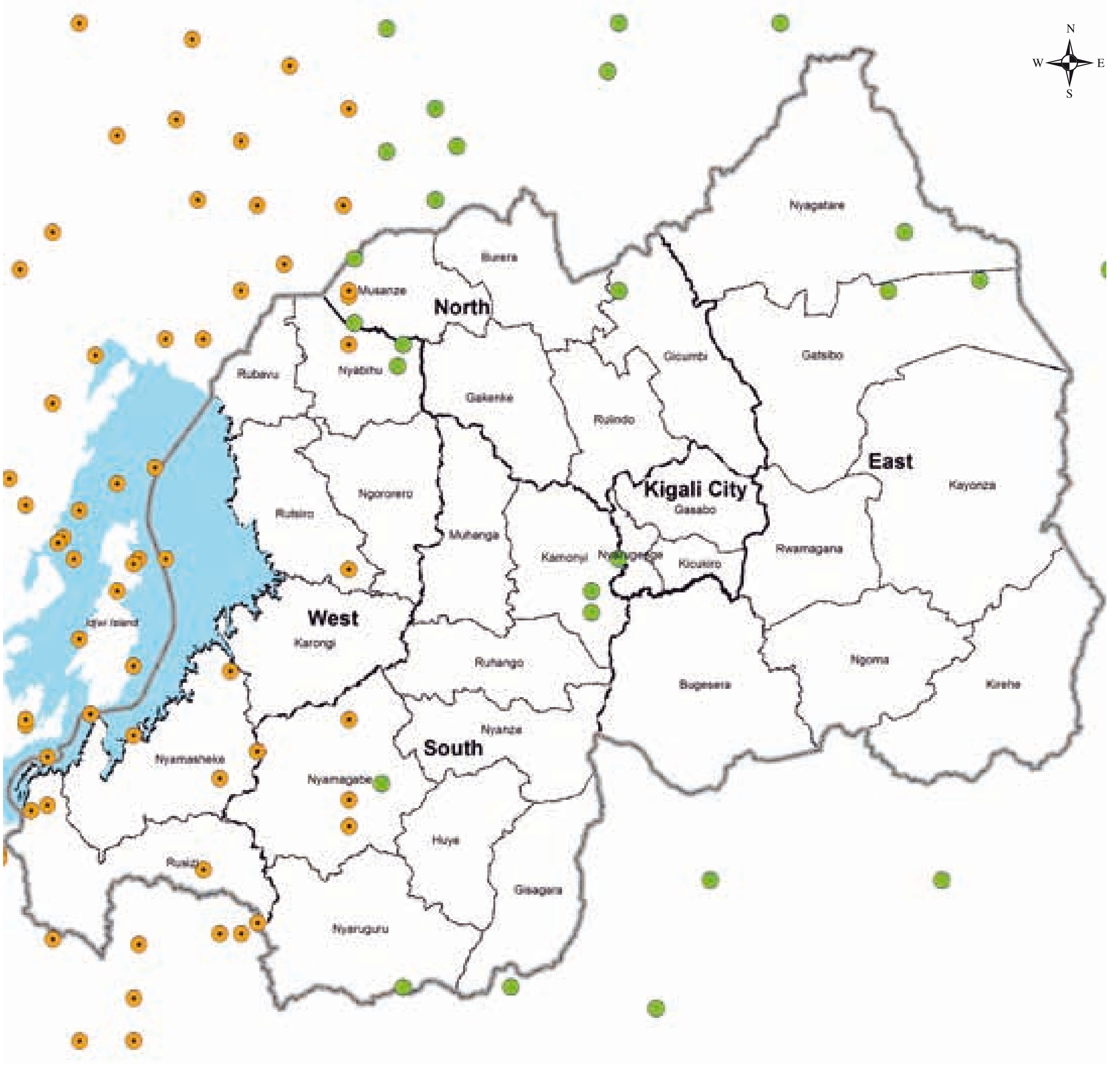
Each seismic source zone was characterized by the following parameters:

- Average rate of occurrence or mean seismic activity rate λ (which is the parameter of the Poisson distribution)
- Level of completeness of the earthquake catalogue Mmin
- Maximum possible earthquake magnitude Mmax
- Gutenberg-Richter parameter b (which indicates the relative number of large and small earthquakes, β= b ln10)
- Focal depth
- Regional attenuation relationship for the strong ground motion, and
- Focal mechanism of earthquakes in the region

These parameters were calculated using the Hazard Modeller's Toolkit and historical data in the case of focal depths and focal mechanism in the region and used for seismic hazard computation.

15 If data was provided by more than one source, the most reliable and likely solution was selected in the following order: ISC, USGS, LWI and BUL.

Figure 41. Spatial distribution of seismic events in and around Rwandan territory



Project Title:
Development of Comprehensive Disaster RiskProfiles for enhancing Disaster Management in Rwanda

Legend

- Country Boundary
- Province Boundary
- District Boundary
- Lake
- Epicenter zone1
- Epicenter zone2

Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 10 20 30 40 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

4.4.4 Earthquake hazard maps

Seismic hazard maps for 2% and 10% probability of exceedance of occurrence in 50 years, corresponding to 2475 years and 475 years return periods respectively, were prepared using a 59-year catalogue compiled for homogeneous magnitudes (Mw), the Hazard Modeller's Toolkit (HMTK) and OpenQuake software package developed by Global Earthquake Model (GEM). The input parameters used for seismic hazard computation are described in 4.4.3.

Using OpenQuake engine, the degree of ground shaking is identified by quantitative measure and is obtained via the recorded ground motion parameters expressed in terms of Peak Ground Acceleration (PGA), Peak Ground Velocity (PGV) or Permanent Ground Deformation (PGD). These parameters give direct and physical measures of the recorded ground motion during an earthquake.

The output is a statistical estimate of the probability of exceedance as a function of PGA called hazard curve. From the hazard curves, OpenQuake extrapolates and produced the mean PGA value expressed in unit of g for a 2% and 10% probability of exceedance in 50 years which correspond to return period of 2475 and 475 years, respectively.

The highest PGA values are found in the region close to the basin of Lake Kivu in the Western Rift Valley of Africa where the PGA values of 0.30g and 0.16 g are expected to be exceeded with probability of 2% and 10% in 50 years, respectively. The seismic hazard diminishes with distance from the Western Rift Valley until almost at Central Rwanda and the chance of exceeding a PGA of 0.05g (the threshold value of engineering interest) with probability of 10% in 50 years is low.

In order to predict the type of damage or loss can be expected in the Rwanda territory with the above probabilities, the computed values of mean PGA were converted in felt intensity. Felt intensity provides a subjective measure of the earthquake strength and is mainly based on human response to the shaking and evaluation of the damage to the structures. Intensity is commonly measured by Modified Mercali Intensity (MMI) scale. In a region with dense strong ground motion network, a relationship between the felt intensity and instrumental ground motion parameters can be established. An empirical MMI-PGA correlation was used to estimate PGA data for historical earthquakes which have MMI information. Such relationship can be extended to obtain PGA value in region without dense strong ground motion network where there is MMI information assigned in the field.

The well-built correlations between felt intensity (MMI) and instrumental ground motion parameters (e.g. PGA) are not yet established in detail for the Great Lakes Region and particularly for Rwanda. In this report, the felt intensity and PGA are correlated using the empirical relation in the form of a table (Table 30) used by USGS (to estimate, the PGA around the epicentral area during the 03 February 2008 Bukavu-Cyangugu (specifically the Districts of Rusizi and Nyamasheke) earthquake. It is important to note that the intensity is very sensitive to many uncontrolled factors such as human response to the shaking and evaluation of the damage to the structures. For more accuracy of intensity measures, the dense digital broadband sensor is needed to calibrate every ground shaking with physical parameter provided by instrument during earthquake. The intensity measure used in this report is only approximate for general view but must not constitute a document for engineers and architects because they need specific value expressed in PGA.

The probability of exceedance of MMI value with probability of 2% and 10% of exceedance in 50 years are also expressed in the form of map.

Seismic hazard maps were produced and presented in terms of MMI after expressing the USGS conversion table values of PGA expressed in term of % of g in decimal by dividing these values per 100 as expressed in OpenQuake. Two return periods were considered: 2,475 and 475 years. These return periods are associated to 2% and 10% probability of exceedance in 50 years respectively. Considering the 10% probability of exceedance in 50 years, the intensity of MMI VI and V are expected to affect Rwandan territory (Figure 42). Meanwhile, when considering the 2% probability of exceedance in 50 years, the whole Rwandan territory can be affected by an earthquake intensity of MMI VI and VII (Figure 43).

Table 31 MMI scale used by USGS

Perceived shaking	Not Felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
Potential damaged	None	None	None	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
Peak acc. (%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
Peack vel. (cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
Instrumental intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+

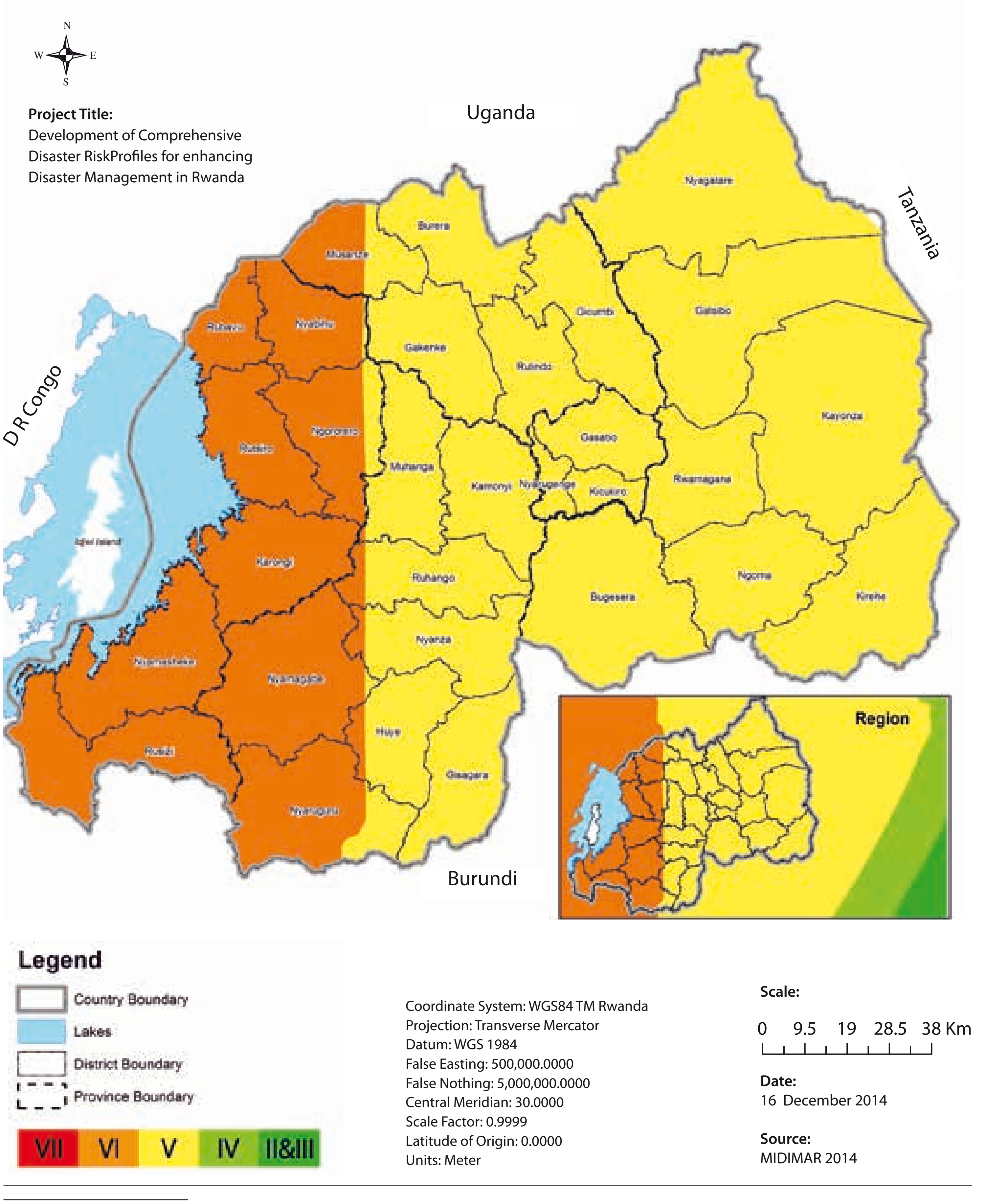
Source: USGS

Table 32. Earthquake hazard zone scale

Zone	MMI Range	PGA (g) correspondent	Shaking	Description
Very high	VII	0.18 -0.34	Very strong	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
High	VI	0.092 – 0.18	Strong	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
Moderate	V	0.039-0.092	Moderate	Felt by nearly everyone; many awakened. Some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.

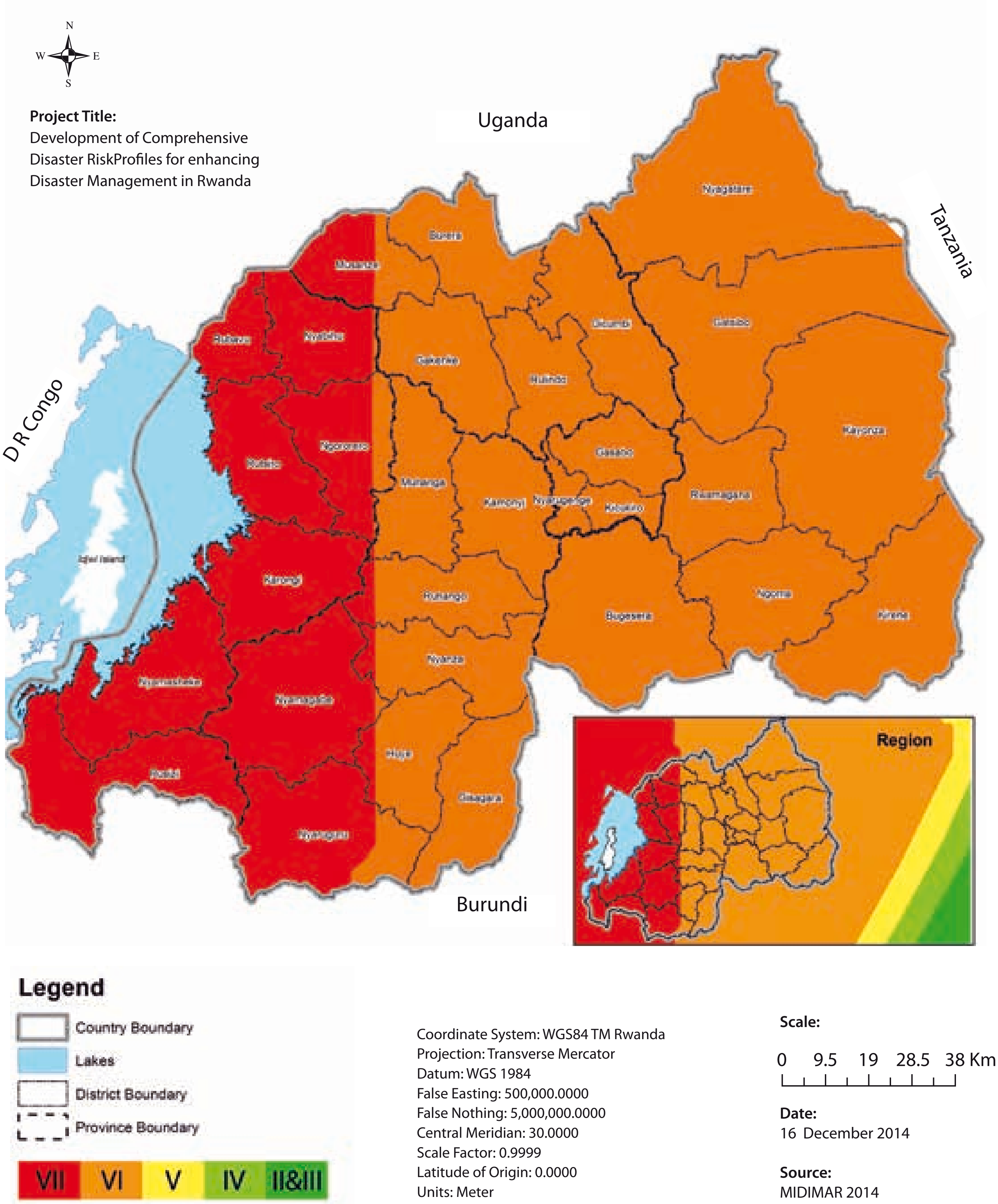
Source of Description: (USGS) http://earthquake.usgs.gov/learn/topics/mercalli.php

Figure 42. Earthquake hazard zonation map at 10% probability of exceedance in 50 years



[16] The description used has been developed by USGS.

Figure 43. Earthquake hazard zonation map at 2% probability of exceedance in 50 years



4.4.5 Earthquake hazard analysis

The mean hazard curve at each of the following sites in Rwanda territory: Musanze (Ruhengeri[17]), Rubavu (Gisenyi), Karongi (Kibuye), Rusizi (Cyangugu), Huye (Butare), Kigali, Gicumbi (Byumba), Gabiro, Ngoma (Kibungo) is evaluated and the following levels of hazard were found (considering PGA):

- Very high to high seismic zone in the Lake Kivu Rift region, where the cities of Rubavu (Gisenyi), Karongi (Kibuye), Nyamasheke and Rusizi (Cyangugu) are located. The PGA, averaged for the four cities, to be exceeded with probability of 2%, and 10% is 0.30g and 0.16g, respectively.

- High to moderate seismic zone in the North West region and southwest region with Neogene volcanics, where the cities of Musanze (Ruhengeri), Muhanga, Ruhango, Nyanza, Huye (Butare) and Nyamagabe are located and in Central and Eastern region of Rwanda including the cities of Kigali, Bugesera, Gabiro and Ngoma. An average PGA in excess of 0.16g, and 0.10 g with probability of 2% and 10%, respectively, was determined in these areas.

- Moderate to low hazard in extreme Eastern region of Rwanda far from the Western Rift. An average PGA in excess of 0.09 g and less than 0.05 g with probability of 2% and 10%, respectively, was determined in these areas.

According to the maps classifying zones according to intensity, the zones that are located close to the basin of Lake Kivu are more exposed to earthquake hazard. The further you go from the Rift, the lower the earthquake intensity. For the two return periods in this study, the MMI is descending from the west to the east from MMI VII to MMI V.

The earthquake hazard distribution maps show that Rwanda can be affected by earthquake intensity of MMI V and VI considering the 10% probability of exceedance in 50 years (Figure 42). Twenty-four percent (24%) of the total area of the country are likely to feel the MMI V. This includes districts of Rusizi, Nyamasheke, and Rubavu at 100% of the area; the districts of Rutsiro, Karongi, Nyamagabe, and Nyabihu between 50% and 97% of the total area; and the districts of Nyaruguru, Musanze, Ngororero, and Nyaruguru at less than 50% of the total area.

The districts of Musanze, Muhanga, Huye, Ngororero, Nyaruguru and Ruhango are likely to feel the seismic

Table 33. Area (%) exposed to different MMI scale per district (10% probability of exceedance in 50 years)

District	MMI Scale	Area Exposed (%)
	V	VI
Bugesera	100	0
Burera	100	0
Gakenke	100	0
Gasabo	100	0
Gatsibo	100	0
Gicumbi	100	0
Gisagara	100	0
Huye	90	10
Kamonyi	100	0
Karongi	0	100
Kayonza	100	0
Kicukiro	100	0
Kirehe	100	0
Muhanga	99	0
Musanze	38	62
Ngoma	100	0
Ngororero	18	82
Nyabihu	3	97
Nyagatare	100	0
Nyamagabe	1	99
Nyamasheke	0	100
Nyanza	93	7
Nyarugenge	100	0
Nyaruguru	18	82
Rubavu	0	100
Ruhango	89	11
Rulindo	100	0
Rusizi	0	100
Rutsiro	0	100
Rwamagana	100	0
Grand Total	**68**	**32**

intensity of MMI VI at over 50% of total area. For the remaining part of the country, the highest MMI to feel is level V (Table 32).

Considering the 2% probability of exceedance in 50 years (Table 33), 40% of the total area of the country are likely to feel the MMI of VII. All districts of Western Province and the districts of Musanze, Nyamagabe and Nyaruguru fall completely under that category. Districts of Muhanga, Ruhango, Nyanza and Huye of Southern Province are partially included in this VII category. The remaining districts fall within intensity MMI VI (Figure 43).

The results obtained in this report are based on a period of around 60 years, and assumed to be complete for events of magnitude Mw >= 3. However, African plate boundaries are generally characterized by slow relative motions (≈ 2mm/yr to ≈ 15mm/yr). Hence, large earthquakes have extremely long recurrence times (De Mets, et al., 1990).

[17] (Ruhengeri) has changed its name to Musanze since 2006 after the reform of local government. This applies to all cities whose names are taken between parenthesis

Table 34. **Area (%) exposed to different MMI scale per district (2% probability of exceedance in 50 years)**

District	MMI Scale	Area Exposed (%)
	V	VI
Bugesera	100	0
Burera	100	0
Gakenke	100	0
Gasabo	100	0
Gatsibo	100	0
Gicumbi	100	0
Gisagara	100	0
Huye	90	10
Kamonyi	100	0
Karongi	0	100
Kayonza	100	0
Kicukiro	100	0
Kirehe	100	0
Muhanga	99	1
Musanze	38	62
Ngoma	100	0
Ngororero	20	80
Nyabihu	3	97
Nyagatare	100	0
Nyamagabe	1	99
Nyamasheke	0	100
Nyanza	93	7
Nyarugenge	100	0
Nyaruguru	18	82
Rubavu	0	100
Ruhango	89	11
Rulindo	100	0
Rusizi	0	100
Rutsiro	0	100
Rwamagana	100	0
Grand Total	**68**	**32**

4.4.6 Application in disaster management and development planning

The socioeconomic conditions in Rwanda are continually changing and planning based on seismic consideration is poor or non-existent. Population growth has led to relatively uncontrolled use of land for building and development of unsuitable sites that are vulnerable to earthquakes.

This seismic hazard maps will contribute to the formulation of national seismic design code for buildings that will assist architects and structural engineers to build earthquake resistant building and retrofitting existent buildings which need to be reinforced.

Combined with structural and non-structural vulnerability, exposure and occupancy models, it will be used as input to estimate the risk expressed in the form of economic losses, fatality or damage distribution due to a single scenario earthquake, for a collection of assets (e.g. buildings, population, etc.), for example, useful for emergency management planning and for raising societal awareness of seismic risk.

4.4.7 Limitations

Except for Butare, no seismographic station was operational in Rwandan until 2013. Therefore, Rwanda Natural Resource Authority installed in early 2014 two additional stations at Ruhengeri (Musanze) and Kigali. However, data collected by those stations are not yet processed. To accurately locate an earthquake, four broadband seismic stations are required and one more station is still lacking. The lack of seismic stations leads to an important uncertainty in the earthquake location on Rwandan territory.

Beside seismic data, geological mapping of faults and geotechnical data for soil are needed in the urban environments that are becoming even more densely populated. Data from soil borings or other testing that show the nature of subsurface is very important to predict the amplification of strong motion due to the variation in the geological site response. For sustainable seismic hazard assessment, a mapping of classification of soil based on the average shears S wave velocity over the top 30 m of soil is needed. This task is done based on geological map, boring and/or geophysical method.

4.4.8 Recommendations

The source zonation can be improved by supplementing the area sources used in this study with fault sources. An effective earthquake disaster mitigation strategy requires that base maps of known faults must be compiled, and efforts to detect possible unknown faults be made using paleoseismology. Paleoseismology is the science of the nature, the timing and the location of pre-instrumental earthquakes. If paleoseismic events are well documented, we can evaluate potential earthquake of specific faults. Information on paleo-earthquakes are highly needed for a sufficiently long period of time because active faults on land have long recurrence cycles. Evidence of paleo-earthquakes can be found by investigating geologic sequences (depositional sediments) through direct excavation survey across active faults.

Seismic hazard analysis shows that the nominal peak ground acceleration value for a return period of 475 years equal or exceed 0.1g in the region close to the Lake Kivu Rift, the North West region and Southwest region with Neogene volcanoes, where the cities of Gisenyi (Rubavu), Kibuye, Cyangugu, Ruhengeri (Musanze) and Butare (Huye) are located, therefore it is recommended that structures be designed for seismic load. Buildings must meet the basic international standards to reduce loss of life in the event of a major earthquake.

For zones of moderate to low hazard (including Kigali city) reaching the threshold PGA of 0.05 g, it is also recommended to use seismic load for a high-rise building.

At the moment three broadband seismic stations are operational across the country. To accurately locate earthquake, it is recommended to add one more in order to have a complete seismic network. Data collected are not yet processed. It is highly recommended to establish a position of Principal Seismologist (geophysicist or physicist with training in seismology) who would be responsible for seismic network operation and the interpretation of seismic data.

For sustainable national seismic hazard assessment, a detailed mapping of classification of soil based on the average shear S wave velocity over the top 30 meters of soil in densely populated area is recommended. This task is done based on geological map, boring and/or geophysical method. This map is important to predict amplification of ground surface motion (e.g. PGA) at a specific site. Damage patterns in past earthquakes show that soil conditions at a site may have a major effect on the level of ground shaking. This division is based on assessment of the seismicity and the expected intensity of ground motion. It was stated that the source zonation could be improved by supplementing it with area/fault sources.

4.5 Windstorm hazard mapping

4.5.1 Background

A storm is any disturbed state of an environment or astronomical body's atmosphere especially affecting its surface, and strongly implying severe weather. It may be marked by significant disruptions to normal conditions such as strong wind, hail, thunder and lightning (a thunderstorm), heavy precipitation (snowstorm, rainstorm), heavy freezing rain (ice storm), strong winds (tropical cyclone, windstorm), or wind transporting some substance through the atmosphere as in a dust storm, blizzard, sandstorm, etc. *(Wikipedia)*.

The speed of regular winds in Rwanda is generally around 1-3 Knots (MIDIMAR, 2013), but in some occasions it can reach 20-25 Knots, which causes damages to roofs of houses, banana plantations and other facilities such as schools made predominantly with weak materials and vulnerabilities of being constructed having the building codes ignored. Normally, the wind speed and direction in Rwanda are variable and seem to have some irregularities in the normal distribution all over the country.

Most of the time, storms are accompanied by rain and their combination becomes more destructive. For heavy rains and storms, it is extremely difficult to design an effective preventive plan. However, there are several small-scale disasters that can be avoided or whose effects can be minimized. In Rwanda such disasters have barely resulted in loss of lives, although millions of francs are often lost in damaged properties and the affected population is often exposed to dangerous health conditions when waiting for new homes.

Storms have been one of the major hazards that caused severe damages in many localized areas of Rwanda. According to MIDIMAR assessment reports (2013), windstorms associated with heavy rain have destroyed many houses and schools in mostly lower land areas of Eastern and Southern Districts including Rwamagana, Kayonza, Kirehe, Gatsibo, Bugesera, Nyagatare, Ngoma and Gisagara and other districts. Some of the localized areas of higher lands of northern and western districts were also affected depending on how severe these events were. The windstorms damages include destruction of the roofing of houses, classrooms, churches and destruction of other infrastructures like cut off electricity and downpour of electrical wires supports (MIDIMAR, 2013).

In 2011, the Rwanda Red Cross reported that Rwamagana District located in the eastern province experienced severe weather. It is estimated that approximately 3,600 people have been affected as result of severe weather in Rwanda, which has resulted into various damages like crop damages, submerged latrines and severe damage to homes including the obliteration of roofs. In fact strong winds from any storm type can damage or destroy vehicles, buildings, bridges and other outside objects, turning loose debris, road complicating efforts to transport food, clean water, etc. (MIDIMAR, 2013).

In March 2012, a heavy rainfall associated with storms severely affected many districts in the eastern province, including Rwamagana, Kayonza, Gatsibo, Ngoma, and Kirehe. It damaged buildings, hectares of crop yields like banana plantation. Note that in most of cases, the storm is accompanied by heavy rain and causes river flooding that aggravates damages.

People living in very fragile houses and with low income are the most fragile. Besides, farmers and mainly small farmers are also considered as a vulnerable group. Their crops, such as banana trees, sorghum, and maize are often damaged by storms.

Table 35. **Storm events and damages/loss (2011-2013)**

Year	District	Death	Injured	Houses destroyed & damaged	Crop Lands affected (ha)
2011	Ngororero			٤٥	53
	Rwamagana			223	455
	Kamonyi				50
	Kayonza			21	31
	Bugesera			37	130
	Ngoma			5	500
	Gatsibo		6	113	52
	Rubavu			66	
	Rulindo			202	1,793
	Nyagatare			0	
	Ruhango			79	545
	Karongi	3		55	2,301
	Nyaruguru	2		40	
	Gicumbi	4		64	
	Total	**9**	**6**	**950**	**5,909**
2012	Bugesera			141	15
	Ngororero			278	
	Kayonza			85	15
	Rwamagana			129	
	Nyagatare			72	
	Kirehe	1		65	
	Gatsibo			35	
	Gicumbi			32	159
	Nyamagabe	4		70	29
	Nyamasheke			48	
	Rubavu	1		121	
	Huye	1		133	20
	Ngoma			28	
	Rusizi			113	
	Gasabo		1	131	21
	Karongi			78	
	Nyanza			45	2
	Burera			3	
	Ruhango			25	
	Kamonyi			155	
	Nyarugenge			9	
	Kicukiro			8	
	Total	7		1,804	261
2013	Nyanza			35	
	Nyamagabe			14	
	Gisagara			10	10
	Rubavu	4		179	38
	Bugesera		6	148	
	Burera	7	14	30	920
	Gakenke			40	20
	Gasabo	1		313	
	Gatsibo			65	4
	Gicumbi			29	
	Kamonyi			126	
	Karongi			6	

Year	District	Death	Injured	Houses destroyed & damaged	Crop Lands affected (ha)
	Kayonza			76	102
	Kicukiro			72	
	Kirehe			376	27
	Muhanga			37	
	Musanze	2		150	
	Ngoma			53	5
	Ngororero			18	
	Nyabihu	4	1	23	
	Nyagatare	6	16	95	18
	Nyamasheke			127	
	Nyarugenge	3		366	
	Nyaruguru			7	4
	Ruhango		4	60	13
	Rulindo		5	299	
	Rusizi	1		199	235
	Rutsiro			20	40
	Rwamagana		1	177	5
	Gakenke			40	20
Total		**28**	**47**	**3,190**	**1,460**

Source: MIDIMAR, 2014 (Annual Report)

4.5.2 Methodology for windstorm hazard mapping

To characterize and map storm hazard, this study adopted the wind speed modeling approach developed by Morjani (2011) which consists of a two-step process:

- Step 1 is to estimate the annual maximum daily mean wind speed for different return periods. At this step, data from meteorological stations (that have been operational for at least three years) have been analyzed and the frequency analysis is carried out.
- Step 2 is to map out the spatial distribution of wind speed intensity by conducting a stepwise regression analysis.

Five main steps have been followed:

1. Extraction of the daily maximum wind speed data from the selected functional meteorological stations.
2. Estimation of the annual maximum mean wind speed for five and ten year return periods using Gumbel frequency analysis.
3. The maximum wind speed data were ranked in ascending order and the empirical frequency was computed for each value using the Hazen formula:

$$F=r-o.5/n \qquad \text{Equation 8}$$

Where r is the rank for each value and n is number of the years of record.

The Gumbel Reduced Variate u is calculated by applying this equation:

$$U=-\ln[-\ln(fx)]=-\ln[-\ln(1-1/T)] \qquad \text{Equation 9}$$

With F(x) = 1-1/T and T = the return period.

The annual maximum mean wind speed value for the desired return period T are calculated using the following statistical model $X_t = a+b\,u = a+b\,(-\ln[-\ln(1-1/t)]$ with X_t = value of variate with a return period T.

4. Interpolation of the Annual maximum mean wind speed for each return period using the selected regression models in GIS tool. The interpolation method used is the Inverse Distance Weighting (IDW). It combines the idea of proximity espoused by Thiessen polygons with the gradual change of a trend surface (Thiessen, 1911). Those measured values closest to the predicted location will have more influence on the predicted value than those farther away.

This distance-decay approach has been applied widely to interpolate climatic data (Legates and Willmott, 1990; Stallings et al., 1992). IDW assumes that each measured point has a local influence that diminishes with distance. The usual expression is:

$$\hat{Z}(s_0) = \left[\sum_{i=1}^{N} w(d_i) Z(s_i)\right] / \left[\sum_{i=1}^{N} w(d_i)\right] \quad \text{Equation 10}$$

where $\hat{Z}(s_0)$, $Z(s_i)$ represent the predicted and observed value at location s_0, s_i, N is the number of measured sample points used in the prediction, w(d) is the weighting function and di is the distance from s_0 to s_i. Based on the structure of IDW expression, the choice of weighting function can significantly affect the interpolation results.

5. The last step was to derive the spatial distribution of the intensity level of wind speed hazard for each return period from the Annual maximum mean wind speed distribution maps. The Beaufort Wind scale has been used to characterize different classes of wind due to its speed (m/s). The Table 36 below gives more details.

4.5.3 Data requirements and data sources

- The current windstorm hazard maps (for five and ten year return periods) are based on the data available at Rwanda Meteorology Agency (RMA). Most of meteorological stations were only installed in 2013 and have less than a year recording. Therefore, this study used data from ten Rwandan weather stations for analysis. These stations are presented in Table 37.

Table 37. Annual maximum mean wind speed by meteorological station and period recorded

No	Weather stations	Years considered	Period	Annual maximum mean wind speed (m/s) recorded
1	Kibungo Kazo	3	2011-2013	11.07
2	Nyagatare	3	2010-2012	12.35
3	Kawangire	3	2011-2013	11.41
4	Byimana	3	2011-2013	9.81
5	Kanombe	10	2000-2009	8.6
6	Gisenyi	8	2002-2009	9.75
7	Kamembe	11	1974-1983	16.91
8	Ruhengeri	4	1978-1981	10.25
9	Butare	3	2012-2014	10.25
10	Byumba	3	2011-2013	13.25

Source: Rwanda Meteorology Agency

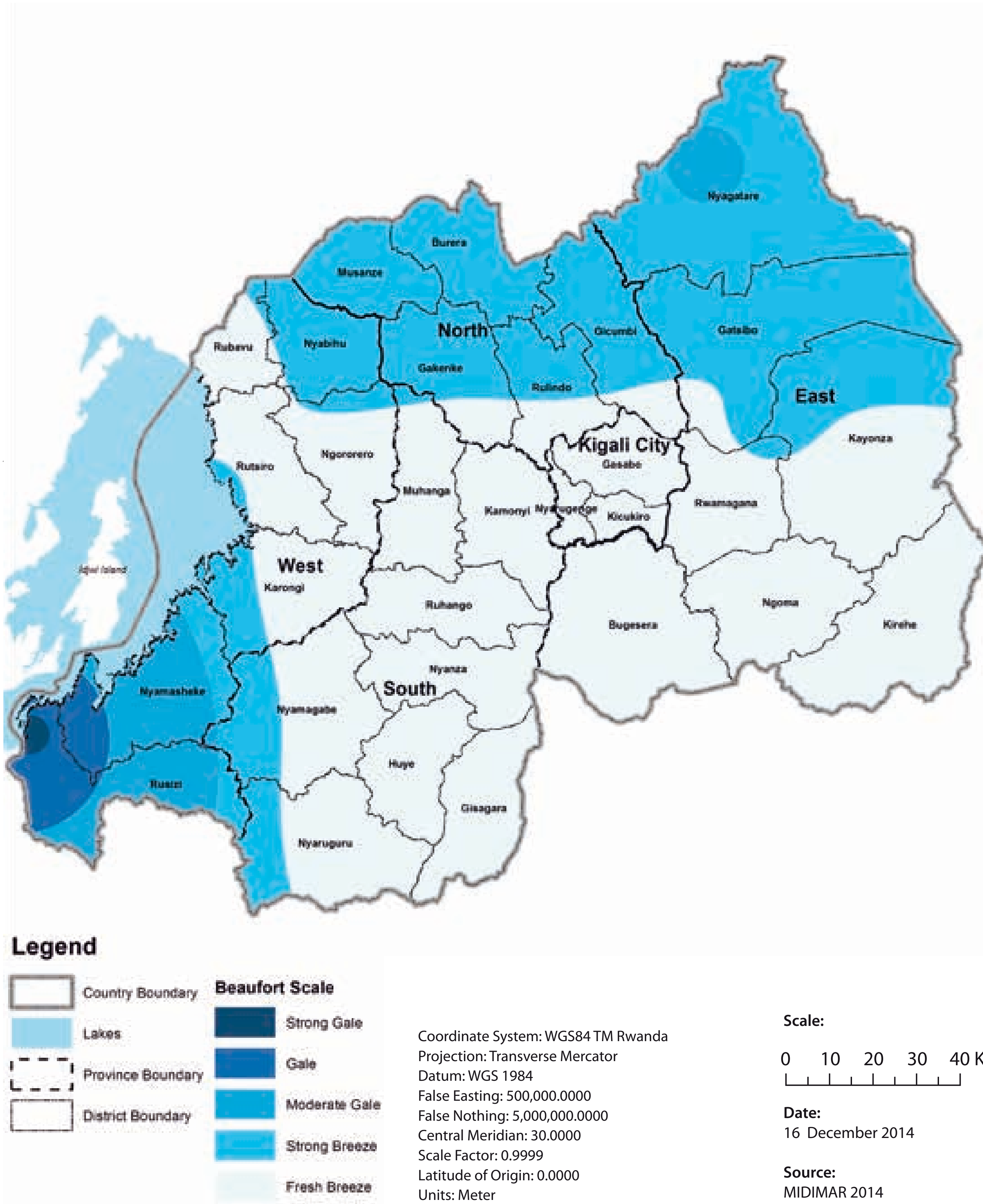
- The annual maximum mean wind speed is considered for those stations because the recording system for some selected meteorological stations provide just the daily maximum (one record per day) which doesn't allow the use of annual maximum daily mean wind speed. The Gumbel frequency analysis for five and ten years return periods was conducted. Results are detailed below (Table 36):

Table 36. Beaufort Windstorm Scale

Beaufort	Description of the windstorm	Observation	Wind speed (m/s)
0	Calm	Smoke rises vertically. The sea is mirror smooth.	0 - 0.15
1	Light Air	Direction of wind shown by smoke drift but not by vanes. Scale-like ripples on sea, no foam on wave crests.	0.15 - 2.7
2	Light Breeze	Wind felt on face, leaves rustle, ordinary vanes moved by wind. Short wavelets, glassy wave crests.	2.7 - 3.6
3	Gentle Breeze	Leaves and small twigs in constant motion, wind extends light flag	3.6 - 7.2
4	Moderate Breeze	Raises dust and loose paper, small branches moved. Fairy frequent whitecaps occur.	7.2 - 8.9
5	Fresh Breeze	Small trees in leaf begin to sway. Moderate waves, many white foam crests.	8.9 - 12.5
6	Strong Breeze	Large branches in motion, whistling heard in telegraph wires. Some spray on the sea surface.	12.5 - 14.5
7	Moderate gale	Whole trees in motion, inconvenience felt when walking into wind. Foam on waves blows on streaks.	14.5 - 20
8	Gale	Twigs broken of trees, generally impeded progress. Long streaks on foam appear on sea.	20 – 22
9	Strong gale	Straight structural damage, e.g. slates and chimney pots removed from the roofs. High waves, crest start to roll over.	22 – 28
10	Storm	Trees uprooted, considerable structural damage. Exceptionally high waves, visibility affected.	28 – 31
11	Violent Storm	Widespread damage	31 – 37
12	Hurricane	Air is filled with spray and foam.	> 37

Source: (NOAA , 2008)

Figure 44. **Strong wind hazard map of five year return period**



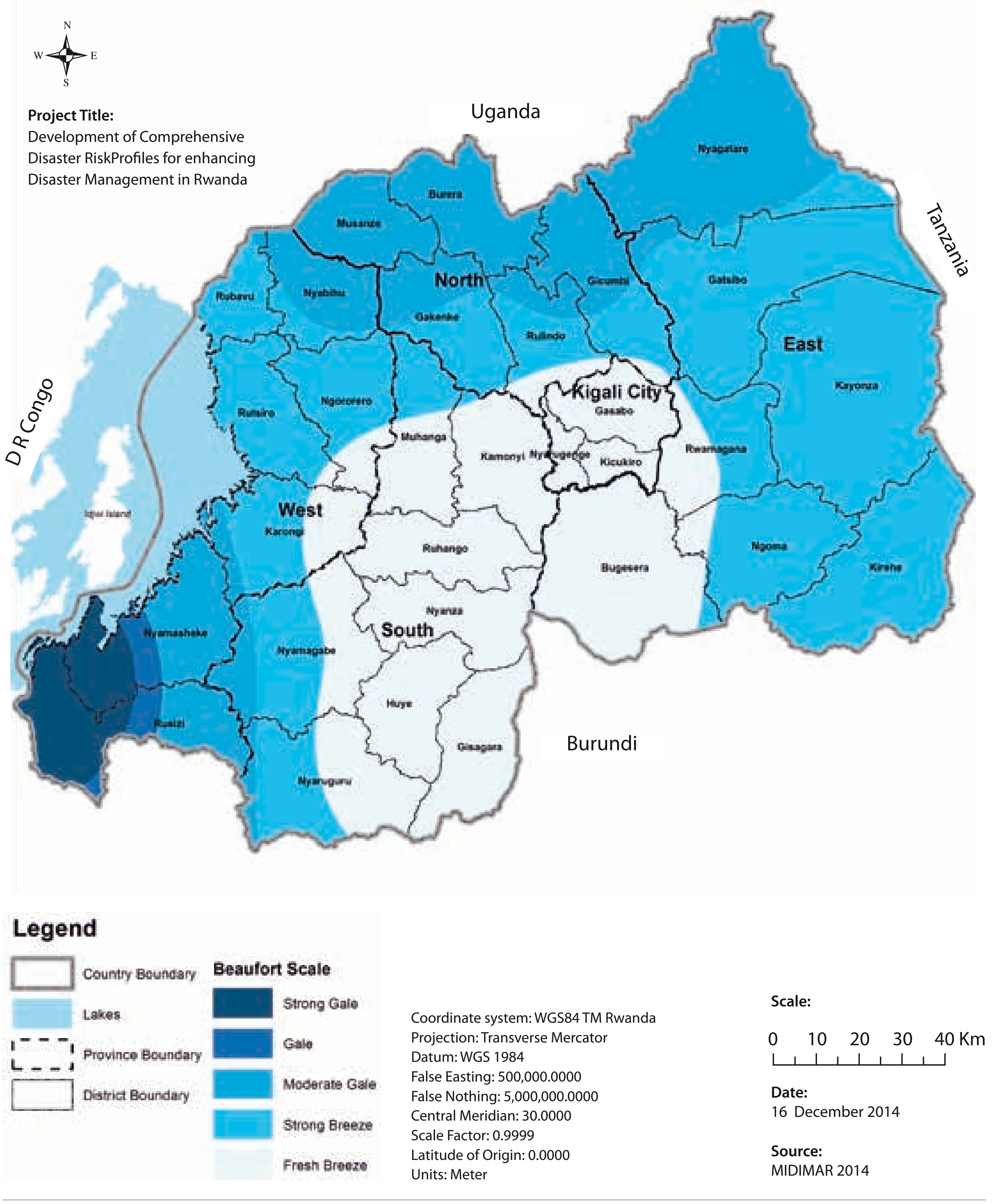
Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 10 20 30 40 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

Figure 45. Strong wind hazard map of ten year return period



4.5.4 Windstorm hazard zonation maps

- The zonation mapping was conducted for two return periods: five and ten years. The zonation map is shown below in Figure 44 and 45.

4.5.5 Windstorm hazard analysis

Considering a five year return period, 9% of the total area of the country is affected by moderate to strong gale. The districts of Rusizi and Nyamasheke are the most exposed to moderate and strong Gale.

For the ten year return period analysis, a small increase in areas exposed to moderate-strong gale were observed. Still the districts of Rusizi and Nyamasheke are the ones highly exposed to Gale and Strong gale wind hazards. Another 29% of the country surface is likely to experience different classes of gale (moderate to strong).

The recorded data on wind speed predict the smallest impact based on the description of Beaufort wind scale. The strongest recorded wind speed is strong gale of which, the description of potential damages is *"Straight structural damage, e.g. slates and chimney pots removed from the roofs. High waves, crest start to roll over"*, with wind speed varying between 22 and 28 m/s. as reported by Beaufort wind scale (Table 36). However, many districts

Table 38. Area (%) exposed to different wind speed categories (5 year return period)

District	Strong Gale	Gale	Moderate Gale	Strong Breeze	Fresh Breeze
Bugesera	0	0	0	0	100
Burera	0	0	0	100	0
Gakenke	0	0	0	77	23
Gasabo	0	0	0	0	100
Gatsibo	0	0	0	91	9
Gicumbi	0	0	0	82	18
Gisagara	0	0	0	0	100
Huye	0	0	0	0	100
Kamonyi	0	0	0	0	100
Karongi	0	0	0	47	53
Kayonza	0	0	0	42	58
Kicukiro	0	0	0	0	100
Kirehe	0	0	0	0	100
Muhanga	0	0	0	5	95
Musanze	0	0	0	100	0
Ngoma	0	0	0	0	100
Ngororero	0	0	0	15	85
Nyabihu	0	0	0	97	3
Nyagatare	0	0	12	88	0
Nyamagabe	0	0	1	32	67
Nyamasheke	0	18	64	18	0
Nyanza	0	0	0	0	100
Nyarugenge	0	0	0	0	100
Nyaruguru	0	0	0	0	73
Rubavu	0	0	0	0	90
Ruhango	0	0	0	0	100
Rulindo	0	0	0	0	41
Rusizi	6	35	49	10	0
Rutsiro	0	0	0	37	63
Rwamagana	0	0	0	6	94
Grand Total	**1**	**2**	**6**	**36**	**55**

Table 39. Area (%) exposed to different wind speed categories (10 year return period)

District	Strong Gale	Gale	Moderate Gale	Strong Breeze	Fresh Breeze
Bugesera	0	0	0	3	97
Burera	0	0	100	0	0
Gakenke	0	0	43	56	0
Gasabo	0	0	0	0	100
Gatsibo	0	0	5	95	0
Gicumbi	0	0	61	35	4
Gisagara	0	0	0	0	100
Huye	0	0	0	0	100
Kamonyi	0	0	0	0	98
Karongi	0	0	26	49	25
Kayonza	0	0	0	100	0
Kicukiro	0	0	0	0	100
Kirehe	0	0	0	100	0
Muhanga	0	0	0	36	64
Musanze	0	0	100	0	0
Ngoma	0	0	0	90	10
Ngororero	0	0	0	80	20
Nyabihu	0	0	77	23	0
Nyagatare	0	0	89	11	0
Nyamagabe	0	0	16	47	37
Nyamasheke	30	14	56	0	0
Nyanza	0	0	0	0	100
Nyarugenge	0	0	0	0	100
Nyaruguru	0	0	8	43	48
Rubavu	0	0	4	96	0
Ruhango	0	0	0	0	100
Rulindo	0	0	26	51	22
Rusizi	56	11	33	0	0
Rutsiro	0	0	14	84	2
Rwamagana	0	0	0	58	42
Grand Total	**4**	**1**	**24**	**42**	**29**

(mainly eastern province) believed to suffer from strong wind hazards and record many damages. The reason is the lack of meteorological stations in the region and the level of wind intensity is underestimated for those districts in the eastern provinces. However, these did not come out of this analysis due to data limitations, as earlier mentioned.

4.5.6 Application in disaster management and development planning

The strong wind hazard maps can be used for different purposes:

- Making decisions about physical and infrastructural development in the country. The maps will help policy makers and decision makers to understand the strong winds distribution across the country and help them to take necessary action to sustain the development through the introduction of necessary programs and measures.
- All the map results will be useful for the planning and design departments to make decisions.
- These will be the basis for future research aiming at better hazard mitigation at larger scale.
- The map will help national and international NGOs to prioritize DRR strategies in highly affected areas.

4.5.7 Limitations

The main limitation of this windstorm analysis has been the data availability. Although more than 190 weather stations are operational across the country, many were installed only in 2013 and have just one year recorded data. To accurately model the windstorm hazard, it requires a long period recorded data. For this study, only three stations (Kanombe, Kamembe and Gisenyi) have more than five years recorded data. To make the interpolation approach possible, the model needed spatially distributed data covering the whole territory as well. The possibility was to retain all weather stations with at least three years of data. That's why the geo-statistical interpolation of existing stations' values underestimated the winds hazard in some districts affected by strong wind hazards in the past.

4.5.8 Recommendations

Daily monitoring of wind information is highly recommended. In addition, there is a need of a networking system of strong wind monitoring and observation which include neighbouring countries especially Tanzania where most of the winds originate from. Strong wind hazard assessment should also be carried out at the local scale in the locations where strong winds are most likely to take place. This can result in a more detailed hazard mapping of windstorm-prone areas that can address some of the gaps identified in this report. The windstorm hazard maps must be updated after at least three years when the data of different meteorological stations will be available. It will allow mapping of the hazard with more accuracy. But to facilitate this task, an organized data collection and treatment system must be established by the Rwanda Meteorology Agency.

Chapter V

Exposure Assessment

5.1 Introduction

5.1.1 What is exposure?

Exposure refers to people, communities and their assets that are exposed to a particular hazard. Exposure refers to the inventory of elements in an area in which hazard event may occur. For this study, the following elements at risk[18] are considered: population, residential building, agriculture (crops), healthcare facilities, education facilities, and transportation facilities (roads). The objective of exposure assessment is to identify selected exposed elements and determine their levels of risk and how such risks affect major economic sectors. It considers assets located in hazard-prone areas, the development of asset profiles, and an analysis of their proneness to various natural hazards.

Exposure can be defined as the total value of elements at risk. It is expressed as the number of human lives and the value of the properties or assets that can potentially be affected by hazards. Exposure is a function of the geographic location of the elements at risk. Exposure assessment is an intermediate step of the whole risk assessment process, which links hazard assessment with assets under consideration. It will provide input to the vulnerability, as demonstrated in Chapter VI.

This chapter presents the exposure assessment of different elements at risk considered for this study such as population, crop (agriculture), residential building, health facilities, education facilities (schools) and transportation infrastructure. It also details the methodology of exposure assessment used for the four hazards namely: drought, landslide, earthquake and windstorm. The exposure of elements at risks to floods is not analysed in this study due to the lack of information aggregated to catchment level while the flood hazard assessment was done by catchment. Available information is aggregated by administrative entities.

5.1.2 Objective and scope of the exposure assessment

The objective of the exposure assessment or profiling is to create a national exposure database of key assets relating to the major economic sectors. It also includes a quantification of a number of assets lying in hazard prone areas, the development of asset profiles and an analysis of their proneness to various natural hazards.

The scope of the exposure assessment includes the following:

- Exposure assessment collects all data related to the various economic sectors' assets from nodal and focal departments. Major sectors include agriculture, housing, health, education and transportation. The analysis is carried out for the sectors that have the potential to be significantly affected and whose detailed data is available. Updated data and information from various relevant sources are collected. The sources are primarily from the National Institute of Statistics of Rwanda (NISR), the Ministry of Education, the Ministry of Health and the Ministry of Infrastructure.

- The spatial sectoral information (housing, population etc.) is overlaid on hazard intensity/susceptibility maps. By applying the GIS tool, the exposed assets are quantified.

- The analysis provides the national sectoral profile located in the hazard zones. The analysis has been carried out based on national and district data.

[18] 'Elements at risk' imply [or has the implication of] objects being located in a hazard-prone area.

5.2 Methodology for exposure assessment

This paragraph demonstrates the methodology for Exposure Assessment, also known as profiling. It explains how the scenarios of the various hazard events are selected as well as the elements at risk. Finally, it presents the structure of the exposure assessment.

5.2.1 Selection of hazard scenarios

As stated in the introduction, four hazards are included in the exposure assessments, namely drought, landslide, earthquake and windstorms. From each hazard one or two scenarios are taken into account in order to do the assessment. For drought, two scenarios have been taken into account: Season A and Season B representing main cropping season in the country. For landslide only one scenario with three levels of susceptibility (very high, high and moderate) is used. In the case of earthquake, two scenarios were analysed for hazard assessment. For exposure assessment, only the scenario of 2475 years return period is taken in account because the recorded intensity of MMI VII and VI are only the one that can cause significant damages according to findings. Windstorm hazard assessment has been done for two scenarios too. But one of 10 years return period will be analysed for exposure assessment because it is the only one that can cause significant damages.

Hazard intensity maps of different return periods used for the exposure assessment are listed in Table 40 below.

Table 40. Considered hazard scenarios of different return periods for exposure analysis

S/N	Hazard	Return Period	
1	Return Period	-	Season A and B, for three drought susceptibility classes: very high, high and moderate susceptibility
2	Landslide	-	Three susceptibility classes: Very high, high and moderate
3	Earthquake	2475 years	Intensity of MMI VII intensities
4	Storms	10-year return period	Moderate gale, gale and strong gale

5.2.2 Targeted elements at risk

The analysis will cover population, housing, agriculture, health, education and transportation sectors. Elements at risk are identified by overlaying geo-referenced inventory maps of elements at risk with hazard maps in a GIS setting.

The spatial interaction between the elements at risk and the hazard footprints was depicted in GIS by simple overlaying of the hazard map with the elements at risk map. The element at risk dataset are aggregated at district level. The aim of the exposure analysis is to build an exposure database that can be used for the assessment of the vulnerability of the elements at risk for four hazards: landslide, drought, earthquake, and windstorm.

5.3 Thematic exposure profiles

This section presents different exposure assessments by hazard. Four exposure assessments have been done: drought, landslide, earthquake and windstorms. Each exposure starts with an overview of the hazard events of the particular hazard in Rwanda. Then the characterization of exposure profiles is demonstrated. It will demonstrate the different scenarios of each hazard (e.g. two scenarios for drought: Season A and Season B and one scenario for earthquake: the 2475 years return period). Then the elements at risk are demonstrated per hazard (e.g. housing or population) as well as the intensity levels.

5.3.1 Exposure to drought

Undertaking the drought exposure assessment helps to provide information which could be used to improve the agriculture sector including food security. The drought exposure assessment is only limited to analysing the exposure of the agriculture sector specifically in terms of total cultivated area and production volume of major crops. It quantifies the agricultural asset, which may be affected by severe drought. It aims to estimate the total cultivated area in hectares (ha) and the amount of crop production in tonnage (t) located in drought prone areas.

Scenarios

A drought hazard assessment (in Chapter IV) has developed drought hazard susceptibility maps for two seasons: Season A and Season B considering the probability of occurrence (as explained in detail in the drought hazard assessment methodology and specifically detailed in Chapter IV, Section 4.1.4, Paragraph 1).

Elements at risk

The exposure of the agricultural sector is analysed in terms of: total cultivated area and the volume of crop production of major crops produced in Rwanda namely maize, sorghum, rice, ordinary beans, climbing beans, banana, Irish potato and cassava.

Intensity levels

The drought hazard assessment has classified drought susceptibility into five classes (very high, high, moderate, low and very low). For the drought exposure assessment, the analysis is made for the two seasons and considered only moderate to very high (3 out of 5) susceptibility classes without including low and very low. Very high indicates > 30% likelihood for a severe drought to occur. High indicates 20-30% and moderate indicates 10-20%. The low susceptibility class indicates only 5-10% likelihood for severe drought to occur and for very low susceptibility class indicates less than 5% likelihood for severe drought to occur, hence, they are not included in the analysis (see Table 14).

5.3.1.1 Overview

Based on the historical data, eleven agricultural droughts occurred in the country leading to crop failure, food shortage and famine (see Table 13). Almost all drought events occurred in either southern province or the eastern province. Three drought events affected the whole country: in 1976-1977, in 1984 and in 2005. The first national drought affected the the most number of people compared to the other droughts in Rwanda where 1.7 million persons were affected. The 2006 drought affected over 1 million people. The most recent drought occurred in June 2014 and affected the districts of Bugesera and Kayonza in the eastern province. Crops in 12 out of the 15 sectors of Bugesera district completely failed (MIDIMAR, 2014). Around 73% of the Rwandan population is working in the agricultural sector (NISR, 2014). Agricultural drought is a challenge they face.

5.3.1.2 Characterization of drought exposure profiles

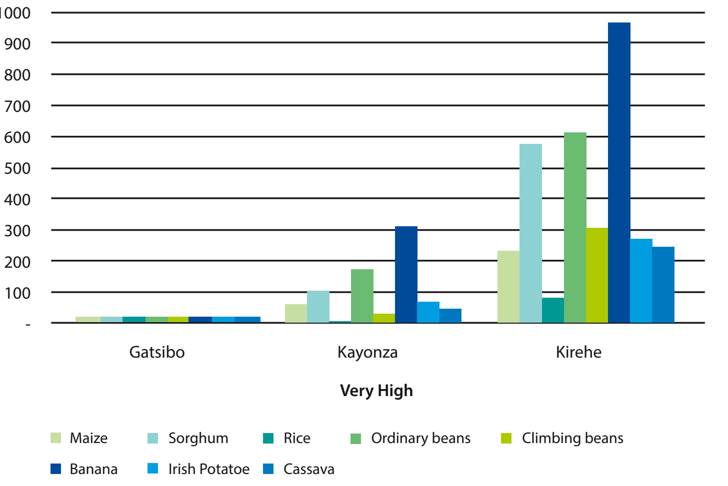
This section demonstrates the figures and analysis of the drought exposure assessment. The first section characterizes the drought exposure in Season A. The second section demonstrates the drought exposure in Season B.

Drought exposure in Season A

a) Agricultural exposure in terms of cultivated area

Figure 46 shows the cultivated area (ha) by major crops exposed to severe drought at very high susceptibility in Season A. The districts of Kirehe and Kayonza in the eastern province are areas of concern, as they are prone to very high drought susceptibility as revealed in the drought hazard susceptibility map. The drought hazard map also shows Gatsibo District as prone to very high drought susceptibility, however, no areas are cultivated with the eight major crops considered in the analysis.

Figure 46. Cultivated area (ha) exposed to severe drought at very high susceptibility in Season A



Specifically, Kirehe District have around 3,300 hectares of land area cultivated with various major crops produced in Season A are exposed to very high drought. These include as follows: 960 ha of banana, 610 ha of ordinary beans, 570 ha of sorghum, 360 ha of climbing beans, 270 ha of Irish potato, 240 ha of cassava, 230 ha of maize and 80 ha of rice. Kayonza District have approximately 760 hectares of land area cultivated with various major crops produced in Season A are exposed to very high drought. These consist of 310 ha of banana, 170 ha of ordinary beans, 100 ha of sorghum, 70 ha of Irish potato, 50 ha of maize, 40 ha of cassava, 10 ha of climbing beans, and 4 ha of rice. In total, there is about 4,000 hectares of land area cultivated with the eight major crops exposed to very high drought susceptibility in Season A.

Figure 47 shows the cultivated area (ha) exposed to severe drought at high susceptibility in Season A. The three (3) districts of Kayonza, Kirehe and Gatsibo have cultivated areas exposed. In total, 11,900 hectares of land area cultivated with the eight major crops are exposed to high drought in Season A with a total of 6,400 hectares of this in Kayonza District, 3,260 hectares in Kirehe District, and 2,200 hectares is located in Gatsibo District. Consistently, areas cultivated with Banana (4,260 ha) register as the largest area exposed to high drought in Season A, followed by areas cultivated with ordinary beans (2,580 ha), areas cultivated with sorghum (1,660 ha), areas cultivated with maize (970 ha), areas cultivated with Irish potato (950 ha), areas cultivated with cassava (730 ha), areas with climbing beans (550 ha), and areas cultivated with rice (180 ha).

Figure 47. Cultivated area (ha) exposed to severe drought at high susceptibility in Season A

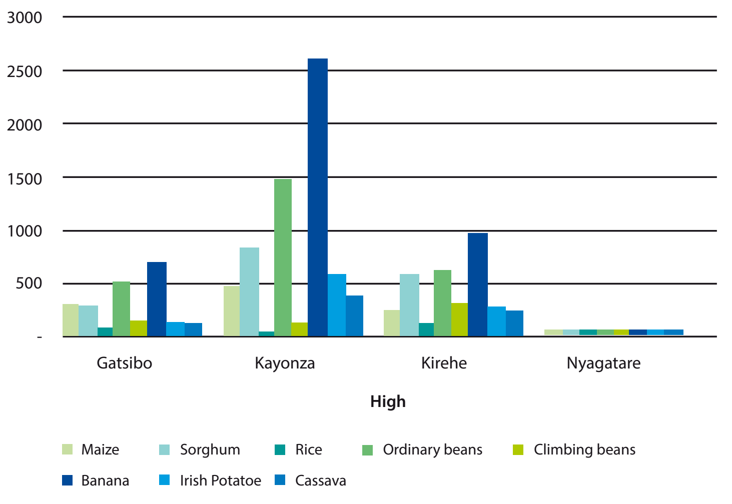


Figure 48 shows the cultivated area (ha) exposed to severe drought at moderate susceptibility in Season A. Six (6) out of the seven districts in the Eastern Province have areas cultivated with the eight major crops exposed. The total exposed cultivated area is 43,300 hectares with 15,000 ha in Nyagatare District, 11,500 ha in Kayonza District, 8,460 ha in Gatsibo District, 7,080 ha in Kirehe District, 1240 ha in Rwamagana and 34 ha in Ngoma. In terms of exposure by types of crops these areas are cultivated of, banana has about 13,850 hectares exposed. This also include 10,600 ha of ordinary beans, 5,390 hectares of sorghum, 5,060 hectares of maize, 2,870 hectares of cassava, 2,640 hectares of Irish potato, 1,980 hectares of climbing beans, and 940 hectares of rice.

Figure 48. Cultivated area (ha) exposed to severe drought at moderate susceptibility in Season A

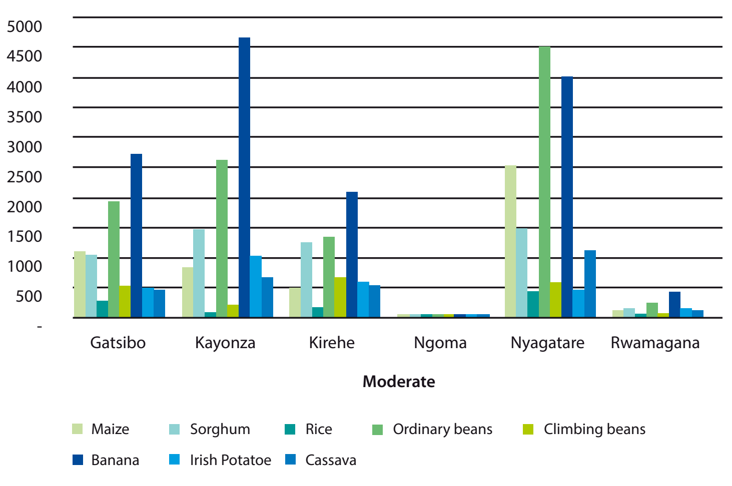
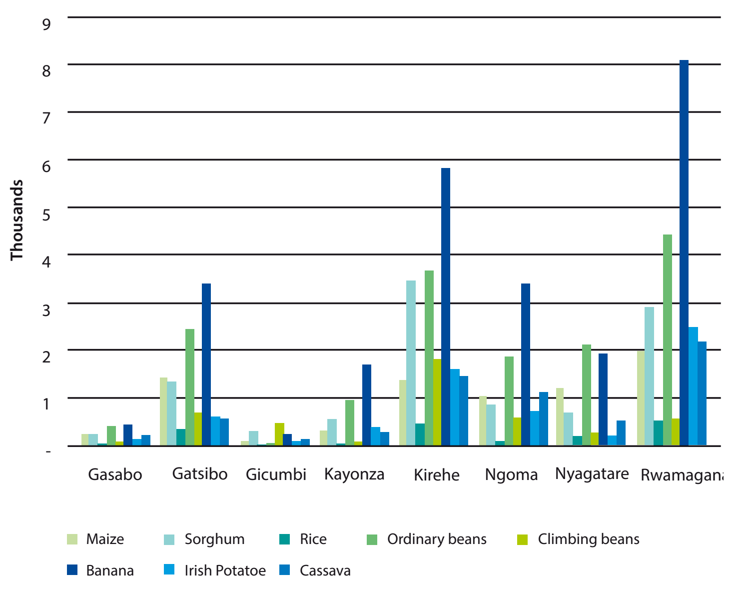


Figure 49 shows the cultivated area (ha) exposed to severe drought at low susceptibility in Season A. Eight (8) Districts have areas cultivated with the eight major crops exposed. These include Gasabo District (1,740ha) in Kigali City, Gicumbi District (1,300 ha) in the northern province and the districts of Gatsibo (10,740 ha), Kayonza (4,180ha), Kirehe (19,680 ha), Ngoma (9,730 ha), Nyagatare (7,120 ha) and Rwamagana (23,100 ha) in the eastern province. The total exposed area is 77,600 hectares. Banana tops the list of eight crops planted in the aforementioned exposed areas with 24,900 hectares. It also includes 15,970 hectares of ordinary beans, 10,280 hectares of sorghum, 7,640 hectares of maize, 6,430 hectares of cassava, 6,200 hectares of Irish potato, 4,520 hectares of climbing beans, and 1,670 hectares of rice.

Figure 49. Cultivated area (ha) exposed severe drought at low susceptibility in Season A

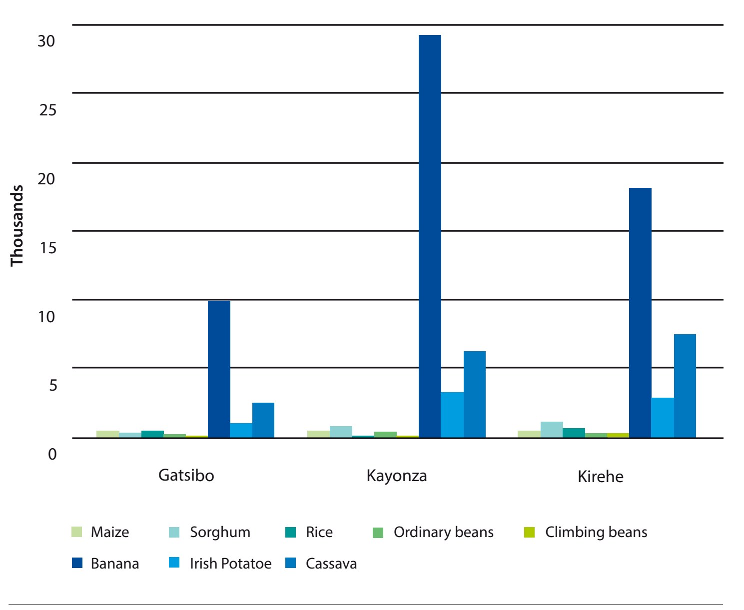


b) Agricultural exposure in terms of crop production

Figure 50 shows the volume of crop production exposed to severe drought at very high susceptibility in Season A. The districts of Kayonza. Kirehe and Gatsibo in the Eastern Province are areas of concern as shown in the drought hazard susceptibility map in Chapter IV. The total volume of crop production exposed is 86,600 tons.

Specifically, Kayonza District has around 40,500 tons of various major crops produced in Season A exposed; Kirehe

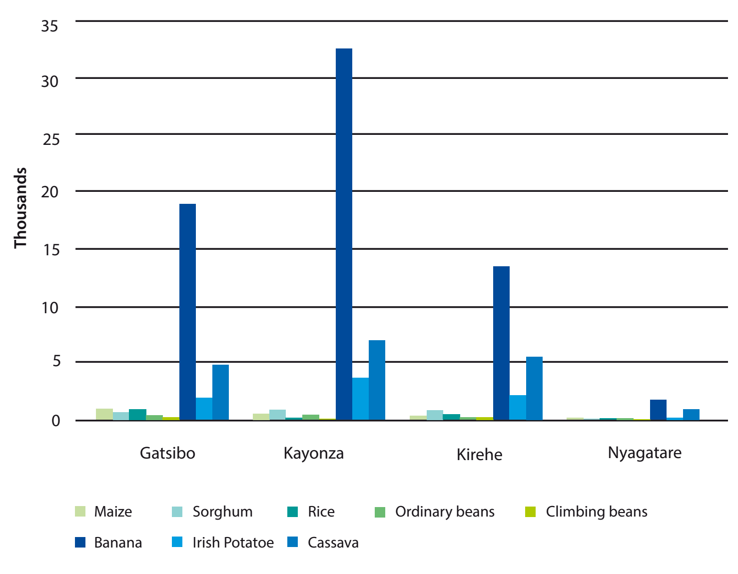
Figure 50. Crop production (in tons) exposed to severe drought at very high susceptibility in Season A



District has about 31,100 tons and Gatsibo District has 15,000 tons of crops exposed. Among these, banana is on top of the list with about 57,100 tons in the three districts. This is followed by cassava (16,230 t), Irish potato (7,110 t), sorghum (2,200 t), maize (1,400 t), rice (1,250 t), ordinary beans (830 t), and climbing beans (440 t).

Figure 51 shows the volume of crop production exposed to severe drought at high susceptibility in Season A. The districts of Kayonza. Gatsibo, Kirehe and Nyagatare in the eastern province are areas of concern as they are prone to high drought susceptibility as revealed in the drought hazard susceptibility map (see Figure 25). The total volume of crop production exposed is 99,900 tons.

Figure 51. Crop production (in tons) exposed to severe drought at high susceptibility in Season A

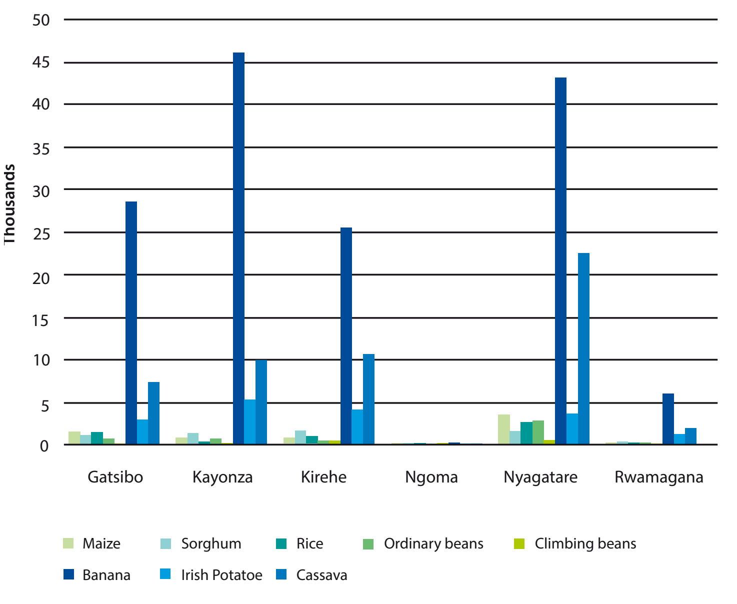


Specifically, Kayonza District has around 45,000 tons of various major crops produced in Season A exposed; Gatsibo District has 28,600 tons, Kirehe District has about 23,080 tons and Nyagatare District has 3,160 tons of crops exposed. Among these, banana is on top of the list with about 66,400 tons in the four districts. This is followed by cassava (18,200 t), Irish potato (7,780 t), sorghum (2,370 t), maize (1,900 t), rice (1,630 t), ordinary beans (1,100 t), and climbing beans (480 t).

Figure 52 shows the volume of crop production exposed to severe drought at moderate susceptibility in Season A. The districts of Nyagatare, Kayonza, Kirehe, Gatsibo, Rwamagana and (a small area of) Ngoma in the eastern province are areas of concern as they are prone to moderate drought susceptibility as revealed in the drought hazard susceptibility map (see Figure 25). The total volume of crop production exposed is 239,700 tons.

Specifically, Nyagatare (79,390 t), Kayonza (63,800 t), Kirehe (43,650 t) and Gatsibo District (43,110) have large amounts of various major crops produced in Season A exposed to severe drought at moderate susceptibility. The amount of crops produced in Rwamagana and Ngoma exposed to severe drought at moderate susceptibility is lower with respectively 9,530 and 210 tons. Among these, banana is on top of the list with about 148,780 tons in the six districts. This is followed by cassava (51,930 t), Irish potato (16,630 t), maize (6,310 t), sorghum (5,420 t), rice (5,180 t), ordinary beans (4,290 t), and climbing beans (1,170 t).

Figure 52. Crop production (in tons) exposed to severe drought at moderate susceptibility in Season A



Drought exposure in Season B

a) Agricultural exposure in terms of cultivated area

Figure 53 shows the cultivated area (ha) exposed to severe drought at very high susceptibility in Season B. Three districts i.e. Kayonza, Kirehe and Gatsibo are the areas exposed considering they are prone to very high drought susceptibility (see Figure 26). A total of 21,400 hectares of land area cultivated with the eight major crops are exposed. Notably, compared to Season A, the total cultivated area exposed has increased for Season B. Specifically, Kayonza District has more cultivated areas exposed numbering to 15,050 hectares comprising of 6,100 ha of banana, 3,440 ha of ordinary beans, 1,930 ha of sorghum, 1,330 ha of Irish potato, 1,080 ha of maize, 870 ha of cassava, 260 ha of climbing beans, and 70 ha of rice. Kirehe District have approximately 6,300 hectares of land area cultivated with various major crops produced in Season B are exposed to very high drought. These consist of 1,870 ha of banana, 1,180 ha of ordinary beans, 1,100 ha of sorghum, 590 ha of climbing beans, 520 ha of Irish potato, 470 ha of cassava, 440 ha of maize and 150 ha of rice. Gatsibo District has a total of 59 hectares of land area cultivated with the eight major crops exposed to very high drought in Season B. These include 19 ha of banana, 13 ha of ordinary beans, 8 ha of maize, 7 ha of sorghum, 4 ha of climbing beans, 3 ha each of Irish potato and cassava, and 2 ha of rice.

Figure 53. Cultivated area (ha) exposed to severe drought at very high susceptibility in Season B

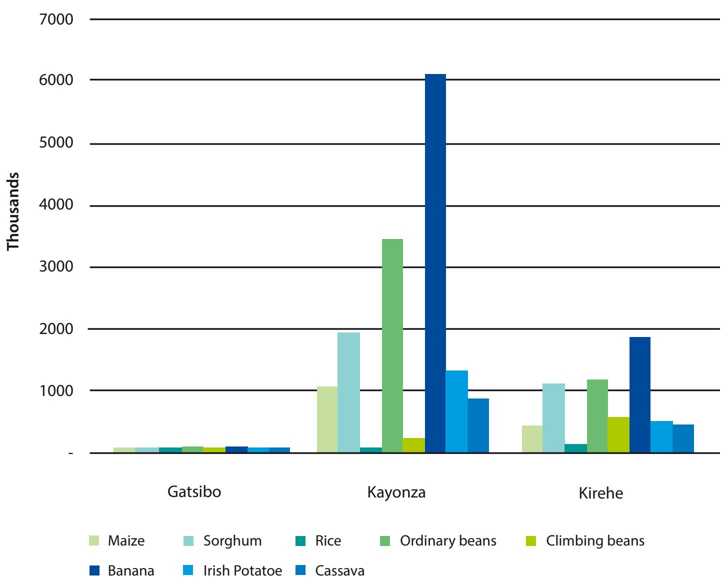


Figure 54 shows the cultivated area (ha) exposed to severe drought at high susceptibility in Season B. Eleven (11) districts have areas cultivated with the eight major crops considered in the analysis exposed. These include all the three districts of Kigali i.e. Gasabo (50 ha), Kicukiro (1,880 ha) and Nyarugenge (1,010 ha); all the 7 districts in the eastern province i.e. Bugesera (14,940 ha), Gatsibo (19,660 ha), Kayonza (7,800 ha), Kirehe (8,670 ha), Ngoma (5,240 ha) and Nyagatare (10,050 ha) and Rwamagana (16,800 ha); and the district of Kamonyi (860 ha) in the southern province. In total, 86,970 hectares of land area cultivated with the eight major crops are exposed to high drought in Season A. In terms of types of crops exposed, banana tops the list with 27,640 hectares exposed. This is followed by ordinary beans (19,640 ha), sorghum (10,640 ha), maize (9,220 ha), cassava (8,270 ha), Irish potato (5,800 ha), climbing beans (3,920 ha), and rice (1,880 ha).

Figure 54. Cultivated area (ha) exposed to severe drought at high susceptibility in Season B

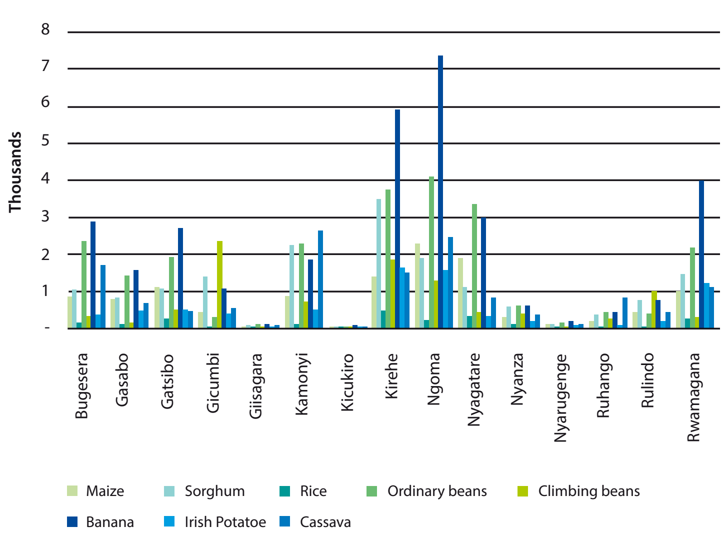


Figure 55 shows the cultivated area (ha) exposed to severe drought at moderate susceptibility in Season B. Considering the drought hazard prone areas (see Chapter IV, Figure 26), fifteen (15) districts have cultivated areas of about 116,300 hectares exposed. These include the districts of Bugesera (9,650 ha), Gatsibo (8,520 ha), Kirehe (19,950 ha), Ngoma (21,100 ha), Nyagatare (11,240 ha), and Rwamagana (11,340 ha) in the eastern province; Gasabo (6,000 ha), Kicukiro (180 ha) and Nyarugenge (670 ha) in Kigali City; Gicumbi (6,420 ha) and Rulindo (3,870 ha) in the northern province; and Kamonyi (11,240 ha), Gisagara (340 ha), Nyanza (3,140 ha) and Ruhango (2,640 ha) in the southern province. In terms of exposure by types of crops in the cultivated areas, banana has about 32,300 hectares exposed. This also include 23,430 hectares of ordinary beans, 16,170 hectares of sorghum, 13,630 hectares of cassava, 11,630 hectares of maize, 9,600 hectares of climbing beans, 7,470 hectares of Irish potato, and 2,080 hectares of rice.

Figure 55. Cultivated area (ha) exposed to severe drought at moderate susceptibility in Season B

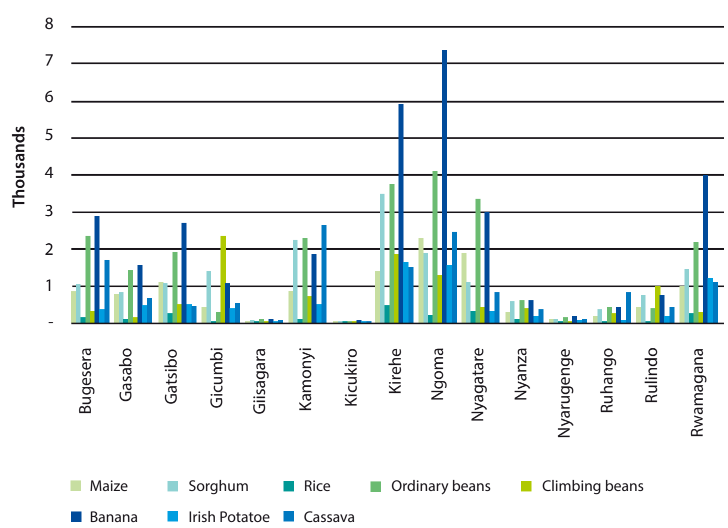
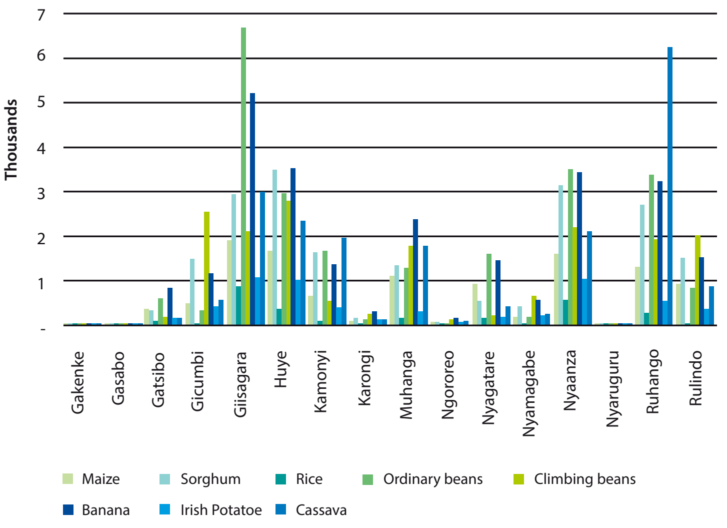


Figure 56 shows the cultivated area (ha) exposed to severe drought at low susceptibility in Season B. Considering the drought hazard prone areas (see Chapter IV, Figure 26), fifteen (15) districts have cultivated areas of around 123,870 hectares exposed. These include the districts of Gatsibo (2,560 ha) and Nyagatare (5,400 ha) in the eastern province; Gakenke (65 ha), Gicumbi (6,900 ha) and Rulindo (7,940 ha) in the northern province; Kamonyi (8,200 ha), Gisagara (23,660 ha), Nyanza (17,470 ha), Huye (18,090 ha), Muhanga (10,020 ha), Nyamagabe (2,430 ha), Nyaruguru (20 ha) and Ruhango (19,500 ha) in the southern province; and districts of Karongi (1,085 ha) and Ngororero (520 ha) in the western province. In terms of exposure by types of crops in the cultivated areas, banana has about 24,940 hectares exposed. This also include 23,090 hectares of ordinary beans, 19,660 hectares of cassava, 19,590 hectares of sorghum, 17,150 hectares of climbing beans, 11,125 hectares of maize, 5,740 hectares of Irish potato, and 2,580 hectares of rice.

Figure 56. Cultivated area (ha) exposed to severe drought at low susceptibility in Season B



b) Agricultural exposure in terms of crop production

Figure 57 shows the volume of crop production exposed to severe drought at very high susceptibility in Season B. The districts of Kayonza. Kirehe and Gatsibo in the Eastern Province are areas of concern (see Figure 26). The total volume of crop production exposed is around 189,650 tons.

Specifically, Kayonza District has around 127,540 tons of various major crops produced in Season B exposed; Kirehe District has about 54,720 tons and Gatsibo District has 7,380 tons of crops exposed. Among these, banana is on top of the list with about 128,560 tons in the three districts. This is followed by cassava (34,050 t), Irish potato (15,830 t), sorghum (4,500 t), maize (2,470 t), rice (1,780 t), ordinary beans (1,700 t), and climbing beans (720 t).

Figure 57. Crop production (in tons) exposed to severe drought at very high susceptibility in Season B

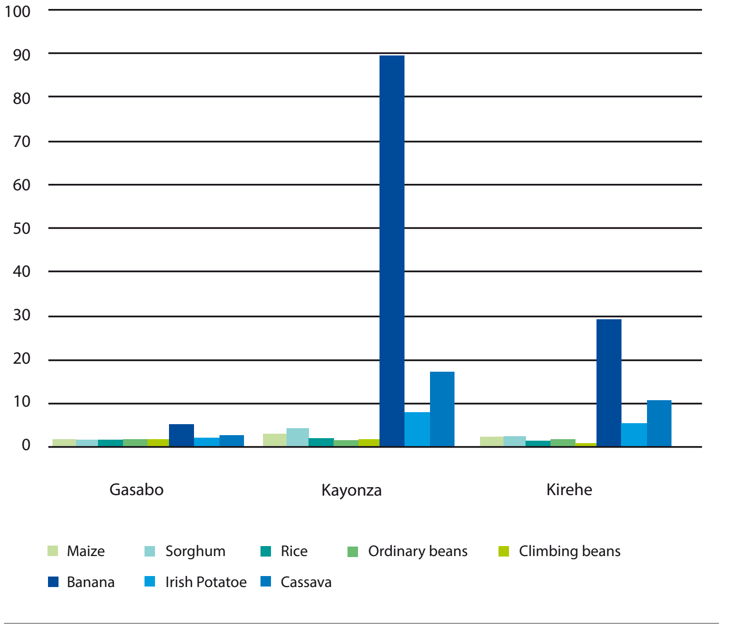


Figure 58 shows the volume of crop production exposed to severe drought at high susceptibility in Season B.[19] The districts of Gatsibo and Rwamagana in the Eastern Province are areas of main concern followed by Nyagatare, Bugesera, Kirehe, Kayonza, Ngoma, Kigali and Kamonyi. They are prone to high drought susceptibility as revealed in the drought hazard susceptibility map (see Figure 26). The total volume of crop production exposed is 520,960 tons.

Specifically, Gatsibo and Rwamagana District have respectively around 124,740 and 123,600 tons of various major crops produced in Season B exposed; Nyagatare District has 59,700 tons, Bugesera District has about 52,360 tons, Kirehe has 51,450 tons, Kayonza has 42,760 tons, Ngoma has 40,290 tons, Kigali has 16,820 tons and Kamonyi District has 9,230 tons of crops exposed. Among these, banana is on top of the list with about 299,160 tons in the nine Districts. This is followed by cassava (134,780 t), Irish potato (41,520 t), maize (12,310 t), sorghum (12,130 t), rice (11,070 t), ordinary beans (7,460 t), and climbing beans (2,500 t).

Figure 58. Crop production (in tons) exposed to severe drought at high susceptibility in Season B

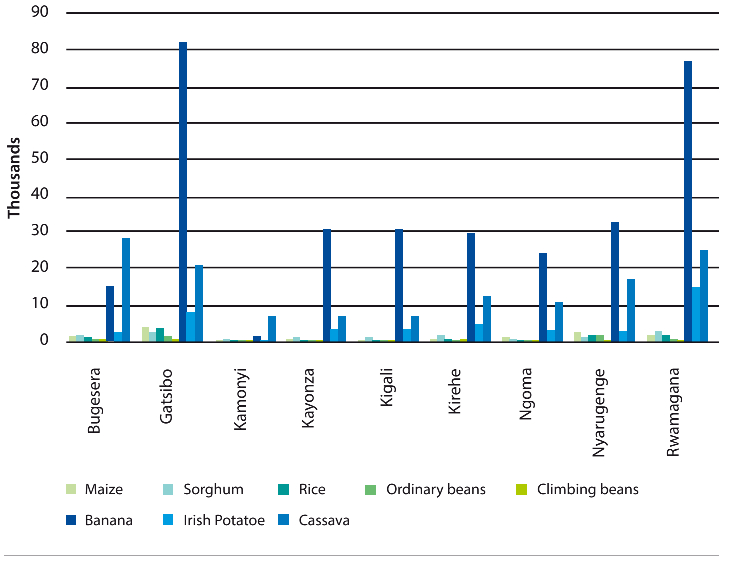
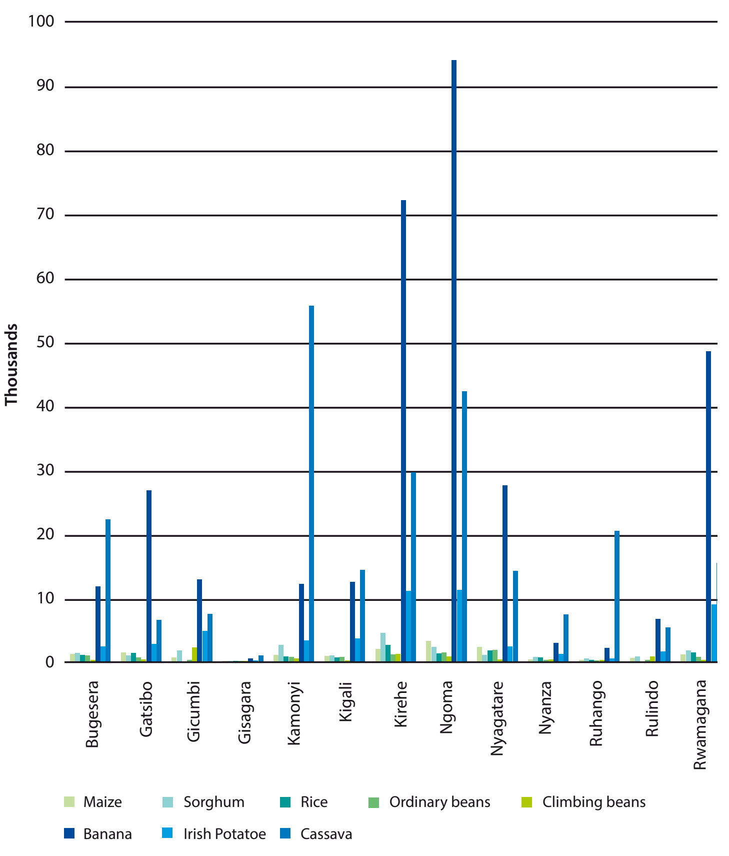


Figure 59 shows the volume of crop production exposed to severe drought at moderate susceptibility in Season B.[20] Nearly half of all Districts in Rwanda (13 out of 30) are prone to moderate drought susceptibility in Season B. The districts are located in all four out of five provinces namely Kigali City, Eastern, Northern, Southern Province (see Figure 26). The total volume of crop production exposed is 691,850 tons.

[19] The analysis is done by district except for the districts located in Kigali City (i.e. Gasabo, Kicukiro and Nyarugenge). As the crop production data was not available for these districts separately, the volume of the crop production is a total of these districts. For the purpose of this analysis, Kigali is considered as one unit.

[20] The analysis is done by district except for the districts located in the province of Kigali City (i.e. Gasabo, Kicukiro and Nyarugenge). As the crop production data was not available for these districts separately, the volume of the crop production is a total of these districts. For the purpose of this analysis, Kigali is considered as one unit.

Figure 59. Crop production (in tons) exposed to severe drought at moderate susceptibility in Season B



Specifically, Ngoma (157,090 t) and Kirehe District (124,650 t) have large amounts of various major crops produced in Season B exposed to moderate drought. The volume of crops are less exposed to severe drought at moderate susceptibility when produced in Rwamagana (78,750), Kamonyi (76,890), Nyagatare (51,515), Bugesera (41,380), Gatsibo (41,100), Kigali (34,170), Gicumbi (30,270 t), Ruhango (24,420 t), Rulindo (16,400 t), Nyanza (13,580 t) and Gisagara (1,600 t). Among these, banana is on top of the list with about 333,330 tons in the thirteen districts. This is followed by cassava (245,570 t), Irish potato (54,080 t), sorghum (18,460 t), maize (14,190 t), rice (11,210 t), ordinary beans (8,260 t), and climbing beans (6,740 t).

5.3.1.3 Comparative analysis of exposure profiles

The drought exposure profiles differ between the two scenarios: Season A and Season B. Foremost, it is noted that the cultivation and [by default] crop production is higher in Season B compared to Season A. In effect, the agricultural exposure is comparatively higher in Season B. There is pattern though in terms of districts and the types of crops exposed at different drought susceptibility levels in both Season A and B. The districts of Kayonza, Kirehe and Gatsibo in the eastern province are more exposed compared to the rest of the districts. However, all seven districts in the eastern province, the three districts in Kigali City and Kamonyi District in the southern province appeared to be exposed as well. Among the eight major crops considered in the analysis, banana, cassava and Irish potato appeared to be the most exposed compared to the rest of the crops.

The total cultivated area exposed to drought at moderate-very high susceptibility in Season B is 224,700 hectares higher by 26% compared to Season A which is 59,230 hectares. In terms of crop production, the exposure is also high in Season B totalling to about 1,402,500 tons of various crops produced. Meanwhile, in Season A there is 426,100 tons of various crops exposed which is about 30% lower compared to Season B.

5.3.1.4 Summary of key findings

- Drought exposure is high during Season B, both in terms of cultivated area and volume of crop production.
- Agricultural exposure to drought is apparent mostly in the eastern province. The districts of Kayonza, Kirehe and Gatsibo are areas of primary concern since the exposure of cultivated areas and crop production is consistent in these districts from moderate to very high susceptibility.
- The four other districts in the eastern province and the three districts of Kigali City (Gasabo, Kicukiro and Nyarugenge) are also exposed to drought at moderate and high susceptibility including Kamonyi in the southern province.
- In terms of crops, banana, cassava and Irish potato are the main crops which have higher volumes of production exposed.

5.3.2 Exposure to landslide

Landslide exposure assessment helps to provide information, which could be used to protect population and to improve settlement planning, housing sector, infrastructure and transportation sector.

Elements at risk

The landslide exposure assessment is limited to the exposure analysis of the following elements at risk: population, housing, health facilities, schools and roads.

Intensity levels

The landslide hazard assessment, as presented in Chapter IV, has developed landslide susceptibility maps. It has classified landslide into five (5) susceptibility classes (very high, high, moderate, low and very low). In this landslide exposure assessment only moderate, high and very high susceptibility classes are included in the analysis. The two other classes (low and very low) were not included as landslides are less likely to occur at these susceptibility levels, at 0.2 and 0 probability respectively.

5.3.2.1 Overview

Based on historical data, 28 landslide events have been recorded in the country within the period 1963 – 2013. As explained in paragraph 4.2.1, only since 2010 and the establishment of MIDIMAR, a systematic recording system is present in Rwanda. This system led to an accurate list of landslide events in the country. The figures show that during this period 74 people died, 22 persons got injured and over 573 houses were destroyed or damaged. The same districts experience landslides more than once (e.g. Burera, Ngororero, Rutsiro, Gasabo, Nyamagabe, Nyarugenge and Rulindo). Most districts that experience landslides are located in the Western or Northern Province. However, landslides do also occur in Nyamagabe (Southern Province) and Gasabo (Kigali City).

5.3.2.2 Characterization of exposure profiles

This section demonstrates the figures and analysis of the landslide exposure assessment. The first section presents the exposure of the population to landslide. The second section demonstrates the exposure of housing. The third section covers the exposure of health facilities to landslide followed by the exposure of education facilities. The final section covers the exposure of transportation sector to landslide.

Population exposure

The landslide exposure assessment for population includes analysis by gender, age, and levels of poverty. The analysis by age considered two classifications: working age population[21] and the dependent age[22] population. The analysis by levels of poverty considered the four levels classified and used by NISR: severely poor, moderately poor, vulnerable to poverty and not poor. The ensuing charts show the exposure of population to landslides at three susceptibility levels: very high, high and moderate.

a) Population exposure by gender

Figure 60 presents the population, classified by gender, exposed to landslide at very high susceptibility. Noting the landslide susceptibility map (in Figure 34), the highlands in western province and some parts of the southern and northern provinces are landslide prone areas with very high susceptibility. The exposure assessment revealed that about 3.34% of the total population are exposed to a landslide at very high susceptibility. Nyamagabe tops the list of districts with the highest number of population exposed to landslide at 53,622 persons (or 15.70% of its population). This is followed by Ngororero with 42,066 (or 12.60%); Rutsiro with 39,976 (or 12.31%); Muhanga with 31,905 (or 9.99%); Karongi with 28,674 (or 8.64%); Gakenke with 28,349 or (8.38%); Nyabihu with 26,281 (or 8.91%); Rubavu with 23,951 (or 5.93%); Nyaruguru with 19,813 (or 6.73%); and Burera with 13,934 (or 4.13%). The rest of the thirteen districts shown in Figure 15 have below 10,000 people exposed while the other seven districts do not appear as there are no exposed population in those areas (i.e. Kicukiro in Kigali, and six districts of the eastern province except Nyagatare).

Figure 60. Population exposed to landslide at very high susceptibility zones

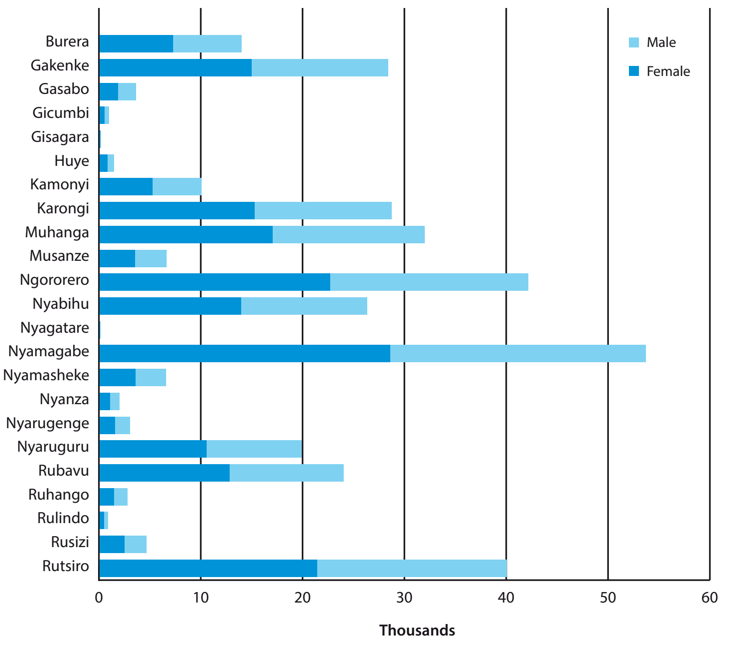


Figure 61 shows the population, classified by gender, exposed to landslide in high susceptibility zones. According to the landslide susceptibility map (in Figure 34), the highlands in western province and some parts of the southern and northern provinces are landslide prone areas with high susceptibility. The high susceptibility zones are mainly found in proximity of very high susceptibility zones. However, high susceptibility zones are also found in eastern province (Bugesera, Gatsibo) and Kigali City (Gasabo district). The exposure assessment revealed that about 11% of the total population are exposed to a landslide at high susceptibility. Nyabihu tops the list of districts with the highest number of population exposed to landslide at 148,941 persons (or 48% of its total population). This is followed by Ngororero with 120,979 (or 36% of district population); Most districts have between 11,726 (Bugesera) and 94,922 (Gakenke) persons exposed to a landslide at high susceptibility. All districts located in eastern province, except for Bugesera, have a ratio of < 6,135 (Gatsibo) to 8 (Kirehe) people exposed to landslide in high susceptibility zones.

[21] NISR classification of working age population is active population. This comprise of those within the age range of 20-64 years old.
[22] NISR classification of dependent age population is inactive population. This comprise of children aged 0-19 and elderly aged >64.

Figure 61. Population exposed to landslide at high susceptibility zones

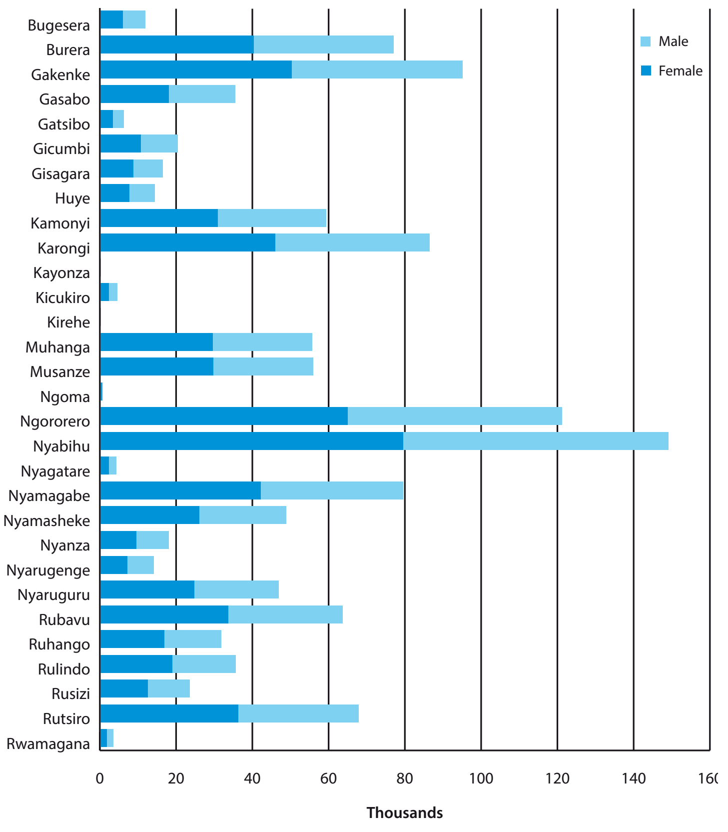


Figure 62. Population exposed to landslide at moderate susceptibility zones

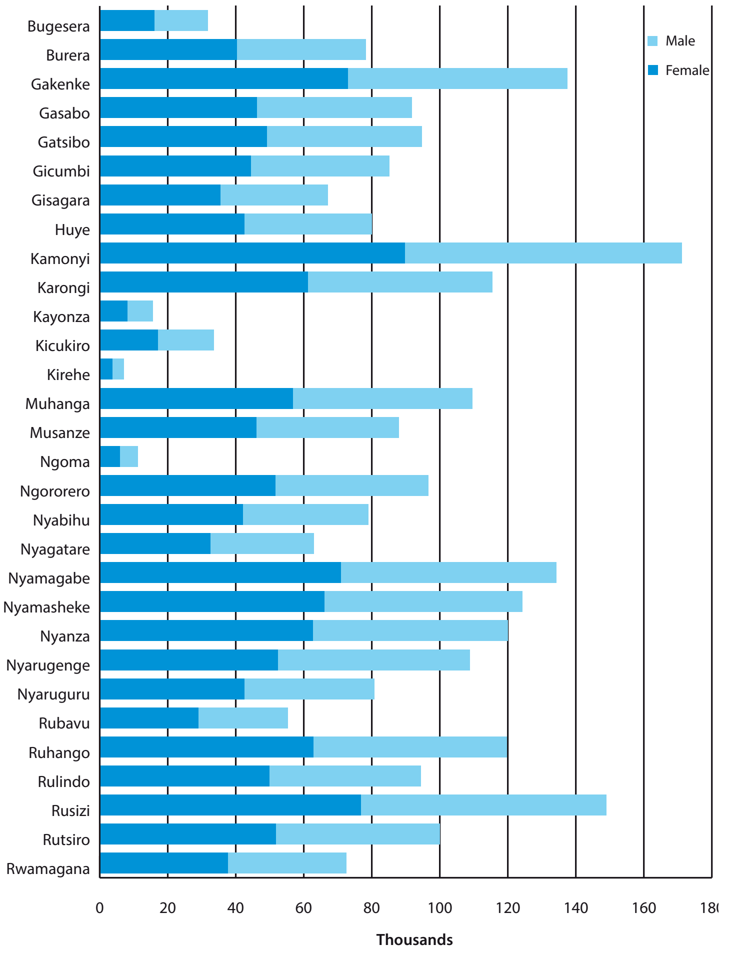


Figure 62 below presents the population, classified by gender, exposed to landslide in moderate susceptibility zones. According to the landslide susceptibility map (in Figure 34), most landslide prone areas with moderate susceptibility are found in and around the highlands in western province and parts of the southern and northern provinces. The farther the population is located from the highlands and mountainous area, the lower the susceptibility level becomes. Most of the districts with population exposed to landslides at moderate susceptibility are also found exposed to high susceptibility as explained in the previous paragraph. However, moderate susceptibility zones are found in every district of Rwanda. The exposure assessment revealed that about 2,612,209, or 25% of the total population, are exposed to a landslide at moderate susceptibility. Kamonyi tops the list of districts with the highest number of population exposed to landslide in moderate susceptibility zone with 171,175 persons (or 50% of total population).

b) Population exposure by age

Figure 63 below shows the population, classified by age, exposed to landslide in very high susceptibility zones. It distinguishes the active population, meaning the population falling within the working age of 20-64 (defined as working age) and the inactive population (dependent age), meaning the population falling within the dependent age of under 20 and above 64 (NISR, 2014). The highlands in western province and some parts of the southern and northern provinces are landslide prone areas with very high susceptibility (in Chapter IV, Figure 34). The exposure assessment revealed that 1,065,573 (86%) of the total population exposed to a landslide at very high susceptibility is labelled as active population compared to 177,113 (14%) labelled as inactive population. Most of these exposed people, both active and inactive, live in Nyamagabe (Active: 43,309 and Inactive 10,313), Ngororero (Active: 37,480 and Inactive: 4,585) and Rutsiro (Active: 35,244 and Inactive: 4,733). In most of the districts (15 out of 23 districts exposed to landslides in high susceptibility zones), the percentage of the active population ranges between 86 – 90. In six districts the percentage of the exposed active population exposed to landslide at very high susceptibility ranges from 80 – 85. In two districts, the percentage of active population exposed is below 80%; Nyarugenge (71%) and Gasabo (79%).

The same analysis of the exposure of active population (working age) and inactive population (dependent age) is made for high susceptibility zones. Figure 64 demonstrates the population exposed to landslide in high susceptibility zones, classified by age. Similarly, the highlands in Western Province and some parts of the Southern and Northern Provinces are landslide prone areas with high susceptibility. The exposure assessment revealed that 2,230,166 (85%) of the total population exposed to a landslide at high susceptibility is labelled as active population compared to 382,043 (15%) being inactive population. Most of these exposed people, both active and inactive, live in Nyabihu (Active: 120,238

Figure 63. Population exposed to landslide at very high susceptibility zones, by age

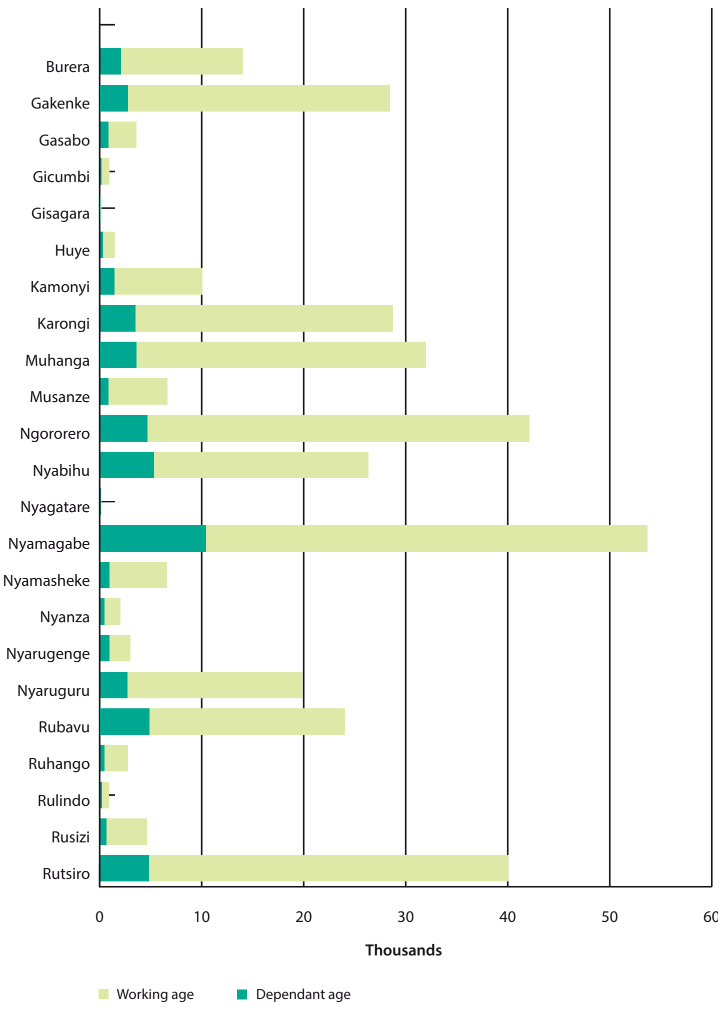
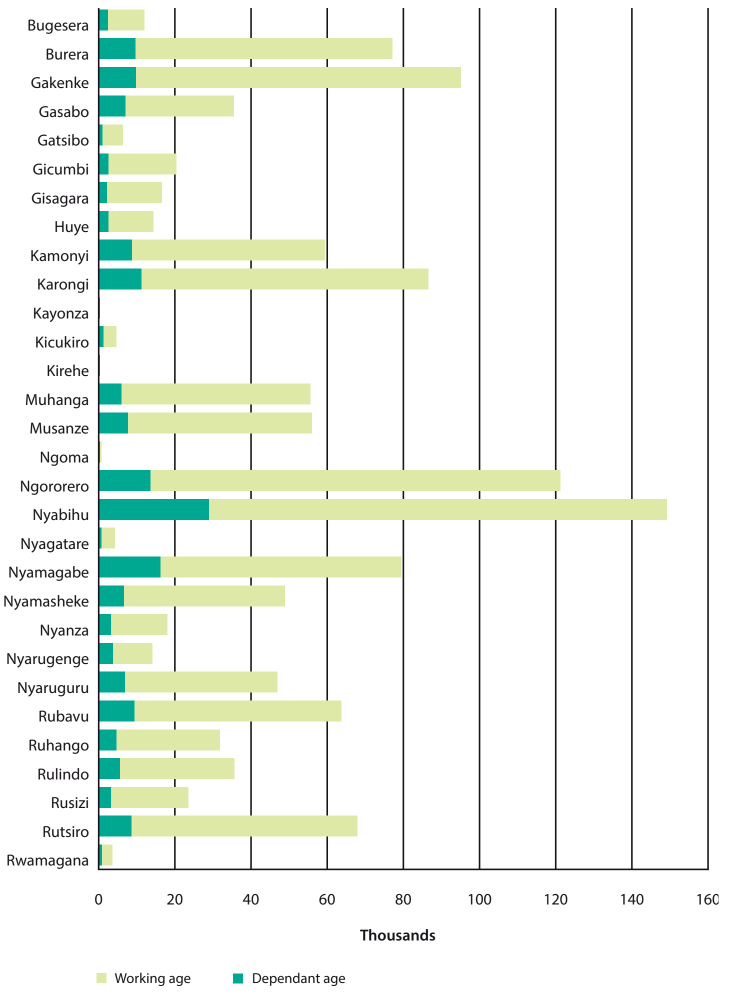


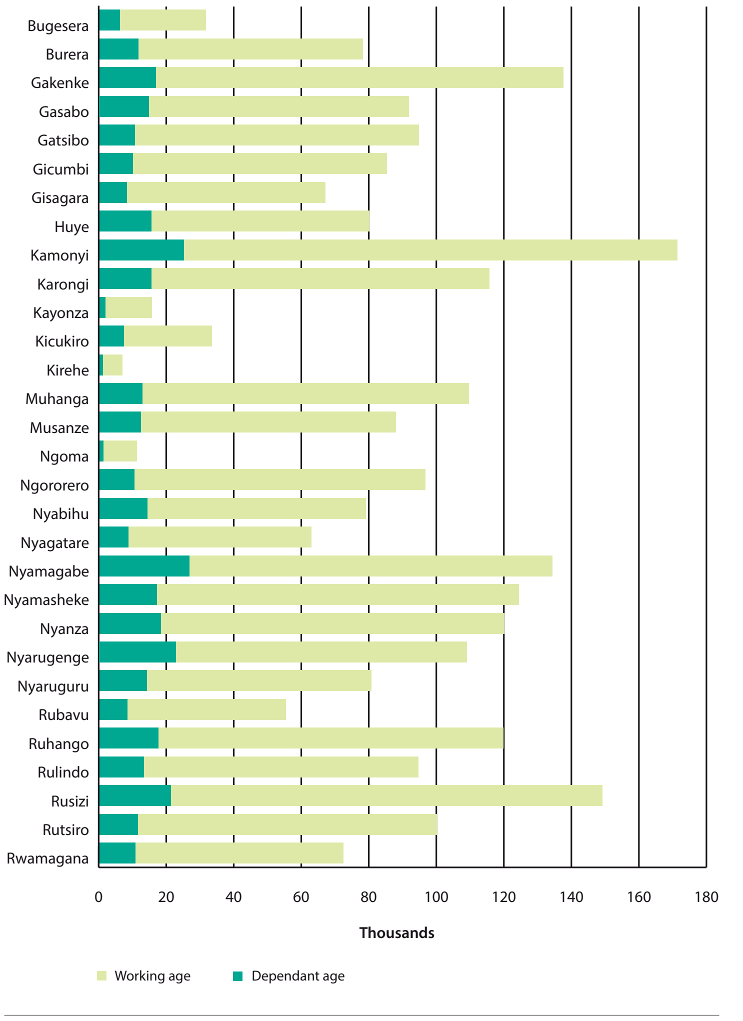
Figure 64. Population exposed to landslide at high susceptibility zones, by age



and Inactive 28,703) and Ngororero (Active: 107,621 and Inactive: 13,358). Kirehe contains a small amount of persons exposed to landslides at high susceptibility zones (Active: 6 and Inactive: 2). In most of the districts (19 out of 30 districts exposed to landslides in high susceptibility zones), the percentage of the exposed active population ranges between 86 – 90. In ten districts the percentage of the active population exposed to landslide at high susceptibility ranges from 80–85. In two districts, the percentage of active population is below 80%; Nyarugenge (75%) and Kicukiro (78%).

The landslide exposure assessment for dependent age and working age population is also made for moderate susceptibility. Figure 65 shows the exposed population by the categories of dependent age and working age. The assessment indicates that about 15% of the total exposed population or 382,043 people, are of dependent age and 85% are working age. Most of the exposed population for both the dependent and working age are located in Nyamagabe and Kamonyi Districts. Kirehe District have the least number of population for both age categories exposed to landslide at moderate susceptibility.

Figure 65. Population exposed to landslide at moderate susceptibility zones, by age



c) Population exposure by levels of poverty

Figure 66 shows the population exposed to landslide at very high susceptibility zones by levels of poverty. Twenty-three (23) districts have population exposed to landslide at this susceptibility level summing up to 345,426 individuals. Among the exposed population, 11.54% (39,878) are severely poor; 31.71% (109,519) are moderately poor; 30.29% (104,641) are vulnerable to poverty; and 26.46% (91,389) are not poor. The trend is also the same across the districts. Considering the 0.8 (or 80%) probability of landslide occurring in this susceptibility level, this is important for disaster managers to note as normally in disaster situations, the poor are the least capable to mitigate and/or cope and recover from disaster impacts. Combining the figure for severely poor and moderately poor, a total of 149,396 poor individuals (43% of the total population exposed) are exposed to landslide at 0.8 probability.

Figure 66. Population exposed to landslide at very high susceptibility zones, by levels of poverty

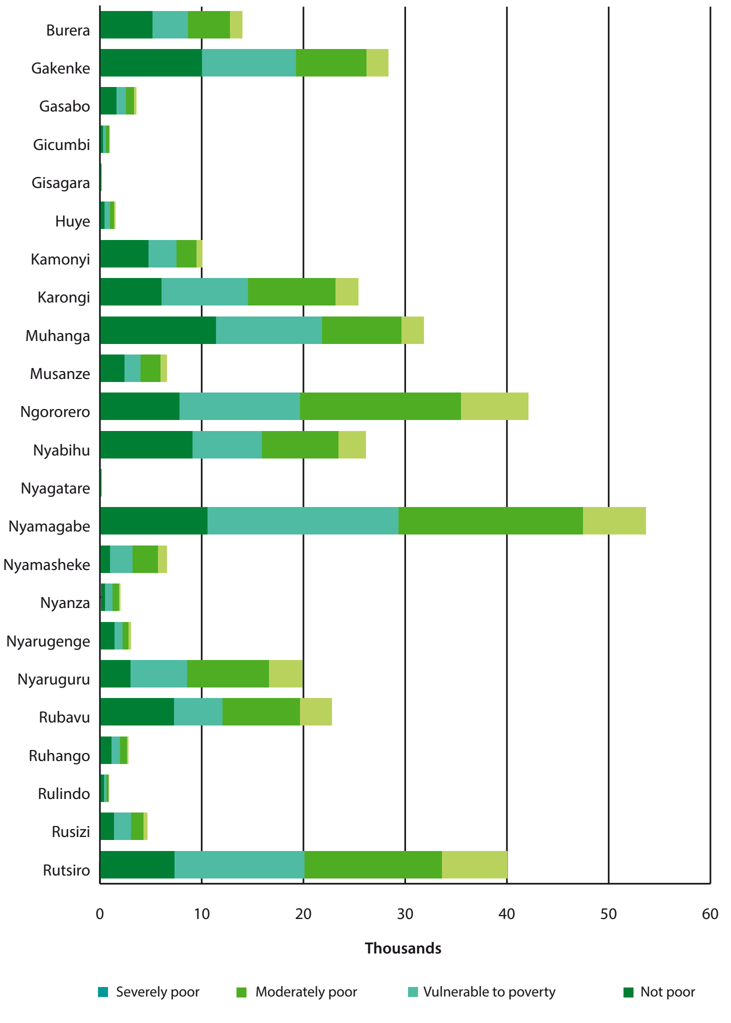


Figure 67 shows the population exposed to landslide at high susceptibility zones by levels of poverty. All the 30 districts have population exposed to landslide at this susceptibility level summing up to 1,229,710 individuals. Among the exposed population, 11.11% (136,638) are severely poor; 30.67% (377,189) are moderately poor; 29.18% (358,872) are vulnerable to poverty; and 29.03% (357,010) are not poor. The trend is also the same across the districts. Considering the 0.6 (or 60%) probability of landslide occurring in high susceptibility level, this is important for disaster managers to note as normally in disaster situations, the poor are the least capable to mitigate and/or cope and recover from disaster impacts. Combining the figures for severely poor and moderately poor, over half a million of poor Rwandan population (42% of the total population exposed to this level of susceptibility) are exposed to landslide at 0.6 probability.

Figure 67. Population exposed to landslide at high susceptibility zones, by levels of poverty

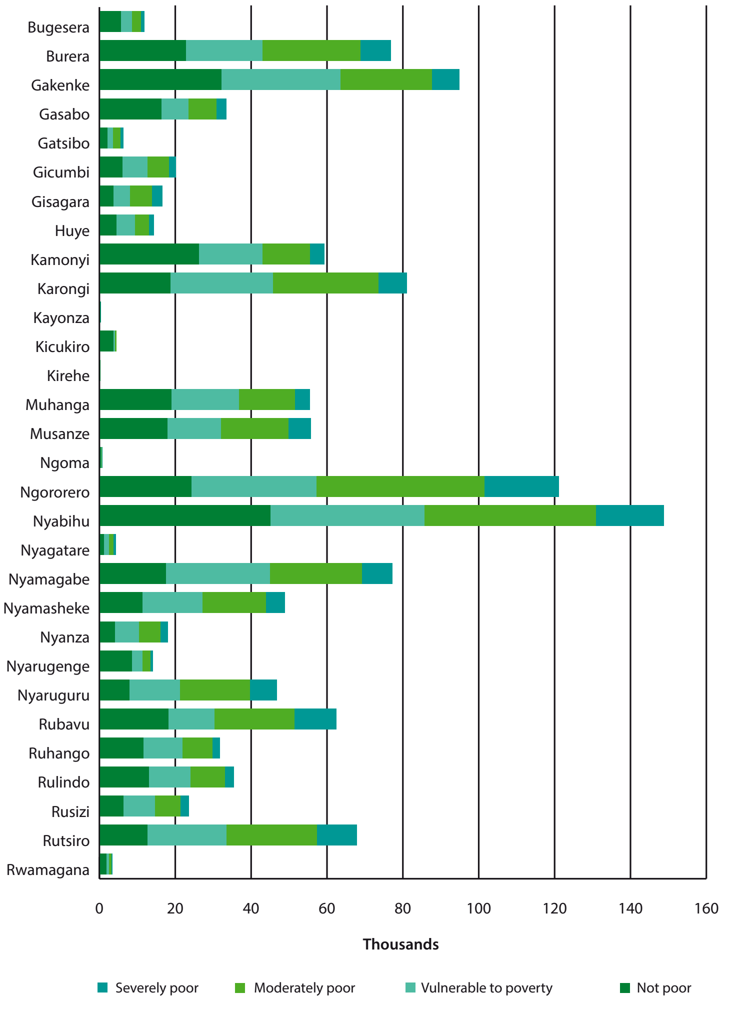
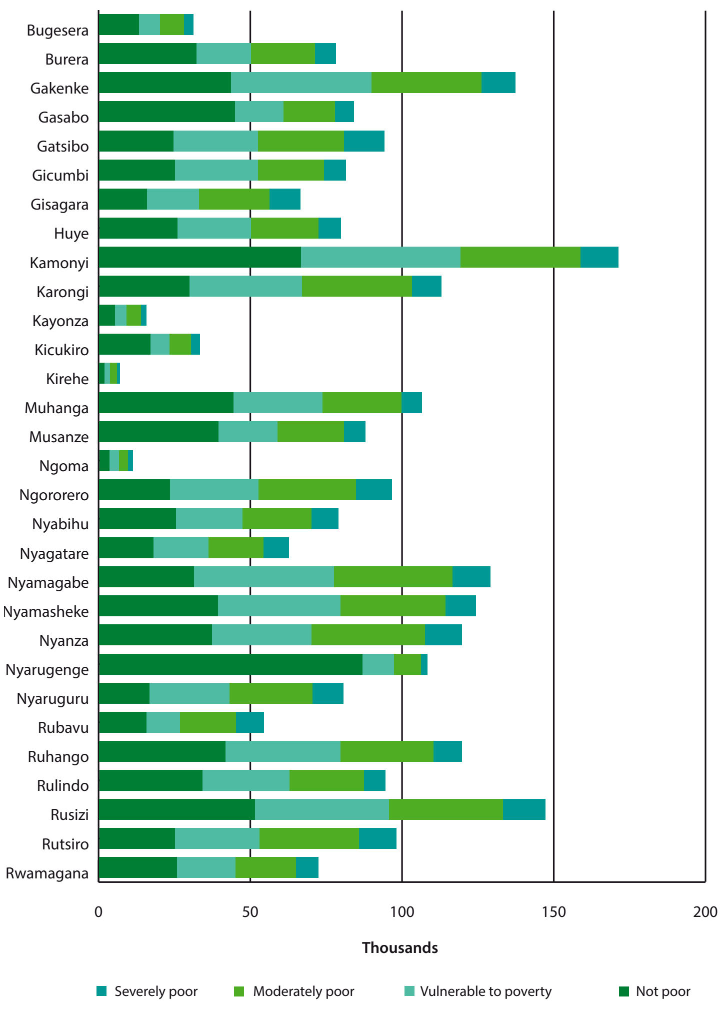


Figure 68 shows the population exposed to landslide at moderate susceptibility zones by levels of poverty. All the 30 districts have population exposed to landslide at this susceptibility level summing up to 2,577,939 individuals. Among the exposed population, 9.47% (244,168) are severely poor; 27.27% (703,104) are moderately poor; 28.34% (730,467) are vulnerable to poverty; and 34.92% (900,199) are not poor. The trend is also the same across the districts (see table below). Considering the 0.4 (or 40%) probability of landslide occurring in moderate susceptibility level, this is important for disaster managers to note as normally in disaster situations, the poor are the least capable to mitigate and/or cope and recover from disaster impacts. Combining the figures for severely poor and moderately poor, nearly a million of poor Rwandan people are exposed to landslide at 0.6 probability.

However, the proportion of the poorest people is high in districts of Rubavu (17% of the total exposed population), Gisagara (15%), Gatsibo (14%), Kirehe, Nyagatare and Ngoma (13%).

In terms of total number of population exposed to this level of susceptibility, 10 districts record more than 100 thousand people exposed. These are district of Kamonyi on top with 171,032 people, followed by Rusizi, Gakenke, Karongi, Nyamagabe, Muhanga, Nyamasheke, Nyanza, Nyarugenge and Ruhango. Housing Exposure

Figure 68. Population exposed to landslide at moderate susceptibility zones, by levels of poverty



a) Housing exposure by wall type

Housing is another sector, which may be affected by landslides. The exposure analysis for housing took into consideration the type of walls of the exposed houses. In general, the type of the wall is important in the occurrence of landslide and determines the resilience of the building. In Rwanda, the houses are built with walls made of sun dried brick, wood and mud, cement, stone, wood cement, plastic, timber and burnt brick. In general, most of the houses' walls are made of weak and non-resistant materials such sundried brick and wood and mud. The ensuing charts show the exposure of housing to landslides at three susceptibility levels: very high, high and moderate.

Figure 69 shows the number of houses exposed to landslide at very high susceptibility zones by wall type. There are a total of 25,555 houses exposed in the 23 districts located in landslide prone areas with very high susceptibility. The exposure is highest for houses made of sundried brick walls which account for 63.50% (16,228 housing units). This is followed by houses made of wood and mud walls at 29.97% (7,659 housing units). The remaining 6.53% (1,668) housing units) exposed are with walls made of other materials i.e. burnt brick, timber, plastic, wood and cement, stone, and cement brick.

The districts of Nyabihu, Ngororero and Burera have more than 2,000 houses exposed. The districts of Gakenke, Karongi, Muhanga, Musanze, Nyamagabe, Rubavu, Rulindo and Rutsiro have over 1,000 houses exposed. Finally, the districts of Gasabo, Gicumbi, Gisagara, Huye, Kamonyi, Nyagatare, Nyamasheke, Nyanza, Nyarugenge, Nyaruguru, Ruhango and Rusizi have less than a thousand houses exposed.

Figure 69. Housing exposed to landslide at very high susceptibility zones, by wall type

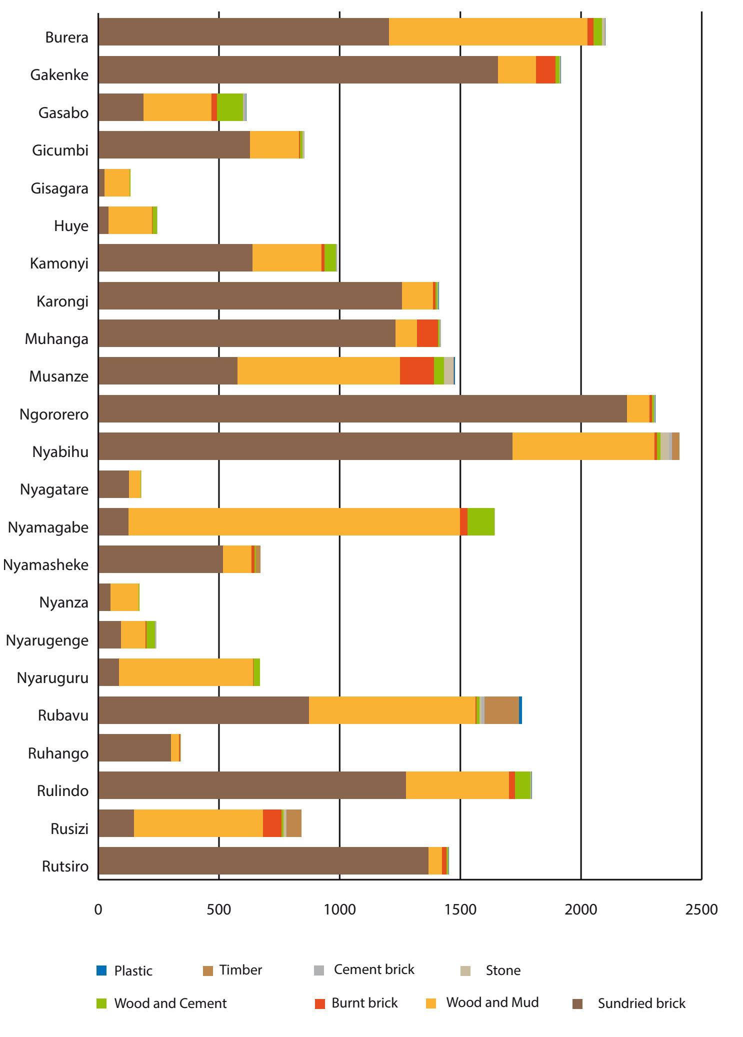


Figure 70 shows the number of houses exposed to landslide at high susceptibility zones by wall type. There are a total of 67,841 houses exposed in all the 30 districts located in landslide prone areas with high susceptibility. The exposure is highest for houses made of sundried brick walls which account for 59% (39,791 housing units). This is followed by houses made of wood and mud walls at 30% (20,100 housing units). The remaining 11% (7,950 housing units) exposed are with walls made of other materials i.e. burnt brick, timber, plastic, wood and cement, stone, and cement brick.

Only the districts of Bugesera, Kayonza, Kirehe, Ngoma, and Nyagatare have less than a thousand houses exposed to landslide at high susceptibility. The rest of the other districts have over 1000 houses exposed ranging from 1000 to over 8000 houses with Nyarugenge District with the most number of houses exposed at 8,294 units.

Figure 70. Housing exposed to landslide at high susceptibility zones, by wall type

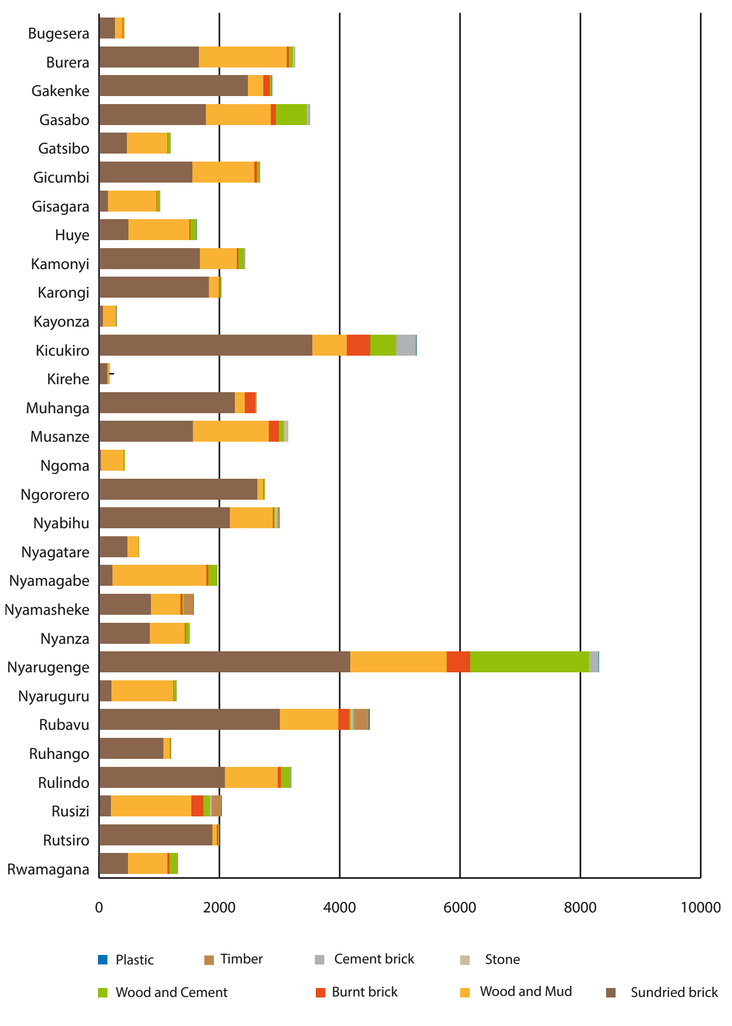
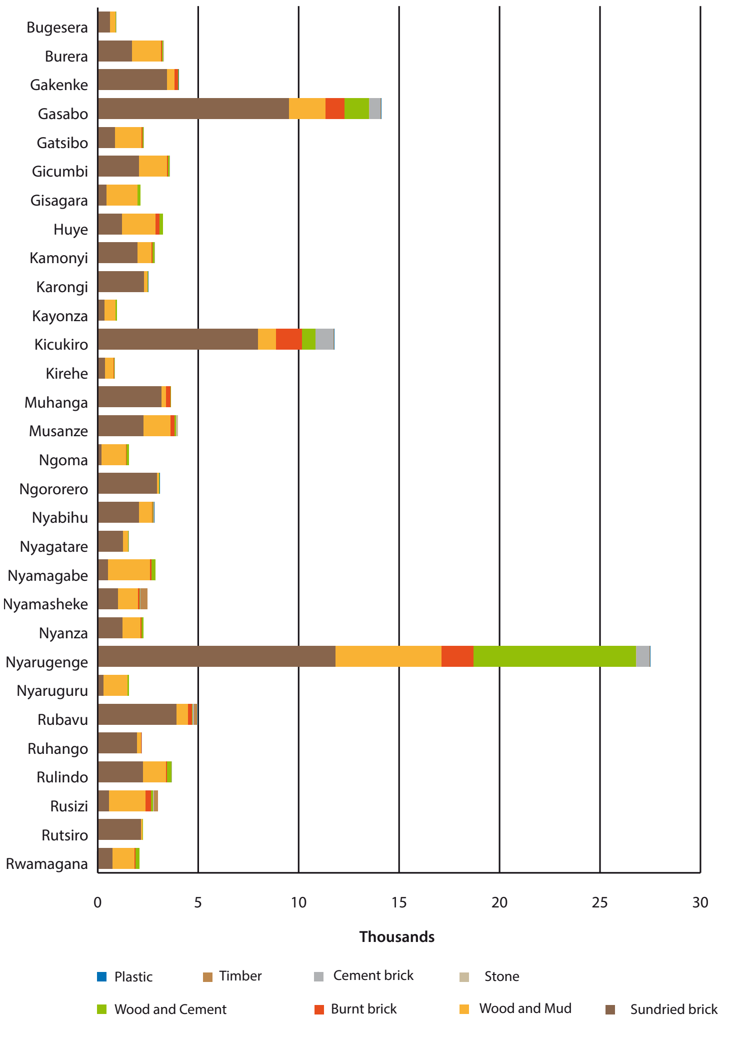


Figure 71 shows the number of houses exposed to landslide at moderate susceptibility zones by wall type. There are 122,736 houses exposed in all 30 districts located in landslide prone areas with moderate susceptibility. The exposure is highest for houses made of sundried brick walls which account for 56.67% (69,558 housing units) of all houses exposed. This is followed by houses made of wood and mud walls at 26.05% (31,982 housing units) and houses made of wood and cement 9,74%(11955). The remaining 7.52% (9,241) housing units exposed are houses with walls made of other materials i.e. burnt brick, timber, plastic, stone, and cement.

The district of Nyarugenge has the highest number of houses exposed to landslide at moderate susceptibility compared to other districts at 27,466, followed by Gasabo (14,067), Kicukiro (11,735) and Rubavu (4,943). Most districts have between 1500 and 3,860 houses exposed. Finally, Bugesera, Kayonza and Kirehe have less than a thousand houses exposed.

Figure 71. Housing exposed to landslide at moderate susceptibility zones, by wall type



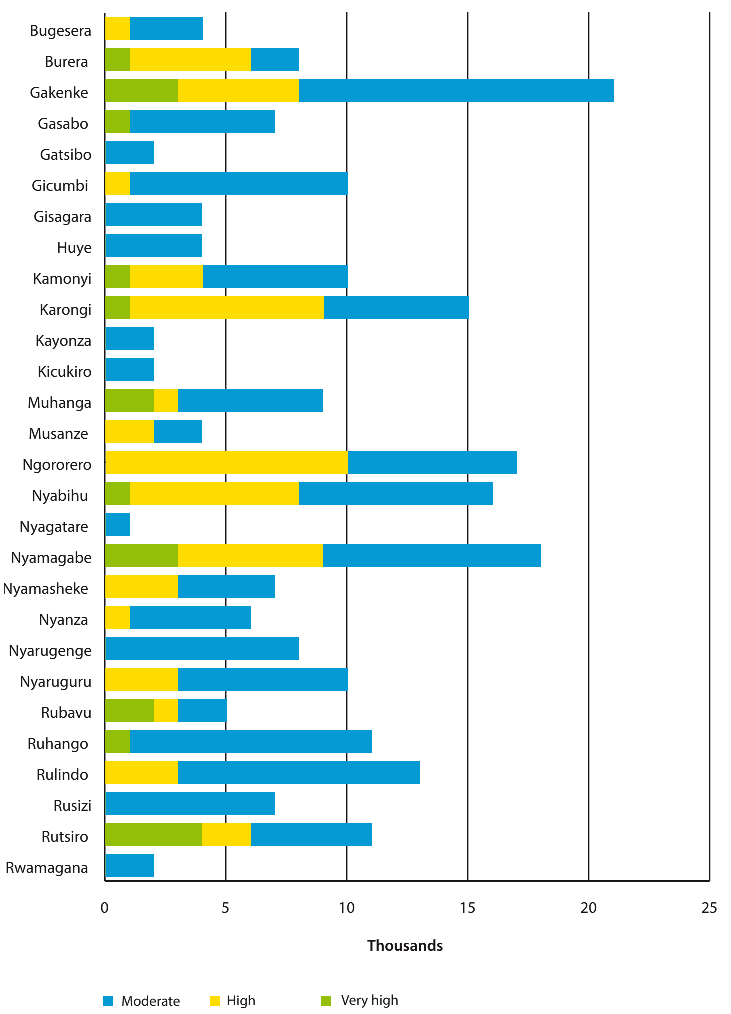
Health exposure

The exposure assessment for the health sector is limited to analysing the exposure of health facilities by district. By health facility it refers to the building or infrastructure only. Health facilities include health posts, health centres, VCT centres, community-owned health facilities, private clinics, private dispensaries, prison dispensaries, police/ military hospitals, district hospitals and national referral hospitals. Out of the total 1,036 health facilities (see Table 6) across the country, only 538 are georeferenced and were considered in the analysis. The ensuing chart (Figure 72) shows the exposure of health facilities to landslides at three susceptibility levels: very high, high and moderate. Out of the total 538 health facilities considered in the analysis, 43% (or 234) are exposed to landslides at varying levels of susceptibility.

a) Exposure of health facilities

Twenty (20) health facilities are exposed to landslides at very high susceptibility zones which include: 4 in Rutsiro, 3 each in Gakenke and Nyamagabe, two each in Rubavu and Muhanga, and 1 each in Burera, Gasabo, Kamonyi, Karongi, Nyabihu and Ruhango. Sixty two (62) health facilities are exposed to landslides at high susceptibility zones which include: 10 in Ngororero, 8 in Karongi, 7 in Nyabihu, 6 in Nyamagabe, 5 each in Burera and Gakenke, 3 each in Kamonyi, Nyamasheke, Nyaruguru, and Rulindo, 2 each in Rutsiro and Musanze, and 1 each in Bugesera, Gicumbi, Muhanga, Nyanza, and Rubavu. A total of 152 health facilities are exposed to landslides at moderate susceptibility zones and these include: 13 health facilities in Gakenke; 10 each in Ruhango and Rulindo; 9 each in Gicumbi and Nyamagabe; 8 each in Nyabihu and Nyarugenge; 7 each in Ngororero, Nyaruguru, and Rusizi; 6 each in Gasabo, Kamonyi, Karongi and Muhanga; 5 each in Rutsiro and Nyanza; 4 each in Gisagara, Huye and Nyamasheke; 2 each in Gatsibo, Kayonza, Kicukiro, Musanze, and Rubavu; and 1 in Nyagatare.

Figure 72. Health facilities exposed to landslide at moderate, high and very high susceptibility



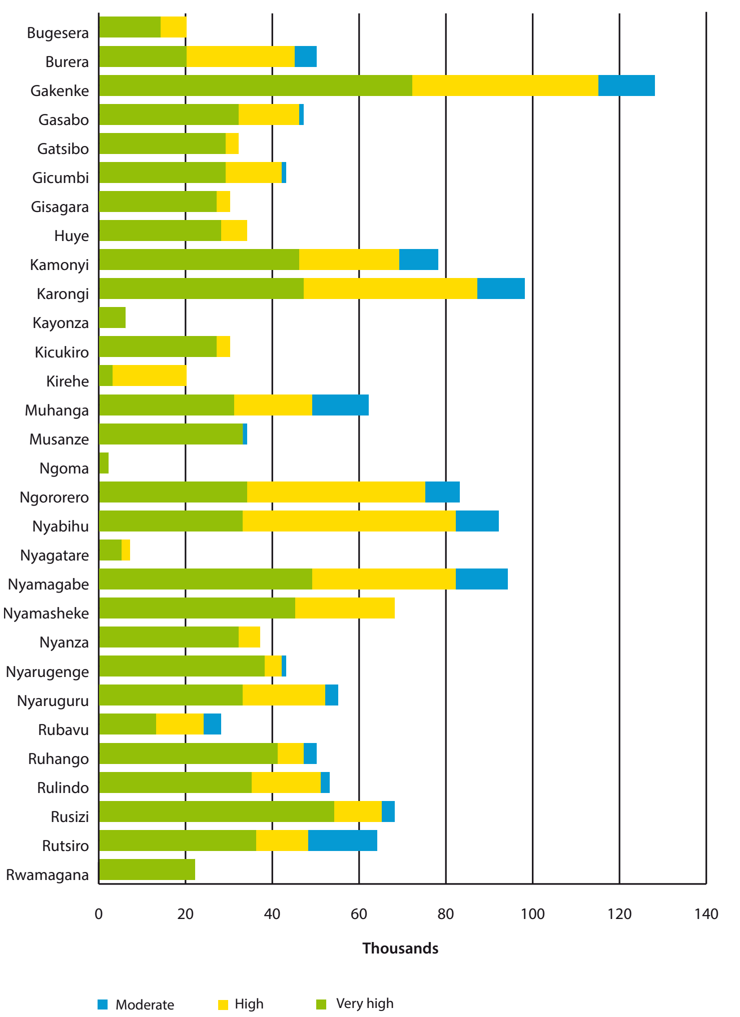
Education exposure

The exposure assessment for the education sector is limited to analysing the exposure of schools. Specifically, it only refers to the school building or infrastructure. Schools include: pre-primary schools, primary schools, secondary schools, and higher learning institutions. The ensuing chart (Figure 73) shows the exposure of schools to landslides at three susceptibility levels: very high, high and moderate. A total of 1,478 schools are exposed to landslides at varying levels of susceptibility.

a) Schools exposure

One hundred sixteen (116) schools are exposed to landslides at very high susceptibility zones from 17 districts; 446 schools in 26 districts are exposed to landslide at high susceptibility; and 916 schools in all 30 districts are exposed to landslides at moderate susceptibility. Gakenke has the most number of schools exposed with 128 schools and Ngoma has the least number of schools exposed with only 2 schools.

Figure 73. Number of schools exposed to landslide at moderate, high and very high susceptibility



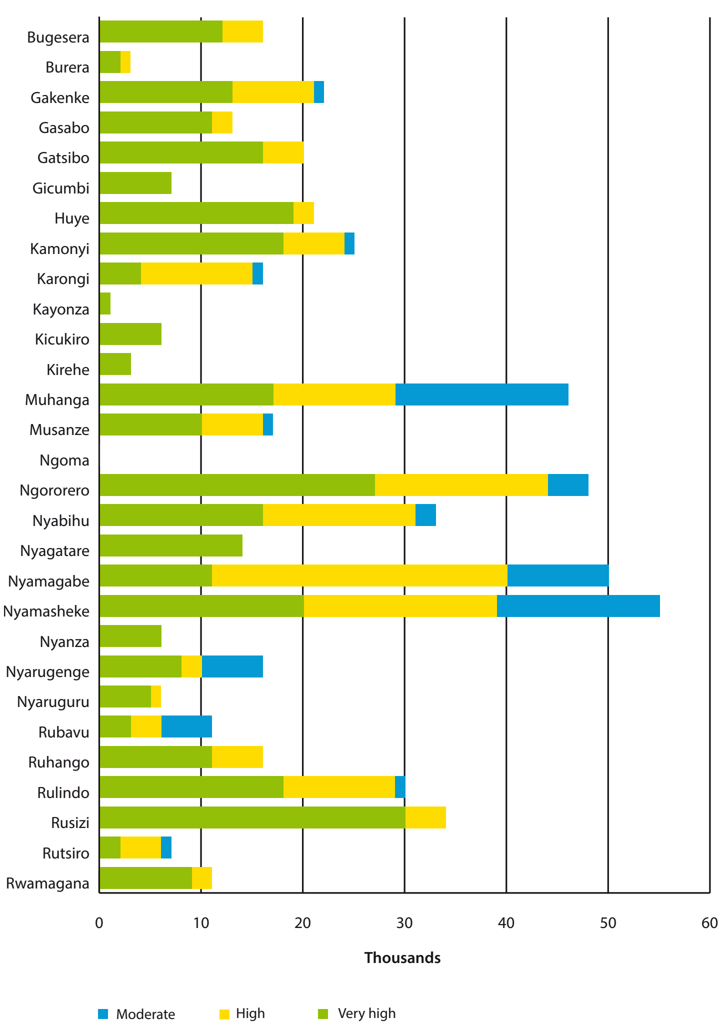
Transportation sector exposure

The exposure assessment for the transportation sector is limited to analysing the exposure of national (paved and unpaved) and district roads. The ensuing shows the exposure of national and district roads to landslides at three susceptibility levels: very high, high and moderate. Paved and unpaved roads at national level are presented separately. Finally, the exposure of district roads to landslide is demonstrated.

b) Exposure of national paved roads

Figure 74 shows the total number of kilometers of national paved roads exposed to landslide at moderate, high and very high susceptibility. A total of 553 kilometers of national paved roads are exposed to landslide at these three susceptibility levels. The district of Nyamasheke has the highest number of national paved roads exposed with 55 kilometers and followed closely by Ngororero and Nyamagabe each with 49 kilometers of national paved roads exposed. Kayonza and Ngoma has the least national paved roads exposed with 1 kilometer and less than a kilometer respectively.

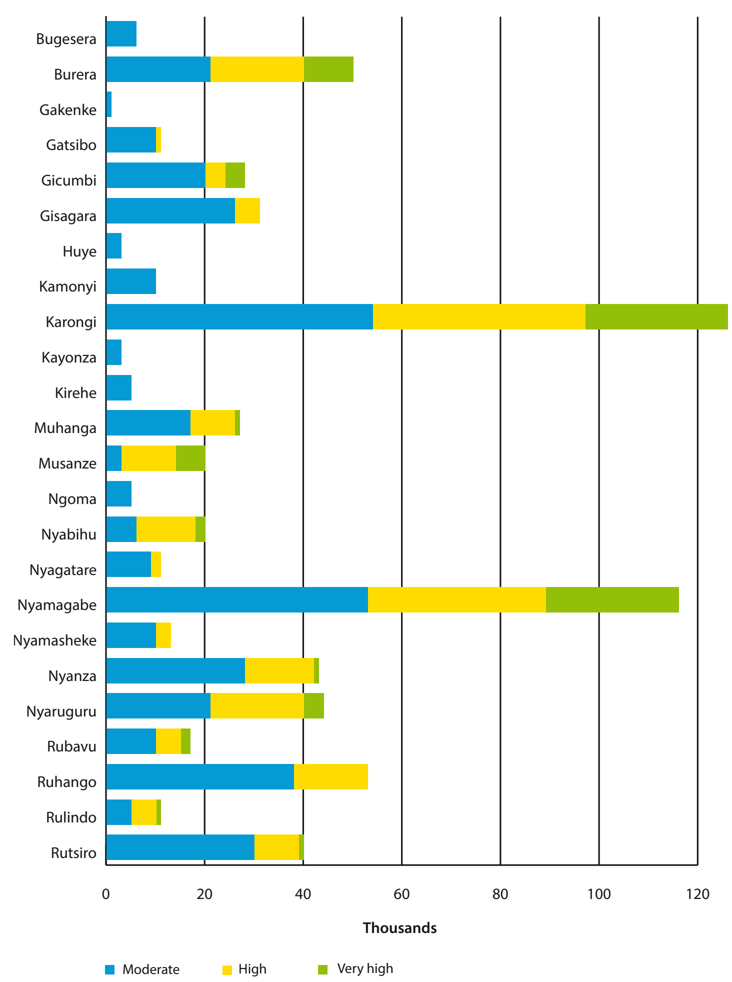
Figure 74. National paved roads (km) exposed to landslide at moderate-very high susceptibility



c) Exposure of national unpaved roads

Figure 75 shows the total number of kilometers of national unpaved roads exposed to landslide at moderate, high and very high susceptibility. A total of 691 kilometers of national unpaved roads are exposed to landslide at these three susceptibility levels. The districts of Karongi and Nyamagabe have the highest number of national unpaved roads exposed with 125 kilometers and 117 kilometers respectively. Gakenke, Kayonza, Huye, Kirehe and Ngoma has the least national unpaved roads exposed at 5 kilometers or less. Note that six districts have no unpaved roads exposed to landslide at the concerned levels. These are Gasabo, Kicukiro, Nyarugenge, Rusizi, Ngororero and Rwamagana.

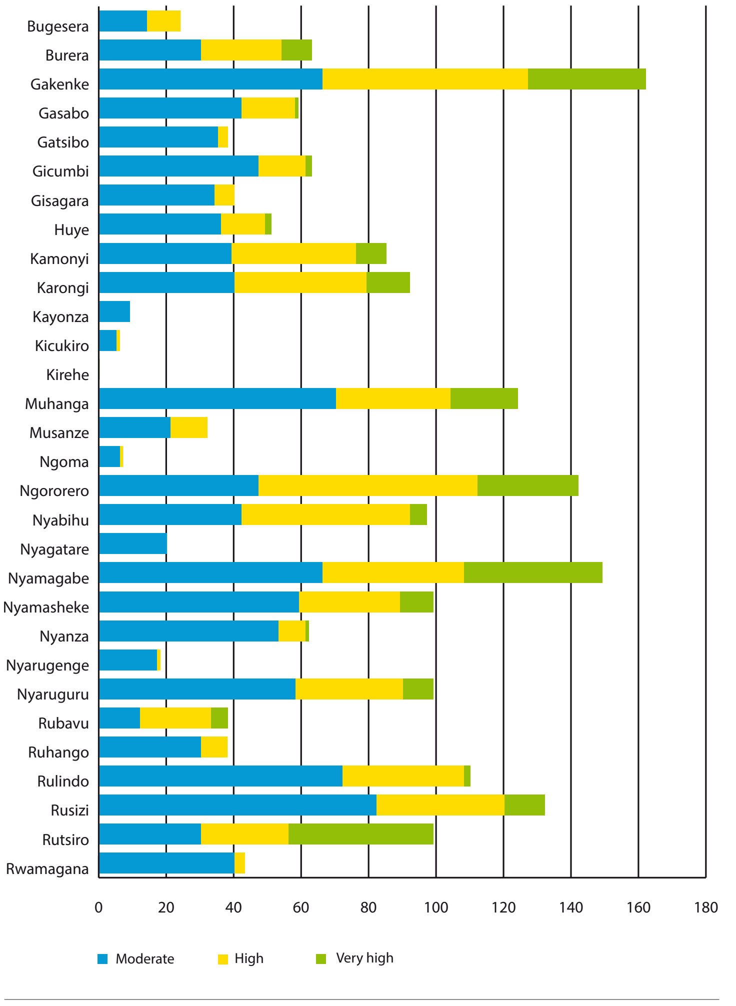
Figure 75. National unpaved roads (km) exposed to landslide at moderate-very high susceptibility



d) Exposure of district roads

The same analysis of landslide exposure has been made for district roads. Figure 76 shows the number of kilometers of district roads exposed to landslide at three susceptibility levels i.e. very high, high and moderate. There are about 2,003 kilometers of district roads exposed to landslide; 249 kilometers are exposed to landslides at very high susceptibility, 629 kilometers are exposed to landslides at high susceptibility, and 1,125 kilometers exposed at moderate susceptibility. The districts of Gakenke, Muhanga, Ngororero, Nyamagabe, Rulindo and Rusizi have more than 100 kilometers of district roads exposed to landslide. Meanwhile, the districts of Burera, Gasabo, Gicumbi, Huye, Kamonyi, Karongi, Nyabihu, Nyamasheke, Nyanza, Nyaruguru and Rutsiro have between 50-100 kilometers of district roads exposed. Bugesera, Gatsibo, Gisagara, Musanze, Nyagatare, Nyarugenge, Rubavu, Ruhango and Rwamagana have between 10-50 kilometers of district roads exposed to landslide from moderate to very high susceptibility. Kayonza and Kicukiro have less than 10 kilometers of district roads exposed and Kirehe has none of its district roads exposed to landslide.

Figure 76. District roads (in km) exposed to landslide at moderate, high and very high susceptibility



5.3.2.3 Comparative analysis of exposure profiles

Given that there is only one scenario considered in the landslide exposure assessment, the exposure profiles are compared by levels of susceptibility and by district.

Population exposure to landslide is increasing based on different susceptibility levels. About 3.34% of the total population in Rwanda is exposed to landslide at very high susceptibility in 23 districts. The number goes higher at high susceptibility with 11% of the population exposed and at moderate susceptibility with 25% of the population exposed in all thirty districts. Comparatively, the population exposure to landslide at very high susceptibility is higher in Nyamagabe, Ngororero and Rutsiro. On the other hand, it is Nyabihu District which has the highest percentage of population exposed to landslides at high susceptibility and Kamonyi District at moderate susceptibility. The population exposure by age indicates that out of the total population exposed, the exposed dependent age population is at 14% compared to 85% of the working age at different susceptibility levels. The percentage of dependent age population exposed slightly varies from one district to the other ranging from about 10-20 percent. By levels of poverty, the population exposure reveals that about an average of 40% of the exposed population are poor. The percentage range from 43% poor population exposed to landslides at very high susceptibility, 42% at high susceptibility and 37% at moderate susceptibility. This in total comprised about 15.3% of the country's total population.

While the population exposure to landslide at very high susceptibility is high in Nyamagabe, Ngororero and Rutsiro, the housing exposure is high in Nyabihu and Burera and Ngororero. Except for the latter, the figure reveals a different trend. This could mean that in Nyabihu and Burera Districts, there are less people occupying houses located in landslide hazard zone at very high susceptibility compared to Nyamagabe and Rutsiro. This could be attributed to the varying average family size between these districts and the levels of poverty. Nyamagabe, Rutsiro and Ngororero are considered to be the poorest districts. Often it is the poorest who tend to settle in hazard-prone locations due to their limited options and the lack of capacity to acquire plots in safer zones. The housing exposure to landslides at high and moderate susceptibility are high in Kigali City specifically in Nyarugenge, Gasabo and Kicukiro. This is relatively due to the higher population density in these areas. By wall types of houses, the highest exposure are for houses made of sundried brick walls followed by houses made of wood and mud walls.

The exposure of health facilities to landslide vary at different levels of susceptibility with 20 health facilities exposed to very high susceptibility, 62 health facilities exposed to high susceptibility and 152 health facilities exposed to moderate susceptibility.

Similarly, the exposure of schools to landslide vary at different levels of susceptibility. Fewer schools are exposed to landslide at very high susceptibility with only about 8% (116) of the total exposed schools. The number goes higher for those schools exposed to landslide at high susceptibility comprising of about 30% (446); and schools exposed to landslide at moderate susceptibility with 62% (916).

The length of national roads exposed to landslides at different susceptibility levels increases with 67 kilometers of paved and 86 of unpaved national road networks exposed to very high susceptibility compared to 170 km and 209 km at high susceptibility and 317 km and 396 km at moderate susceptibility. For the District roads, the same trend is evident with 249 kilometers exposed to landslide at very high susceptibility; 629 kilometers at high susceptibility; and 1,125 kilometers at moderate susceptibility. While most of the exposed national roads are located in the Districts of Nyamasheke, Ngororero, Nyamagabe and Karongi, most of the District roads exposed to landslide are located in Gakenke, Muhanga, Ngororero, Nyamagabe, Rulindo and Rusizi.

5.3.2.4 Summary of key findings

- The population exposure to landslides is evident in the highlands of the Western, Southern and Northern provinces. Results show that 3.34% of the country's population is exposed to landslides at very high susceptibility; 11% at high susceptibility and 25% at moderate susceptibility. About 14% of the exposed population is dependent comprising of children aged <20 years and elderly aged >64 years.

- Over 1.6 million poor Rwandan population (about 15.3% of the total population of the country) is exposed to landslides from moderate to very high susceptibility with majority coming from the Districts of Nyamagabe, Ngororero, Rutsiro, Nyabihu and Kamonyi.

- The housing exposure to landslides is highest in Nyabihu, Burera and Ngororero at very high susceptibility; and it is highest in the 3 Districts in Kigali City at high and moderate susceptibility. The exposure is highest amongst houses with sundried brick walls at an average of 60%[23] for various susceptibility levels. This is followed by houses made of wood and mud walls at an average of 29%[24] for various susceptibility levels

- The exposure of health facilities to landslides is high at 43%[25] or a total of 234[26] health facilities exposed at varying levels of susceptibility. Most of these health facilities are located in the Districts of Gakenke, Ngororero, Nyabihu, Nyamagabe, Ruhango, Rulindo, Gicumbi and Karongi.

- A total of 1,478[27] schools are exposed to landslides at varying susceptibility levels. This is about 25%[28] of the total schools in the country. Most of these schools are located in the Districts of Gakenke, Karongi, Nyamagabe, Nyabihu, Ngororero, Kamonyi, Rusizi, Rutsiro and Muhanga. Gakenke District has the most number of schools exposed with 128 schools while Ngoma District has the least number of schools exposed with only 2 schools.

- The transportation sector, specifically national roads which connects districts together for purposes of domestic and international trade, service delivery, tourism, manufacturing and processing and general access are also exposed to landslides at different susceptibility levels. A total of 553 kilometers of paved national roads and 691 kilometers of unpaved national roads are exposed to landslides. These figures represent respectively 45% and 39% of total [classified] national paved and unpaved roads in the country. Most of these roads are located in the Districts of Nyamasheke, Ngororero and Nyamagabe for the paved national roads and the Districts of Karongi and also Nyamagabe for the unpaved national roads.

- The total District roads exposed to landslides is 2,003 kilometers. This represents about 74% of the total length of the [classified] District roads in the country. Mostly are located in the Districts of Gakenke, Muhanga, Ngororero, Nyamagabe, Rulindo and Rusizi where over a 100 kilometers of roads are exposed. On the other hand, Kayonza and Kicukiro Districts have less than 10 kilometers of district roads exposed and Kirehe has none.

[23] The percentage of sundried brick wall-made houses exposed, ranging from 63.50% for very high susceptibility; 59% for high susceptibility; and 56.675 for moderate susceptibility

[24] The percentage of wood&mud wall-made houses exposed, ranging from 29.97% for very high susceptibility; 30% for high susceptibility; and 26.05% for moderate susceptibility.

[25] The total health facilities georeferenced and included in the analysis is 538 only out of the 1,036 health facilities in the country.

[26] Comprise of 20 health facilities exposed to landslide at very high susceptibility; 62 health facilities at high susceptibility; and 152 at moderate susceptibility.

[27] Comprise of 116 schools exposed to landslide at very high susceptibility; 446 at high susceptibility; and 916 at moderate susceptibility.

[28] The total schools in the country according to the 2014 Randa Statistical Yearbook published by NISR is 5,968.

5.3.3 Exposure to earthquake

The earthquake exposure assessment provides information about the physical and social elements or assets, which are located in earthquake hazard prone areas. The assessment provides information to policy makers, decision makers, and planners about mitigation measures or interventions required for these elements. Primarily, earthquake impacts on physical infrastructures, often followed by other social sectors.

Scenario

The earthquake hazard assessment has developed hazard maps for two return periods: 2475-year return period and 475-year return period (see Figure 42 and Figure 43). For this report, the exposure assessment is only analysed for the 2475-year return period with 2% probability of exceedance in 50 years, specifically for intensities MMI VII and MMI VI. The Modified Mercali Intensity (MMI) scale has been explained in paragraph 4.4.4. The 475-year return period is not considered in the report since based on the damage probability matrix in Table 45 in Chapter VI, the damage probability for intensities MMI VI and MMI V for the 475-year return period is almost non-existent except for about 10% for Category 3 structure (Cat.3)[29] at Damage Level 1 (D1).[30]

Elements at risk

For this report, the exposure of population and primary physical assets such as housing, health facilities, education and transportation are analyzed.

Intensity levels

There are only two intensity levels apparent in Rwanda: Intensity MMI VI and intensity MMI VII. Both intensity levels are analysed.

5.3.3.1 Overview

Based on the historical data, five earthquake events occurred in Rwanda from 2000 – 2008 (see Table 30). These events together resulted in 85 deaths and 2547 affected persons. The earthquake of 17 January 2001 resulted in more casualties compared to the subsequent earthquakes. The affected districts are located in Western Province, near Lake Kivu.

5.3.3.2 Characterization of exposure profiles

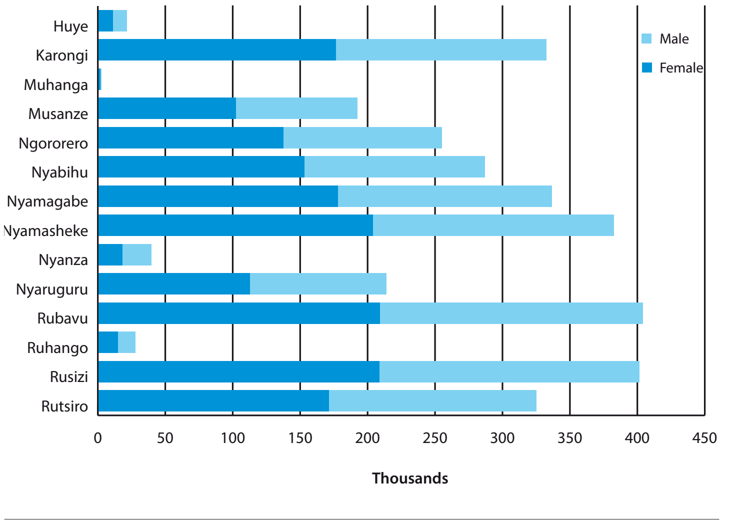
Population exposure

In the same manner as the exposure assessment for landslide in the preceding section, the earthquake exposure assessment for population includes analysis by gender, age, and levels of poverty. The analysis by age considered two classifications: working age population[31] and the dependent age[32] population. The analysis by levels of poverty considered the four levels classified and used by NISR: severely poor, moderately poor, vulnerable to poverty and not poor. The ensuing charts below show the exposure of population to earthquake for the 2475-year return period at two intensities: MMI VII and MMI VI.

a) Population exposure by gender

The population exposure to earthquake at intensity MMI VII is shown in Figure 77. After overlaying the earthquake hazard map (see Figure 43) with the population data of the different districts, the population exposure to earthquake indicates five districts in the western province namely Karongi, Nyamasheke, Rubavu, Rusizi, and Rutsiro have 100% of their population exposed to earthquake at this intensity. Nyabihu and Ngororero Districts have 97% and 76% of their population exposed respectively. Meanwhile, there are six districts in the southern province which have their share of exposed population. Nyamagabe accounts for 88% of its population exposed to earthquake at MMI VII, followed by Nyaruguru with 72% and Nyanza (12%), Ruhango (8%), Huye (6%), and Muhanga (.71%). The district of Musanze in the northern province also has about 52% of its population exposed. In total, there are 3,214,378 individuals (or 30.57% of the country's population) are exposed to earthquake at intensity MMI VII.

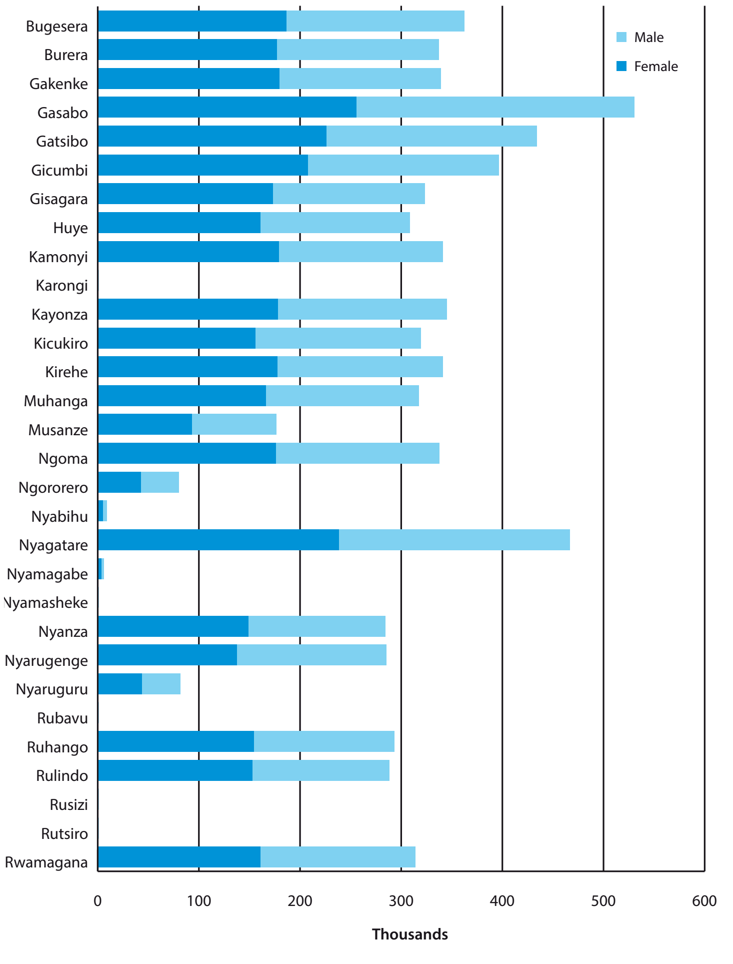
Figure 77. Population exposed to earthquake with MMI VII intensity



[29] As defined in Chapter VI of this report Cat. 3 refers to houses with walls made from plastic sheeting, bamboo or grass
[30] As defined in Chapter VI of this report, D1 means 'damaged with minor cracks or just slightly damaged (at approximately 25%)
[31] NISR classification of working age population is active population. This comprise of those within the age range of 20-64 years old.
[32] NISR classification of dependent age population is inactive population. This comprise of children aged <20 years and elderly aged >64 years.

The same analysis of population exposure to earthquake is also made for MMI VI. The result is shown in Figure 78. Out of the 25 districts located in the earthquake hazard zone at intensity MMI VI, sixteen Districts have 100% of their population exposed. These include the districts of Bugesera, Burera, Gakenke, Gasabo, Gatsibo, Gicumbi, Gisagara, Kamonyi, Kayonza, Kicukiro, Kirehe, Ngoma, Nyagatare, Nyarugenge, Rulindo and Rwamagana. Also showing significant number are the districts of Muhanga (99%), Huye (93%), Ruhango (91%), Nyanza (87%) and Musanze (47%). The districts of Nyaruguru and Ngororero have 27% and 23% respectively. Meanwhile, Nyabihu and Nyamagabe have below 3% of their population exposed to earthquake at MMI VI. In total, about 7,300,629 people or (69% of the total country population) are exposed to earthquake at this intensity.

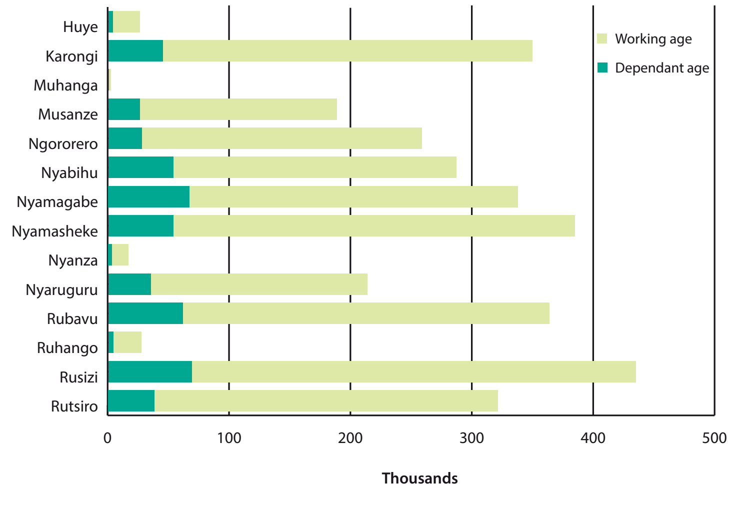
Figure 78. Population exposed to earthquake with MMI VI intensity



b) Population exposure by age

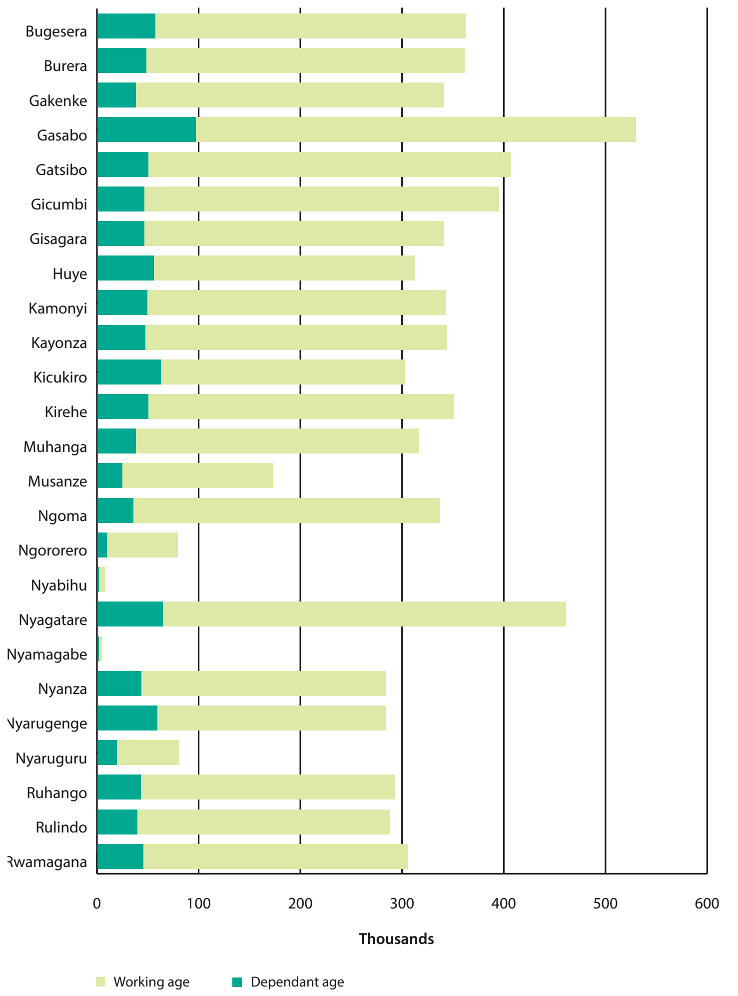
The population exposure to earthquake was also assessed in terms of working age and dependent age. Information generated from this analysis are important as these matter to disaster managers and decision-makers for consideration in planning for contingency, preparedness, response and recovery. Figure 79 shows the graphical presentation of the population exposed to earthquake at MMI VII intensity by age (working or dependent age). A total of 2,722,507 working age population are exposed to earthquake in this intensity. Meanwhile, a total of 484,132 individuals at dependent age are exposed to earthquake in this intensity. Of the total exposed dependent age population, Rusizi has about 14.16% (68,546) dependents exposed followed by Nyamagabe with 13.79% (66,769), Rubavu with 12.61% (61,064), Nyabihu with 11.04% (53,442), and Nyamasheke with 11.02% (53,335). Five (5) other districts have above 5% of the dependent age population exposed i.e. Karongi (44,864), Rutsiro (37,897), Nyaruguru (34,864), Musanze (25,618) and Ngororero (27,345). Four (4) districts have below 5% of the dependents age population exposed i.e. Huye, Muhanga, Nyanza, and Ruhango.

Figure 79. Population exposed to earthquake with MMI VII intensity, by age



The same analysis is also made for earthquake MMI VI intensity. Figure 80 shows the graphical presentation of the population exposed to earthquake at MMI VI intensity by age (working or dependent age). A total of 6,246,489 working age population are exposed to earthquake in this intensity. Meanwhile, a total of 1,061,390 individuals at dependent age are exposed to earthquake in this intensity. About 9.06% of the dependent age population exposed is from Gasabo District. The other districts with dependent age population exposed at a rate below 6% include the districts located in seismic zone with MMI VI intensity as revealed by the earthquake hazard map in Figure 43.

Figure 80. Population exposed to earthquake with MMI VI intensity, by age

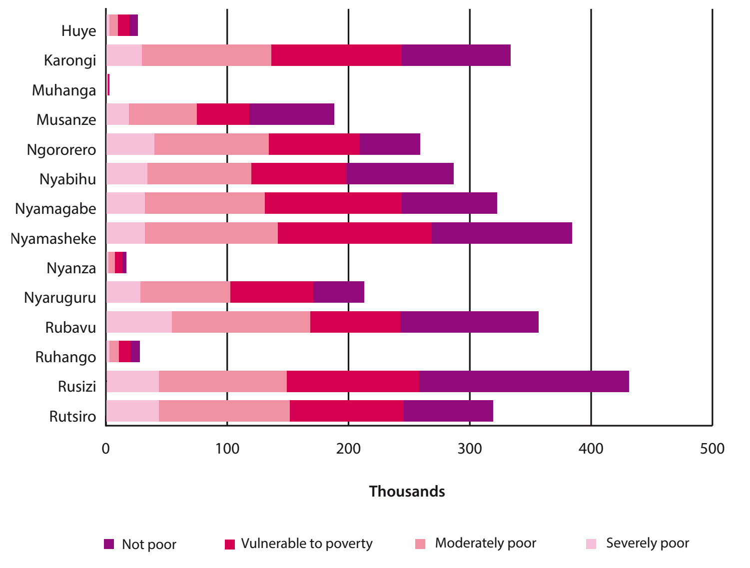


c) Population exposure by levels of poverty

The population exposure to earthquake is also assessed by levels of poverty. It is important to ascertain how much of the poor population are exposed since they are less financially capable of coping with and recovering from disaster impacts. The information generated from this assessment will be helpful to disaster managers and decision-makers in designing interventions and developing plans for preparedness, response and recovery including mitigation measures.

Figure 81 presents the population exposed to earthquake at MMI VII intensity by levels of poverty. There are 357,327 severely poor population exposed to earthquake at this intensity. Of this number; 53,646 are from Rubavu, 43,102 from Rutsiro, 42,828 from Rusizi, 39,442 from Ngororero, 33,430 from Nyabihu, 31,653 from Nyamagabe, and 31,645 from Nyamasheke. It can be noted that the exposure is high in areas located along the western section of the East African Rift System due to their proximity to the potential epicentres. The other districts prone to earthquake at this intensity have severely poor population exposed ranging from over hundred up to 30,000 individuals. The moderately poor population exposed is totalling to 971,653 while about 915,906 individuals categorised as vulnerable to poverty are exposed too. Meanwhile, a significant number of about 912,932 not poor population are also exposed to earthquake at this intensity.

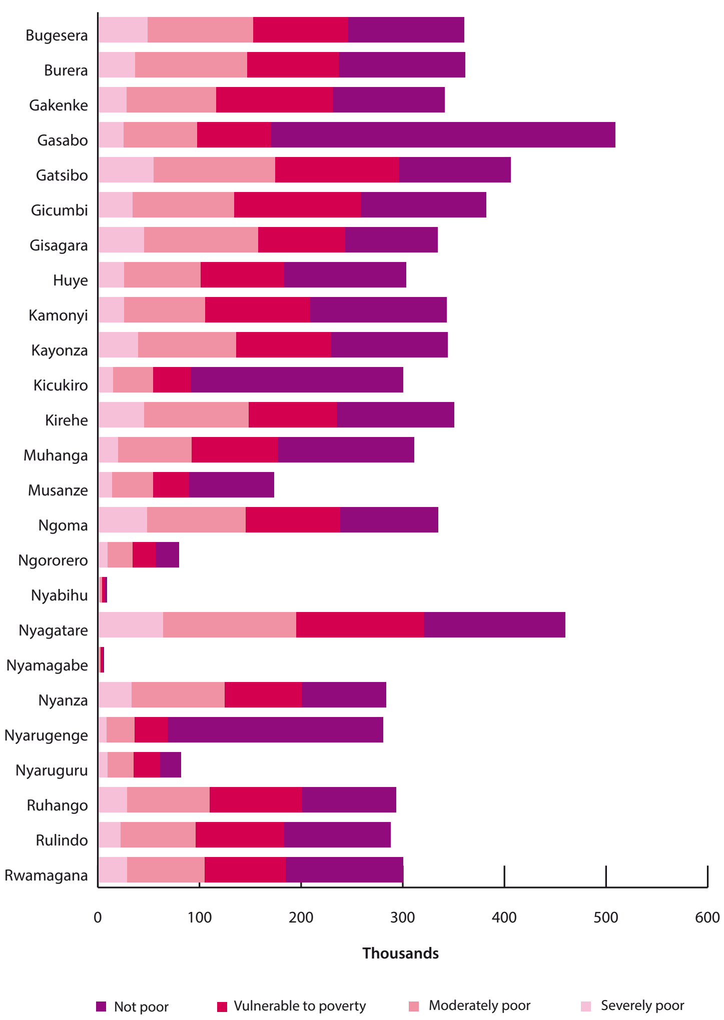
Figure 81. Population exposed to earthquake with MMI VII intensity, by levels of poverty



Combining the figure for severely poor and moderately poor, a total of 1,328,980 poor population in the country are exposed to earthquake with MMI VII intensity.

Similar analysis for the population exposure to earthquake by levels of poverty was also made for MMI VI intensity. The analysis was made for the 25 districts located in earthquake hazard zone at this intensity as revealed by the hazard map in Figure 43. Considering the two lowest poverty levels - severely poor and moderately poor, data indicates that there a total of 2,538,727 poor Rwandan population exposed to earthquake of intensity VI. While it is important to ascertain how much of the poor are exposed, it is equally vital to know that there are about 1.8 million population vulnerable to poverty and over 2.8 million population belonging to the 'not poor' category are exposed to earthquake. For the severely poor population exposed, the districts of Nyagatare and Gatsibo have >50,000 individuals exposed. Another 19 districts have severely poor population exposed to earthquake ranging from 12,905 – 48002 individuals. Five (5) districts have <10,000 severely poor population exposed to earthquake at intensity VI namely Ngororero, Nyabihu, Nyamagabe, Nyaruguru and Nyarugenge. The low number for the first four districts is attributed to the small portion of the, districts located in the seismic zone at intensity VI. The larger part of these districts is situated in the seismic zone at intensity VII (as elaborated above). Meanwhile for Nyarugenge District, the low exposure is attributed to its lower number of severely poor population.

Figure 82. Population exposed to earthquake with MMI VI intensity, by levels of poverty



Housing Exposure

a) Housing exposure by wall type

In Chapter II, section 2.8 of this report, the classification of housing in Rwanda is described. Housing is classified according to the physical characteristics of private households. The classification focuses on the materials used to build walls, roof and floor. The exposure assessment identifies the number of houses in each hazard prone area. The earthquake exposure assessment of housing considered the classification of houses by wall type. In Rwanda, the houses are built with walls made of sun dried brick, wood and mud, cement, stone, wood cement, plastic, timber and burnt brick. In general, most of the houses' walls are made of weak and non-resistant materials such sundried brick and wood and mud. The ensuing charts show the exposure of housing to earthquake for the 2475-year return period at two intensities: MMI VII and MMI VI.

Figure 83 shows the graphical presentation on the number of houses (by wall type) located in a seismic zone with MMI VII intensity. The earthquake hazard assessment (in Chapter IV, Figure 43) indicated 14 districts to be prone to an earthquake of this intensity. Rubavu, being one amongst the densely populated district, tops the list of districts with a high number of houses exposed to earthquake at 87,441 houses. This is followed by Rusizi with 82,973 houses, Nyamasheke (81,630 houses), Nyamagabe (73,270 houses), Karongi (73,011 houses), Rutsiro (70,951 houses), Nyabihu (63,386 houses), Ngororero (60,228 houses), Nyaruguru (45,177 houses), and Musanze (42,760 houses). The other four districts have below 10,000 houses exposed i.e. Ruhango with 6,472 houses, Huye with 5,987 houses, Nyanza with 3,889 houses, and Muhanga with 535 houses. This is because only small parts of these districts are in the seismic zone with MMI VII intensity as can be gleaned from the earthquake hazard map. In terms of wall types, houses with walls made of sundried brick have the most number exposed at 55.65% (1,341,037 houses). Houses with walls made of wood and mud follows at 35.79% (862,513 houses). The rest of the exposed houses (8.54%) are those with walls made of other materials.

Figure 83. Housing exposed to earthquake with MMI VII intensity, by wall type

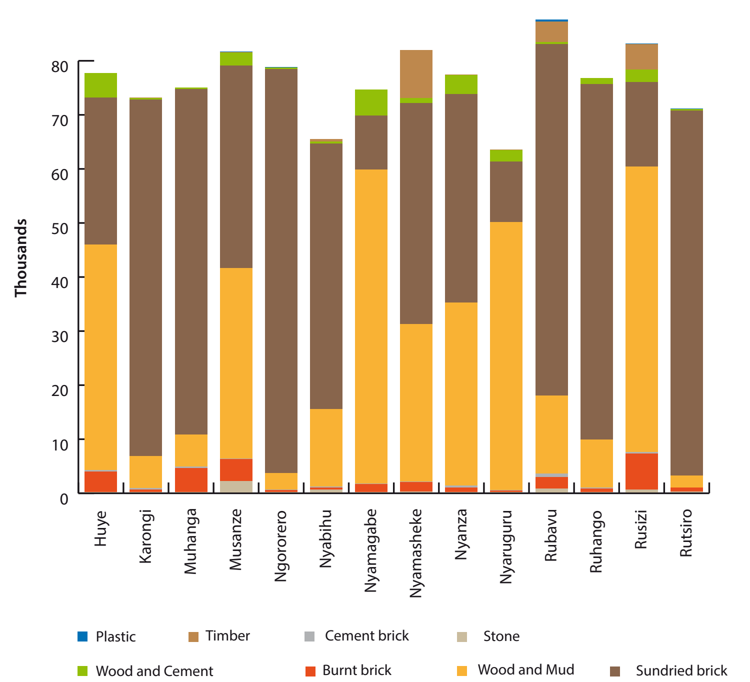
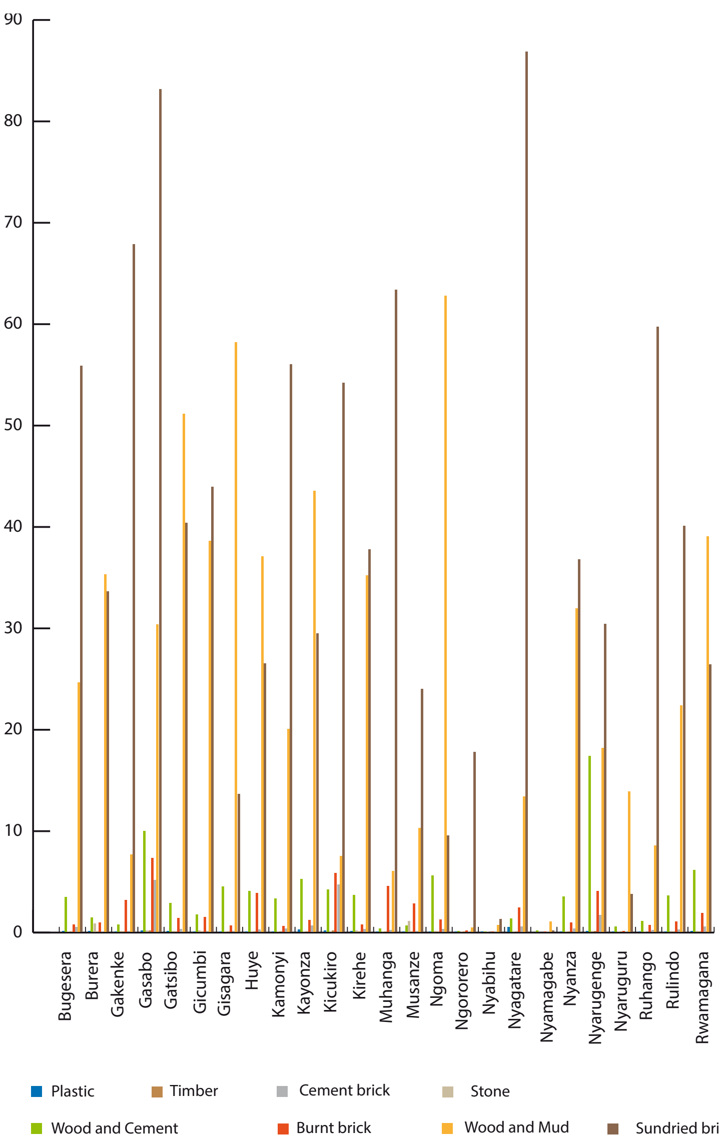


Figure 84 shows the graphical presentation of the number of houses (by wall type) located in a seismic zone with MMI VI intensity. The earthquake hazard assessment (in Figure 42) indicated 25 districts to be prone to an earthquake of this intensity. The districts of Gasabo and Nyagatare are with the highest number of houses exposed with 136,086 and 104,880 respectively. Eighteen (18) districts have houses exposed ranging between 50,000-100,000 units. These include: Bugesera, Burera, Gakenke, Gatsibo, Gicumbi, Gisagara, Huye, Kamonyi, Kayonza, Kicukiro, Kirehe, Muhanga, Ngoma, Nyanza, Nyarugenge, Ruhango, Rulindo and Rwamagana. Musanze district have 38,801 houses exposed while the other four districts have below 20,000 houses exposed i.e. Ngororero, Nyaruguru, Nyabihu and Nyamagabe.

In terms of wall types, similar to MMI VII, houses with walls made of sundried brick have the most number exposed at 59.64% (126,069 houses). Houses with walls made of wood and mud follows at 33.02% (69,783 houses). The rest of the exposed houses (7.34%) are those with walls made of other materials.

Figure 84. Housing exposed to earthquake with MMI VI intensity, by wall type



Health exposure

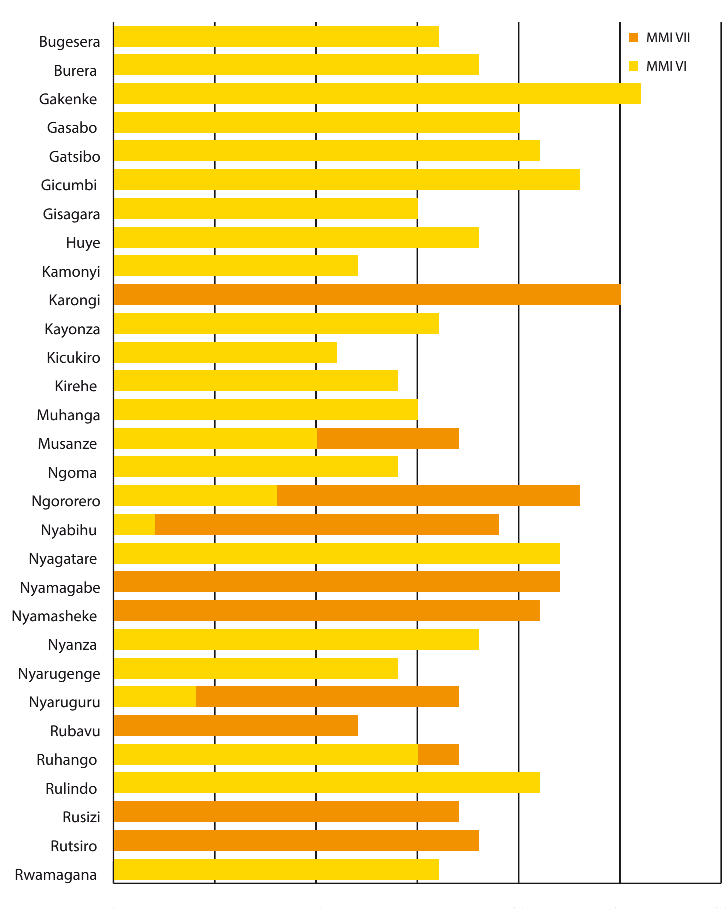
a) Exposure of health facilities

The earthquake exposure assessment for the health sector is limited to analysing the exposure of health facilities by District, which specifically refers to the building or infrastructure only. Health facilities include health posts, health centers, Voluntary Counselling and Testing centers, community-owned health facilities, private clinics, private dispensaries, prison dispensaries, police/military hospitals, district hospitals and national referral hospitals. Out of the total 1036 health facilities (see Chapter II, Table 6) across the country, only 538 are georeferenced and were considered in the analysis. The ensuing chart (Figure 85) shows the exposure of health facilities to earthquake at two intensities: MMI VII and VI.

Considering the 2% of probability of exceedance in 50 years (2475-year return period), 31% of the total georeferenced health facilities are exposed to and/or located in earthquake hazard prone areas at MMI VII. Figure 39 shows the health facilities exposed to earthquake at this intensity. The districts of Karongi, Nyamagabe and Nyamasheke have more than twenty health facilities exposed. Meanwhile, the districts of Ngororero, Nyabihu, Nyaruguru, Rubavu, Rusizi and Rutsiro have between ten and twenty health facilities exposed. Musanze and Ruhango, on the other hand, have less than ten health facilities exposed to earthquake at MMI VI.

The number of health facilities exposed to earthquake at MMI VI are more with 69% of the total georeferenced health facilities. The districts of Gakenke, Gasabo, Gatsibo, Gicumbi, Gisagara, Nyagatare and Rulindo have more than 20 health facilities exposed. Meanwhile, the districts of Bugesera, Burera, Huye, Kamonyi, Kayonza, Kicukiro, Kirehe, Muhanga, Musanze, Ngoma, Nyanza, Nyarugenge, Ruhango and Rwamagana have between ten and twenty health facilities exposed. Ngororero, Nyabihu and Nyaruguru, on the other hand, have less than ten health facilities exposed to earthquake at MMI VI.

Figure 85. Number of health facilities exposed to earthquake at MMI VII and VI intensities



Education exposure

a) Schools exposure

The earthquake exposure assessment for the education sector is limited to analysing the exposure of schools. Specifically, it only refers to the school building or infrastructure. Schools include pre-primary schools, primary schools, secondary schools, and higher learning institutions. The ensuing chart (Figure 86) shows the exposure of schools to earthquake at two intensities: MMI VII and MMI VI.

Considering the 2% of probability of exceedance in 50 years (2475-year return period), 30% of the total georeferenced schools are exposed to and/or located in earthquake hazard prone areas at MMI VII. This represents a total of 1,014 schools. Figure 40 shows the schools exposed to earthquake at this intensity. The districts of Karongi, Nyamagabe, Nyabihu, Rusizi, and Rutsiro have more than 100 schools exposed. Meanwhile, the districts of Musanze, Ngororero, Nyamasheke, Nyaruguru and Rubavu have between 50-100 schools exposed. The districts of Huye, Nyanza, and Ruhango have less than ten schools exposed to earthquake at intensity MMI VII.

There are more schools exposed to earthquake at intensity MMI VI at 70% (2,317 schools in total). The districts of Gakenke, Gasabo, Gatsibo, Gicumbi, Huye, Kamonyi, Kicukiro, Muhanga, Nyagatare and Ruhango have more than 100 schools exposed. Meanwhile, the districts of Bugesera, Burera, Gisagara, Kayonza, Kirehe, Musanze, Ngoma, Nyanza, Nyarugenge, Rulindo and Rwamagana have between 50-100 schools exposed. Ngororero and, Nyaruguru, and Nyabihu have thirty, 23, and ten schools respectively exposed to earthquake at this intensity and the District if Nyamagabe have two schools exposed.

Transportation sector exposure

The exposure assessment for the transportation sector is limited to analysing the exposure of national roads (paved and unpaved) and district roads. The ensuing charts show the exposure of national and district roads to earthquake at two considered intensity: MMI VI and MMI VII. Paved and unpaved roads at national level are presented separately.

a) Exposure of national paved roads

According to Figure 87 below, a total of 1,211 kilometers of national paved roads are exposed to earthquake. These include 391 kilometers of paved roads exposed to earthquake of MMI VII and 820 kilometers exposed to earthquake of MMI VI.

The districts of Nyamasheke, Rusizi and Nyamagabe record for themselves 50% of length of paved roads exposed to earthquake of MMI VII, with 196 kilometers over 391 kilometers exposed in total.

Figure 86. Number of schools exposed to earthquake at MMI VII and VI intensities

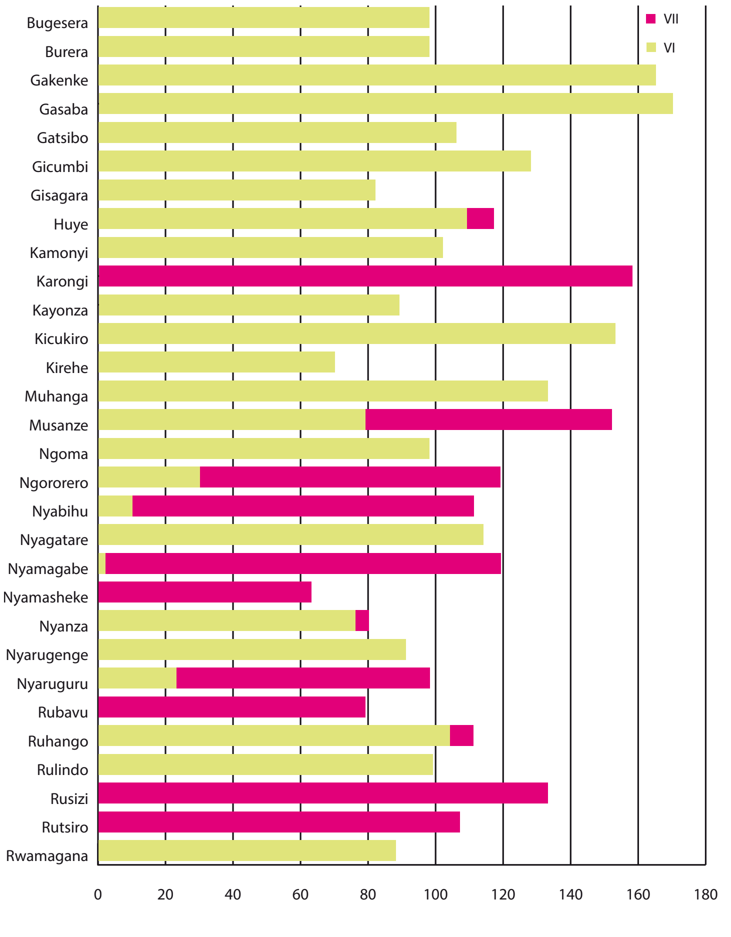
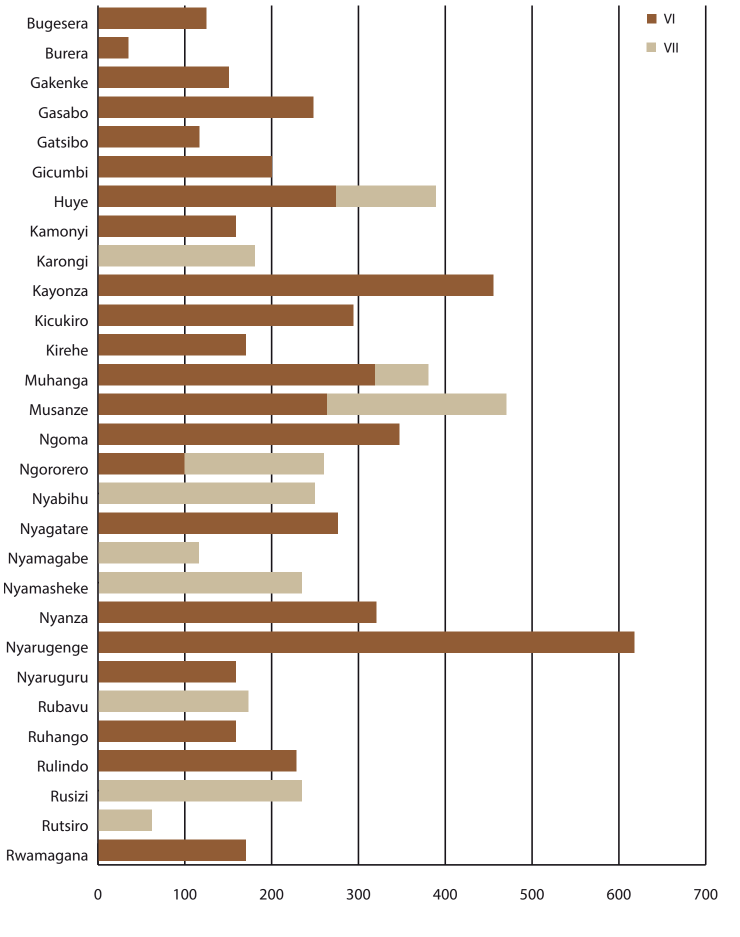


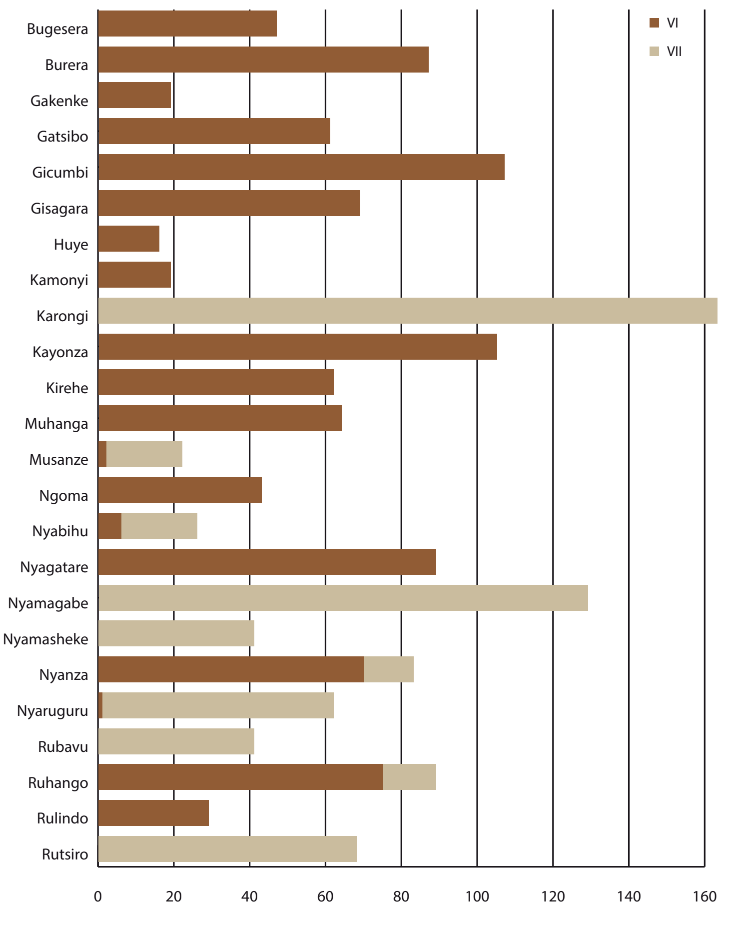
Figure 87. National paved roads (in km) exposed to earthquake at MMI VII and VI intensities



b) Exposure of national unpaved roads

For unpaved national roads, a total of 1,539 kilometers are exposed to earthquake of both MMI (VII and VI). A total of 570 kilometers of national unpaved roads are exposed to earthquake of MMI VII and the districts of Karongi and Nyamagabe have the highest records with 164 kilometers and 129 kilometers respectively. The Figure 88 gives more details.

Figure 88. National unpaved roads (in km) exposed to earthquake at MMI VII and VI intensities

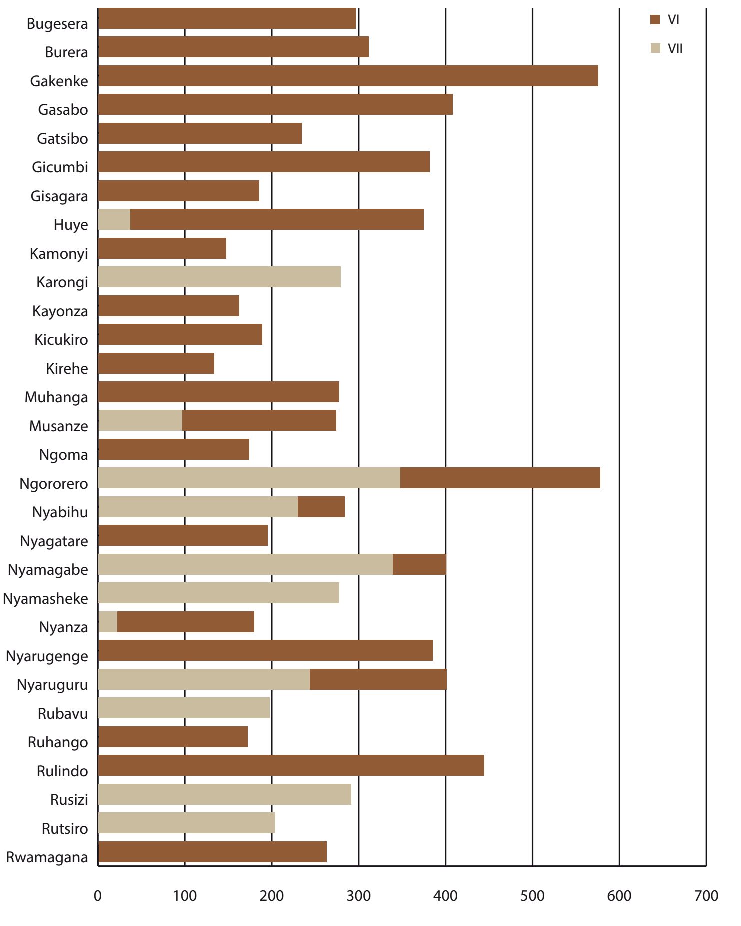


c) Exposure of district roads

The same analysis for earthquake exposure has been made for district roads. Figure 89 shows the number of kilometers of district roads exposed to earthquake at intensities VII and VI. There are about 3,899 kilometers of district roads exposed to earthquake. Of this, 1,393 kilometers are exposed to MMI VII in 12 districts (Huye, Karongi, Musanze, Ngororero, Nyabihu, Nyamagabe, Nyamasheke, Nyanza, Nyaruguru, Rubavu, Rusizi and Rutsiro) and 2,506 kilometers exposed to MMI VI in 25 districts. Rusizi District has the most number of kilometers of district roads exposed to earthquake at 214 km and Ruhango has the least with only 56 km.

Figure 89 District roads (in km) exposed to earthquake at MMI VII and VI intensities

Figure 89. District roads (in km) exposed to earthquake at MMI VII and VI intensities



5.3.3.3 Comparative analysis of exposure profiles

The exposure profiles for earthquake is differentiated here in terms of intensity: MMI VII and MMI VI at 2,475-year return period. Considering the size of the country, Rwanda's earthquake hazard zonation maps indicate that the whole country is prone to earthquake at a maximum intensity of VII and VI. In effect, the exposure is also high for the different elements at risk.

The population exposure to earthquake intensity VII is high in the Western Province with five districts namely Karongi, Nyamasheke, Rubavu, Rusizi, and Rutsiro have 100% of their population exposed. Meanwhile, 16 districts from the other Provinces including Kigali City namely Bugesera, Burera, Gakenke, Gasabo, Gatsibo, Gicumbi, Gisagara, Kamonyi, Kayonza, Kicukiro, Kirehe, Ngoma, Nyagatare, Nyarugenge, Rulindo and Rwamagana have 100% of their population exposed to earthquake intensity VI. In terms of age groups, given that the entire country is exposed to earthquake, only differing in terms of which intensity they are exposed, all the working age and dependents are exposed. About 15% dependent age population and 85% working age population of the country are exposed to earthquake at intensities VII and VI. About 5% (almost half a million) of the dependent-age are exposed to MMI VII and 10% (or a million dependents) exposed to MMI VI.

About 350,000 of the severely poor population in the country are exposed to earthquake at intensity VII while about 700,000 severely poor population are exposed to earthquake at intensity VI. Most of these severely poor population exposed to intensity VII are in Rubavu, Rutsiro, Rusizi, Ngororero, Nyabihu, Nyamagabe and Nyamasheke. Meanwhile, most of the severely poor population exposed to intensity VI are found in the districts of Gatsibo and Nyagatare. The number of poorest Rwandan exposed to earthquake at intensity VII and VI is much higher when combining the figures for severely poor and moderately poor population. A total of 1.3 million poor population in the country are exposed earthquake with MMI VII intensity and another 2.5 million poor Rwandans are exposed to earthquake of intensity VI.

The housing exposure to earthquake is also very high at both intensities VII and VI. Comparing the exposure at two intensities, more houses are exposed to intensity VI with about 1.7 million houses than to intensity VII, with about 700,000 houses. Moreover, the exposed houses are those with walls made of sundried bricks and wood & mud materials comprising about 90% of the houses consistent across the two intensities.

Given that a larger area of the country is prone to earthquake at intensity VI compared to the area prone to earthquake at intensity VII, the number of health facilities exposed are also high at intensity MMI VI than at intensity MMI VII comprising of 369 and 169 health facilities respectively. These are big numbers considering the importance of health facilities in disaster situations. The capacity of the health sector to provide services in case of disasters could be hampered or undermined significantly if these health facilities remain to be in a very high exposure.

The same goes for the exposure of the education sector. There are more schools exposed to earthquake at intensity MMI VI than intensity MMI VII with 2,317 and 1,014 schools respectively. An earthquake occurring at day time is one specific scenario to be considered knowing the very high exposure of schools to earthquake at both intensities as this will mean a high potential for direct impact to school children, young students, teachers and non-teaching personnel and officials.

The length of national roads and district roads exposed to earthquake is higher as expected in areas prone to earthquake at intensity VI compared to areas prone to earthquake at intensity VII. Furthermore, there are more unpaved national roads exposed compared to paved national roads at 1,539 kilometers and 1,211 kilometers respectively. The same goes for the district roads where there are more district roads exposed to earthquake at intensity VI compared to those exposed to intensity VII.

5.3.3.4 Summary of key findings

- About 3.2 million people or 31% of the country's population are exposed to earthquake at intensity MMI VII. The rest of the 69% or summing up to approximately 7.3 million Rwandans are exposed to earthquake at intensity MMI VI.

- The population in all the districts in the western province are exposed to earthquake intensity VII including some districts in the southern and northern provinces. The rest of the country is also exposed to earthquake at intensity MMI VI.

- The districts of Rusizi, Nyamagabe, Rubavu, Nyabihu, and Nyamasheke have above 50 thousand dependent-age population exposed to earthquake at intensity VII. Owing to population density in these areas, the districts of Gasabo, Kicukiro, and Nyarugenge in Kigali City and Nyagatare in the eastern province have over 50 thousand of its dependent-age population exposed to earthquake at intensity VI. In sum, the population exposure to earthquake in Rwanda is comprised of 15% dependents and 85% working-age population.

- Combining the two categories of the poor in Rwanda i.e. severely poor and moderately poor, approximately about 1.3 million Rwandans are exposed to earthquake of MMI VII and another 2.5 million people in the country are exposed to earthquake of MMI VI. This is about 36% of the total population of the country. This is a very high exposure considering the demographic size of the country. Majority of the poor Rwandans exposed are from the districts of Rubavu, Rutsiro, Rusizi, Ngororero, Nyabihu, Nyamagabe and Nyamasheke including Gatsibo and Nyagatare.

- The housing exposure to earthquake of a 2475-year return period is very high in Rwanda at 100% given that the entire country is located in a seismic zone with a maximum intensity of MMI VI and VII. A total of 29% of the houses in Rwanda are exposed to earthquake with intensity VII and the other 71% of the houses are exposed to earthquake with intensity VI. There is a very high exposure for houses made of sundried bricks and wood & mud since most of the houses in Rwanda are made of walls with these materials comprising 90% of the houses assessed. As expected, most of these houses are located in the western province specifically the districts of Rusizi, Nyamasheke, Karongi, Rutsiro, Nyabihu and Ngororero, Nyaruguru in the southern province and Musanze in the northern province for MMI VII and the districts of Gasabo in Kigali City and Nyagatare in the eastern province for MMI VI.

- The exposure of the health sector to earthquake is also very high comprising of 52% of the total health facilities in the country exposed. About 31% of the exposed health facilities are exposed to earthquake at intensity MMI VII and 69% are exposed to earthquake at intensity MMI VI. The districts of Karongi, Nyamagabe and Nyamasheke have each more than twenty health facilities exposed to MMI VII. Meanwhile the districts of Gakenke, Gasabo, Gatsibo, Gicumbi, Gisagara, Nyagatare and Rulindo account for over twenty health facilities exposed to MMI VI.

- The exposure of the education sector to earthquake of 2475-year return period is also at 100% given the entire country is prone to seismic hazard at intensities VI and VII. Thirty percent of the schools georeferenced are exposed to earthquake at intensity VII and the rest of the 70% are exposed to earthquake at intensity MMI VI. The districts of Karongi, Nyamagabe, Nyabihu, Rusizi, and Rutsiro have more than 100 schools exposed to MMI VII and the districts of Gakenke, Gasabo, Gatsibo, Gicumbi, Huye, Kamonyi, Kicukiro, Muhanga, Nyagatare and Ruhango have more than 100 schools exposed to MMI VI.

- A total of 1,211 kilometers of national paved roads are exposed to earthquake. These include 391 kilometers of paved roads exposed to earthquake of MMI VII and 820 kilometers exposed to earthquake of MMI VI. The districts of Nyamasheke, Rusizi and Nyamagabe record for themselves 50% of the total length of paved roads exposed to earthquake of MMI VII at 196 kilometers.

- A total of 1,539 kilometers of unpaved national roads are exposed to earthquake of both MMI (VII and VI), 570 kilometers are exposed to earthquake of MMI VII and the districts of Karongi and Nyamagabe have the highest records with 164 kilometers and 129 kilometers respectively and 969 kilometers are exposed to earthquake at intensity VI.

- There are about 3,899 kilometers of district roads exposed to earthquake. Of this, 1,393 kilometers are exposed to MMI VII in 12 districts (Huye, Karongi, Musanze, Ngororero, Nyabihu, Nyamagabe, Nyamasheke, Nyanza, Nyaruguru, Rubavu, Rusizi and Rutsiro) and 2,506 kilometers exposed to MMI VI in 25 districts. Rusizi District has the most number of kilometers of district roads exposed to earthquake at 214 km.

5.3.4 Exposure to windstorms

5.3.4.1 Overview

According to the MIDIMAR Annual Report of 2014, 44 people died because of storm events during 2011 – 2013. Another 54 people got injured, 5,944 houses were destroyed or damaged and more than 7.630 ha of crop lands were affected (see Figure 25).

The exposure assessment for windstorm provides vital information about the elements and assets, which are located in the storm paths or the windstorm hazard prone areas. The information generated from the assessment are important and useful to disaster managers and decision-makers as basis for plans and interventions on preparedness, early warning, response recovery, and mitigation.

Elements at risk

In Rwanda, windstorm primarily affects physical infrastructure such as housing and public buildings. It also affects some crops mainly bananas and corn. However, for this report, the assessment has been limited to analysing the exposure of population and primary physical assets such housing, health facilities, and schools. The housing exposure is analysed by type of roof.

Scenario

The windstorm hazard assessment (in Chapter IV) has developed hazard maps for two return periods: 10-year return period and 5-year return period (Figure 44 & Figure 45). For this section, the exposure assessment is only analysed for the 10-year return period. Based on the expected damage matrix as elaborated in (Chapter VI, Table 15), significant expected damages (D1-D3[33]) for structure categories (Cat. 1 – Cat. 2[34]) are only notable for the 10-year return period. Expected damage may be non-existent in 5-year return period.

Intensity levels

For this study only the three (top) scales are analysed. These are: strong gale, gale and moderate gale. The lower scales are not analysed as the potential impact or damage is very minor.

[33] As defined in Chapter VI of this report, D1, D2, D3 refer to different damage state of a structure as a result of a storm impact
[34] As defined in Chapter VI of this report, Cat.1&Cat.2 refer to categories of houses with walls made of industrial, concrete, asbestos and local tiles and walls made of iron sheets, grass and cartons respectively

5.3.4.2 Characterization of exposure profiles

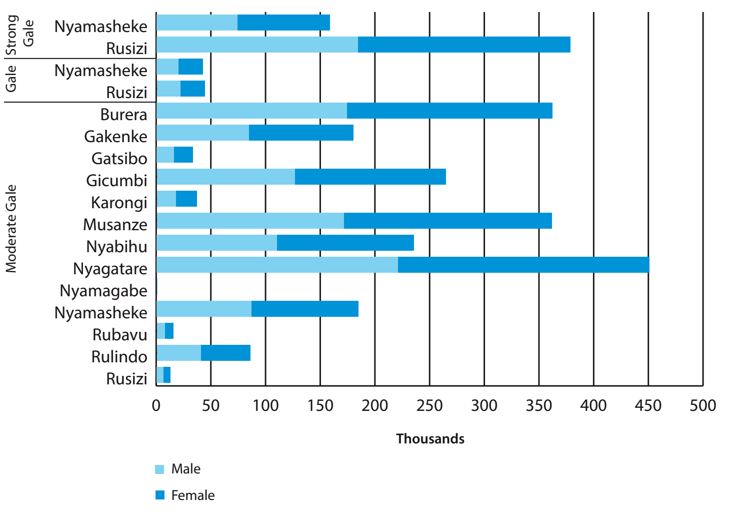
Population exposure

The population exposure to windstorms has been assessed here in terms of gender, age (working and dependent age), and by levels of poverty. The ensuing charts show the results of this exposure assessment.

a) Population exposure by gender

Considering the 10-year return period, 13 districts are exposed to windstorms with a scale from moderate gale, gale and strong gale as shown in Figure 90. This consists of 2,841,804 total population exposed to windstorms. All of the 13 Districts are exposed to moderate gale while only Nyamasheke and Rusizi exposed to gale and strong gale with a population of 86,038 and 535,957 exposed respectively.

Figure 90. Population exposed to windstorms of 10-year return period



b) Population exposure by age

In terms of age i.e. working and dependent age, Figure 91 shows the population exposure. A total of 2,434,717 are exposed. Of this number, 16% are dependent age and 84% are of working age. Most of them are exposed to moderate gale only. Only Nyamasheke and Rusizi have population of both age categories exposed to gale and strong gale windstorms.

c) Population exposure by levels of poverty

By levels of poverty, the population exposed to windstorms at a scale of moderate gale, gale and strong gale revealed that 10% of the severely poor population are exposed as shown in Figure 92. The rest of the exposed population comprised of about 27% moderately poor; 28% of those vulnerable to poverty and 34% of the not poor. Combining the figures of severely poor and moderately poor, the total poor Rwandans exposed to windstorms is 1,068,351.

Figure 91. Population exposed to windstorms of 10-year return period, by age (working and dependent age)

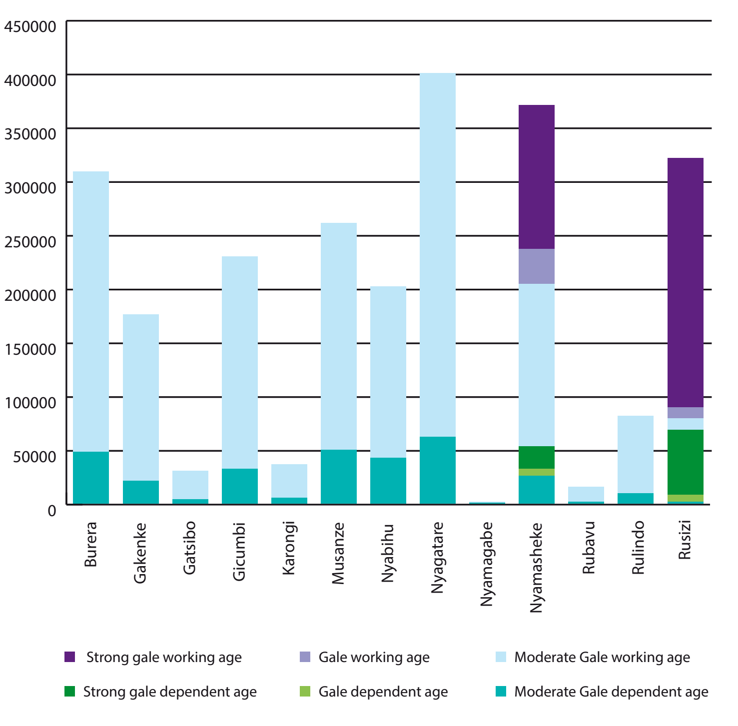
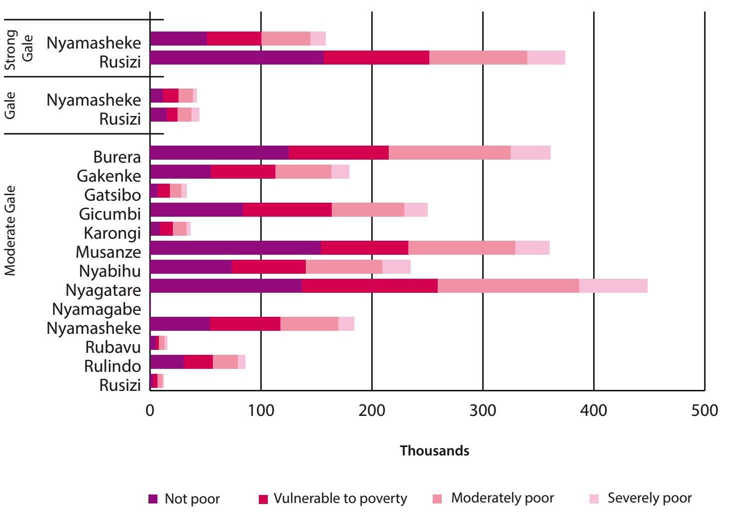


Figure 92. Population exposed to windstorms of 10-year return period, by levels of poverty



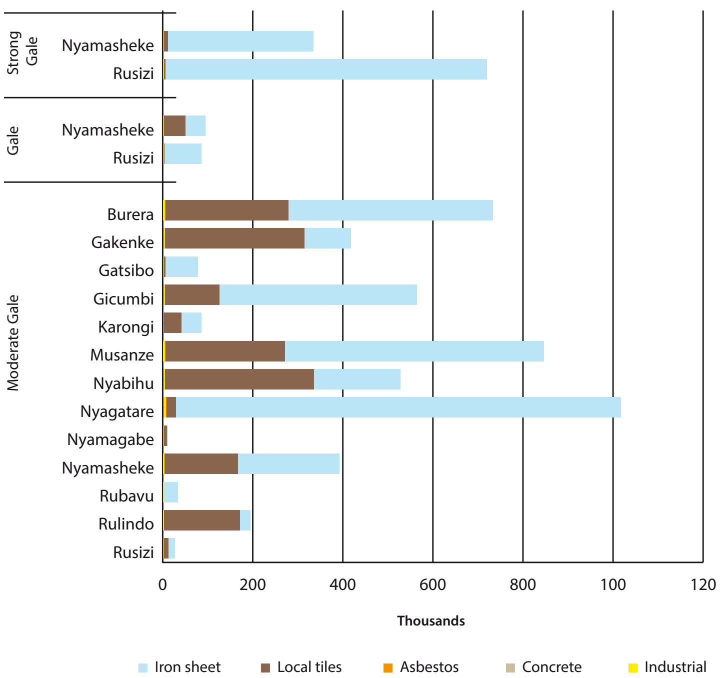
Housing exposure

a) Housing exposure by type of roof

The windstorms exposure assessment for the housing sector is done considering the type of roof. In general, the roof is the first part of the house to be damaged in the case of windstorms and therefore determines the resilience of the house. In Rwanda, the roofing of houses are classified as: industrial, concrete, asbestos, local tiles and iron sheet.

Figure 93 shows the houses exposed to windstorm for a 10-year return period. A total of 614,421 housing units in 13 Districts are exposed with 70.48% are made of iron sheet roofing; 28.96% with local tiles as roof; and the remaining 0.54% are houses with roofs made of other materials such as asbestos, industrial and concrete. Twenty percent of the houses are exposed to gale and strong gale in Nyamasheke and Rusizi districts. The other 80% are exposed to moderate gale across the 13 districts.

Figure 93. Housing exposed to windstorm of 10-year return period, by type of roof



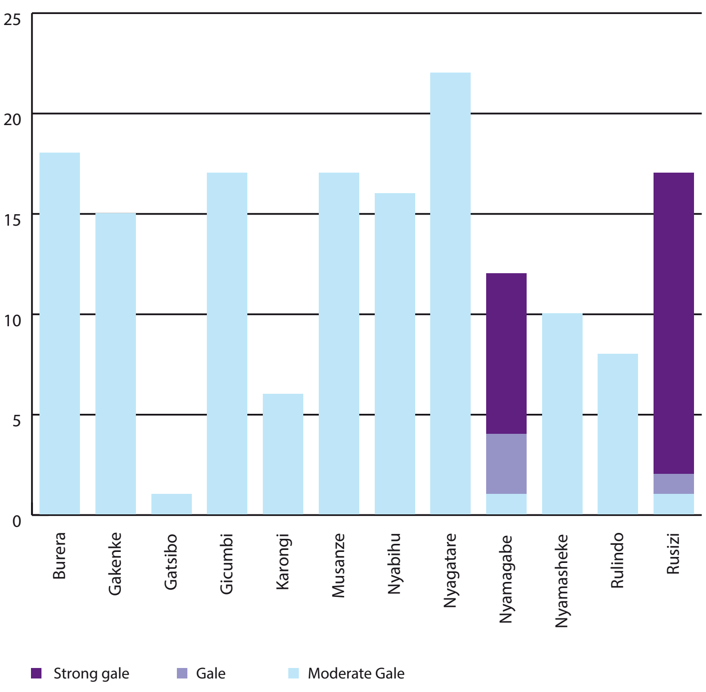
Health exposure

a) Exposure of health facilities

The windstorm exposure assessment for the health sector is limited to the analysis of health facilities (also as elaborated in the other sections above).

Figure 94 shows the number of health facilities exposed to windstorms of a 10-year return period. Of the total 615 georeferenced health facilities, 148 (24%) are exposed to windstorms. Of this number, 23 (16%) are exposed to strong gale, four (3%) are exposed to gale and 132 (89%) of health facilities are exposed to moderate gale. The districts of Nyamasheke and Rusizi have 10 and 17 health facilities respectively exposed and the 16 health facilities in Rusizi are exposed to gale and strong gale.

Figure 94. Number of health facilities exposed to windstorms of 10-year return period



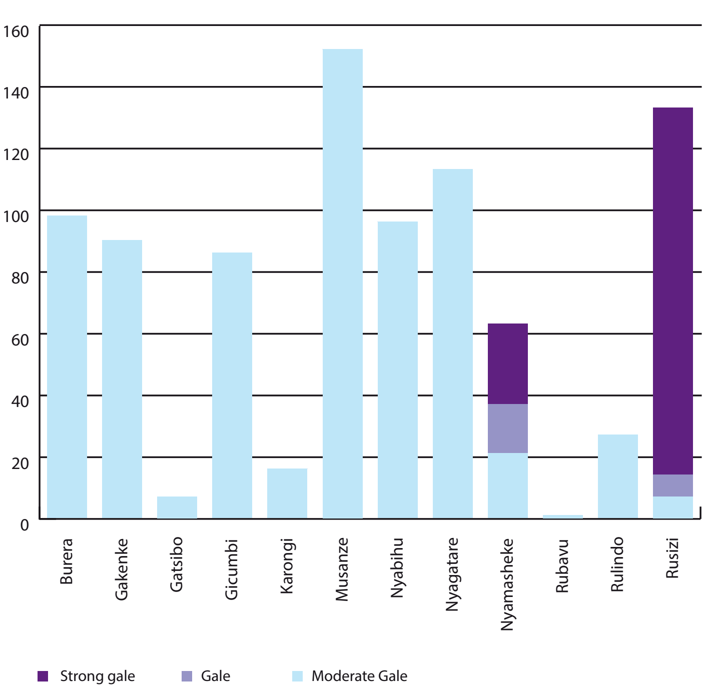
Education exposure

a) Schools exposure

The analysis for the education sector is limited to assessing the exposure of schools to windstorms at a 10-year return period considering only the three scales of moderate gale, gale and strong gale.

As can be gleaned from Figure 95, a total of 882 schools are exposed to windstorms from moderate gale to strong gale. This is out of the total 990 schools recorded. About 81% are exposed to moderate gale, 3% exposed to gale and 16% exposed to strong gale across the 12 districts located in the windstorm prone areas.

Figure 95. Number of schools exposed to windstorms of 10-year return period



5.3.4.3 Comparative analysis of exposure profiles

Considering only one scenario of a 10-year return period for windstorms, the country's exposure profiles could be compared in terms of intensity i.e. moderate gale, gale and strong gale.

Amongst the 2.8 million total population exposed to windstorms, majority (78%) is exposed to an intensity of moderate gale only. Meanwhile, only 22% are exposed to higher intensities of gale and strong gale.

Among the population exposed in the 13 districts, around 400,000 or 16% are dependents while about 2 million of whom are working age population. The districts of Nyamasheke have over 50,000 dependents exposed and Rusizi has about 70,000 dependents exposed. Mostly (82%) are exposed to moderate gale while about 18% of are exposed to gale and strong gale. It is important to ascertain the number of dependent-age population exposed so as to inform corresponding disaster contingency plans, early warning and preparedness actions for areas with high exposure.

The population exposure by levels of poverty indicates that about 37% of the exposed are poor Rwandans comprised of the severely poor and moderately poor combined. Although most are exposed to only moderate gale windstorms these poor population of Nyamasheke and Rusizi are also exposed to gale and strong gale.

The housing exposure to windstorms for a 10-year return period is also high. A total of over 600,000 houses are exposed. Of this number 20% are exposed to windstorms at higher intensities of gale and strong gale while the 80% are exposed to moderate gale only.

The exposure of health facilities is high for moderate gale windstorms with 89% of the total exposed health facilities. Comparatively, a much lower number of health facilities are exposed to gale and strong gale windstorms at only 3% and 16% respectively.

The exposure of schools is high for moderate gale windstorms with 81% of the total exposed schools. Comparatively, there is a low number of schools exposed to gale and strong gale with only 3% and 16% respectively.

5.3.4.4 Summary of key findings

- Approximately 2.8 million Rwandans are exposed to windstorms at intensities of moderate gale to strong gale across 13 districts. About 22% of this are from Rusizi and Nyamasheke districts comprising of 384,373 people and 434,357 people respectively. The other 78% are distributed across the other 11 districts namely; Burera, Gakenke, Gicumbi, Karongi, Musanze, Nyabihu, Nyagatare, Nyamagabe, Rubavu and Rulindo. The latter are exposed only to moderate gale windstorms.

- The total number of dependent age population exposed to windstorms is about 400,000 and they are distributed across the 13 districts mentioned above and over 2 million of whom are working age population. Nyamasheke and Rusizi districts have population exposed to windstorms at higher intensities of gale and strong gale.

- About 1 million poor Rwandans are exposed to windstorms from moderate gale to strong gale and they come from the 13 districts above mentioned.

- More than half a million (approximately 600,000) houses are exposed to windstorms. Most of these houses are with roofing made of iron sheets (78%) and local tiles (29%). The highest exposure is in Nyamasheke and Rusizi districts.

- Out of the total health facilities considered in the analysis, 148 (or 24%) are exposed to windstorms. Most are exposed to moderate gale, however, there are 16 health facilities in Rusizi District exposed to gale and strong gale.

- A total of 882 schools (about 89%) are exposed to windstorms from moderate gale to strong gale. Of this number a total of 145 are exposed to strong gale and 119 of which are found in Rusizi District. The other 26 are found in Nyamasheke.

Chapter VI

Vulnerability Assessment

6.1 Introduction

6.1.1 What is vulnerability assessment?

The National Risk Atlas consists of hazard, exposure, and vulnerability profiles and estimation of economic cost. The hazard and exposure assessment have been undertaken as shown in Chapter IV and V which essentially entail the mapping, evaluation and analysis hazard zones and exposure of the different elements at risk. This chapter discusses the ensuing step of the risk assessment process – the vulnerability assessment.

Vulnerability assessment is a systematic examination of building, elements, facilities, population groups or components of the economy, which helps to identify features that are susceptible to damage from the effects of natural hazards. Vulnerability is a function of the existing hazards and the characteristics and quality of resources or population exposed to those hazards. Vulnerability can be estimated for individual structures, for specific sectors or for selected geographic areas, e.g. areas with the greatest development potential or already developed areas in hazardous zones. For this project, the vulnerability assessment aims to diagnose the parameters governing the weakness and strength of the elements at risk.

Only 4 out of the 5 hazards mapped/assessed is considered in the vulnerability assessment, namely: drought, landslide, earthquake and windstorms. Vulnerabilities of elements at risk to floods was not included due mainly to lack of data. In order to undertake a robust vulnerability assessment to floods a customized detailed data set of elements at risks aggregated by river catchments is required and these data sets are not currently available in the country.

6.1.2 How to use the vulnerability profiles?

There are various reasons why a vulnerability assessment can be useful. The bullet points below state a few of them and also explains how the vulnerability profiles can be used.

- The vulnerability assessment provides a basic framework that can be used to understand the linkages between hazard, exposure, vulnerability and risk of various physical, social and infrastructural assets that exist in various geographical and development zones of the country.

- The vulnerability assessment diagnoses the characteristics of the physical and social elements with respect to a specific hazard's severity, which reflects the strength and weaknesses of the assets. Thus, VAs develops a basic understanding about the sector's vulnerability and provides evidence based approach for disaster risk reduction (DRR).

- The vulnerability assessment will provide details of vulnerability of different elements at risk to various geological and hydro-meteorological hazards. This will further enable policy makers and decision makers to understand potential damage to a particular element. Vulnerability assessment is an essential tool for apex planning bodies like the Ministry of Finance and Economic Planning (MINECOFIN) and other key sectorial ministries and institutions for the allocation of funds and resources for DRR.

6.2 Thematic vulnerability profiles

6.2.1 Vulnerability to drought

6.2.1.1 Overview

A drought hazard assessment (in Chapter IV) has developed drought hazard susceptibility maps for two seasons: Season A and Season B considering the probability of occurrence.

Elements at risk

The exposure of the agricultural sector is analysed in terms of: total cultivated area and the volume of crop production of major crops produced in Rwanda namely maize, sorghum, rice, ordinary beans, climbing beans, banana, Irish potato and cassava.

Intensity levels

The drought hazard assessment has classified severe drought susceptibility into five classes (very high, high, moderate, low and very low). For the drought exposure assessment, the analysis is made for the two seasons and considered only moderate to very high (3 out of 5) susceptibility classes without including low and very low. Very high indicates > 30% likelihood for a severe drought to occur. High indicates 20-30% and moderate indicates 10-20%. The low susceptibility class indicates only 5-10% likelihood for severe drought to occur and for very low susceptibility class indicates less than 5% likelihood for severe drought to occur, hence, they are not included in the analysis (see Chapter IV, Table 14).

6.2.1.2 Methodology

The vulnerability assessment for drought, in this study, is limited to the population and the agricultural sector. The vulnerability of the population adopted the methodology of the study done by WFP in which the vulnerable households per district were identified. Thus the information on the vulnerable households was used to assess the total number of population that might be affected by different levels of severe drought. On the other hand the analysis of vulnerability of major crops to drought hazard followed the study done by FAO on the estimate of harvest loss due to the occurrence of severe drought.

The precision of the vulnerability assessment depends upon the classification of crops cultivated and the particular characteristics of the analysed district. The vulnerability of agriculture to drought conditions is closely related to the challenges of sustainable agriculture and food security (WFP, 2012). Thus, the information on the vulnerability status of agricultural drought is crucial for the development and implementation of long-term drought management measures. The vulnerability of the crops and the population exposed to different classes of drought are assessed at district level.

The vulnerability assessment to drought has two dimensions; the first is the spatio-temporal variability of the drought hazard. This can be explained as the change of the drought probability throughout the year accompanied by the change of the drought probabilities in different areas in time. The second dimension is the spatio-temporal variability of the vulnerable groups. For example, the change in crop farming per season per area and the population movements throughout the year and space. Thus the vulnerability assessment should take into account these two dimensions. Various studies clearly showed that the best approach in vulnerability assessment is the one reaching down to the households level (WFP, nd) (UNISDR & GAR, 2013). Namely, the vulnerability can vary significantly among households within same area due to factors like sex, age, location, and other conditions shaped by economic, social, and political processes. For this reason, the information on the vulnerable households in Rwanda was used to assess the total number of population that might be affected by different susceptibility levels of drought.

This methodology[35] was also used by WFP in the Comprehensive Food Security and Vulnerability and Nutrition Survey (CFSVA) and is applied to the Rwanda context (WFP, 2012). On the other hand, the analysis of vulnerability of major crops to the drought hazard was based on the FAO study. FAO analysed the estimate of harvest loss due to the occurrence of severe drought (FAO, 1998). They used information on harvest (Kg/ha) and the harvest area (in) per district in order to estimate the total loss per district in tones.

In order to identify the vulnerable population, the approach as described in the guidelines of the WFP CFSVA is used (WFP, 2012). The identification approach combines the WRSI with population data, livelihood wealth index indicators from the CFSVA and the Nutrition Survey. Note that, as countries customize the CFSVA at the national level, data collected from other (more up-to-date) national surveys can be used to refine and update the population vulnerability profiles.

For instance, based on the Water Balance Model, a Water Requirement Satisfactory Index (WRSI) of 80 percent leads to a harvest of only 50%. A household depending 70% on agriculture would – as a primary effect – lose 35 percent of its livelihood because of the drought (Harrison & Butterfield, 1996). The total number of losses in terms of crop production have been calculated using the information provided in Table 42. The table shows the estimate done by FAO for crop yield in relation to WRSI.

The contribution of agriculture related activities to households was assessed to define the level of the vulnerability of a household to rainfall deficit. For example, a low contribution of agriculture to a household may imply that this household is not heavily dependent on agriculture and therefore less likely to be affected by a

[35] The methodology referred to here is the methodology used by the Africa Risk Capacity. The focus is on the effects of drought on the population depending on agricultural activities for livelihood and source of income. The vulnerable populations in the ARC methodology are estimated according to two factors: resilience, which is a household's distance from the national poverty line and exposure, which is the percentage of a household income that comes from agricultural activities (production, casual labour and livestock). Based on these two factors and a household survey a drought vulnerability profile of populations living in the country was created. Africa Risk Capacity (ARC) is a specialized agency of the African Union (AU) to help Member States improve their capacities to better plan, prepare and respond to extreme weather events and natural disasters, therefore protecting the food security of their vulnerable populations.

Table 41. Classification of water-limited crop performance according to FAO in relation to WRSI (Harrison & Butterfield, 1996)

% yield in relation to maximum (potential) yield	Performance	WRSI
>100	Very good	100
90-100	Good	95-99
50-90	Average	80-94
20-50	Mediocre	60-79
10-20	Poor	50-59
<10	Crop failure	<50

rainfall deficit compared to those who are dependent on agriculture. A population relying on agriculture or livestock that are exposed to rainfall shortages, living in higher risk areas, and having a lower capacity to cope with these shortages (low resilience), are more likely to become vulnerable because of rainfall deficits (WFP, 2012).

Figure 96 shows the distribution of households vulnerable to rainfall deficit. It also shows the probability of rainfall deficit in different areas. These values are used in the vulnerability assessment. Further, the severe drought probabilities have been taken into account.

6.2.1.3 Characterization of vulnerability profiles

Drought vulnerability in Season A

a) Vulnerability of population

The fact that there is a higher probability of rainfall deficit for both Season A and B in the southern and eastern province has been shown in Chapter IV, paragraph 4.1.4. The vulnerability assessment indicates that the districts in the eastern province are most vulnerable to rainfall deficit as well as Kigali City and the eastern zone of the southern province. There is huge temporal change of the drought hazard throughout the year, which makes Season B more hazardous compared to Season A.

In Season A, as shown in Figure 97 and Figure 98, the districts of Kayonza, Kirehe, Nyagatare and Gatsibo have more than 80% of the total population vulnerable (at 31%, 22%, 18%, and 12% respectively). Note that only 8 districts are predicted to be affected by severe drought. The total number of people vulnerable to the effects of severe drought is 48,808.

Figure 96. Percentage of vulnerable households per district (WFP, 2012)

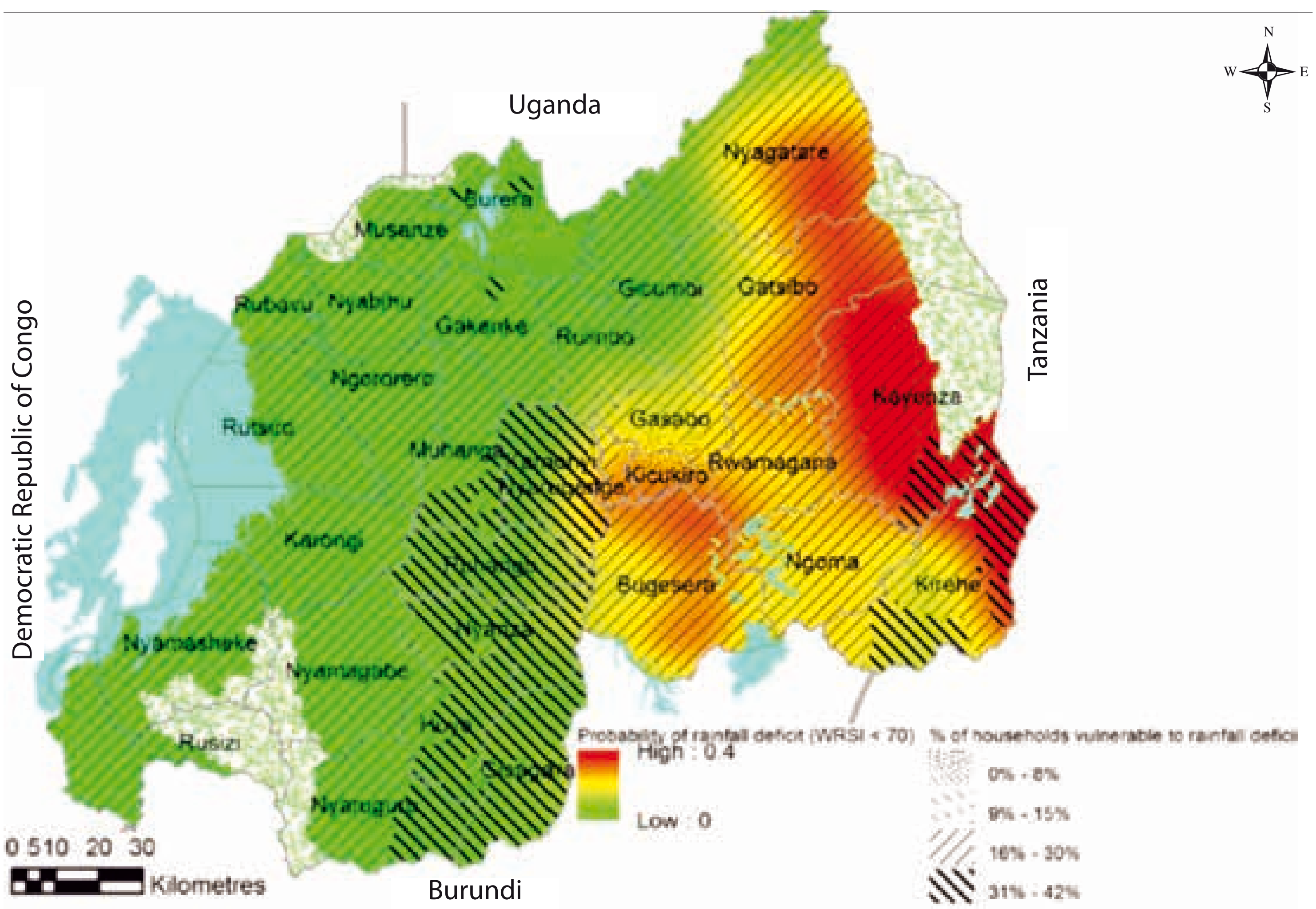


Figure 97. Map of the population vulnerable to severe drought in Season A

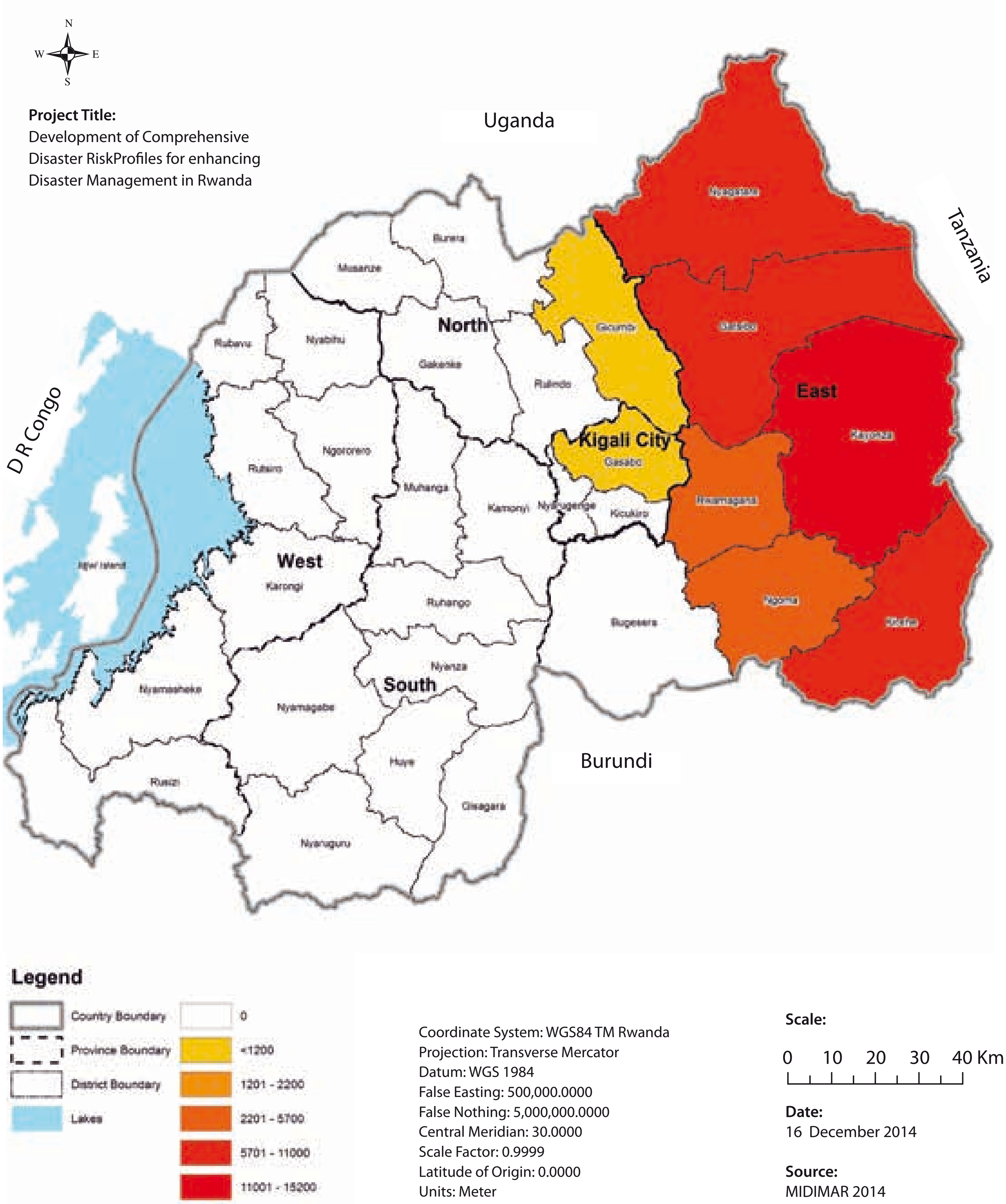
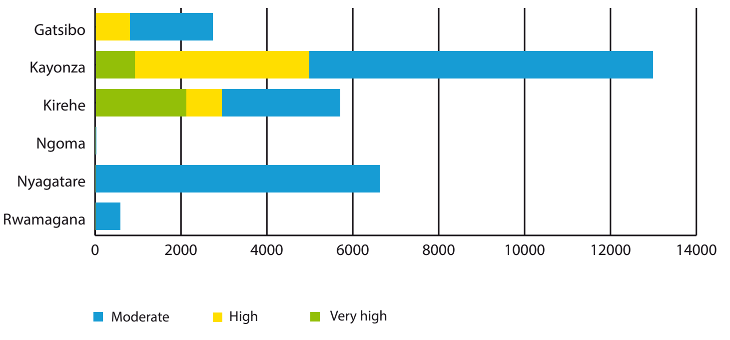


Figure 98. Population vulnerable to severe drought in Season A



b) Agriculture vulnerability

The data used in the crop vulnerability analysis are from the Ministry of Agriculture and Animal Resources (MINAGRI, 2014). Two types of information were combined with the drought hazard probability and the exposure of the crops: crop yields estimates by district (Kg/Ha) and harvested area estimates by district (Ha).

The vulnerability of the agriculture sector in season A is summarized in Figure 99, Figure 100, and Figure 101 for very high, high and moderate susceptibility respectively. The most vulnerable crop in Season A is banana accounting for an average of 64% of the total crops vulnerable to severe drought at moderate to very high susceptibility levels. Following next is Irish potato with 20% of the total crop vulnerable. It is important to stress that the most vulnerable crops are the main staple food of Rwandan households which may imply that if these crops are affected by severe drought, it could cripple availability of food supply and will impact food security of the population in the areas of concern.

For an intensity of very high susceptibility in Season A, the highest crop vulnerability is in Kayonza which has about 50% of the total vulnerable crops countrywide. The district of Kirehe and Gatsibo count for 25% and 16% respectively.

Figure 99. Crop yield (tons) vulnerable to drought at very high susceptibility in Season A

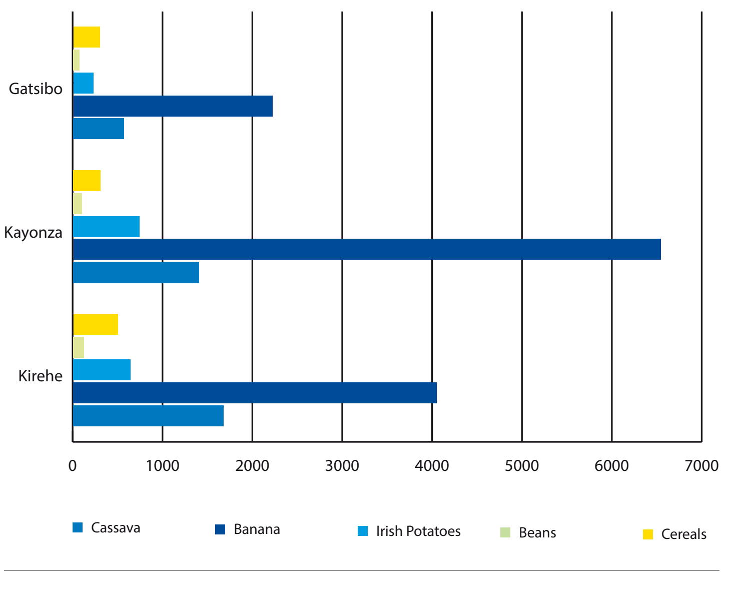
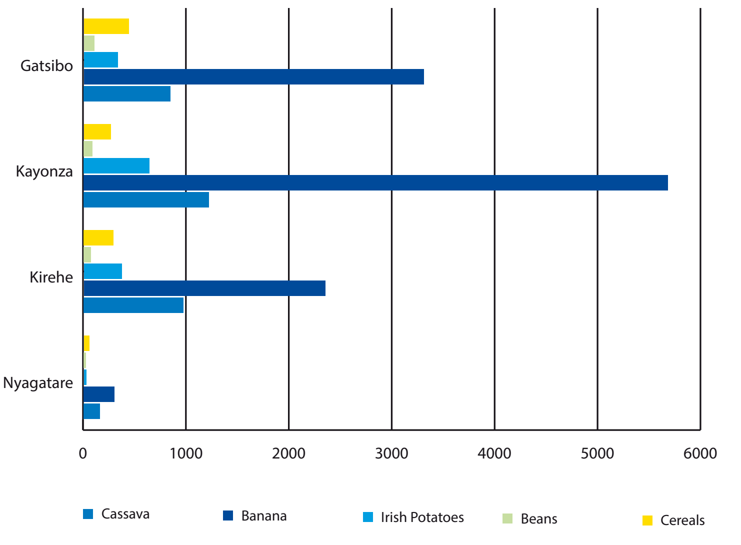


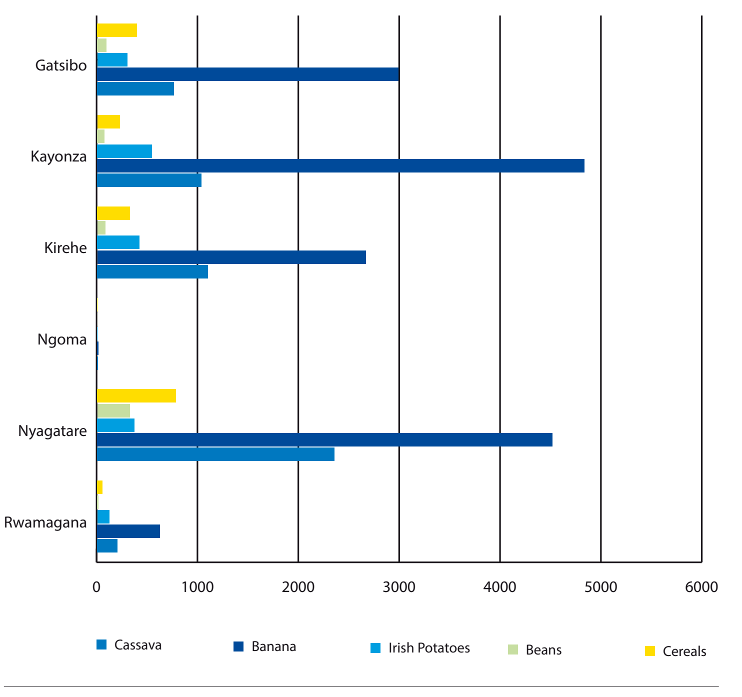
Figure 100. Crop yield (tons) vulnerable to drought at high susceptibility in Season A



A total of 19,390 tons of crops are vulnerable to severe drought at very high susceptibility.

The total volume of crops vulnerable to severe drought at high susceptibility decreased to 17,475 tons compared to the volume vulnerable at very high susceptibility. Kayonza still accounts for 45% of the vulnerability while Gatsibo, Kirehe and Nyagatare get respectively 29%, 23% and 3% of the crop vulnerability.

Figure 101. Crop yield (tons) vulnerable to drought at moderate susceptibility in Season A



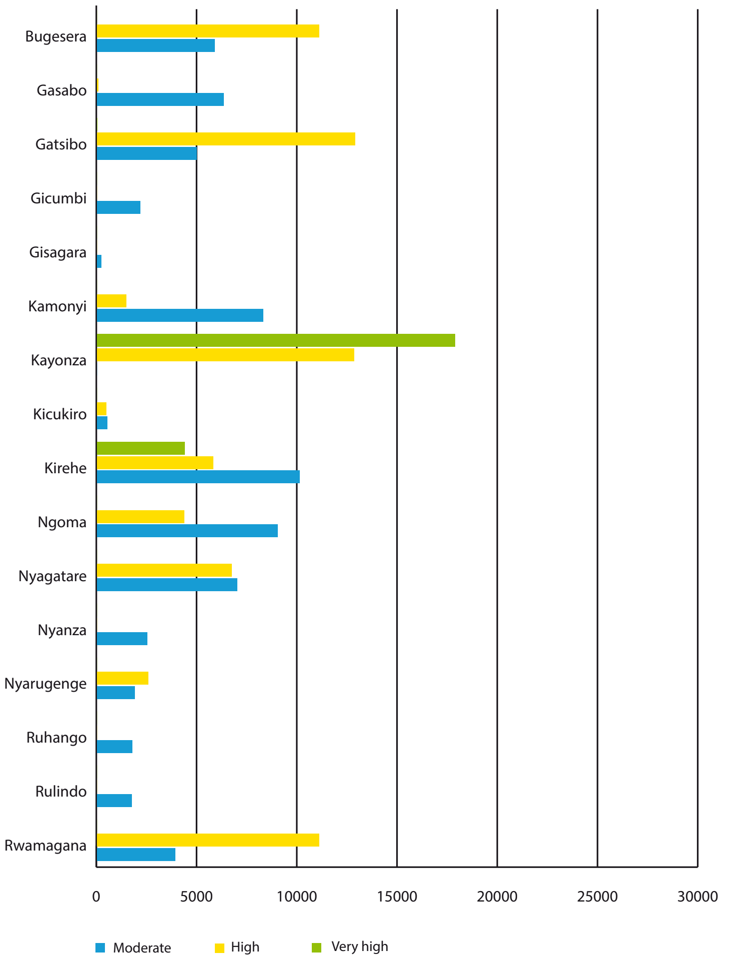
More volume of crops are vulnerable to severe drought at moderate susceptibility. The total vulnerable crops is 25,168 tons. This is owing to the wider area of drought prone zones and therefore higher exposure, too. The highest vulnerability is in Nyagatare which has 33% of the total volume of crop vulnerable to severe drought at moderate susceptibility. Kayonza, Kirehe and Gatsibo also record a high crop vulnerability at 27%, 18% and 17% respectively. Banana, cassava and Irish potato are the most vulnerable crops.

Drought vulnerability in Season B

a) Vulnerability of population

The total number of vulnerable population to severe drought in season B is 157,786 countrywide. There are in drought class of medium to very high probability of severe drought. Note that, only 6 district are safe from the effect of drought hazard. As shown in Figure 102 and Figure 105 the districts Kayonza, Kirehe, Gatsibo, and Bugesera have the highest number of population at risk with 15%, 10%, 9%, and 8% respectively of the total population at risk countrywide in season B.

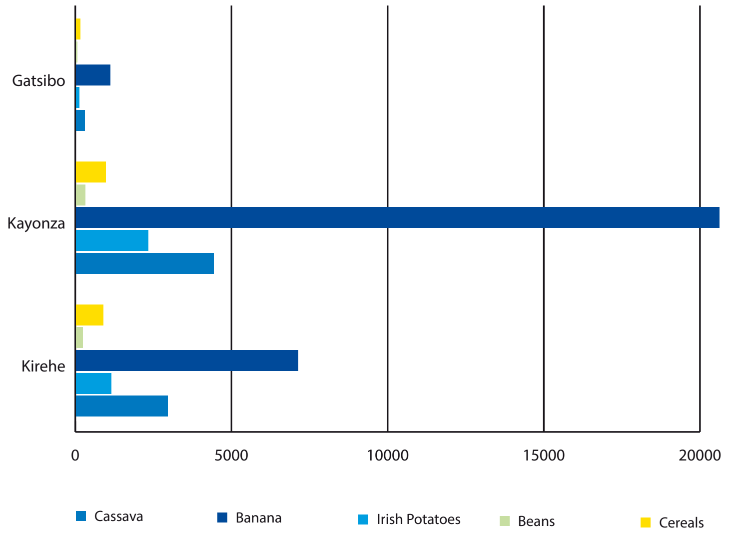
Figure 102. Population vulnerable to severe drought in Season B



b) Agriculture vulnerability

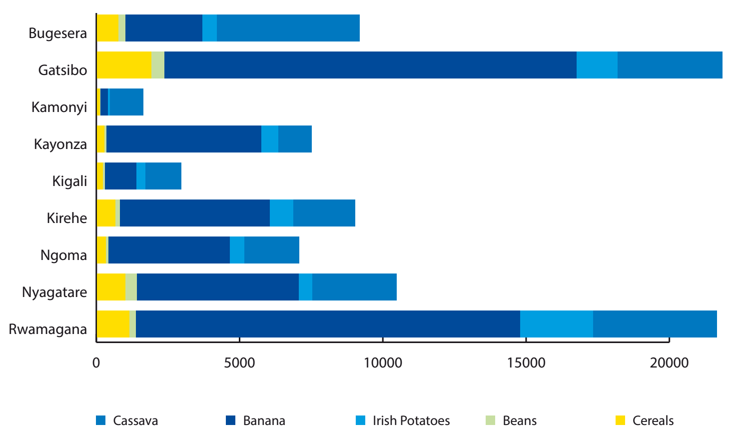
The vulnerability of agriculture is much higher in Season B. The estimated vulnerable crops for season B are summarized in the ensuing charts. The eastern and southern provinces have the highest estimates of crop losses. The highest crop losses in season B are in the districts of Kayonza (20%), Rwamagana (16%), Ngoma (15%), Gatsibo (15%), Kirehe (15%), and Bugesera (8%). Note that the total estimated crop yield production is 191,763 tones. A total of 42,480 tons of various crops produced in Season B is vulnerable to severe drought at very high susceptibility.

Figure 103. Crop yield (tons) vulnerable to drought at very high susceptibility in Season B



For severe drought at high susceptibility, a total of 91,167 tons of various crops are vulnerable. Among the crops, banana is the most vulnerable followed by cassava. The districts of Gatsibo and Rwamagana have the most volume of crops vulnerable to severe drought at very high susceptibility. Meanwhile, Nyagatare and Bugesera have about half of these volume of crops vulnerable.

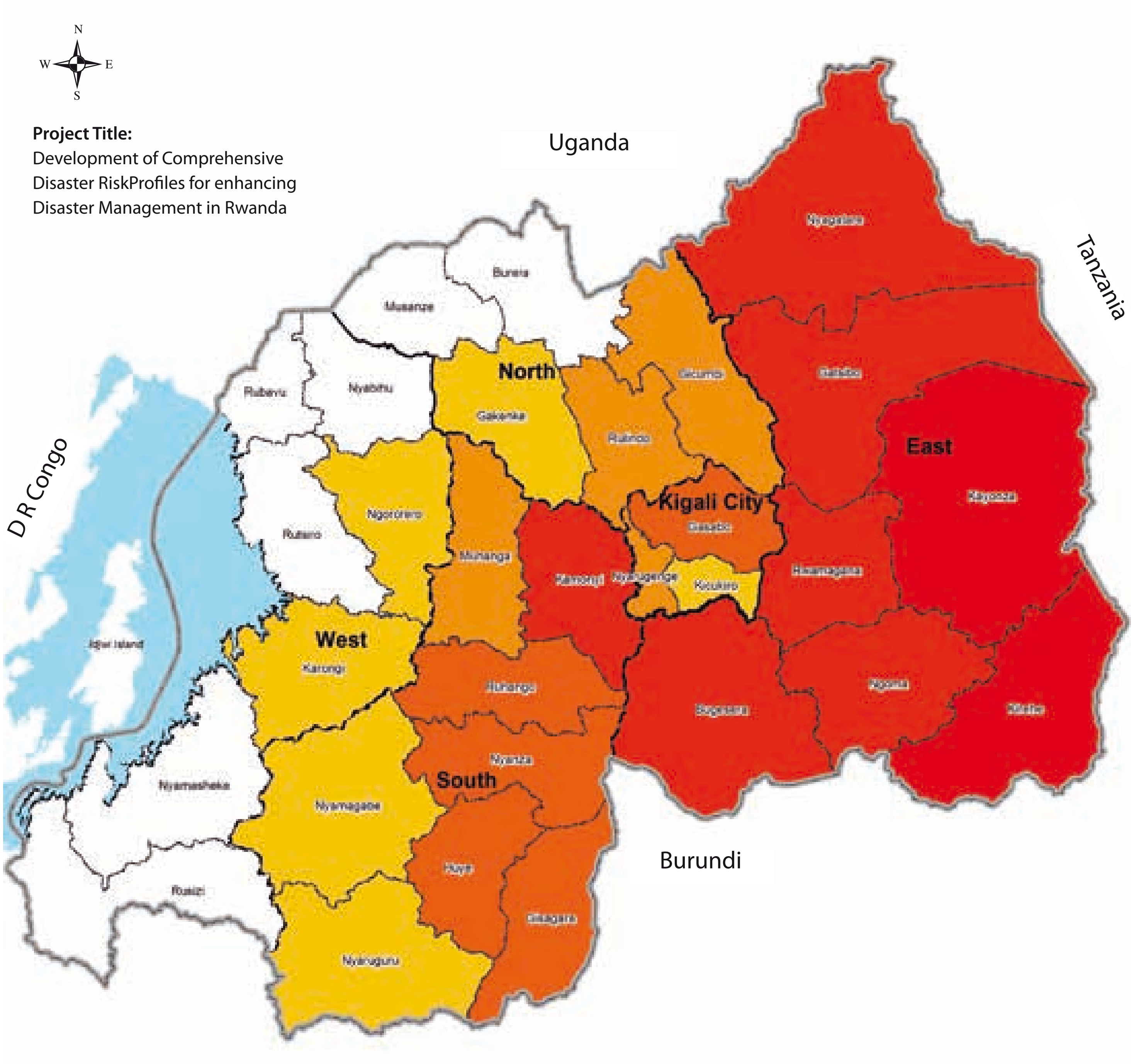
Figure 104. Crops yield (tons) vulnerable to drought at high susceptibility in Season B



A total of 58,116 tons of crops are vulnerable to severe drought at moderate susceptibility. Banana and cassava are the crops with high vulnerability particularly in the districts of Rwamagana, Ngoma, Kirehe and Kamonyi.

In total, there are about 191,763 tons of major crops produced in Season B which are vulnerable to severe drought from moderate to very susceptibility. Of this volume, banana has the highest yield which is vulnerable at 57% of the vulnerable crops. This is followed by cassava at 27% and Irish potatoes at 8%. All the 7 districts in the Eastern Province record the highest volume of crops vulnerable to sever drought with Kayonza, Kirehe, Gatsibo and Rwamagana topping the list in chronological order.

Figure 105. Map of the population vulnerable to drought in Season B



Legend

	Country Boundary		0
	Province Boundary		< 1000
	District Boundary		1000 - 5000
	Lakes		5000 - 10000
			10000 - 20000
			20000 - 30000

Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
Datum: WGS 1984
False Easting: 500,000.0000
False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

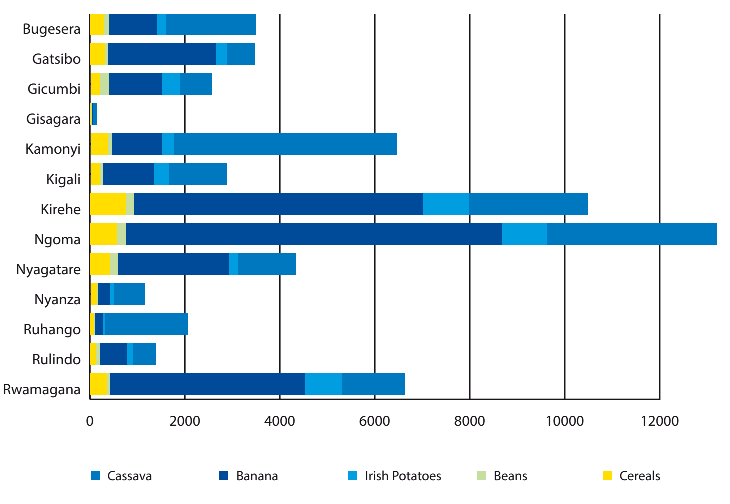
Scale:

0 10 20 30 40 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

Figure 106. Crop yield (tons) vulnerable to drought at moderate susceptibility in Season B



6.2.1.4 Comparative analysis of vulnerability profiles

Considering the two drought scenarios of Season A and Season B and taking into account the hazard zonation maps where severe drought in Season B is more extensive geographically compared to Season A at moderate to very high susceptibility levels, the vulnerability assessment also indicates that there are more vulnerable population to severe drought in Season B than in Season A. Season B accounts for a total of over 150,000 vulnerable population while Season A has about slightly over 48,000 vulnerable population. In terms of location, the vulnerability trend is consistent to be highest in the Eastern Province, some parts of Kigali City and the Southern Province.

Agriculture vulnerability is also higher in Season B compared to Season A. About 190,000 tons of major crops produced in Season B is vulnerable to severe drought in Season B from moderate to very high susceptibility. In contrast, there is much lesser volume of crops produced in Season A which is vulnerable. It is only about 62,000 tons of major crops combined.

In Season A, more yield of banana are vulnerable to severe drought followed by Irish potato and cereals. However, in Season B, banana is the most vulnerable followed by cassava and Irish potatoes. The districts in the eastern province are with the most crops vulnerable to severe drought.

6.2.1.5 Summary of key findings

- The number of people vulnerable to severe drought are 28,582 and 157,786 for Seasons A and B respectively.
- For Season A scenario, the districts of Kayonza, Kirehe, Nyagatare and Gatsibo have more than 80% of the total population vulnerable (comprised of 31%, 22%, 18%, and 12% respectively). There are fewer Districts with vulnerable population to severe drought in Season A.
- For Season B scenario, the districts of Kayonza, Kirehe, Gatsibo, and Bugesera have the highest number of vulnerable population with 15%, 10%, 9%, and 8% respectively of the total population at risk countrywide. There are a total of 16 districts which have population vulnerable to severe drought in Season B.
- A total of 62,033 tons and 157,786 tons of major crops are vulnerable to severe drought in Season A and Season B respectively.
- Banana and cassava are the most vulnerable crops with 149,190 tons and 64,111 tons respectively for both Season A and Season B. Irish potatoes is also following closely as the next most vulnerable
- It has been observed that agriculture vulnerability to drought decreases from the eastern to the western part of the country. The districts of Kayonza, Kirehe, Gatsibo and Nyagatare are the areas with highest volume of crops vulnerable to severe drought.

6.2.2 Vulnerability to landslide

6.2.2.1 Overview

The ultimate goal of landslide hazard and risk studies is to protect the population, the economy and the environment against potential damage caused by landslides. This requires an accurate assessment of the level of threat from a landslide: an objective reproducible, justifiable and meaningful measure of risk (Crozier and Glade, 2005). Risk, in this context, is seen as a disaster that could happen in the future. Considering this relationship, it is evident that an accurate assessment model is of utmost importance as it may under- or over-estimate the occurrence of future events. However, there is not yet a common agreement on risk assessment at least for landslide disasters and still many issues on methods and data remain partially under research.

On the other hand, landslide vulnerability assessment is still considered a difficult process since it depends on several factors like landslide type and the way its impact may generate different degrees of damage. The vulnerability maps are expressed with values between 0 and 1, where 0 means no damage and 1 means total damage. Note that, the slope susceptibility of different parts of the country was discussed in Paragraph 4.2. This section discusses the vulnerability of Rwanda to landslides.

The vulnerability assessment is conducted based on the only one susceptibility scenario produced in this study. For details on the scenario, refer to Chapter IV.

Elements at risk

The vulnerability analysis is limited to the following elements at risk: population, houses, health care facilities, schools and roads.

Intensity levels

In this vulnerability to landslide assessment only moderate, high and very high susceptibility classes are included in the analysis. The two other classes (low and very low) were not included as landslides are less likely to occur at these susceptibility levels, at 0.2 and 0 probability respectively.

6.2.2.2 Methodology

In contrast to other natural hazards such as floods and earthquakes, it is very difficult to assess vulnerability to landslides due to the complexity and the wide range of slope failure processes. Various researches highlighted the vulnerability assessment as the weakest part of landslide risk assessment. Relatively little work has been done on the quantification of physical vulnerability due to landslides (van Westen, et al., 2006). The analysis of vulnerability of this study followed the example proposed by Michael-Leiba, et al. (2000). They performed an analysis of the vulnerability of residents, buildings, and roads to landslides.

For population and buildings on hill slopes, data were derived from the NISR, while for roads on hill slopes, the assessment is based on information provided by RNRA. The approach to provide vulnerability values for landslide risk analysis at a small scale introduces numerous assumptions, but the approach has a practical application and is indeed of high interest for planning agencies (Michael-Leiba, et al. (2000). The vulnerability values used in this project are summarized in Table 5. The values demonstrated in this table are the average vulnerability values of the elements at risk from 0 up to 1. For example, at a landslide on a hill slope, the vulnerability of residents is 0.05.

Table 42. Vulnerability of various element at risk with respect to landslide

Elements at risk	Vulnerability Scoring		
	On hill slope	Susceptibility to proximal debris flow	Susceptibility to distal debris flow
Residents	0.05	0.9	0.05
Buildings	0.25	1.0	0.1
Roads	0.3	1.0	0.3

Source: (Michael-Leiba, et al., 2000)

6.2.2.3 Characterization of vulnerability profiles

a) Vulnerability of population

The casualty to population due to different slope susceptibility levels are shown in Figure 107 and Figure 108. In total, 7,400 are potential casualties due to the effects of slope failures. The districts of Kigali City i.e. Gasabo, Nyarugenge show a bigger number of casualty to landslide. Nyarugenge has the highest number of casualty with 12% of the total. This can be explained mainly by higher densities of the population in these districts and the concentration of informal settlements located in landslide-prone areas. Other districts with high number of casualty are: Burera (6%), Kicukiro (6%) and Nyabihu (6%) and Gakenke (5%). In general, the districts in the eastern province have less potential casualty compared to the rest of the country. The results are in correlation with the historical casualty records due to landslides where casualties are high in the western province as well as in the city of Kigali as indicated in Table 17, Chapter IV.

Figure 107. Population vulnerable to moderate to very high slope susceptibility

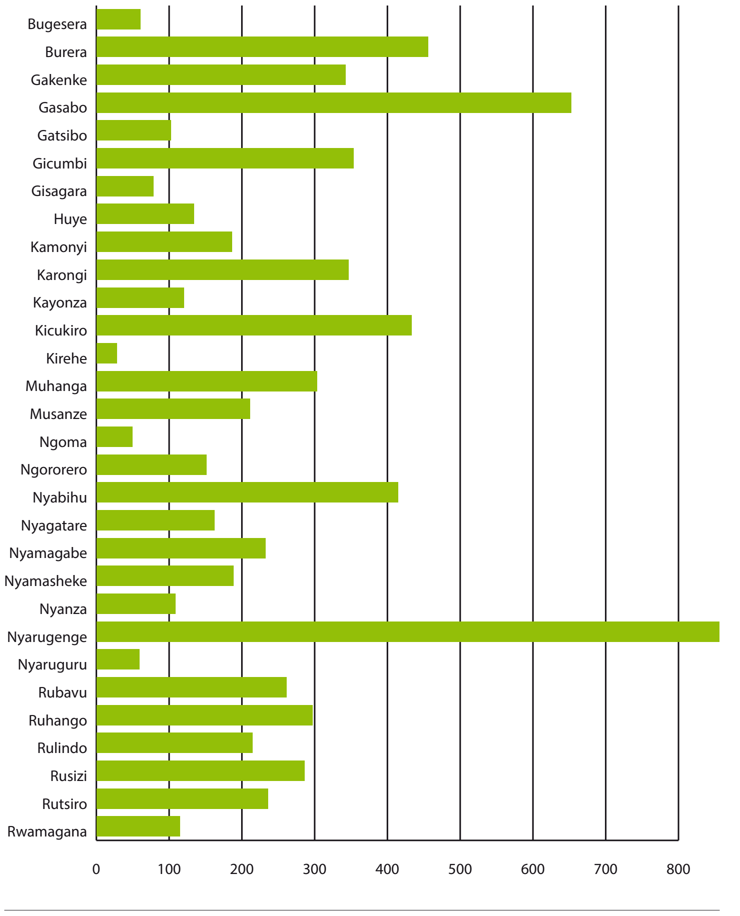
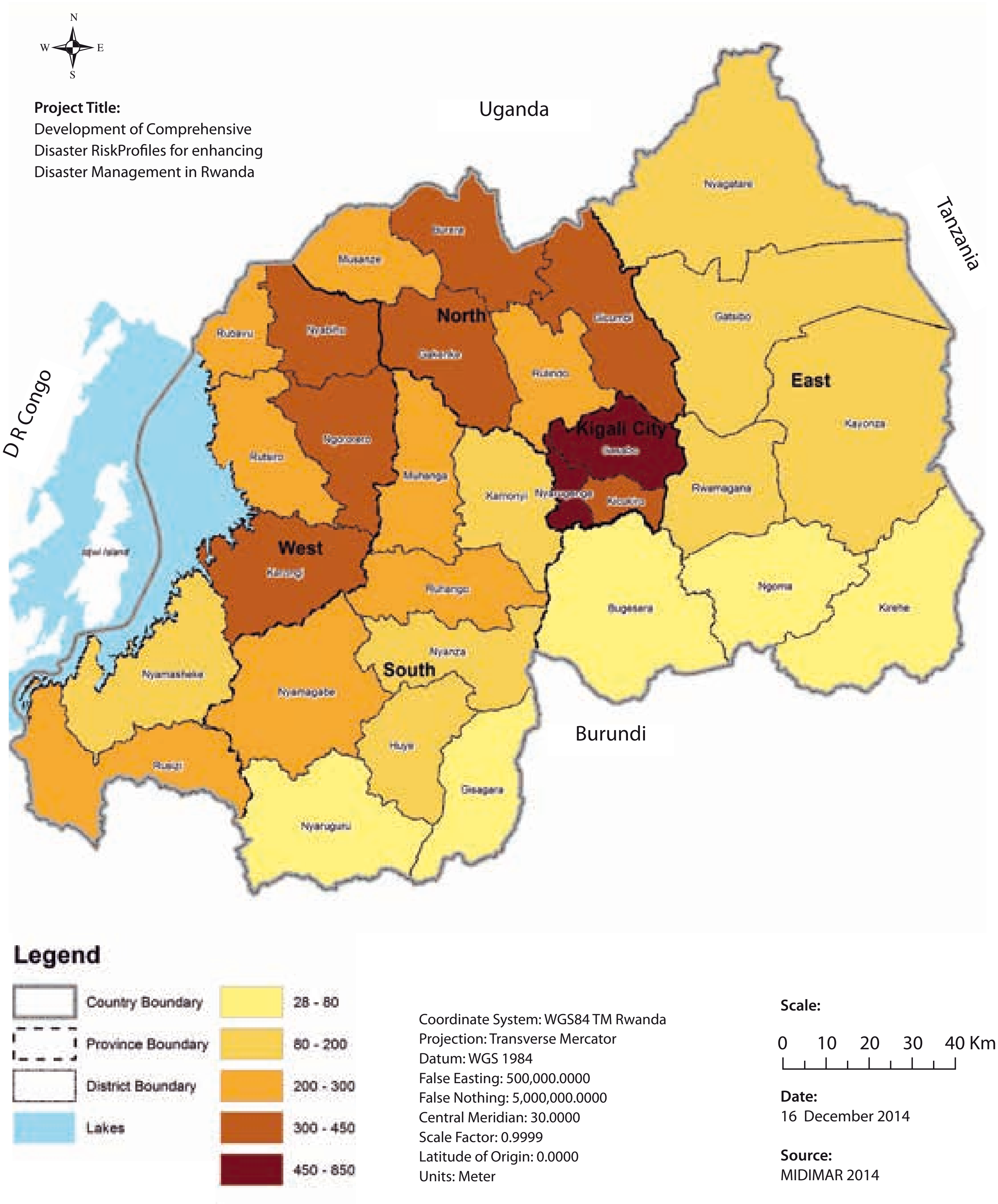


Figure 108. Map of the population vulnerable to moderate to very high slope susceptibility



b) **Vulnerability of houses**

The number of houses vulnerable to moderate to very high slope susceptibility is summarized in the ensuing Figure 109. Around 29,200 houses in the country are vulnerable to landslide. The districts of Kigali City shows the higher number of vulnerable houses where, of the total number of vulnerable houses, Nyarugenge has 15%, Kicukiro 8%, and Gasabo 7%. This can be explained by the higher densities of the population in these districts and the concentration of informal settlements located in landslide-prone areas. In general, the districts of the eastern province are less vulnerable compared to the rest of the country.

Around 60% of vulnerable houses in the country are made of sundried bricks while 29% are wood and mud. This explains the large number of fatalities and injuries linked to landslide damages in most of the places, due to houses made of weak materials (around 90% of the total vulnerable houses). Houses in Kirehe and Ngoma are less vulnerable to landslides. Less than 1% of the total vulnerable houses in the country are located in these districts.

Figure 109. Number of houses vulnerable to moderate to very high slope susceptibility

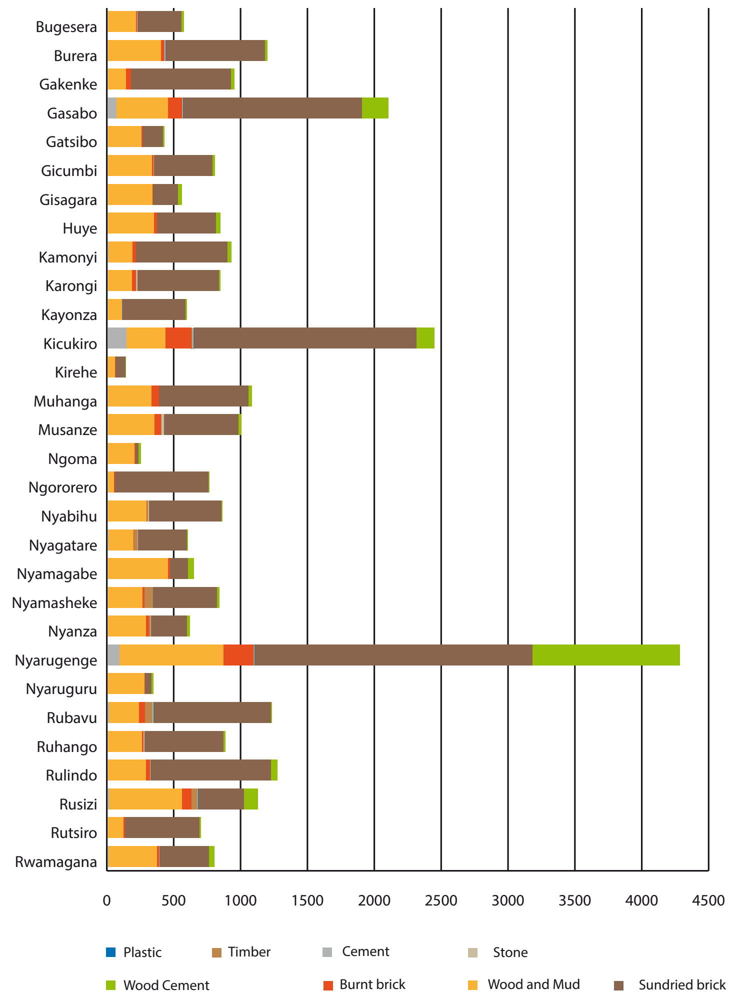


Figure 110. Map of the estimated total number of houses vulnerable to landslide

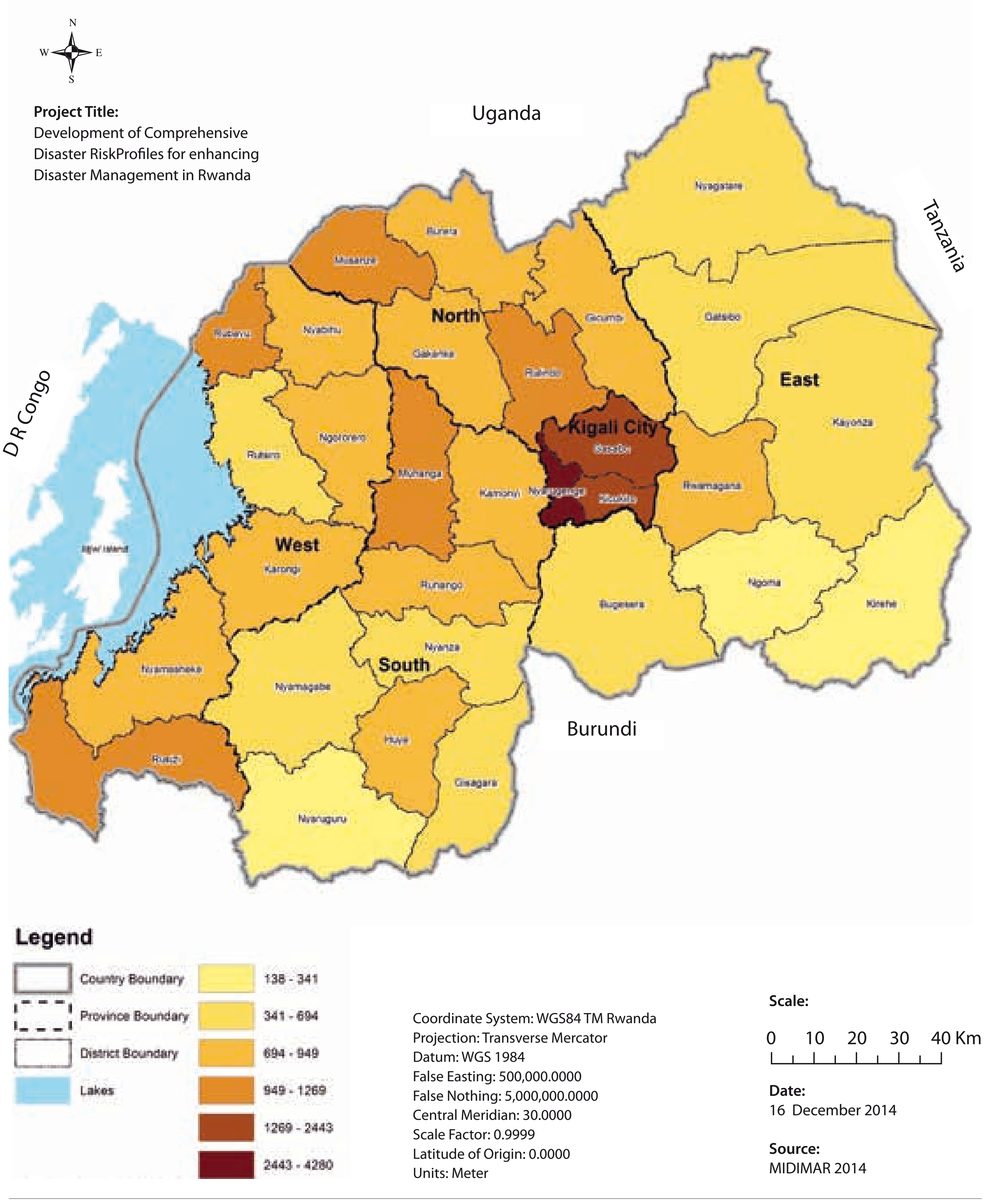


Figure 111. Map of the major house types vulnerable to landslide

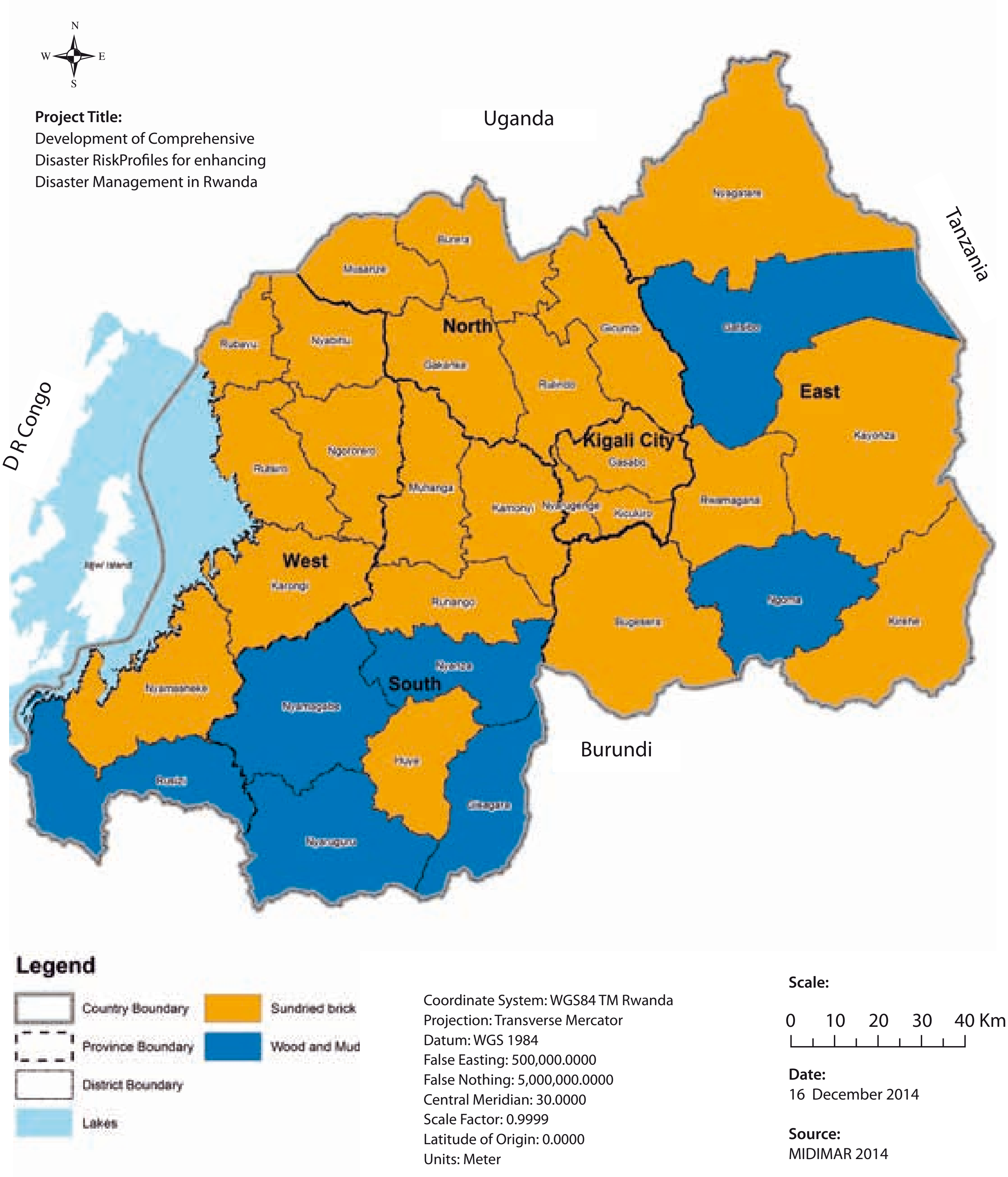


Figure 112. Map of the estimated houses made of sundried brick walls vulnerable to landslide

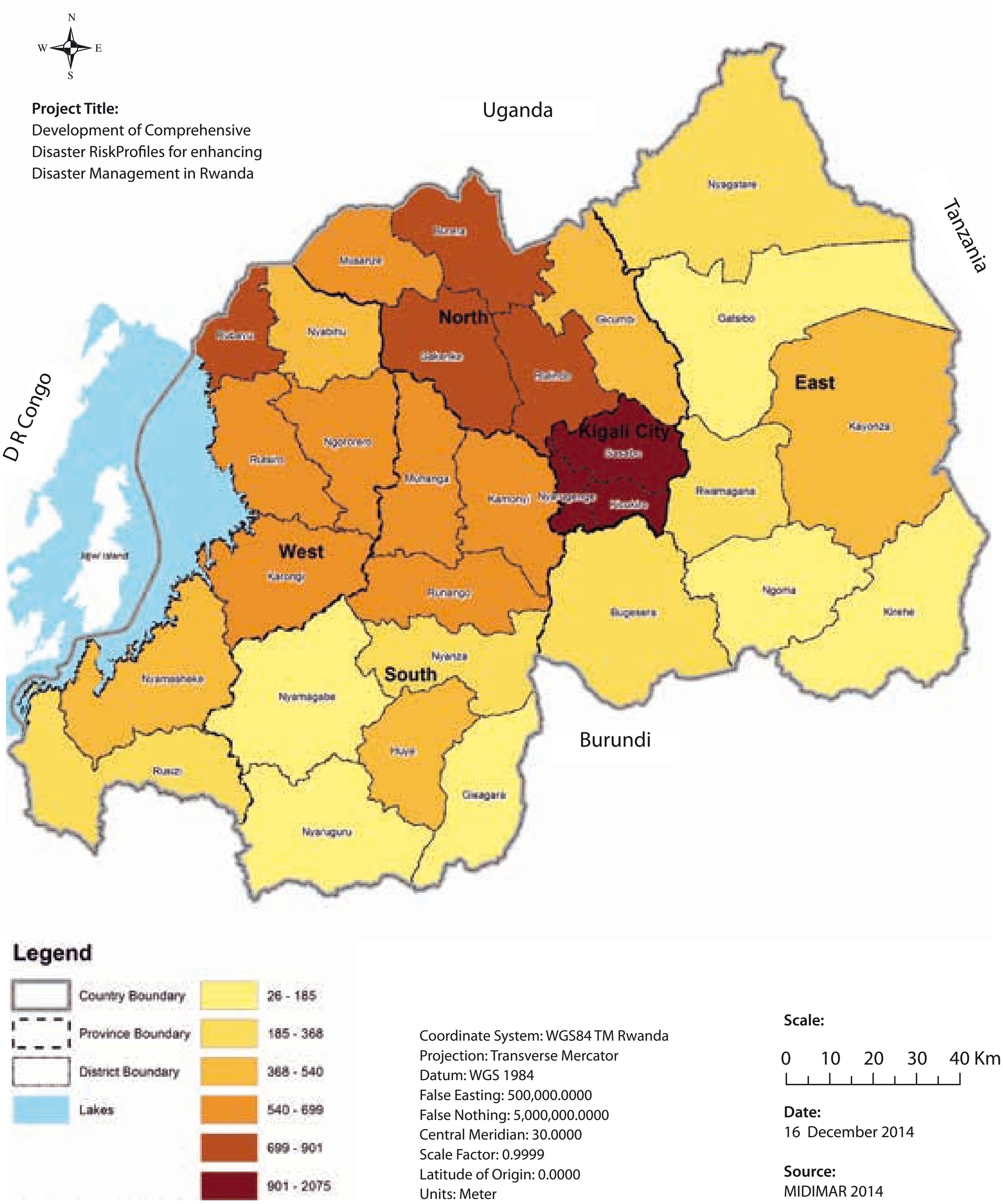
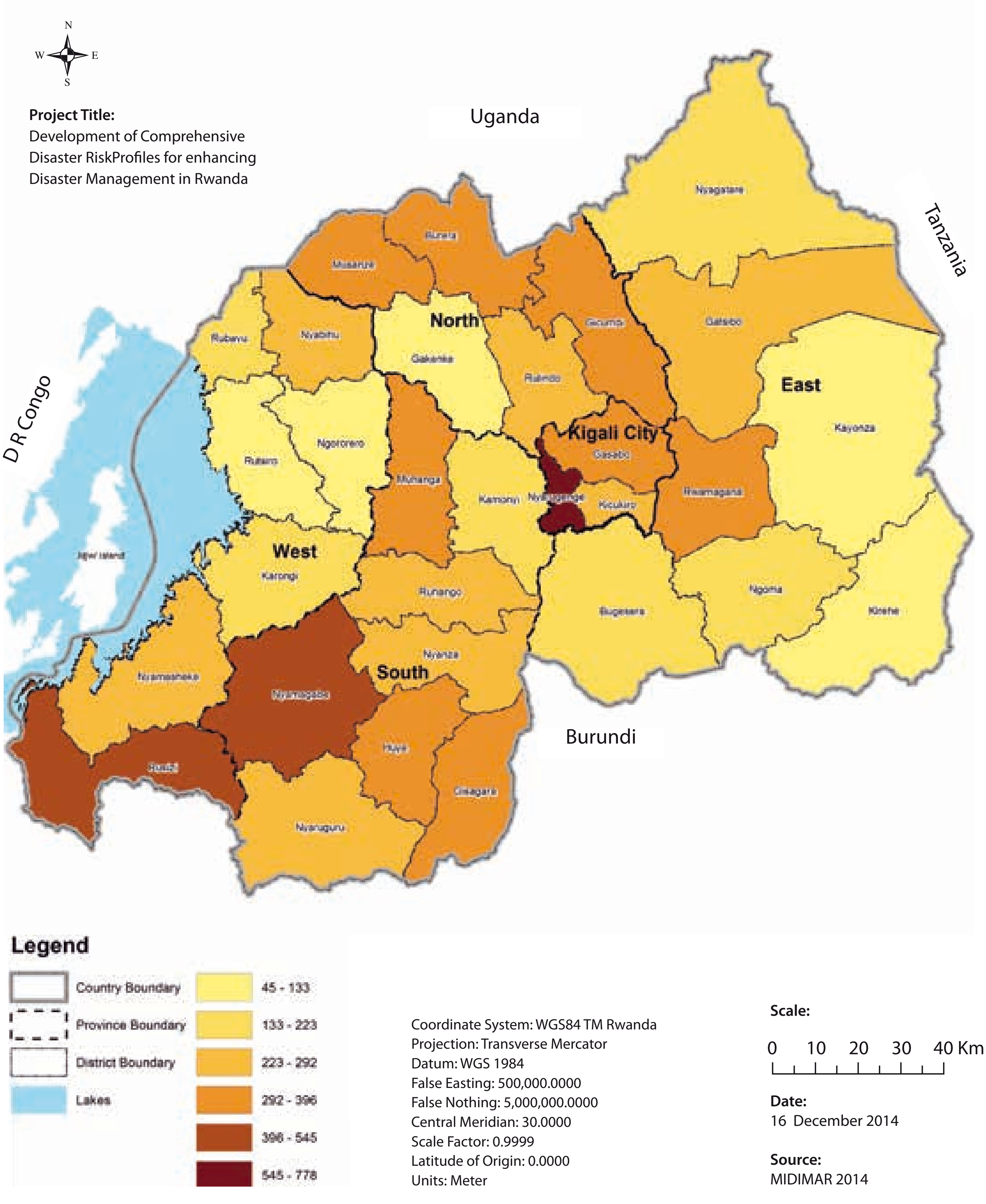


Figure 113. Map of the estimated houses made of wood and mud walls vulnerable to landslide

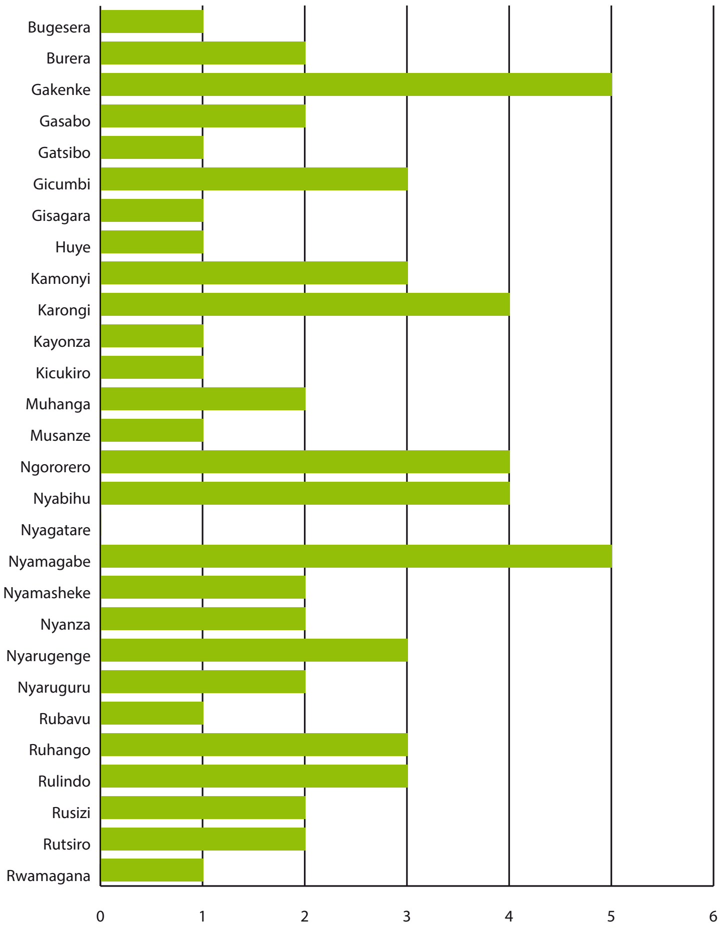


c) Vulnerability of health facilities

The analysis focused on the vulnerability of health facilities in terms of buildings exposed to landslide. Building typology of health facilities is not available. Based on the information gathered from national experts it was determined that all health facility buildings are classified Cat.1. Figure 114 and Figure 116 show the distribution of health facilities vulnerable to landslides across the country.

Gakenke, Ngororero, Nyamagabe, Nyabihu, and Karongi have the highest number of health facilities vulnerable to landslides. The districts of Gakenke and Nyamagabe have each, 5 facilities being 9% of the total number of health facilities vulnerable to landslides countrywide. Ngororero and Nyabihu follow with 7% each respectively. The health facilities less vulnerable to landslides are located in the Eastern Province, especially in Nyagatare, Kayonza, and Gatsibo while Kirehe and Ngoma have no health facility vulnerable to landslide.

Figure 114. Number of health facilities vulnerable to moderate to very high slope susceptibility



d) Vulnerability of schools

The analysis focuses on the vulnerability of schools mainly considering the school buildings exposed to landslide. Building typology for school buildings is not available. Based on information gathered from national experts it was determined that all school buildings are classified Cat.1.

The number of schools located in areas of moderate to very high landslide susceptibility is higher in the western and central part of the country as shown in Figure 115 and Figure 117, specifically in the district of Gakenke. Gakenke has 32 schools vulnerable to landslides with a susceptibility ranging from moderate to very high. This makes the total schools vulnerable to landslides countrywide 8%. Districts with high number of schools vulnerable to landslides are Rusizi (6% of the total schools countrywide), Kamonyi (5%), Karongi (5%), Nyamagabe (5%), and Nyamasheke (5%). Similar to the health facilities, the schools the eastern province are less vulnerable to landslides compared to the schools in the western part of the country.

Figure 115. Schools vulnerable to moderate to very high slope susceptibility

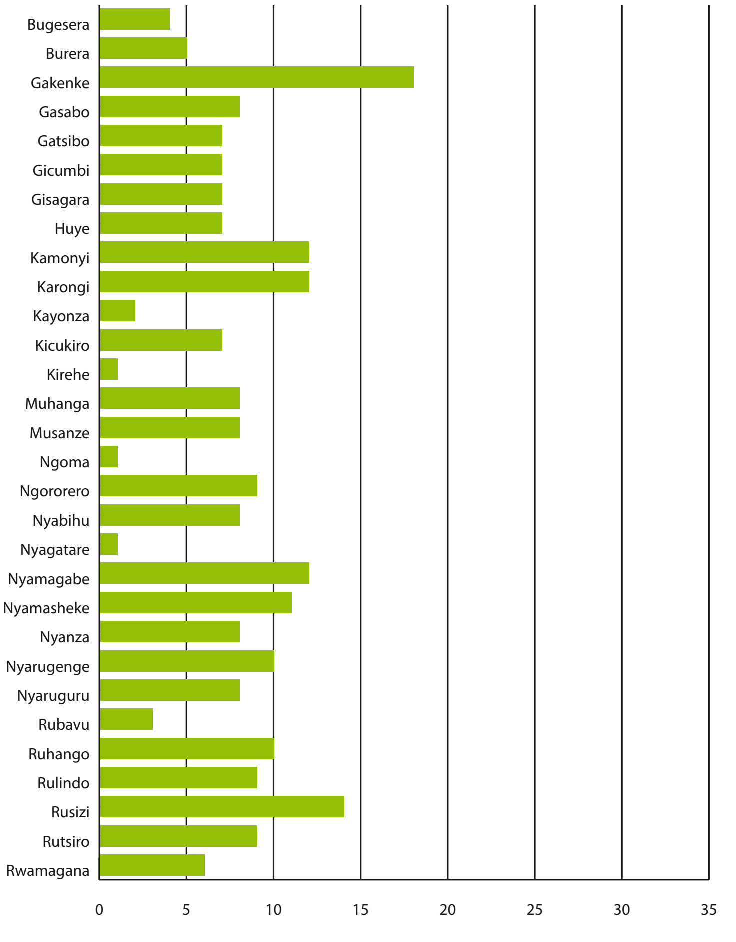


Figure 116. Map of the health facilities vulnerable to moderate to very high slope susceptibility

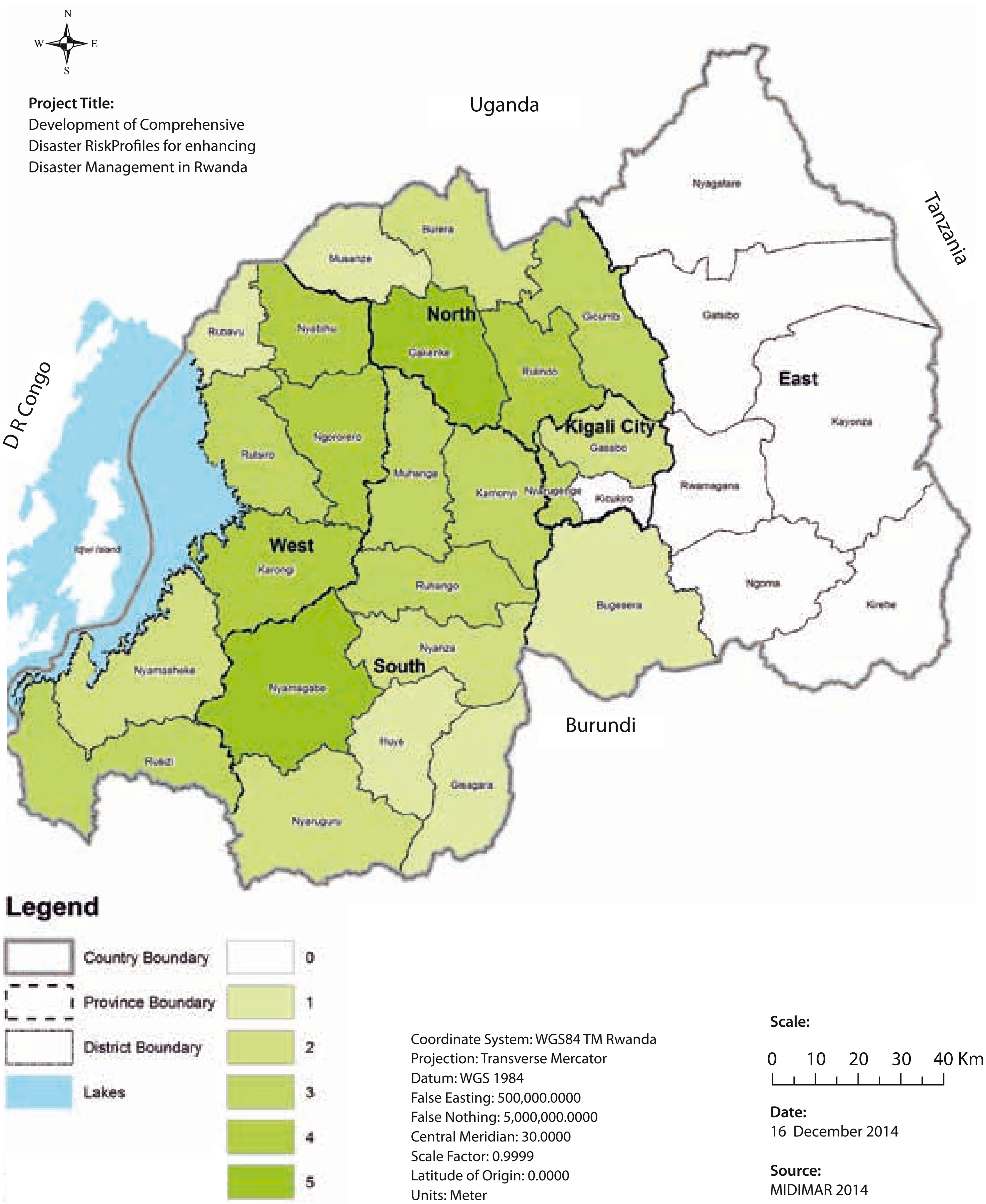
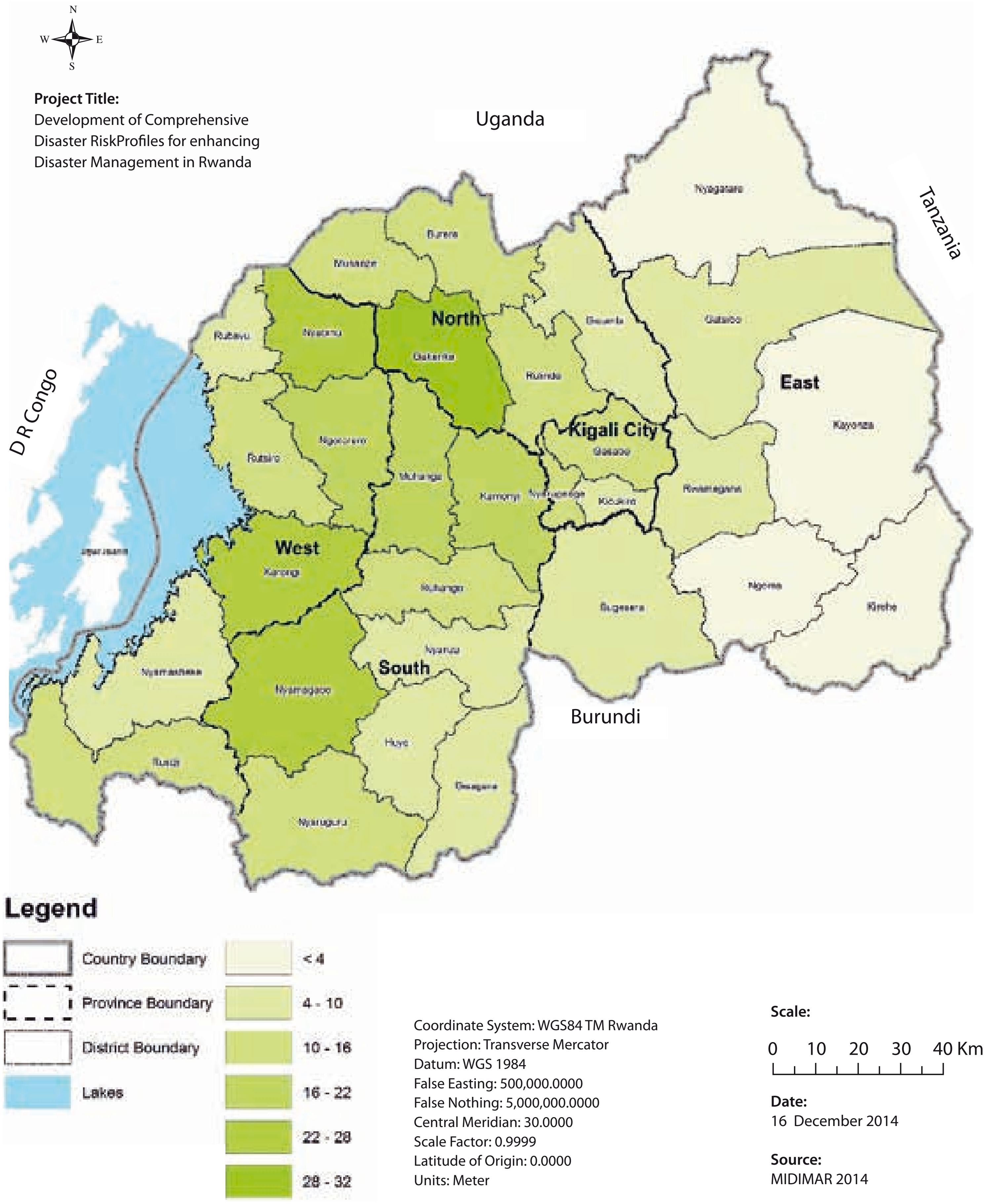


Figure 117. Map of schools vulnerable to moderate to very high slope susceptibility



e) Vulnerability of roads

The length in kilometer of national and district roads vulnerable to landslides on hill slopes has been analyzed and is presented in the ensuing figures below. The national roads are further segregated to paved and unpaved roads. Around 165 kilometers of paved national roads are vulnerable to landslides. The roads located in the districts of Nyamasheke, Ngororero, Nyamagabe, and Muhanga are the most vulnerable with 10%, 9%, 9%, and 8% respectively of the total vulnerable roads countrywide. The district of Kayonza, and Ngoma are unlikely to be affected by landslide on hillslopes. The district of Gisagara has no paved national road.

Meanwhile, there is around 210 kilometers of unpaved national roads which are vulnerable to landslide. The roads in the districts of Karongi and Nyamagabe have the highest vulnerability with 18% and 17% of the total vulnerable national unpaved road length. On the other hand, Huye, Kayonza and Kirehe has only a kilometer each of unpaved national road vulnerable to landslide.

On the one hand, around 600 kilometers of district roads are vulnerable to landslide hazard from moderate to very high susceptibility. The results are summarized in Figure 118. Note that the districts of Gakenke, Rusizi, Ngororero, Nyamagabe, and Muhanga are the most vulnerable district with more than 6% of the total vulnerable length of district roads each. The district of Kirehe is the least vulnerable followed by Kicukiro and Kayonza, Bugesera, and Nyagatare with less than 1% of the total vulnerable district road length each.

Figure 118. Length (in km) of paved national roads vulnerable to moderate to very high slope susceptibility

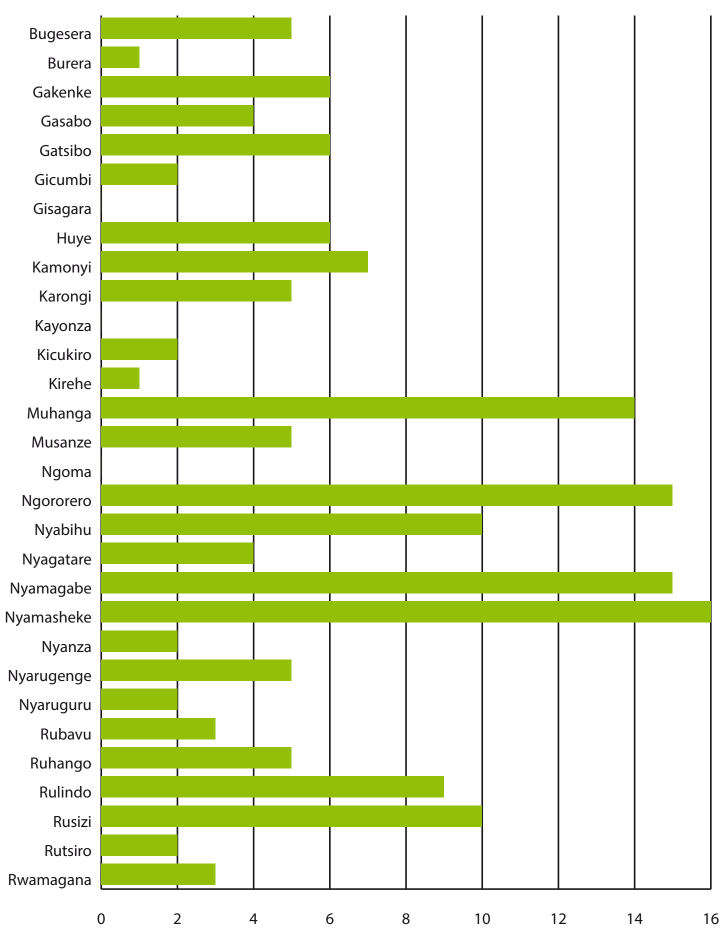


Figure 119. Length (in km) of unpaved national roads vulnerable to moderate to very high slope susceptibility

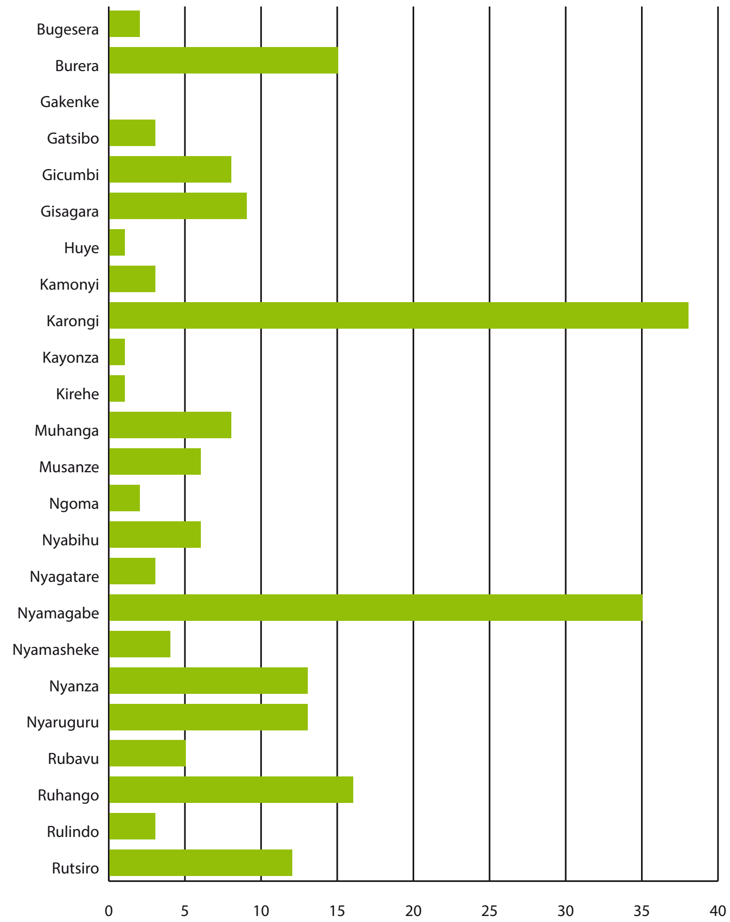


Figure 120. Length (in km) of district roads vulnerable to moderate to very high slope susceptibility

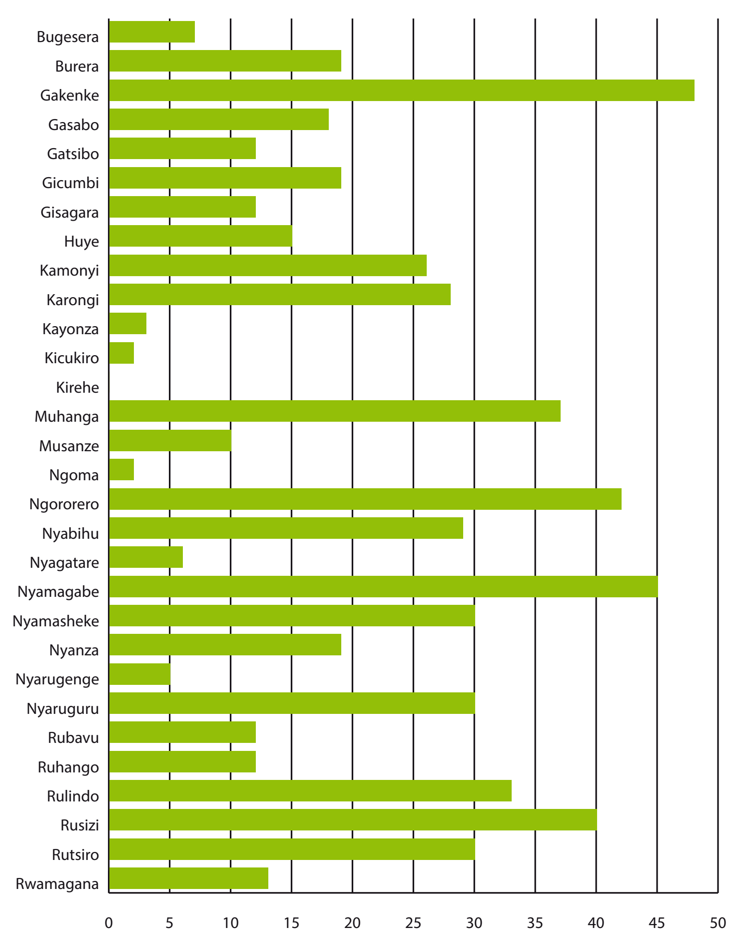


Figure 121. Map of the estimated vulnerable paved national roads (km) across the country

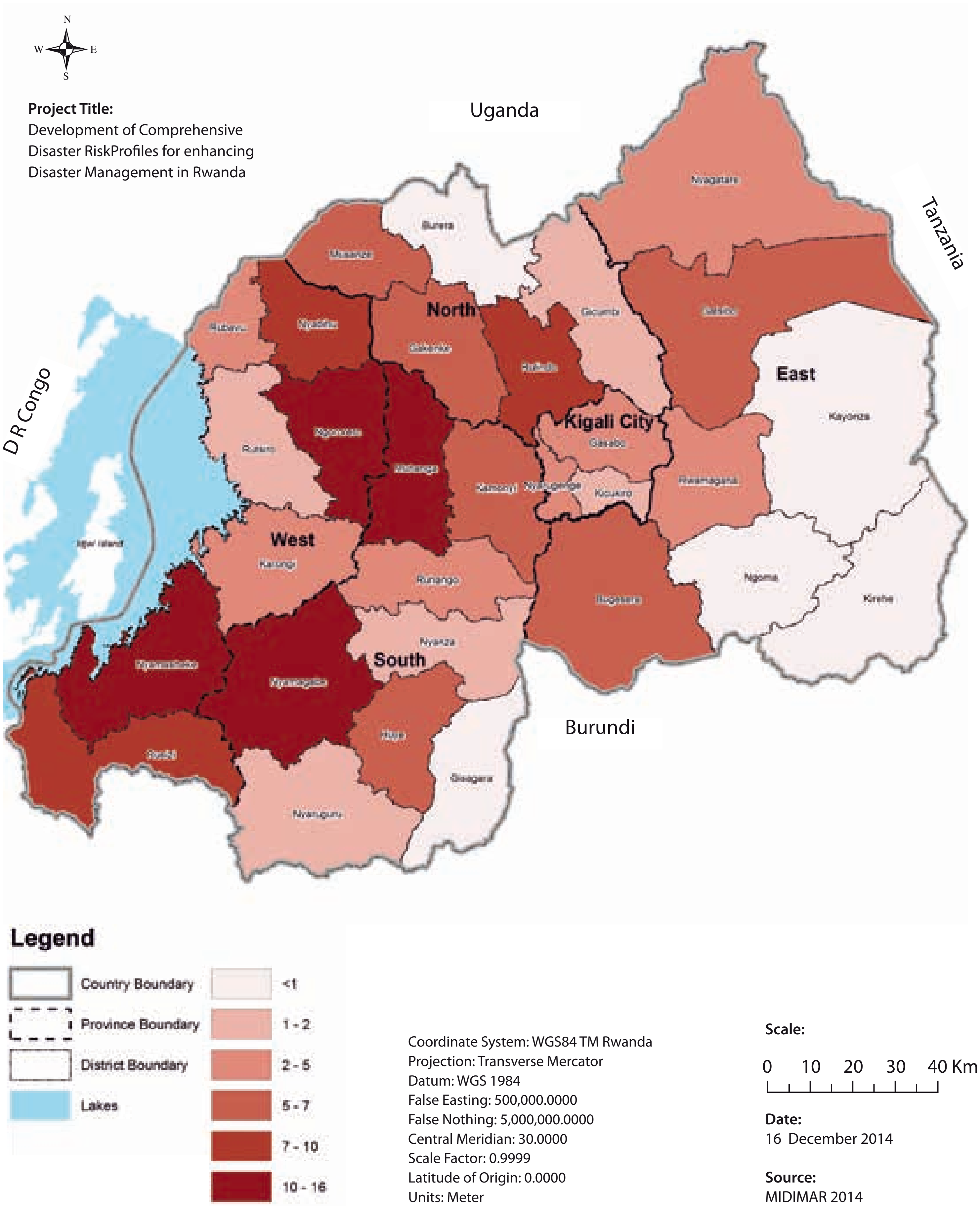


Figure 122. Statistics of estimated kilometers of vulnerable unpaved national roads by district

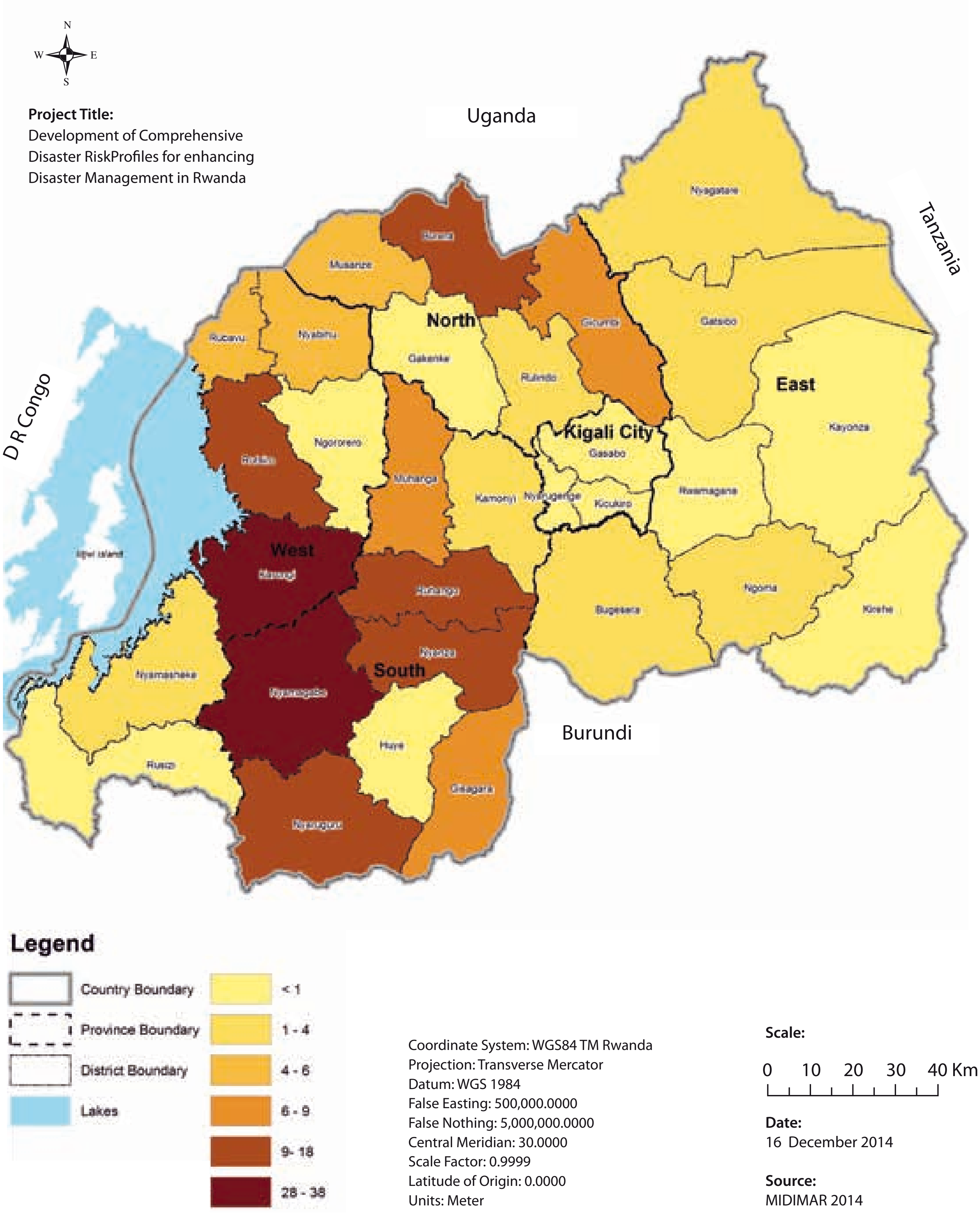
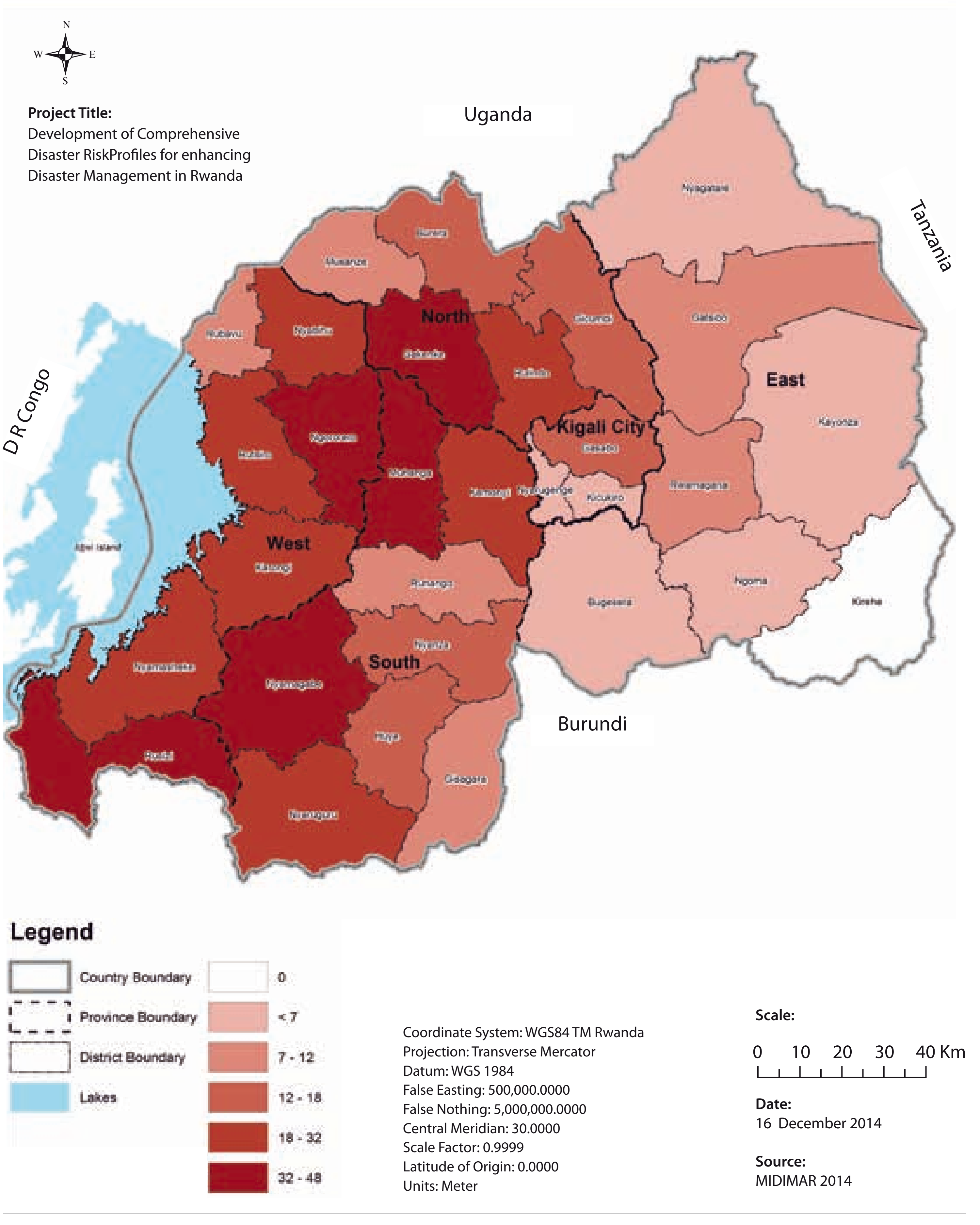


Figure 123. Statistics of estimated kilometers of vulnerable district roads (km) across the country



6.2.2.4 Comparative analysis of vulnerability profiles

The vulnerability assessment to different landslide susceptibility classes has been analysed by taking into account moderate, high, and very high classes. The vulnerability of population, houses, health facilities, schools, and roads have been analysed.

The districts of Kigali City have the highest number of vulnerable population and houses mainly due to its high population density in marginal lands on steep slopes compared to other districts. However, the districts in the western province also have high number of people vulnerable to landslides. In contrast, there is less vulnerable population in the eastern part of the country.

Compared to other districts, the 3 districts of Kigali City namely: Nyarugenge, Kicukiro and Gasabo have high number of houses vulnerable to landslides. By type of houses, those with walls made of sundried bricks and wood and mud are the most vulnerable with 17,384 and 8,442 houses respectively compared to houses made of other wall materials.

The vulnerability of health facilities is high in districts in the western province, specifically the districts of Ngororero, Nyabihu and Karongi including Gakenke in the north and Nyamagabe in the south. On the other hand, the health facilities less vulnerable to landslides are located in the eastern province, especially in Nyagatare, Kayonza, and Gatsibo while Kirehe and Ngoma have no health facility vulnerable to landslide.

The vulnerability of schools is high in Gakenke, Ngororero, Nyabihu and Nyamagabe with over 20 schools each are vulnerable to landslide. The rest of the districts have vulnerable schools which range from 20 schools and below with Kayonza having only 1 school vulnerable to landslide.

The vulnerability of paved national roads is high in the districts of Nyamasheke, Ngororero, Nyamagabe, Muhanga, Rusizi and Nyabihu with over 10 kilometers of paved national roads are vulnerable to landslide. The rest of the districts have less than 10 kilometers of paved national roads vulnerable while Gisagara, Kayonza and Ngoma have no paved national roads vulnerable to landslide. Meanwhile, for the unpaved national roads, Karongi and Nyamagabe accounts for the highest number of kilometers vulnerable with 38 and 35 kilometers respectively. Overall, there are more unpaved national roads which is vulnerable than paved national roads.

Comparing with the national roads, most of the district roads which are highly vulnerable are located in Gakenke, Ngororero, Muhanga, Rusizi, Rulindo, Nyamasheke, Nyaruguru and Rutsiro have the most number of kilometers of district roads vulnerable to landslide. One notable observation is that Ngororero District has high number of both its national and district roads vulnerable to landslide. The rest of the districts have vulnerable district roads ranging at 30 kilometers and below.

6.2.2.5 Summary of key findings

- There are a total of 7,431 people countrywide who are vulnerable to landslides, about 26% of which are located in Nyarugenge, Gasabo and Kicukiro districts in the capital Kigali City and about 25% are from the districts in the western province. The other 21% are in districts of the northern province. 13% in districts of the southern province and only 8% from districts in the eastern province. The high population density and concentration of informal settlements in the urban centers like Kigali City is cited as a key factor in the high population vulnerability in these areas.

- The total vulnerable houses to landslides from moderate to very high susceptibility is 29,215. Nyarugenge District has the highest number of vulnerable houses with 4,280 followed by Kicukiro with 2,444 houses and Gasabo with 2,101. As can be noted, more vulnerable houses are found in districts in the urban center i.e. Kigali City.

- Sixty-two (62) health facilities countrywide are vulnerable to landslide. Gakenke and Nyamagabe have the highest number vulnerable with 5 health facilities each and Ngororero, Karongi, and Nyabihu with 4 health facilities each. The rest of the districts have a range of 1 to 3 health facilities vulnerable with the exception of Nyagatare, Ngoma and Kirehe which do not have any single health facility vulnerable to landslide.

- The vulnerability of education sector considered only schools. In total, 360 schools are vulnerable to landslide impacts.

- The transportation sector is also highly vulnerable to landslide where 165 km of national paved roads, 207 km of national unpaved roads, and 604 km of district roads are vulnerable to landslide.

6.2.3 Vulnerability to earthquake

Vulnerability of a community or society has many dimensions: environmental, physical, economical, financial, social, etc. there are different approaches and methodologies for measuring these vulnerabilities. For this study, physical and social vulnerability is assessed based on the exposure of property and social elements at risk. Risk is quantified as the amount of elements at risk, damage state of the elements at risk to different hazard intensity, monetary value of the damage, and the probability of occurrence of the event with a given magnitude/intensity based on the earthquake intensity map presented in Paragraph 4.4.

6.2.3.1 Overview

The earthquake hazard assessment (in Chapter IV) has developed maps for two return periods: 2475-year and 475-year return periods (Figure 42 & Figure 43). For this report, the exposure assessment is only analysed for a hazard scenario with a return period of 2475 years with 2% probability of exceedance in 50 years, specifically for intensities MMI VII and MMI VI. The scenario with a 475-year return period is not considered because the damage probability for intensities MMI VI and MMI V is minor except for about 10% for Category 3 structure (Cat.3) at Damage Level 1 (D1).

Elements at risk

For this report, the exposure of population and primary physical assets such as houses, health facilities, schools and roads are analyzed.

Intensity levels

There are only two intensity levels apparent in Rwanda: Intensity MMI VI and intensity MMI VII. However, the MMI VII is the one with possible structural damages. Thus this section on vulnerability assessment only analysed the vulnerability with regard to MMI VII.

6.2.3.2 Methodology

Vulnerability assessment relied on the use of probability damage matrix (PDM) for physical vulnerability assessment and lethality ratio for Population Casualty Estimation (PCE). There are three existing methods for constructing probability damage matrix: empirical, modelling, and subjective. The empirical method is the assessment of the damage observations of the past earthquakes and evaluation of the relative frequencies of damage states in order to estimate the likelihood of possible damage states. Ideally, when subjective biases are minimized, empirical method is the most reliable way to obtain damage state probabilities. Modelling method consists of dynamic analysis of structures. Subjective method involves the subjective judgment of experts depending on their past experience on seismic damage assessment (Askan & Yucemen, 2010).

For this study the Modified Mercali Intensity (MMI) was used. According Coburn and Spence (1992) the intensity is a measure of the felt effects of an earthquake rather than the earthquake itself. It is a measure of how severe the shaking wave was at any location. For any earthquake, the intensity is strongest close to the epicentre and attenuates away with distance from the source of the epicentre. Larger magnitude earthquakes produce stronger intensities at their epicentres. Intensity is assessed by classifying the degree of shaking severity using an intensity scale.

The intensity level is assigned for a particular location from the visible consequences left by the earthquake and from reports by those who experienced the shaking. The level of intensity is identified by a Roman numeral commonly on a scale from I to X (or even up to XII), indicating that the scale describes a succession of states but is not numerical. The hazard assessment highlighted that the highest MMI in Rwanda is VII for the hazard scenario of a return period of 2475 years with 2% probability of exceedance in 50 years. According Grünthal (1998) as reported in Coburn and Spence (2002), the following are the characteristics of the intensities as expected for Rwanda. As highlighted, the vulnerability assessment relied on the outcome of the earthquake hazard assessment in section 4.4 of Chapter IV and exposure information as detailed in section 5.3.3 of Chapter V. The vulnerability function of the population, house, health facilities, schools, and roads relied on the field survey done by MIDIMAR and the literature review as explained below.

Based on the field survey conducted by MIDIMAR following the 2008 earthquake. Different house categories have been identified as follows:

- Cat.1: Houses with walls made from Reinforced Cement Concrete (RCC), burnt bricks with cement or stones with cement;
- Cat.2: Houses with walls made from wood/mud, sundried bricks or timber;
- Cat.3: Houses with walls made from plastic sheeting, bamboo/grass.

Various studies identified the effects of different seismic intensities on structures and population. For the scope of this study, the example given by Arya A (1987) and the European Macro-seismic Scale Report (Coburn & Spence, 2002) was used as summarized in Table 44 below.

Table 43. Different levels of damage as found in The European Macro-seismic Scale Report of 1998 and adapted to Rwandan context

• Damage to buildings • Definitions of quantity: "Few" means less than about 15%; "many" means from about 15% to about 55%; "most" means more than about 55%.	
Intensity VI: Slightly damaging	A few building of class Cat.3 suffer damage of D1;
Intensity VII: Damaging	Most buildings of vulnerable Cat.3 suffer damage of D3. Many buildings of vulnerable Cat.2 suffer damage of D2, and few of D3. A few buildings of vulnerable Cat.1 suffer damage of D1 and D2.

The level of structural damages explained below have been adapted to the context of Rwanda as follows:

- D1: Damaged with minor cracks or just slightly damaged (at approximately 25%);
- D2: Damaged with large cracks or moderately damaged (at approximately 50%);
- D3: Damaged with partial collapse or severely damaged (at approximately 75%);
- D4: Damaged with complete collapse or completely collapsed (at approximately 100%).

Table 45 shows the vulnerability values used in the estimation of the number of houses, schools and health facilities affected by different levels of damage depending on the MMI scale. For example, in the event of an MMI VII earthquake, 40% of all Cat. 2 houses (wood/mud, sundried bricks or timber) located in Rwanda will be damaged with large cracks or moderately damaged (D2). Note that all schools and health facilities have been classified as Cat. 1.

Table 44. Damage probability matrix for houses, school buildings and health facilities

	MMI VI				MMI VII			
	D1	D2	D3	D4	D1	D2	D3	D41
Cat. 1	-	-	-	-	5%	25%	-	-
Cat. 2	-	-	-	-	10%	40%	5%	-
Cat. 3	10%	-	-	-	-	-	75%	-

The methodology for estimating loss of life and injury is based on the lethality ratio developed by Coburn and Spence (2002) as has been used in Nepal (ADPC, 2010) and Timor-Leste (2013). The number of affected people (M) can be expressed as:

M = Noh (M1*M2*M3*(M4+M5)

The model is developed on the basis of five major factors i.e., Population per Building (M1), Occupancy at Time of Earthquake (M2), Occupants Trapped by Collapse (M3) and Injury Distribution at Collapse (M4), Post collapse mortality (M5) and Number of houses (Noh).

Table 45. Parameters used to calculate the casualty

Factor	Value Description	
Population per building (M1)	Based on population/houses per district	
Occupancy at time of earthquake (M2)	Day time Night time	40% 95%
Occupants Trapped by Collapse (M3)	MMI VI MMI VII	- 5%
Injury severity scale (M4)	Dead Life threatening Hospitalized injury Light injury	20% 30% 30% 20%
Post collapse mortality (M5)	95%	

The population per building (M1) is calculated based on 2012 census data (NISR, 2012). The M1 factor for Rwanda is based on the population per building in each district. This value is calculated from the total population divided by the total number of houses in the district. Occupancy at the time of earthquake (M2) is divided by occupancy at daytime and night time. Occupants trapped by Collapse (M3) are based on studies conducted by Okada et al. (1991). The research is based on data from developing countries taking into account the number of people trapped in collapsed buildings due to earthquakes. The causes of death and injury varies considerably. In masonry buildings, the primary cause of death is suffocation from the weight and dust of collapsed walls or roofing. Noji (1989) proposes a number of injury severity scales. One of the simplest and most useful is the four point standard triage categorization of injuries (M4). The last factor considered the equation is post-collapse mortality (M5). The Table 7 gives in detail the values used in fatalities estimation.

6.2.3.3 Characterization of vulnerability profiles

a) Vulnerability of population

The population casualties due to earthquake have been analysed for daytime and night-time scenarios. The casualty profile of the population due to earthquakes (intensity VII) is presented in Figure 124 and Figure 126.

These illustrate the distribution of casualties in different severity stages (light injury, hospitalized, life threatening and dead) based on daytime and night-time scenarios. The Coburn fragility model has been adopted to calculate the vulnerable population.

The analysis reveals that the night-time scenario shows more casualties than the daytime scenario. A total of 6,770 people are vulnerable to earthquake in a night-time scenario. The districts of Rubavu, Rusizi and Nyamasheke have the most number of vulnerable people and the casualties (dead and life threatening) are comparatively higher in these districts, 28% of all estimated casualties.

On the other hand, Huye, Nyanza and Muhanga have the least number of vulnerable people to earthquake. On the other hand, in a daytime scenario, the vulnerable population is lower with only 2,819. It is consistent that most of these vulnerable population are from Rubavu, Rusizi and Nyamasheke. The districts in the Eastern Province are less vulnerable.

Figure 124. Estimated number of casualties for a night-time scenario for earthquake hazard at 2% of probability of exceedance in 50 years

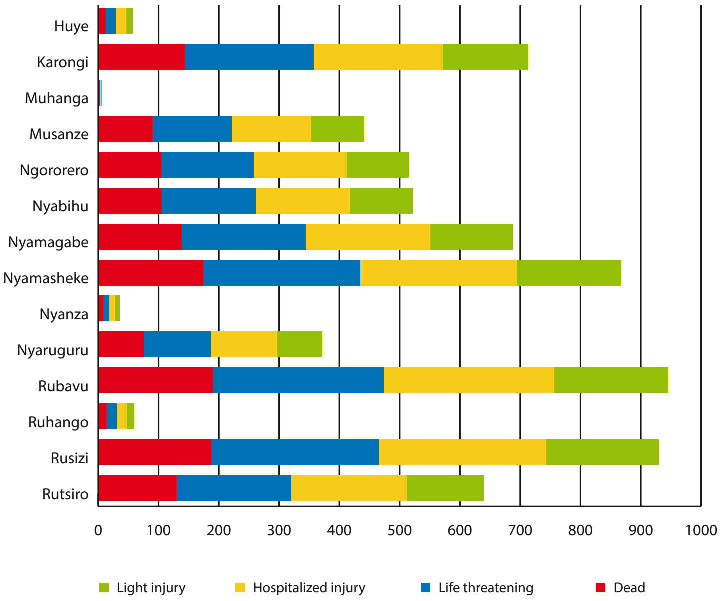


Figure 125. Estimated number of casualties for a daytime scenario for earthquake hazard at 2% of probability of exceedance in 50 years

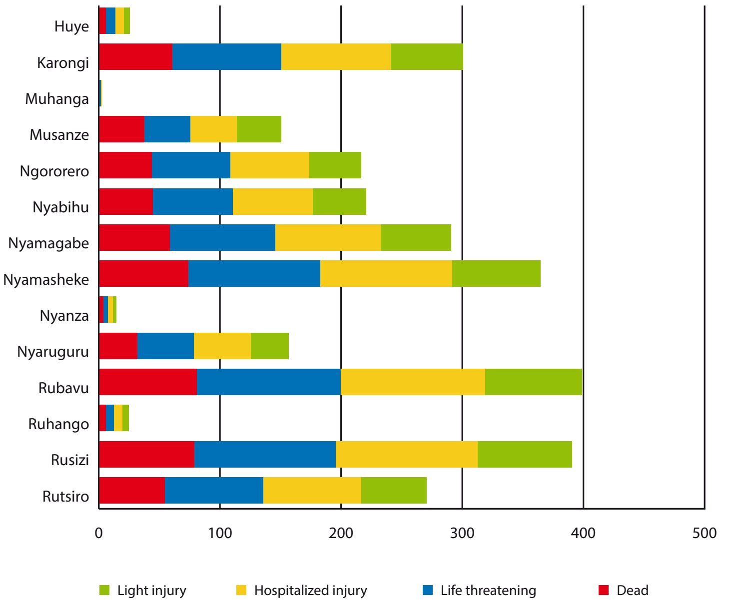


Figure 126. Map of estimated number of casualties for a night-time scenario for earthquake hazard at 2% of probability of exceedance in 50 years

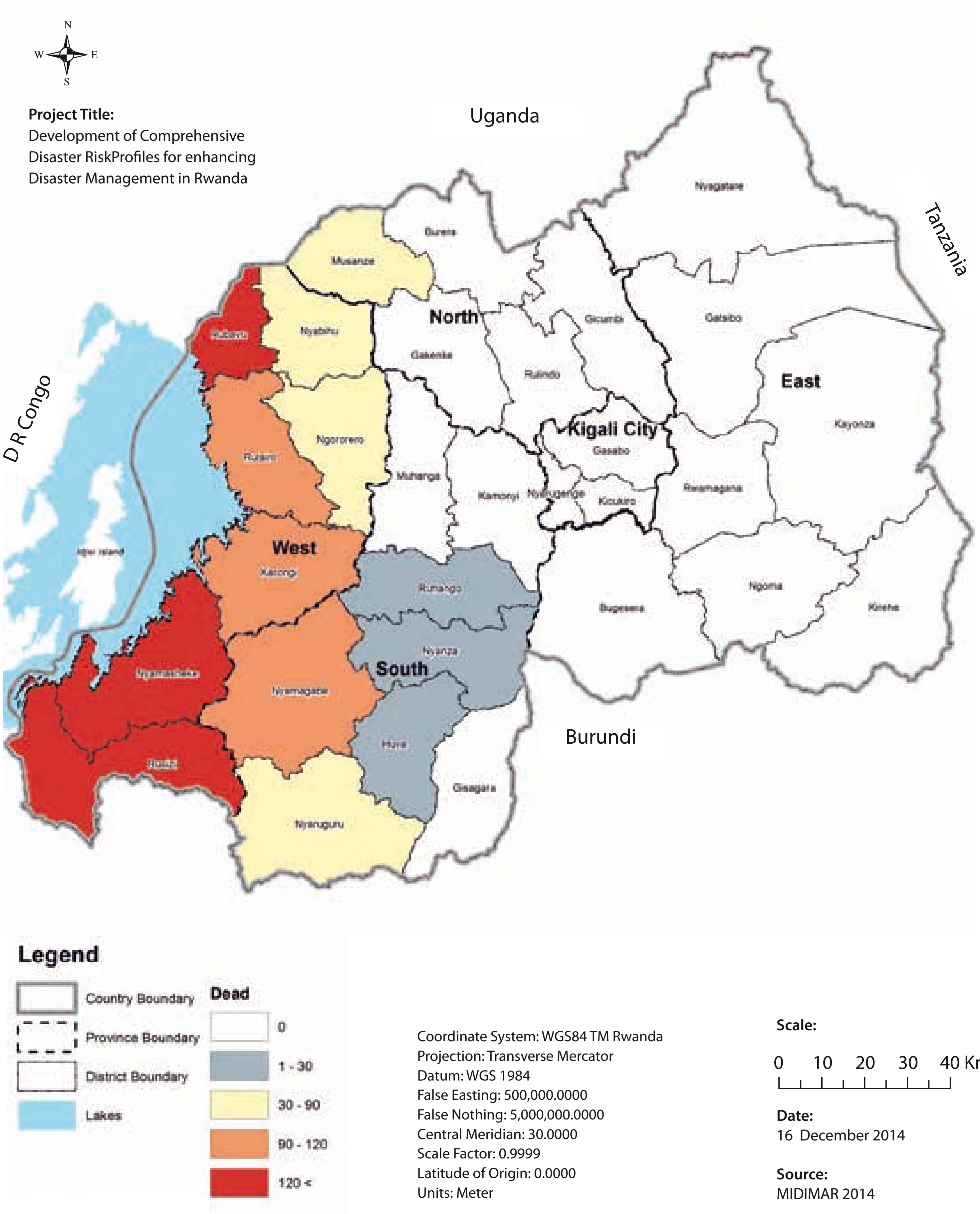
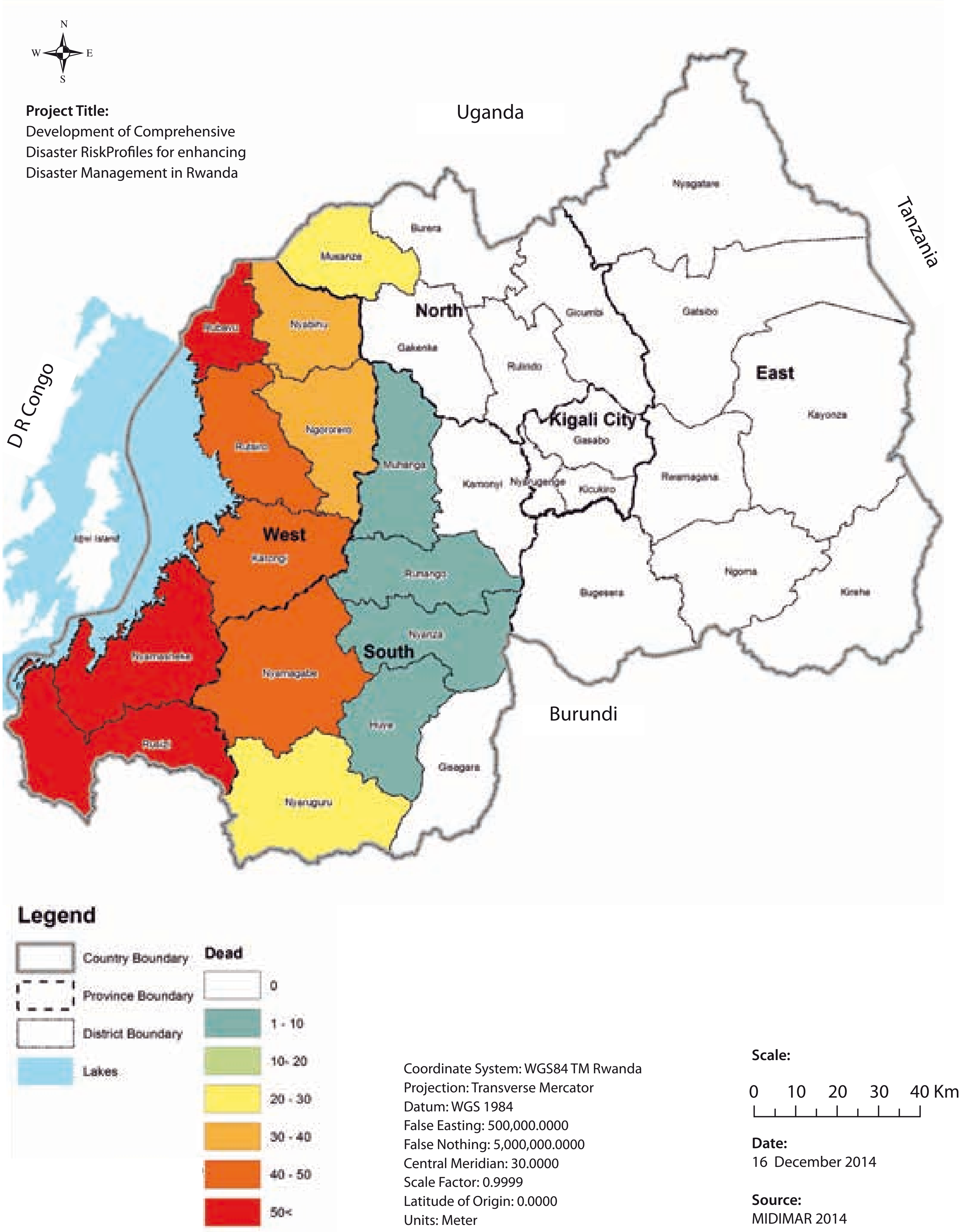


Figure 127. Map of estimated number of casualties for a daytime scenario for earthquake hazard at 2% of probability of exceedance in 50 years



b) Vulnerability of houses

The impacts of earthquake of MMI VII on different house categories have been analyzed. This study found that the impacts vary considerably from one category to another and from one district to another. The summary of the estimated houses damage are summarized in Figure 128.

For Cat. 1 houses, the highest damage is D2. Note that Rusizi has the highest number of houses which could be damaged at D2 with 37% of total estimated houses to be damaged. Among the houses in Cat. 2 the highest level of damage is D3. The districts of Nyamasheke, Rubavu and Rusizi are the ones with more estimated damages, 12% each of the total number of estimated damaged houses. Among houses in Cat. 3, the highest damage expected is D3, and Rubavu have more houses expected to be damaged at this level with 46% of the vulnerable houses.

In total, there are 378,900 houses vulnerable to earthquake. Most of these houses could experience a D2 damage state with 73% among the vulnerable houses. The other 18% could incur D1 damage and about 9% could have D3 damage.

Figure 128. Number of Cat. 1 houses vulnerable to an earthquake at 2% of probability of exceedance in 50 years

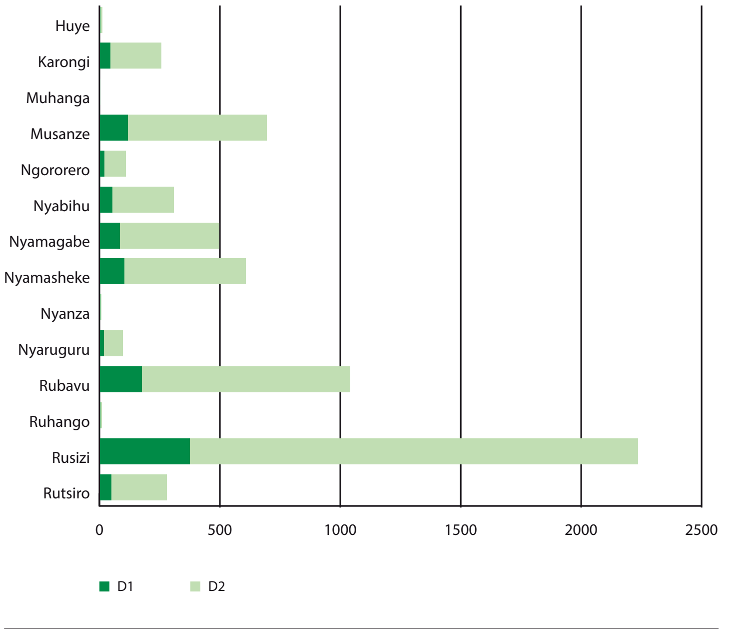
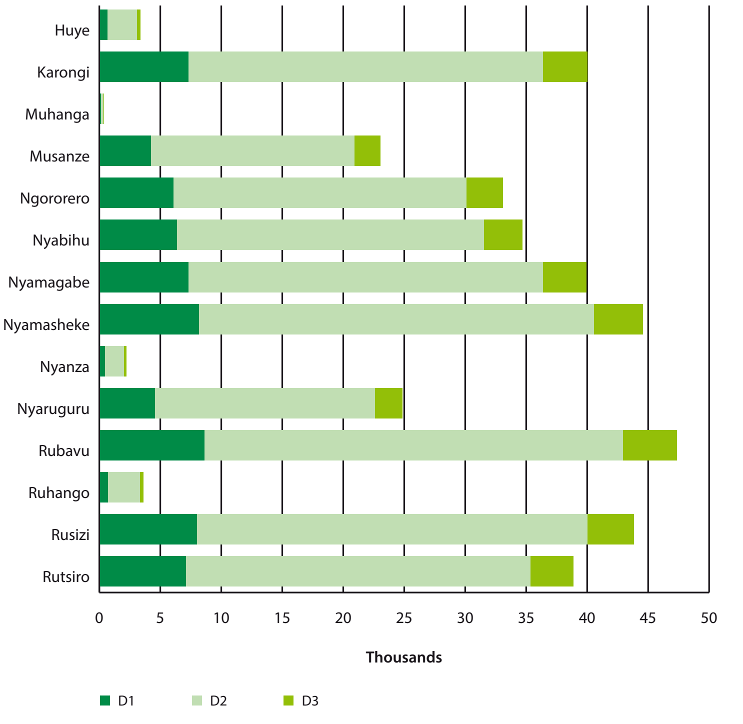


Figure 129. Number of Cat. 2 houses vulnerable to an earthquake at 2% of probability of exceedance in 50 years



c) Vulnerability of health facilities

The analysis focuses on the vulnerability of health facility buildings exposed to earthquakes. Building typology for health facility buildings is not available. Based on information gathered from national experts it was determined that all health facilities are classified Cat.1. The districts of Karongi and Nyamagabe have the highest damage score of 6 when the level of damage considered is D2. A total of 52 health facilities are vulnerable to earthquake, most (43) could have a damage state of D2 and 9 health facilities could have D1 damage.

Figure 130. Number of health facilities vulnerable to an earthquake at 2% of probability of exceedance in 50 years

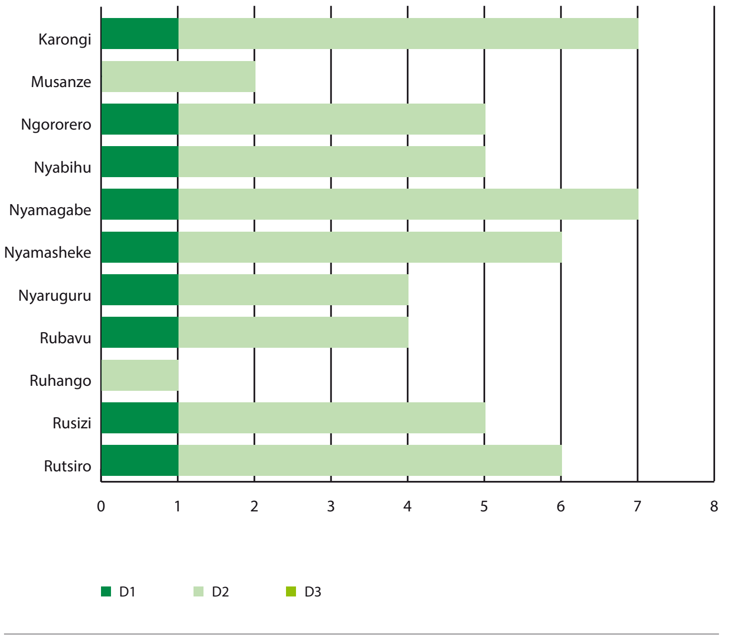


Figure 131. Map of the houses vulnerable to an earthquake at 2% of probability of exceedance in 50 years.

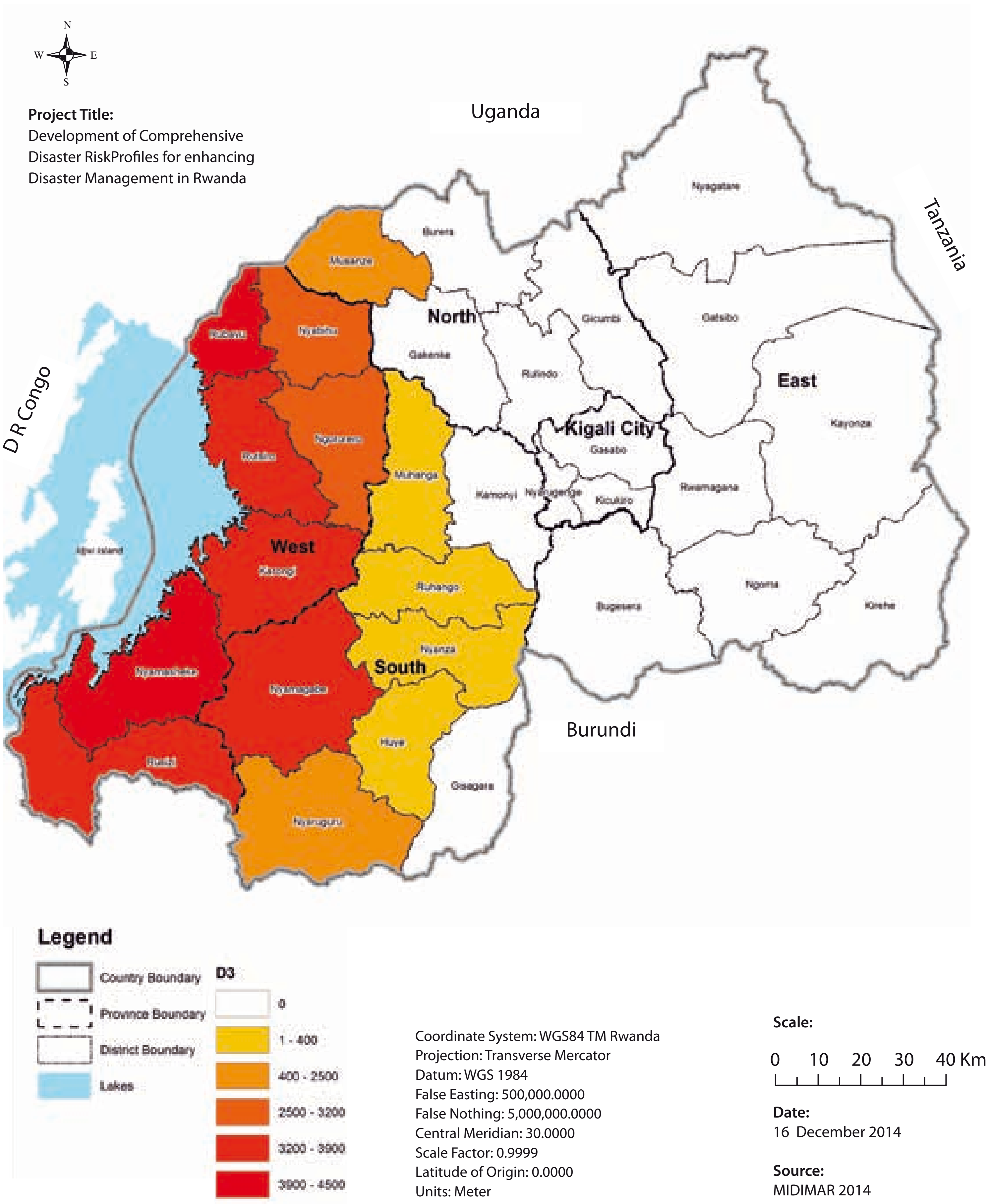
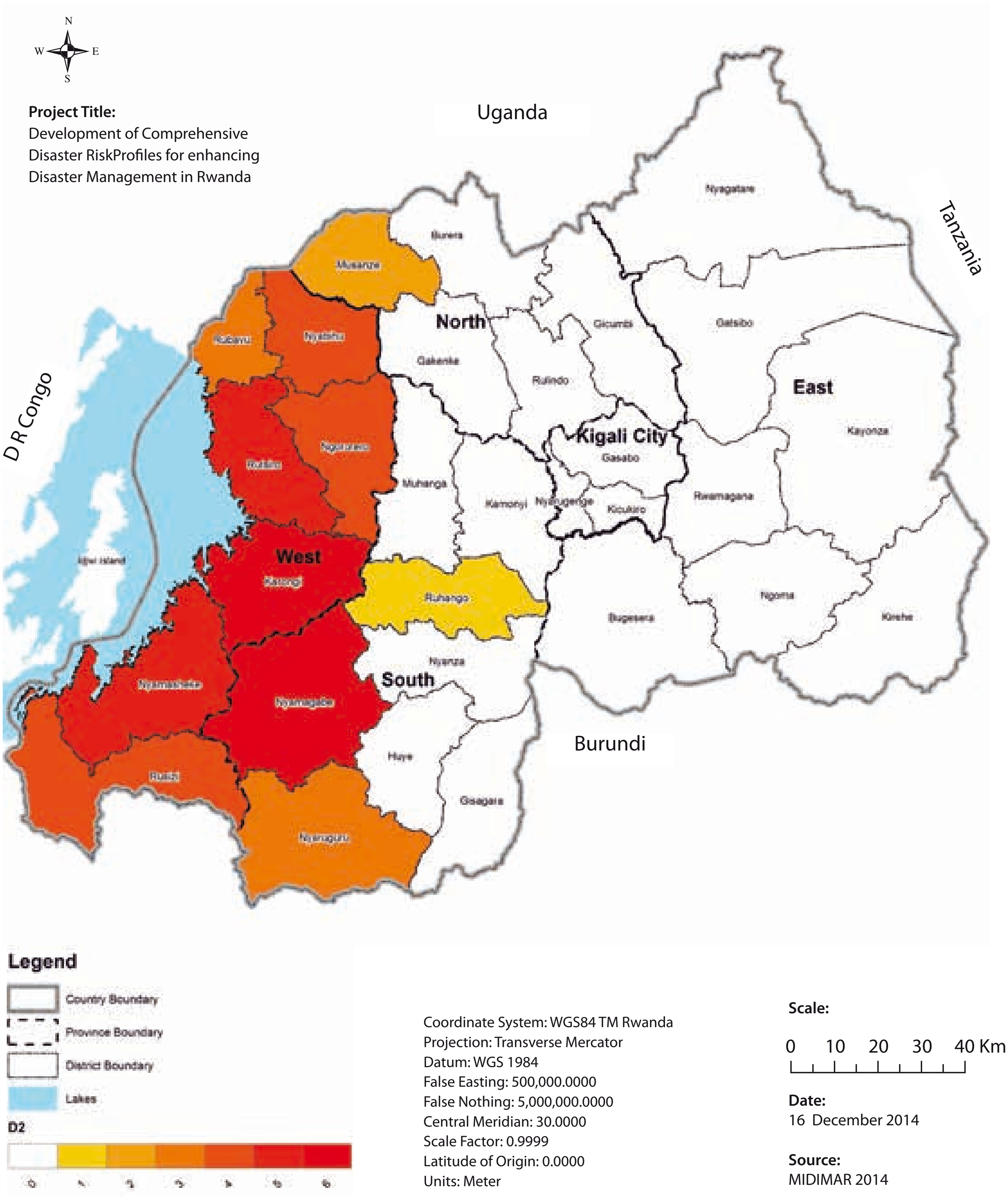


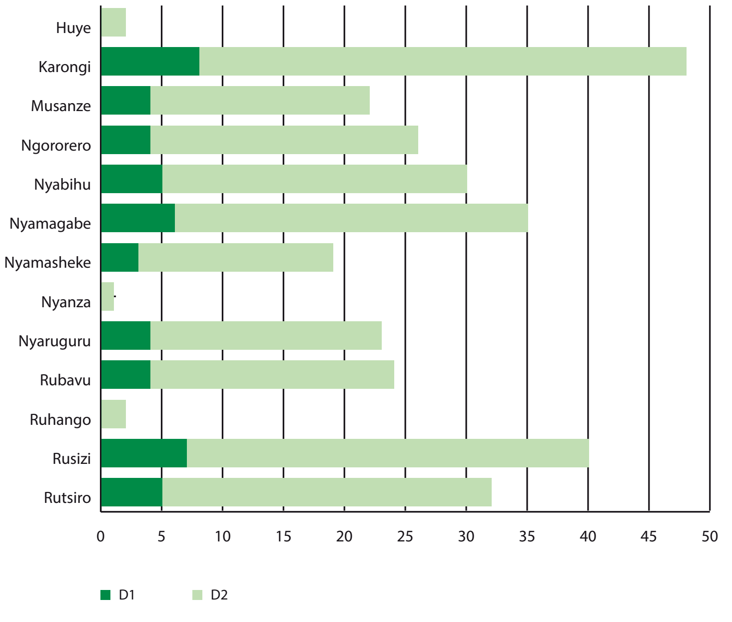
Figure 132. Map of vulnerable health facilities at D2 damage level to an earthquake at 2% of probability of exceedance in 50 years



d) Vulnerability of schools

The analysis focuses on the vulnerability of school buildings exposed to earthquakes. Building typology for school buildings is not available. Based on information gathered from national experts it was determined that all school buildings are classified Cat.1. The highest expected level of damage on schools is D2. As shown in Figure 133, the districts of Nyamasheke have the highest damage score of 40 schools or 15% of the country's schools. It is followed by Karongi and Nyamagabe and Nyabihu, 14%, 11%, and 9% respectively. In total, there are 304 schools vulnerable to earthquake. Most of which, a sum of 254 schools could experience a damage of D2 and the other 50 schools could incur a D1 damage.

Figure 133. Number of schools vulnerable to an earthquake at 2% of probability of exceedance in 50 years



6.2.3.4 Comparative analysis of vulnerability profiles

The vulnerability of different sectors to earthquake have been analyzed. The analysis was only made for one scenario, the 2475-year return period.

The vulnerability of population as determined by the casualties (dead and life threatening) expected for an earthquake with MMI VII are comparatively higher for Nyamasheke, Rusizi, and Rubavu than in other districts. Specifically, the districts in the Eastern Province is with the least number of vulnerable population. Another dimension of the population vulnerability to earthquake which could be differentiated is the casualty profile for a nighttime and daytime scenario. There is more casualties expected for a night-time scenario compared to daytime scenario.

The vulnerability of houses to earthquake reveals high vulnerability also in the Western Province with majority coming from Nyamasheke, Rubavu and Rusizi. The least vulnerable houses are those in Eastern Province. There are more Cat.2 houses vulnerable compared to Cat.1 houses. Further, the highest damage that Cat. 2 houses could incur is D3 while the maximum damage that Cat. 1 houses could experience is D2.

For the health facilities, the vulnerability to earthquake is high in Karongi and Nyamagabe with 6 health facilities each vulnerable. The highest damage that could be experience by most of these vulnerable health facilities is D2 while only 9 health facilities are expected to experience D1 damage state.

There are many schools vulnerable to earthquake. The vulnerability is high in the districts of Nyamasheke, Karongi, Nyamagabe and Nyabihu. A higher number of these vulnerable schools could incur a damage of D2 compared to only about 50 schools could likely experience a D1 damage.

6.2.3.5 Summary of key findings

- The population vulnerable to earthquake varies from 6,770 on a nighttime scenario to 2,820 people on a daytime scenario.

- Most of the districts in the western province are more vulnerable with Rubavu, Rusizi, and Nyamasheke topping the list. The least vulnerable are the population in the eastern province.

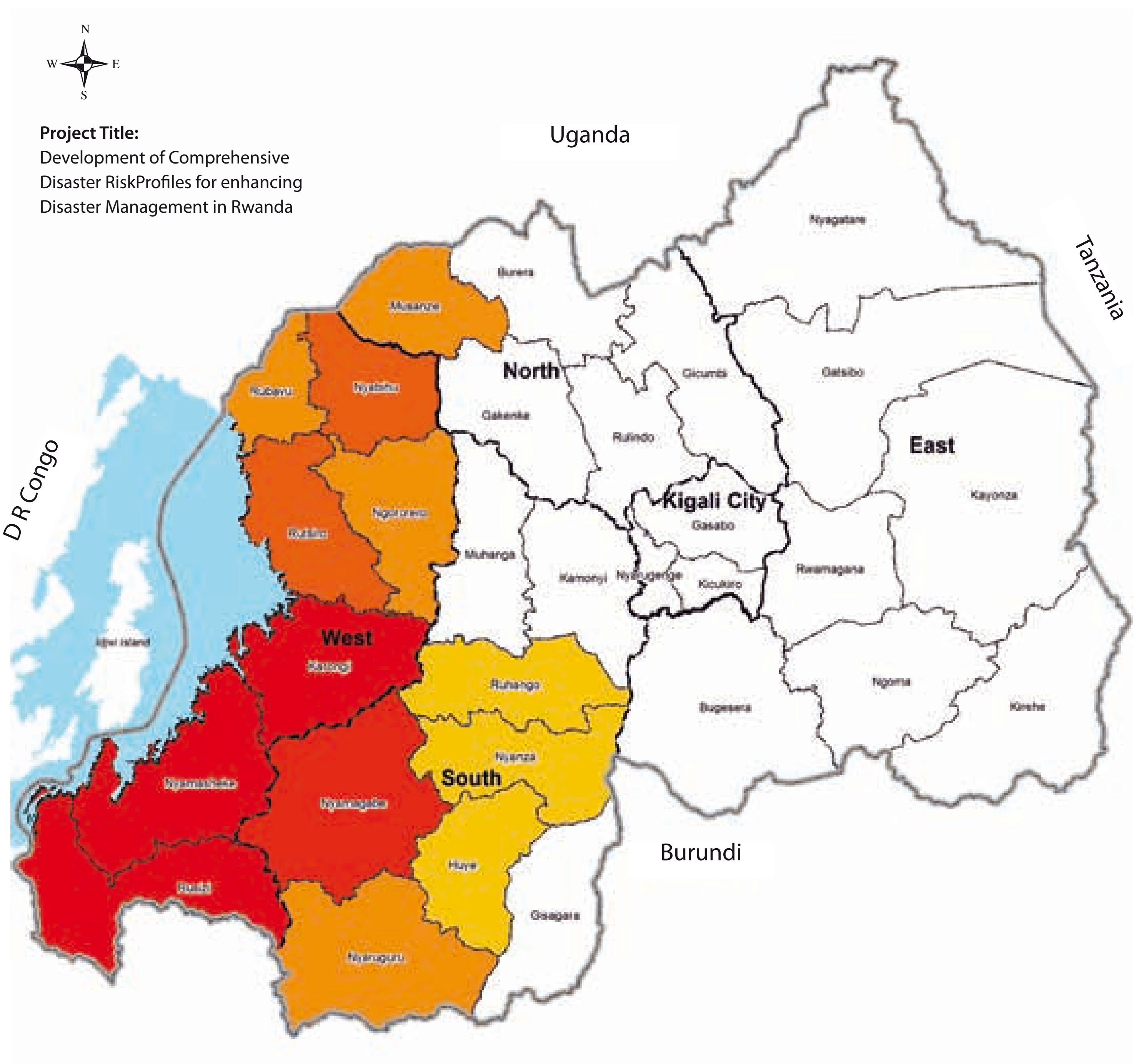
- In total, there are 378,900 houses vulnerable to earthquake. Most of these houses could experience a D2 damage state accounting for more than with 70% of the vulnerable houses. The other 18% could incur D1 damage and about 9% could have D3 damage.

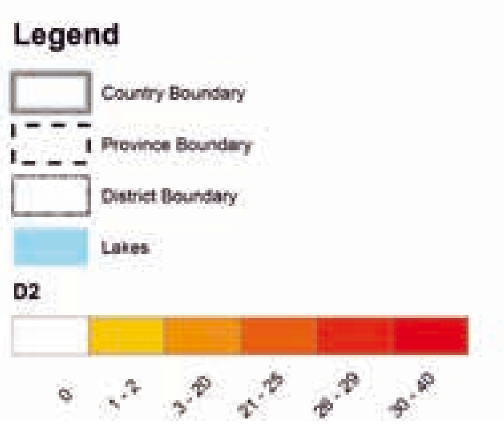
- The districts of Nyamasheke, Rubavu and Rusizi have the most number of vulnerable houses in both Cat.1 and Cat. 2 types of houses.

- A total of 52 health facilities are vulnerable to earthquake, most (43) could have a damage stage of D2 and 9 health facilities could have D1 damage. Karongi and Nyamagabe has the most number of health facilities vulnerable with 6 each. The rest of the districts have 5 and below.

- In total, there are 304 schools vulnerable to earthquake. Most of which, a sum of 254 schools could experience a damage of D2 and the other 50 schools could incur a D1 damage. Most of these vulnerable schools are expected to have D2 damage state.

Figure 134. Map of schools vulnerable to earthquake at 2% of probability of exceedance in 50 years at D2 damage level





Coordinate System: WGS84 TM Rwanda
Projection: Transverse Mercator
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False Nothing: 5,000,000.0000
Central Meridian: 30.0000
Scale Factor: 0.9999
Latitude of Origin: 0.0000
Units: Meter

Scale:
0 10 20 30 40 Km

Date:
16 December 2014

Source:
MIDIMAR 2014

6.2.4 Vulnerability to windstorms

6.2.4.1 Overview

The windstorm susceptibility in different parts of the country is discussed in Paragraph 4.5. Windstorms mainly affect physical infrastructure including houses and agriculture. The vulnerability assessment emphasizes the identification of causative factors that affect the structures. This could include type of material used in building construction i.e. type of roofing used for houses.

The windstorm hazard assessment (in Chapter IV) has developed maps for two return periods: 10-year return period and 5-year return period (see Figure 44 and Figure 45). For this section, the vulnerability assessment is only analysed for the 10-year return period. Based on the expected damage matrix as elaborated in Table 44, significant expected damages (D1-D3) for structure categories (Cat. 1 – Cat. 2) are only notable for the 10-year return period. Expected damage may be minor in the 5-year return period.

Elements at risk

In Rwanda, windstorms primarily affect physical infrastructure such as residential and public buildings. It also affects some crops mainly banana and corn. However, for this report, the assessment has been limited to analysing the vulnerability of population and primary physical assets such houses, health facilities, and schools.

Intensity levels

For this study only the three (top) scales of susceptibility are analysed. These are: strong gale, gale and moderate gale. The lower scales are not analysed because few damages can result from this levels on intensities.

6.2.4.2 Methodology

There are several methodologies proposed for windstorm vulnerability assessment. The most relevant to the study includes Xu Y.L. et al. (1997), Stewart M.G. et al. (2002), Jean-Paul Pinelli et al. (2004), Carol J. Friedland (2009) and HAZUS.

Xu Y.L et al. (1997) have proposed detailed studies on damage estimation of metal roof cladding subject to wind loading. The study analyzes the comparison of fatigue damage caused by the new fatigue loading currently used in Australia and Europe with respect to the design life of roofing sheets, wind return period, annual occurrence of cyclone, and others. The limit fatigue load-bearing capacity of roofing sheets is also obtained.

Mark G. Stewart et al. (2002) discussed risk analysis procedures developed to predict economic risks due to changes to existing housing vulnerability over time. The wind hazard and building vulnerability models are based on exposure of residential construction to cyclones in North Queensland, Australia, which emphasizes the effects of enhanced (post-1980) building standards in North Queensland.

Jean-Paul Pinelli et al. (2004) explained the development of a practical probabilistic model for the estimation of expected annual damage induced by hurricane winds on residential structures. The estimation of the damage is accomplished through establishing basic damage modes for building types and defining possible damage states, whose probabilities of occurrence are calculated as functions of wind speeds from Monte Carlo simulations. The paper describes the conceptual framework for the proposed model and illustrates its application for a specific building type with hypothetical probabilistic inputs. Actual probabilistic input must be based on laboratory studies, post-damage surveys, insurance claims data, engineering analyses and judgment and Monte Carlo simulation methods. The proposed components-based model is flexible and transparent.

The vulnerability assessment of Rwanda related to windstorms has been analysed. In view of housing typology in Rwanda and scope of the study, it was essential to develop a simple methodology, which could be understood and undertaken for further studies by disaster management, development departments and agencies in the country.

The Beaufort scale provided a clear profile of damage as presented in Table 47. The information provided by the Table 48 merged with the estimates made by MIDIMAR (2013) was used in the analysis. MIDIMAR found that most of house damages are linked to poor construction techniques. It was noted that while constructing houses, local residents do not consider wind direction sometimes due to negligence and also due to lack of skills in that area. This information was used in combination with the damages expected from typical wind on Beaufort scale (California-Water-Boards, 2015).Two categories of houses have been identified and classified based on the roof materials, as follows:

Cat. 1: Industrial, concrete, asbestos, local tiles

Cat. 2: Iron sheets, grass and cartons

The number of the population vulnerable was calculated using the methodology proposed by Coburn & Spence (2002). According to MIDIMAR, the level of death and injuries in case of heavy wind incidents is not very high. Some of houses, when they collapse due to a heavy wind, neither kill nor cause serious injuries to people. In all of the MIDIMAR research and reports, they found that only very few people were injured after a heavy wind occurred in their location. Thus, the estimation of the total number of houses that might collapse led to an estimation of the total number of fatalities to be affected in daytime and night-time scenarios consistent with the findings of MIDIMAR. Note however, that in their findings MIDIMAR found that there is an estimated 4% of loss of lives.

Table 46. Beaufort wind force scale land based (California-Water-Boards, 2015)

Beaufort Number	Wind Speed (m/s)	Description	Land conditions
6	8-13.9	Strong Breeze	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic trash tip over.
7	13.9-17.2	Moderate Gale	Whole trees in motion. Effort needed to walk against the wind. Swaying of skyscrapers may be felt, especially by people on upper floor
8	17.2-20.7	Gale	Twigs broken from treed. Cars veer on road
9	20.7-24.5	Strong Gale	Larger branches break off trees and some small trees blow over. Construction/temporally signs and barricades blow over. Damage to circus tents and canopies

Table 47. Damage states and their descriptions from (Goyal & Data, 2012)

Damage	Damage States	Description
D1	Minor to moderate	Partial failure of roofs, minor damage to walls like cracks, etc. failure of roof cover, failure of binders/ fastenings, creation of gaps, etc. distortion of alignments
D2	Moderate too high	Severe damage to boundary walls, more than half of the roof fails severe dislocation of roof members and connectors, heavy cracks and damages in the walls
D3	High to failure	Failure of walls, failure of complete roof, failure of most joints, tilting or uplifting of the structure (repair of the buildings is almost meaningless)

Table 48. Expected damage per house category

Wind scale		D1	D2	D3
Moderate gale	Cat.1	-	-	-
	Cat.2	5%	1%	-
Gale	Cat.1			
	Cat.2	10%	5%	
Strong Gale	Cat.1	5%	5%	
	Cat.2	5%	20%	5%

6.2.4.3 Characterization of vulnerability profiles

a) Vulnerability of population

The casualty of population to windstorms is estimated vis the number of collapsed houses for night-time and daytime scenarios. Strong gale is the only scale considered since on the expected damage, D3 (with a damage state of high to failure) is only possible at strong gale at 5%.

Based on this estimation, there is about 490 people from Nyamasheke (140) and Rusizi (350)[36] could comprise the casualty to strong gale windstorms for a night-time scenario. The level of effects could range from light injury to death. Of this total, about 19% respectively could result to death or have light injury and 31% respectively could have injuries which are life threatening or which would require hospitalization.

For a daytime scenario, about 206 people from Nyamasheke (60) and Rusizi (146) could comprise the casualty to strong gale windstorms. The levels of effects are the same as cited above. About 41% of the vulnerable population could be either dead or have light injuries respectively and 62% could have life threatening and hospitalized injuries respectively.

Table 49. Number of population vulnerable to windstorms at night-time scenario, and the level of effects

Strong Gale	Dead	Life threatening	Hospitalized injury	Light injury
Nyamasheke	28	42	42	28
Rusizi	69	104	104	69

Table 50. Number of population vulnerable to windstorm at daytime scenario, and the level of effects

Strong Gale	Dead	Life threatening	Hospitalized injury	Light injury
Nyamasheke	12	18	18	12
Rusizi	29	44	44	29

[36] Due to the data limitations as cited in Chapter IV which only allowed the extrapolation of the results of the hazard assessment using the available data from only 10 weather stations, the findings only pointed to two districts likely to experience strong gale. Addressing this data gap has already been included as part of the study recommendations. Having said this though, the level of uncertainty is reduced given that based on reports by MIDIMAR (2013), the south western part of the country suffer severe effects of winds compared to the other parts of the country. However, strong winds are more frequent in the east with less human casualties.

b) Vulnerability of houses

The vulnerability of houses to windstorms have been analyzed by different levels of damage. Based on the Beaufort scale, only the districts of Rusizi and Nyamasheke are believed to suffer from strong gale and gale as shown in section 4.5.4 in Chapter IV while 13 districts could experience moderate gale. There are 136 Cat. 1 houses vulnerable to strong gale windstorms in the said districts – 98 houses in Nyamasheke and 38 houses in Rusizi with 50% vulnerable to D1 (damage state of minor to moderate) and the other 50% vulnerable to D2 (damage state of moderate to high).

For Cat. 2 houses under the same windstorm scale of strong gale, there are a total of 2,081 houses vulnerable, 649 of which is in Nyamasheke and 1,432 in Rusizi. Of this number, about 25% are vulnerable to minor to moderate damage state, 50% to moderate to high damage state and 25% vulnerable to high to failure damage state.

Meanwhile, only Cat. 2 houses are vulnerable to gale and moderate gale windstorms. Under a gale windstorm, there are 1,282 houses vulnerable with 50% vulnerable to D1 damage state and the other 50% vulnerable to D2 damage state

For moderate gale windstorms, there are 1,595 houses in the 13 districts which are prone to windstorms at moderate gale are vulnerable with the damage state which could occur to these houses is only D1 (minor to moderate damage). A large number of these vulnerable houses are found in Nyagatare, Musanze, Gicumbi and Nyamasheke with 31%, 18%, 14% and 7% respectively.

In total, there are about 5,094 houses vulnerable to windstorms from moderate gale to strong gale. Most of these are Cat. 2 houses with roofing made of iron sheets, grass and cartons. The highest damage state that these houses could incur is D3 – a damage state of high to failure and these are the vulnerable houses located in Nyamasheke and Rusizi.

Table 51. Number of Cat.1 houses vulnerable to strong gale windstorms

Windstorm Scale	District	Damage State		
		D1	D2	D3
Strong Gale	Nyamasheke	49	49	-
	Rusizi	19	19	-

6.2.4.4 Comparative analysis of vulnerability profiles

Based on a windstorm scale of strong gale and comparing between daytime and nighttime scenarios, the vulnerable population is higher on a nighttime scenario with about 486 people vulnerable than in daytime scenario where

Table 52. Number of Cat. 2 houses vulnerable to windstorms at strong gale, gale and moderate gale

Windstorm Scale	District	Damage State		
		D1	D2	D3
Strong Gale	Nyamasheke	162	325	162
	Rusizi	358	716	358
Gale	Nyamasheke	224	224	-
	Rusizi	417	417	-
Moderate Gale	Burera	229	-	-
	Gakenke	52	-	-
	Gatsibo	36	-	-
	Gicumbi	221	-	-
	Karongi	22	-	-
	Musanze	289	-	-
	Ngororero	0	-	-
	Nyabihu	97	-	-
	Nyagatare	501	-	-
	Nyamagabe	0	-	-
	Nyamasheke	113	-	-
	Nyaruguru	0	-	-
	Rubavu	16	-	-
	Rulindo	12	-	-
	Rusizi	7	-	-
	Rutsiro	0	-	-
Total	**5,094**			

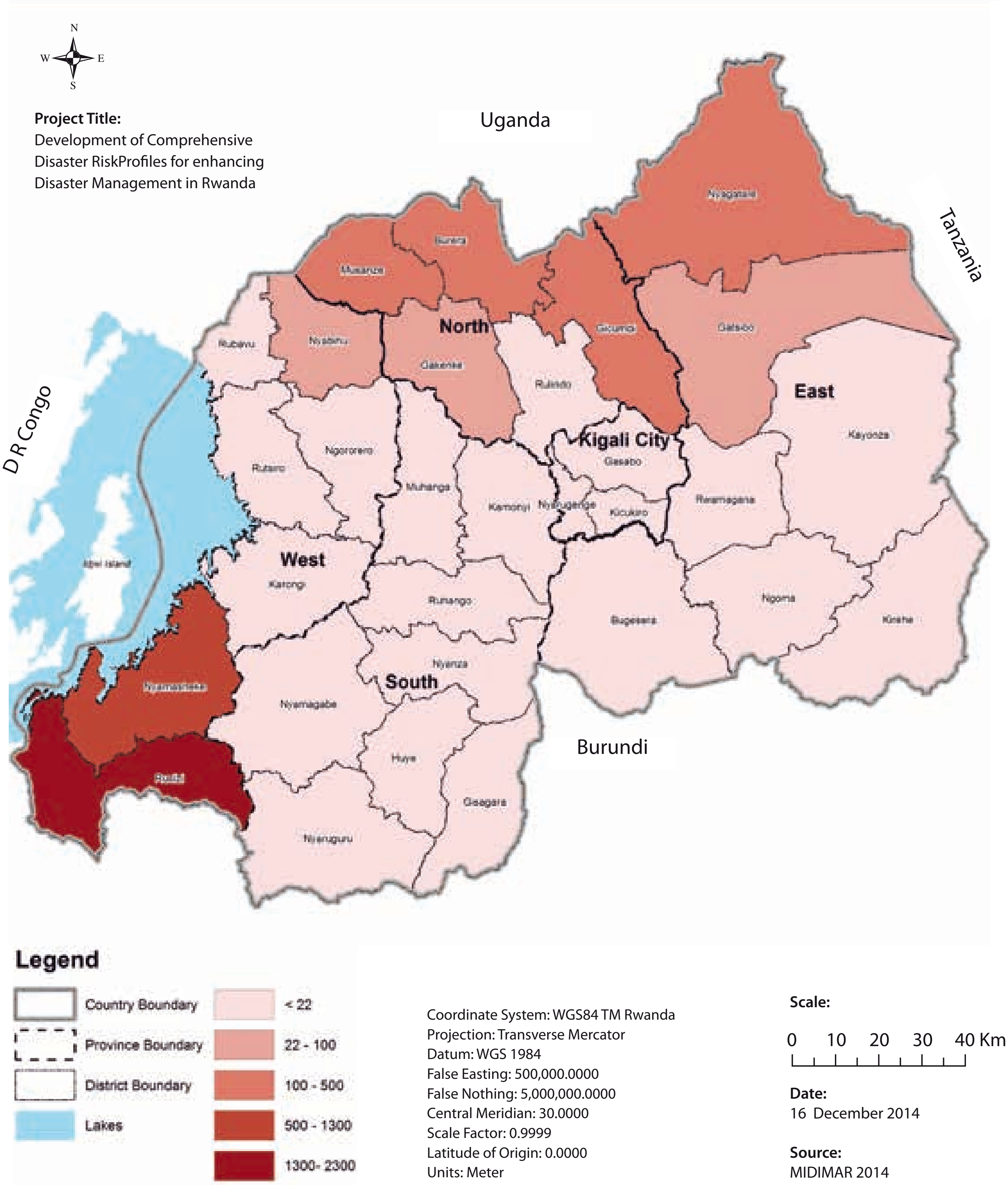
only 206 people are vulnerable in Nyamasheke and Rusizi Districts. There is no variant for either scenarios in as far as the degree of effects to the vulnerable people.

In terms of the vulnerability of houses, there are more Cat. 2 houses vulnerable compared to Cat. 1 houses. It is important to reiterate that Cat. 1 houses are comprised of those houses with roofs made of industrial, concrete, asbestos and local tiles and Cat. 2 houses are those with roofs made of iron sheets, grass and cartons. While both Cat. 1 and Cat. 2 houses are vulnerable to moderate gale, gale and strong gale, only Cat. 2 houses are vulnerable to gale and moderate gale. There is no Cat. 1 house which is vulnerable to gale and moderate gale. Furthermore, 56% of the total vulnerable houses could incur damage state of D1, 34% damage state of D2 and 10% damage state of D3.

6.2.4.5 Summary of key findings

- A total of 692 people are vulnerable to strong gale windstorms where D3 damage state is expected wherein houses could collapse and impact on the occupants resulting to deaths and injuries. These vulnerable people are located in Nyamasheke and Rusizi Districts as these are the areas where a strong gale is likely to occur. More are vulnerable to a nighttime scenario than daytime scenario.

Figure 135. Map of the total estimated number of houses vulnerable to windstorms damages



- A total of 5,094 houses are vulnerable to windstorms at a scale ranging from moderate gale to strong gale.
- There are 136 Cat.1 houses vulnerable to strong gale windstorms in the districts of Nyamasheke and Rusizi. The expected damage could be D1 and D2.
- A total of 4,958 Cat. 2 houses are vulnerable to windstorms of which 42% are vulnerable to strong gale, 26% to gale and 32% to moderate gale.
- A total of 45% of the vulnerable Cat. 2 houses are found in Rusizi, 23% in Nyamasheke and 32% are located in the other 11 districts which are prone to windstorms.

Chapter VII

Estimation of Economic Cost

7.1 Introduction

Following the vulnerability assessment, the next and final step in a risk assessment process is loss/impact estimation. The estimation of loss/impact is essentially expressing the physical damage in monetary value or estimating the economic cost. It also involves an analysis of the implications of these damage to the functioning of a system, otherwise referred to as 'functioning loss". And lastly, it involves the analysis of macro- and long-term impacts of the damage and functioning losses i.e. economic impacts, social impacts and financial impacts, etc.

For this study, the estimation is limited to the calculation of the economic cost [or direct loss] representing the equivalent monetary value of the damage of some elements at risk i.e. direct physical damage to houses, health facilities, roads and crops. The analysis of (i) the functioning loss i.e. economic loss including lost jobs, business interruptions, repair and reconstruction costs; and the social impacts, including estimates of shelter requirements, displaced households and increased population exposure to hazards were not considered in this study, and (ii) the analysis of the macro or long term impacts is not also covered in this study. These two however, have been highlighted in the recommendations as one of the important next steps for the risk assessment in Rwanda.

Furthermore, the estimation of economic cost in this study is also limited to selected elements at risk depending on the availability and quality of the data. Specifically, the estimation of economic cost had been limited for the following elements at risk: houses, health facilities, national paved roads, and crops for the following hazards: landslide, earthquake, drought, and windstorm. The estimation of economic cost is also based on the assumption that these elements at risk will incur total damage hence only the replacement value of the asset has been considered. The repair cost for partially damaged assets was not included in the estimation of economic cost for this study.

It is important to note that the estimation of economic cost presented in this report is based on an overall hazard scenario approach and not on a 'per event' scenario approach. The overall hazard scenario approach simply means taking the assumption granting that the country (or the specific districts) will experience the hazard all at once at a given exposure and vulnerability of the assets. The potential economic cost therefore is an estimation of the overall or cumulative economic cost, which represents the total economic cost profile of a specific element at risk in a hazard-prone area. Therefore, this estimate is not suitable for scenario-based contingency and recovery planning, but can be a valuable reference for strategic risk and disaster management planning.

7.2 Methodology for estimation of economic cost

The estimation of economic cost is a function of the total exposure, the damage state of each element at risk, and their replacement or repair cost. The calculation of potential economic costs due to different hazards were done using the formula as demonstrated below:

Table 53. Parameters considered in estimation of economic cost

Element at risk		Tempopral Probability	Amount (economic value)	Vulnerability	Cost of vulnerable assets
A		0.1	100000	0.1	1000
B		0.1	50000	1	5000
C		0.1	200000	0.5	10000

For this study, the replacement costs for the assets considered for estimation of economic cost are as follows as provided by different concerned government agencies. These replacement costs are the current prevailing prices used in the country.

a) Replacement cost for houses

Table 54. Replacement price of houses by wall type (as of May 2015)

House classification by wall material	Replacement price or cost (in Rwf)
Cement	5,000,000
Burnt bricks	5,000,000
Sundried bricks	4,000,000
Wood and cement	1,500,000
Wood and mud	1,500,000

Source: Rwanda Housing Authority

b) Replacement cost for health facilities

Table 55. Replacement price of different health facilities (as of May 2015)

Type of health facility	Replacement price or cost (in Rwf)
National Reference Hospitals	-
District Hospital	5,165,510,000
Health Centre	569,000,000
Health Post	70,000,000

Source: Ministry of Health

c. Market price for crops (as of 2015)

Table 56. Replacement price of different crops (as of May 2015)

Crop	Price per kg in Rwandan Francs	Price per tons in Rwandan Francs
Banana	150	150000
Beans	350	350000
Irish Potatoes	100	100000
Cassava	200	200000
Cereals [37]	445	445000

Source: Retrieved from www.esoko.rw

d) Replacement cost for paved national roads

The cost of one kilometer of road is estimated to be 1,565,680 USD or 1,080,092,164 Rwf. (Source: Rwanda Transportation Development Agency).

7.3 Economic cost profiles by hazard

The ensuing section is the analysis of the economic cost profiles by hazard for selected assets or elements at risk. Due to limited data available on the replacement costs, only the potential monetary economic cost of the below indicated assets were considered and analysed i.e. crops, houses, health facilities and paved national roads.

7.3.1 Economic costs of elements at risk due to drought

7.3.1.1 Crops

Given the two drought scenario i.e. Season A and Season B, the estimated monetary losses [or economic costs] from damaged crops produced during the two seasons could be 1.9 and 6.9 billion Rwandan francs respectively. These losses [economic costs] were estimated for the eight major crops considered in the exposure and vulnerability analysis in the preceding chapters.

For Season A, the highest losses [economic costs] could be experienced by Kayonza at around 810 million Rwandan francs; followed closely by Kirehe with about 640 million Rwandan francs of losses and Gatsibo with about 470 million Rwandan francs. Meanwhile, the districts of Ngoma, Nyagatare and Rwamagana could incur losses of not over 25 million Rwandan francs.

The highest losses [economic costs] could be from Banana at 880 million Rwandan francs. Cassava is next with about 500 million Rwandan francs. Cereals which comprised of maize, rice and sorghum follow next with about 340 million Rwandan francs in total estimated losses. Meanwhile Irish potatoes could incur about 160 million Rwandan francs of losses and beans could have losses of about 70 million Rwandan francs.

Table 57. Estimated monetary losses from crops due to drought in Season A

District	Estimated Losses (in Rwf)					
	Cereals[38]	Beans [39]	Irish Potatoes	Banana	Cassava	Total
Gatsibo	116,310,037	21,205,576	29,579,367	198,115,338	100,863,654	466,073,972
Kayonza	89,210,472	22,286,135	73,432,128	435,078,530	186,363,003	806,370,269
Kirehe	128,414,390	24,373,664	55,784,262	236,127,640	195,156,237	639,856,193
Ngoma	50,136	12,497	29,110	158,888	143,597	394,228
Nyagatare	5,757,888	1,864,120	911,586	7,478,720	7,797,807	23,810,122
Rwamagana	2,775,823	443,836	2,125,674	7,446,301	4,798,485	17,590,119
Total	**342,518,747**	**70,185,829**	**161,862,128**	**884,405,417**	**495,122,782**	**1,954,094,903**

[37] The cost for cereals comprised the average of the costs for maize (195/kg or 445,000/ton); rice (750/kg or 750,000/ton); and Sorghum (390/kg or 390,000/ton)
[38] Cereals include maize, rice and sorghums
[39] Beans is comprised of long beans and ordinary beans

Table 58. Estimated monetary losses from damaged crops due to drought in Season B

District	Estimated Losses (in Rwf)					
	Cereals	Beans	Banana	Irish Potatoes	Cassava	Total
Bugesera	96,899,566	26,342,696	79,229,155	22,322,772	294,750,708	519,544,896
Gatsibo	250,328,142	45,639,677	426,393,506	63,662,158	217,083,682	1,003,107,166
Gicumbi	10,058,188	8,247,612	13,286,763	7,168,493	15,662,801	54,423,857
Gisagara	640,260	155,288	401,932	143,328	1,861,864	3,202,672
Kayonza	179,650,818	44,879,512	876,155,138	147,876,607	375,295,243	1,623,857,318
Kamonyi	29,032,346	5,881,666	19,082,591	7,372,713	171,400,542	232,769,858
Kigali	32,910,131	8,586,108	40,526,092	16,800,427	92,919,783	191,742,541
Kirehe	250,056,789	47,461,972	459,802,984	108,626,715	380,020,823	1,245,969,283
Ngoma	63,328,047	15,785,032	200,693,723	36,769,244	181,380,073	497,956,120
Nyagatare	130,544,049	42,263,723	169,559,113	20,667,675	176,793,502	539,828,061
Nyanza	6,549,401	1,596,075	2,906,061	1,663,065	15,498,891	28,213,493
Ruhango	3,578,539	1,107,158	2,115,330	695,388	41,839,083	49,335,498
Rulindo	5,784,656	3,270,828	7,065,326	2,275,676	11,445,422	29,841,908
Rwamagana	143,289,547	22,911,053	384,382,262	109,728,500	247,700,482	908,011,844
Total	**1,202,650,479**	**274,128,400**	**2,681,599,975**	**545,772,761**	**2,223,652,901**	**6,927,804,516**

For Season B, the highest estimated losses [economic costs] is also expected in Kayonza, Kirehe and Gatsibo. These are the districts which have large areas cultivated with these major crops and with high exposure and vulnerability at the same time. Kayonza could incur an estimated total losses of 1.6 billion Rwandan francs; Kirehe with 1.2 billion Rwandan francs and Gatsibo has about 1 billion Rwandan francs as potential losses from damaged crops.

The district of Gisagara could have the least estimated losses [economic costs] with only about 3 million Rwandan Francs. The rest of the districts as indicated in Table 58 could have estimated losses ranging from 28 to 900 million Rwandan francs.

7.3.2 Economic costs of elements at risks due to landslide

7.3.2.1 Houses

Considering the landslide hazard scenario as detailed in the previous chapter and the vulnerability of houses to landslide taking into account the damage state by category of houses, the total potential losses [economic costs] which could be incurred nationwide is approximately over 9.2 billion Rwanda francs (equivalent to about13.5 million US dollars). The current prevailing replacement cost per house in Rwanda was used to estimate the loss (see Table 54).

The three districts of Kigali City namely, Nyarugenge, Kicukiro, and Gasabo recorded as top 3 amongst those which could incur the highest potential losses due to impacts of landslide to houses. Nyarugenge could incur the highest losses amounting to about 1.2 billion Rwandan francs. Kicukiro is next with about 895 million Rwandan francs and Gasabo with about 708 million Rwandan francs.

The least potential losses [economic costs] which could be incurred due to the impacts of landslide to houses is recorded in the districts of Kirehe, Ngoma and Nyaruguru with less than a hundred Rwandan francs of potential losses. Nyaruguru could incur direct loss of about 64 million Rwandan francs; Ngoma could incur direct losses of about 45 million Rwanda francs; and Kirehe is expected to incur direct losses of about 40 million Rwandan francs.

The rest of the districts as stated in Table 60, are expected to incur direct losses [economic costs] ranging from 100 million up to a maximum of 1.2 billion Rwandan francs.

Table 59. Estimated monetary losses from damaged houses due to landslide at moderate to very high susceptibility

District	Number of houses	Estimated losses (in Rwf)
Bugesera	568	170,308,920
Burera	770	372,217,713
Gakenke	949	342,366,717
Gasabo	2,101	708,516,444
Gatsibo	427	104,471,278
Gicumbi	801	233,481,475
Gisagara	555	131,836,396
Huye	843	245,052,265
Kamonyi	926	320,286,401
Karongi	843	289,741,729
Kayonza	593	208,759,176
Kicukiro	2,444	895,410,814
Kirehe	138	40,011,134
Muhanga	1,079	349,688,327
Musanze	999	301,332,094
Ngoma	248	45,147,206
Ngororero	762	291,306,445
Nyabihu	858	263,666,449
Nyagatare	599	178,662,839
Nyamagabe	644	135,298,030
Nyamasheke	835	241,187,865
Nyanza	615	166,162,898
Nyarugenge	4,280	1,268,387,235
Nyaruguru	342	64,901,676
Rubavu	1,228	412,109,030
Ruhango	880	283,363,605
Rulindo	1,270	427,147,650
Rusizi	1,123	274,260,495
Rutsiro	694	246,462,152
Rwamagana	797	219,000,751
National - Total	**29,215**	**9,230,545,211**

7.3.2.2 Health facilities

Analysing the losses [economic costs] which could incur due to the likely impacts of landslide to the health facilities based on the prevailing replacement price or cost of health facilities, the total estimated losses nationwide is approximately 2.7 billion Rwandan francs. The 2.6 billion Rwandan francs of which are losses could incur from damaged health centers and about 28 million Rwandan francs are losses from damaged health posts. There are no expected losses from district hospitals.

The districts of Gakenke, Nyamagabe and Rulindo is estimated to incur the highest potential losses from the damaged health facilities due to landslides. Gakenke's potential loss is estimated at over 233 million Rwandan francs; followed by Nyamagabe which could have about 227 million Rwandan francs of losses; and Rulindo to lose about 170 million Rwandan francs if and when landslide strikes these areas.

Meanwhile, the Districts of Bugesera, Gasabo, Gisagara, Huye, Musanze and Rubavu could incur the least in terms of losses from damaged health facilities caused by landslide. Each district's potential loss is estimated to be around 56 million Rwandan francs only. The rest of the districts could incur losses of between 56 million to 233 million Rwandan francs as can be gleaned from Table 60 below.

Table 60. Estimated monetary losses due to damaged health facilities by landslide at moderate to very high susceptibility

Districts	Health Post	Health Centres	District Hospitals	Total
Bugesera	-	56,900,000	-	56,900,000
Burera	-	113,800,000	-	113,800,000
Gakenke	5,512,500	227,600,000	-	233,112,500
Gasabo	2,450,000	56,900,000	-	59,350,000
Gatsibo	-	-	-	-
Gicumbi	-	113,800,000	-	113,800,000
Gisagara	-	56,900,000	-	56,900,000
Huye	-	56,900,000	-	56,900,000
Kamonyi	-	113,800,000	-	113,800,000
Karongi	-	170,700,000	-	170,700,000
Kayonza	-	-	-	-
Kicukiro	-	-	-	-
Kirehe	-	-	-	-
Muhanga	-	113,800,000	-	113,800,000
Musanze	-	56,900,000	-	56,900,000
Ngoma	-	-	-	-

Contd...

Districts	Health Post	Health Centres	District Hospitals	Total
Ngororero	14,000,000	113,800,000	-	127,800,000
Nyabihu	7,000,000	170,700,000	-	177,700,000
Nyagatare	-	-	-	-
Nyamagabe	-	227,600,000	-	227,600,000
Nyamasheke	-	113,800,000	-	113,800,000
Nyanza	-	113,800,000	-	113,800,000
Nyarugenge	-	113,800,000	-	113,800,000
Nyaruguru	-	113,800,000	-	113,800,000
Rubavu	-	56,900,000	-	56,900,000
Ruhango	-	113,800,000	-	113,800,000
Rulindo	-	170,700,000	-	170,700,000
Rusizi	-	113,800,000	-	113,800,000
Rutsiro	-	113,800,000	-	113,800,000
Rwamagana	-	-	-	-
National - Total	**28,962,500**	**2,674,300,000**	**-**	**2,703,262,500**

7.3.2.3 Paved national roads

Considering the same landslide hazard scenario as detailed in the previous chapter and the vulnerability of paved national roads to landslide based on the damage state, the total potential losses [economic costs] on paved national roads nationwide is approximately 54.5 billion Rwandan francs (or equivalent to about 80.2 million US dollars). The current[40] prevailing replacement cost per kilometer of paved national roads of 1,080,092,164 Rwf or 1,565,680 USD was used to estimate the loss.

The potential direct losses [economic costs] to paved national roads is highest in the districts of Nyamasheke, Nyamagabe and Ngororero. Nyamasheke could incur a loss of 5.4 billion Rwandan francs (or equivalent to 7.9 million US dollars); Nyamagabe could incur a loss of about 4.8 billion Rwandan francs (or about 7.1 million US dollars) and Ngororero could incur a loss of about 4.8 billion Rwandan francs (or about 7 million US dollars).

The districts with the least potential losses to paved national roads due to landslide is Kayonza and Ngoma with 65.6 million Rwandan francs (about 96 thousand US dollars only) and 43.6 million Rwandan francs (or about 64 thousand US dollars only) respectively. Gisagara district which has no paved national roads will incur zero loss for this asset.

Table 61. Estimated monetary losses from damage on paved national roads due to landslide at moderate to very high susceptibility

District	Road Length (in Km)	Estimated losses (in million Rwf)
Bugesera	5.27	1,733
Burera	1.01	333
Gakenke	6.32	2,079
Gasabo	3.86	1,270
Gatsibo	5.98	1,964
Gicumbi	2.26	743
Gisagara	-	-
Huye	6.31	2,076
Kamonyi	7.29	2,398
Karongi	4.66	1,533
Kayonza	0.20	66
Kicukiro	1.76	580
Kirehe	0.98	322
Muhanga	13.75	4,520
Musanze	5.23	1,719
Ngoma	0.13	44
Ngororero	14.67	4,824
Nyabihu	9.83	3,232
Nyagatare	4.27	1,404
Nyamagabe	14.81	4,871
Nyamasheke	16.48	5,420
Nyanza	1.77	582
Nyarugenge	4.69	1,542
Nyaruguru	1.63	537
Rubavu	3.46	1,139
Ruhango	4.94	1,624
Rulindo	8.90	2,927
Rusizi	10.17	3,345
Rutsiro	2.00	657
Rwamagana	3.21	1,055
National - Total	**165.84**	**54,536**

[40] Prevailing replacement cost or price used as of 2015

7.3.3 Economic cost of elements at risk due to earthquake

7.3.3.1 Houses

Losses [economic cost] to earthquake of an intensity of MMI VII could also be devastating. Specifically, for damaged houses alone, the estimated monetary losses is at 10.3 billion Rwandan francs (which converts roughly to about 15 million US dollars). Highest losses are likely in the highlands of Rubavu, Rusizi, Nyamasheke, Nyamagabe, Karongi and Rutsiro which could incur more than a billion Rwandan francs of monetary losses due to earthquake. Minimal losses could be incurred in Muhanga with only about 7.7 million Rwandan francs.

Table 62. Estimated monetary losses from damaged houses due to an earthquake at 2% probability of exceedance

District	Number of houses	Estimated losses (in Rwf)
Huye	3,286	86,804,765
Karongi	39,952	1,064,598,563
Muhanga	294	7,751,457
Musanze	22,965	645,789,556
Ngororero	33,043	873,686,374
Nyabihu	34,614	927,956,084
Nyamagabe	39,890	1,079,104,086
Nyamasheke	44,512	1,207,107,688
Nyanza	2,136	56,282,046
Nyaruguru	24,772	656,101,198
Rubavu	47,294	1,302,856,591
Ruhango	3,555	93,669,584
Rusizi	43,783	1,294,544,003
Rutsiro	38,803	1,035,665,125
National - Total	**378,900**	**10,331,917,120**

7.3.3.2 Health facilities

An earthquake of intensity MMI VII at 2% probability of exceedance in the country could result to losses from damaged health facilities. The total estimated monetary losses to damaged health facilities is about 11.3 billion Rwandan francs.

The estimated losses [economic costs] is highest in Karongi District which is about 1.9 billion Rwandan francs and this is due to damaged health centers and a district hospital. The districts of Nyamagabe, Rusizi, Rutsiro, and Nyamasheke could also incur losses of over a billion Rwandan francs. The rest of the districts with health facilities vulnerable to earthquake as indicated in Table 64 also could incur losses ranging from 190 million to a billion Rwandan francs.

By type of health facilities, the losses is highest for damaged health centers at 6 billion Rwandan francs; followed by losses for damaged district hospitals at about 5.1 billion Rwandan francs; and losses due to damaged health posts at about 91 million Rwandan francs.

Table 63. Estimated monetary losses due to damaged health facilities by an earthquake of 2% probability of exceedance

Districts	Health Post	Health Centres	District Hospitals	Total
Karongi	0	876,260,000	1,084,757,100	1,961,017,100
Musanze	8,235,294	217,558,824	0	225,794,118
Ngororero	34,239,130	371,086,957	561,468,478	966,794,565
Nyabihu	13,815,789	561,513,158	339,836,184	915,165,131
Nyamagabe	11,136,364	814,704,545	821,785,682	1,647,626,591
Nyamasheke	5,000,000	772,214,286	368,965,000	1,146,179,286
Nyaruguru	0	535,529,412	303,853,529	839,382,941
Rubavu	11,666,667	426,750,000	430,459,167	868,875,834
Ruhango	2,058,824	117,147,059	75,963,382	195,169,265
Rusizi	5,147,059	585,735,294	759,633,824	1,350,516,177
Rutsiro	0	806,083,333	430,459,167	1,236,542,500
Total	**91,299,127**	**6,084,582,867**	**5,177,181,513**	**11,353,063,507**

7.3.4 Economic cost of elements at risk due to windstorm

7.3.4.1 Houses

The impacts of windstorms could also be devastating and could affect about 3,685 houses of different types/ categories. The total estimated losses [economic costs] from damaged houses is around 1.6 billion Rwandan francs. The losses is high in Rusizi which could incur about 363 million Rwandan francs and Nyagatare with estimated losses at 344 million Rwandan francs. The other districts which could incur large amount of losses are Nyamasheke, Musanze, Burera and Gicumbi. Meanwhile, the other vulnerable districts to windstorms may not incur any loss such as Ngororero, Nyamagabe and Nyaruguru.

Table 64. Estimated monetary losses from damaged houses due to windstorms

District	Number of houses	Losses (in Rwf)
Burera	229	157,437,500
Gakenke	52	35,750,000
Gatsibo	36	24,750,000
Gicumbi	221	151,937,500
Karongi	22	15,125,000
Musanze	289	198,687,500
Ngororero	0	0
Nyabihu	97	66,687,500
Nyagatare	501	344,437,500
Nyamagabe	0	0
Nyamasheke	767	240,687,500
Nyaruguru	0	0
Rubavu	16	11,000,000
Rulindo	12	8,250,000
Rusizi	1,443	363,112,500
Rutsiro	0	0
National - Total	**3,685**	**1,617,862,500**

7.4 Summary of key findings

- The total economic costs of crops in the drought-prone areas could be estimated approximately 8.8 billion Rwandan francs according to both drought hazard scenarios in Season A and Season B. The economic loss of crops in Season B is higher than Season A. These losses are concentrated mainly in the eastern province, in particular, Kayonza, Kirehe and Gatsibo potentially incurring the highest losses.

- The total economic costs of the damaged houses due to landslide is estimated to be approximately over 9.2 billion Rwandan francs. The loss is highest in the most densely populated districts of Nyarugenge, Kicukiro and Gasabo.

- The total economic costs of the damaged health facilities to landslides is estimated to about 2.7 billion Rwandan francs. Most of these losses (99%) are incurred from damaged health centers and only about 1% are incurred from damaged health posts. There is zero loss from district hospitals as there are no recorded district hospitals vulnerable to landslide. The districts of Gakenke, Nyamagabe and Rulindo are expected to have the highest losses for this asset and hazard.

- Landslide could also cause a total economic cost of approximately 54.5 billion Rwandan francs nationwide due to damages of paved national roads. The losses are high in Nyamasheke, Nyamagabe and Ngororero where there are many paved national roads vulnerable to landslide.

- Earthquake with an intensity of MMI VII could also result to a potential losses [economic costs] of 10.3 billion Rwandan francs due to damaged houses. The highlands of Rubavu, Rusizi, Nyamasheke, Nyamagabe, Karongi and Rutsiro could incur high losses. On the other hand, minimal losses is expected in Muhanga.

- About 11.3 billion Rwandan francs is the estimated losses [economic cost] nationwide from damaged health facilities which could be incurred due to an earthquake of intensity MMI VII. Karongi could incur the highest losses of about 1.9 billion Rwandan francs. The other districts which could also expect high losses are Nyamagabe, Rusizi, Rutsiro and Nyamasheke.

- Damaged houses resulting from windstorms in Rwanda could incur an economic costs of about 1.6 billion Rwandan francs. The districts of Rusizi and Nyagatare could incur high losses.

Chapter VIII

Applications of the National Risk Atlas

The present risk atlas generated a considerable set of risk information and knowledge including data sets compiled ranging from hazard to exposure, from vulnerability to loss, with a nation-wide coverage, which is structured to meet the extensive needs and requirements for hazard and risk information from different stakeholders. However, different end users have different information needs for quite different purposes. In this regard, risk profiles presented are tailored to the needs of stakeholders in terms of specific context of policy and decision-making.

This chapter presents some initial thoughts as to how to tailor-fit the atlas to create a set of hazard and risk information for specific policy and decision making in disaster management, agricultural development and food security, and urban development, settlement planning, land use and relocation of population from high-risk zones. The recommendations were made mainly based on group discussions with the relevant stakeholders.

8.1 Application of the risk atlas in disaster management

Disaster management is one of the main areas where the risk information generated by the National Risk Atlas could be put to use and concrete application. An in-depth consultation and brainstorming session was held with the technical staff of the Ministry of Disaster Management and Refugee Affairs (MIDIMAR). The objective of the consultation was to conduct a thematic analysis to generate useful information for policy and decision making in disaster management based on the National Risk Atlas of Rwanda.

A critical analysis of the hazard, exposure and vulnerability profile of the country and corresponding loss estimation generated by this risk assessment study, the MIDIMAR discussed and deliberated on the specific set of risk information that the Ministry required to effectively inform and enhance disaster management in the country. Specifically, in order to strengthen the Ministry's technical capacity to fulfil its mandate of leading the country's disaster management agenda, in all phases of the disaster risk management cycle, including risk reduction, emergency preparedness and response capacity, recovery, mitigation and early warning.

The following are the key recommendations for the thematic analysis to be undertaken as a follow-up actions or way forward:

- Use the population and vulnerability profiles per district as basis for estimating scenarios of potential caseloads of the national contingency plans for earthquake, landslide, windstorms and drought which is developed by the Ministry in cooperation with other key sectorial ministries, partners and donors. MIDIMAR will initiate the updating of the different National Contingency Plans for earthquake, landslide and drought and utilize the risk information in developing scenarios and determining potential caseloads for the National Contingency Plan for windstorms.

- Use the windstorm and flood hazard zonation maps to inform the establishment and enhancement of the early warning system of the concerned hotspots districts.

- Subset a district-level hazard, exposure, vulnerability, and risk profiles to enable prioritization of targeted districts for disaster risk reduction interventions including public risk awareness campaigns and disaster risk reduction education program of the Ministry of Disaster Management and Refugee Affairs.

- Prepare an executive summary of the country multi-risk profile to be used by the Ministry of Disaster Management and Refugee Affairs and other stakeholders for resource mobilization to support different programs and projects aimed at reducing disaster risks, addressing vulnerability and building resilience.

- Generate scenarios of potential damages based on the levels of vulnerability and exposure based in projected intensities of specific hazard events in order to enable the technical staff in-charge of early warning system to improve the accuracy and timelines of emergency alerts for particular areas.

- Utilize the hazard zonation maps including the exposure and vulnerability profiles (per hazard) as reference and basis in the design of a context-specific disaster risk reduction education materials and public awareness campaign tailor-fit to specific audience and targets.

- Generate the hazard zonation maps per district at a scale that is adequate for implementing on-the-ground risk reduction interventions for the respective hazard including particularly to aid emergency responders and preparedness planning in terms of identifying buffer zones and potential evacuation areas, determining safe evacuation routes, safe location to set-up stores for the preposition of emergency supplies and stocks.

As noted above, these are just few of the important activities that should be undertaken to ensure that the National Risk Atlas is utilized and applied effectively in key decisions, policies and strategies in disaster management. The MIDIMAR will take this further forward by undertaking a continuous analysis of information needs and generate specific risk information from the Atlas that will be used and applied to specific policies, decision and strategies.

8.2 Application of the National Risk Atlas in food security study

Agriculture is one of the major sectors that most population depends on and food security is a key issue of concern of the country. This is another key area where the risk information from the National Risk Atlas could provide useful input to inform government and other stakeholders' interventions. An in-depth consultation and brainstorming session was held with the technical staff of the Ministry of Agriculture and Animal Resources (MINAGRI) and the UN World Food Programme (WFP). The objective of the consultation is to understand the needs and requirements for hazard and risk information for improving national policies and decision making related to agriculture, in particular, food security.

For this specific sector, only the drought risk profile has been taken into consideration since this is the only part of the Risk Atlas where the agriculture sector has been analyzed.

The following are the key recommendations that guide specific interventions to be undertaken in the area of agricultural development and food security study:

- The Ministry of Agriculture and Animal Resources (MINAGRI) will use the drought hazard zonation maps including the drought exposure and vulnerability profiles as guide in its current programme for the construction of agriculture infrastructure such as irrigation systems for the drought-prone areas.

- Information derived from the drought hazard risk profile could be used as input for the development of agricultural insurance instruments to specific regions or crops. Broadly, the drought hazard risk profile would contribute to the Government of Rwanda's efforts to develop a comprehensive disaster risk financing strategy that incorporates risk retention (e.g. emergency or contingency funds for drought) as well as risk transfer mechanisms (such as agricultural insurance schemes as above cited).

- The MINAGRI will use the drought hazard zonation maps for Season B where the exposure and vulnerability are high is useful to enable it to focus its technical preparation for the Season. The set of drought risk information will enable the Ministry to prioritize and focus its intervention.

- Extract the drought vulnerability profiles per District from the risk atlas for use by the MINAGRI in developing a realistic contingencies for drought emergencies i.e. prepositioning of food stocks for emergencies in case of food scarcity and lack of supply caused by droughts.

- The MINAGRI will utilize the drought zonation maps from the risk atlas including the vulnerability profile maps to improve preparedness. Specifically, it will be used as basis and solid justification for planning and earmarking funds for drought preparedness and contingencies of concerned districts.

- The MINAGRI is also venturing on their own mapping work of the agriculture sector. The risk maps e.g. drought hazard zonation maps, etc. will be used to further inform their own comprehensive mapping of the sector. The improved data sets of the agriculture sector will enhance future risk mapping of the sector.

- The World Food Programme as one of the key partners of the MINAGRI supporting food security programs in Rwanda will also utilize the drought risk profiles from this study in their respective planning, programming and resource mobilization.

- The MINAGRI will use the exposure profile for crops and cultivated areas for planning of what types of crops and timing for planting and harvesting.

The Ministry of Disaster Management and Refugee Affairs (MIDIMAR) is expected to take the lead role in continuously engaging other relevant government line ministries and agencies e.g. the Ministry of Agriculture and Animal Resources (MINAGRI) as well as other concerned stakeholders in the agriculture and related sectors to explore sector areas where the Risk Atlas could contribute to improve decision-making regarding investments and building resilience to adverse natural events.

8.3 Application of the National Risk Atlas to urban development and settlement planning, land use and relocation of population from high-risk zones

The risk information generated by this study is also very useful for the sector in charge of urban development, settlement planning, land use and relocation of population from high risk zones. A consultation and brainstorming session was held with technical staff of the Rwanda Housing Authority in order to gather their inputs on how the risk information produced by this study could better aid them in enhancing policy, strategies and decision-making related to this sector.

The following are the key recommendations that guide specific interventions to be undertaken in the area of urban development and settlement planning, land use and relocation of population from high-risk zones:

Utilize the risk information generated and provided by this study to:

- Inform the updating of the guidelines on basic housing construction for protection against natural hazards
- Be used in updating the master development plans of the Districts
- Update the land use plan
- Update urban development policies and guidelines
- Risk-proof the related by laws, orders and regulations and booklets developed by the Ministry of Infrastructure and the Rwanda Housing Authority
- Risk-proof the Rwanda building code [Note: The code will be available and effective this June 2015. This however, is updated and renewable every two years, hence the risk information could be used by then]

Chapter IX

Recommendations to Enhance Disaster Risk Assessment in Rwanda

This chapter presents a number of recommendations to further enhance hazard and risk assessment in Rwanda. Based on the lessons learned, issues and challenges and gaps identified during the preparation of this study, a number of key recommendations and forward actions need to be implemented in order to improve risk assessment process in the country including the standardization of tools and methodologies and the sustainability and use of the risk information presented by the National Risk Atlas.

While the preceding chapter highlighted on how to use the risk information generated by the Risk Atlas in decision making and policy formulation, this chapter focuses on key recommendations on how to undertake risk assessment and enhance it further.

The matrix below sums up the key recommendations of the study:

Sn#	Recommendations	Concerned or responsible stakeholders	
		Lead	Others
1.	**Promoting application of the National Risk Atlas**		
	• Conduct thematic analysis for specific policy and decision making by considering risk profiles in areas and aspects such as disaster preparedness, health, education, local development, tourism development, etc.	MIDIMAR	MINISANTE MINEDUC MINALOC RDB PSF
2.	**Maintenance and further development of the National Risk Atlas (towards the establishment of National Risk Information System for dynamic risk mapping)**		
	a. Establishing a programme for improving and developing data infrastructure for hazard and risk assessment		
	• Generate a complete set of meteorological data, i.e. rainfall, temperature, moisture, evapotranspiration to enable the risk assessment of different types of drought (e.g. agricultural drought, hydrological drought, and meteorological drought) using other models such as Standard Precipitation Index (SPI). For SPI model to be used, the data set should be a continuous data for the last 30 years (at minimum). Hence, to allow the use of SPI to undertake the risk assessment of hydrological and meteorological drought in the country, it is further recommended for the Rwanda Meteorological Agency to do an extrapolation of the available data in a series to fill in the data gaps for some years and build at least a 30-year meteorological data infrastructure.	METEO RWANDA	RNRA MINAGRI MIDIMAR
	• The flood hazard assessment was hampered by the lack of necessary data for a full hydrologic and hydraulic modelling. In addition to that, only river floods were taken into consideration in few catchments leaving behind the flash floods that are affecting major urban areas including Kigali City. There is a need of data collection for better flood studies in the country. The data needed are: (i) High temporal resolution data of a long period that can help the estimation of different intensities, durations, and frequency (idf), (ii) High resolution data on land cover, (iii) Soil's hydraulic properties, (iv) River profiles or sizes, and (v) Calibration data like discharges.	RNRA	METEO RWANDA MIDIMAR MINERENA NELSAP

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Sn#	Recommendations	Concerned or responsible stakeholders	
	• In order to make the landslide hazard assessment and mapping more robust, there is a need to compile and build historical landslide event catalogue to contain additional technical information about the landslide origins. While the existing disaster database of the MIDIMAR captures the impacts of landslide events (i.e. number of deaths, injuries, houses damaged, etc.), the landslide catalogue should include a more in-depth and detailed landslide event data such as the following: (a) geographic coordinates of the exact location of the landslide, (b) type of landslide, and (c) the trigger i.e. rainfall, earthquake, and human factors. This could be done by ensuring that under the coordination and leadership of MIDIMAR, an assessment team comprised of experts i.e. geologist, structural engineer, disaster managers, etc. be deployed to the location of the landslide to assess and gather these information.	RNRA/GMD	MININFRA MIDIMAR MINERENA
	• Improve the source zonation of earthquakes by supplementing the area sources of the earthquake hazard assessment with data on fault sources. Fault mapping is important and once the fault data is available, the seismic hazard mapping will be more robust. This may not be feasible for Rwanda alone to undertake such mapping, hence, this could be proposed as a regional initiative of the East African Community (EAC) including some neighbours in the Central Africa region.	RNRA/GMD	MININFRA MIDIMAR MINERENA
	• There is a need to improve and complete the seismic network monitoring and detection in the country. As of date, there are only three broadband seismic stations operational in Rwanda. It is herein recommended to add one more seismic station to complete the network. It is further recommended that an assessment of the current coverage, densities and sensing capabilities of the existing seismic Observation Network should be undertaken in order to generate cost estimations of the resources required to make the country's Observation Network at par with international standards.	RNRA/GMD	MININFRA MIDIMAR MINERENA
	• In line with the above, it is also highly recommended to create a position of Principal Seismologist (geophysicist or physicist with training in seismology) in the Geology Department of the Rwanda Natural Resources Authority who would be mainly responsible for seismic network operation and interpretation of seismic data of the country.	RNRA	MINERENA
	• For sustainable national seismic hazard assessment, a detailed mapping of classification of soil based on the average shear S wave velocity over the top 30 meters of soil in densely populated area is recommended. This task is done based on geological map, boring and/or geophysical method. This map is important to predict amplification of ground surface motion (e.g. PGA) at a specific site. Damage patterns in past earthquakes show that soil conditions at a site may have a major effect on the level of ground shaking. This division is based on assessment of the seismicity and the expected intensity of ground motion.	RNRA	MINAGRI MIDIMAR MINERENA
	• As noted, Rwanda has now about 41 Automatic Weather Stations (AWS) and 13 manual synoptic weather stations established across the country. There still remain about 40 more AWS needed to substantially, cover the entire country. For the wind information/data to be robustly complete for the entire country, there is a need to complete the installation of the remaining stations. Further, it is recommended that the Rwanda Meteorological Agency to record and maintain a database of daily wind information i.e. speed, direction, etc. and share them to MDIMAR for updating of the wind data sets to enable a more robust and country-wide hazard mapping and assessment of windstorms. The existing assessment only managed to use data of (only) the past three years from only 10 weather stations. Hence, the windstorm hazard zonation maps have some limitations. The windstorm hazard assessment was done by extrapolating available data from the 10 weather stations across the country and generate the windstorm zonation maps. In order to address these data gaps, the data on wind information and its details should be recorded, compiled and shared with MIDIMAR.	METEO RWANDA	REMA MIDIMAR MINERENA RNRA MINAGRI

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Sn#	Recommendations	Concerned or responsible stakeholders	
	• It is further recommended to establish a networking system for strong wind monitoring observation with neighbouring countries e.g. Tanzania, DRC, where most of the winds originate. The data generated and shared through this network could help in making the windstorm hazard assessment more robust and reliable.	METEO RWANDA	MINIRENA
	• For all hazards, it is recommended that all disaster events from any type of hazard currently recorded, compiled and analyzed by the MIDIMAR should contain a recording of information of the disaster event with specific and exact location which could be done through geo-referencing them as soon as they occur. A geo-referenced historical disaster database could help significantly in making the hazard assessment process more robust, feasible and cost-efficient.	MIDIMAR	MINALOC Districts
	• All the elements at risks are also recommended to be geo-referenced for ease of use and treatment for exposure and vulnerability assessment. The data set should also be disaggregated ideally up to village level at specific geo-referenced locations. A particular example of this is the hectares of cultivated areas with various crops. The crop cultivation area is not on a geo-referenced record system hence it was challenging to undertake the exposure and vulnerability assessment accurately. There remains a level of uncertainty due to the data gaps.	NISR	MIDIMAR MINISANTE MINEDUC MINERENA MINAGRI MININFRA RTDA RHA
	b. Develop plausible hazard event scenarios		
	• Due to the data limitation, this study doesn't develop a set of plausible hazard event scenarios for the major hazards, i.e. earthquake, flood, drought, and landslide. Hazard event scenarios and associated risk scenarios are essential to disaster preparedness including contingency planning, pre-disaster recovery planning, stockpiles, shelter planning, etc., as well as disaster risk financing mechanism. Hence, the need to develop plausible hazard event scenarios.	MIDIMAR	
	• It is also recommended that windstorm hazard assessment be undertaken at a local scale (District level) especially in locations of high susceptibility zones.	MIDIMAR	METEO RWANDA RNRA REMA
	• It is also recommended that the Season C drought scenario also be assessed as the amount of production during this season influence the market and affects pricing of basic commodities and agriculture products which impacts further on most vulnerable population. As soon as the cultivated areas are geo-referenced and map, the drought risk assessment for the Season C drought scenario could be undertaken which mainly involves crops cultivated in marshland areas or in wetlands during the dry season.	MIDIMAR	MINAGRI RAB NISR METEO RWANDA
	c. Continuing development of the National Risk Atlas to include loss/impact estimation		
	• The loss and impact estimation component of this study is only limited to the calculation of direct loss and only for some elements at risk. It is therefore recommended that resources be mobilized from donors and partners to support the commissioning of a follow-up study specifically to undertake the calculation and analysis of the functioning loss and the macro-economic impacts to the country of different hazard scenarios.	MIDIMAR	MINECOFIN NISR
	• Developing national risk information system (National Risk Observatory, NRO) to enable dynamic risk mapping, by integrating the Atlas into existing DRR portal	MIDIMAR	NISR RNRA RCMRD
	• A lot of data have been generated and/or collected during the risk assessment process. These data have been compiled and treated and maintained in a data set in GIS-formats specifically in vector and raster file formats. It is therefore recommended that all these data sets be uploaded in the disaster knowledge portal of the MIDIMAR to allow updating in real time and online treatment and use of the data by all interested stakeholders and partners.	MIDIMAR	NISR RNRA RCMRD

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Sn#	Recommendations	Concerned or responsible stakeholders	
3.	**Institutionalization of hazard and risk assessments**		
	• Develop national guidelines for hazard risk assessment and mapping	MIDIMAR	
	• Develop national guidelines for establishing national hazard risk information system	MIDIMAR	
	• Standardization of the framework and methodologies for hazard risk assessment	MIDIMAR	
	• Develop national training on hazard risk assessment and its use in policy and decision-making, including use of the tools	MIDIMAR	UR
	• Establish a national team for guiding and supporting relevant stakeholders to conduct hazard and risk assessment and mapping on their own. The national team can be composed of a set of specialist with expertise of geological and meteorological hazard modeling, vulnerability risk modeling and assessment.	MIDIMAR	UR
	• Risk management solution development i.e. conduct economic analysis for risk management solutions.	MIDIMAR	All concerned stakeholders
4.	**Conduct of risk assessment of other hazards and other in-depth assessments**		
	• Owing to the mountainous terrain/topography and due to the poor sewage and waste water management system, the City of Kigali and other urban areas in Rwanda are faced with potential landslides threats. All houses in Kigali have cesspools (or septic tanks) installed underground. Wastewater from all these cesspools penetrate into the soil (by the principle of communicating vessels) and eventually end up putting pressure on the land and cause the land to move. Therefore, a detailed assessment is herein recommended to understand and ascertain the risks associated with sewage and waste water contamination of the soil as a trigger factor to landslides.	City of Kigali	MIDIMAR MINIRENA
	• In terms of scope, the study only covered five hazards. On flood hazard, the assessment was limited to river flooding. Building upon the data sets, tools, methodology, and the expertise developed including the experience and lessons learned from this study, it is therefore recommended to launch the same risk assessment process covering other hazards affecting the country (i.e. lightning, CO_2 in Kivu Lake, fires, volcanic eruption, traffic accidents, epidemic and diseases) and complete the flood risk assessment as soon as data required becomes available.	MIDIMAR	All concerned stakeholders
5.	**Updating of the National Risk Atlas**		
	• Risks are dynamic owing to rapid changes in the country's demographic, social and economic processes. Therefore, risk assessment should also be dynamic so as to keep up with these changes. In order for the National Risk Atlas to remain relevant, useful and sustained, it is recommended that it be updated every 5 years. This aligns with Rwanda's strategic plans (such as EDPRS, EICV, etc.). This will enable the use and integration of the assessment findings in the analysis and planning.	MIDIMAR	All concerned stakeholders
6.	**Other recommendations**		
	• The guidelines for DRR mainstreaming into the Economic Development and Poverty Reduction Strategy (EDPRS2) should be updated based on the information contained in the National Risk Atlas in order to guide MINECOFIN on its priorities on disaster management as a cross-cutting issue.	MIDIMAR	MINECOFIN
	• The risk information provided by the atlas should be used to update the following: • The land use master plans both at national and district levels • The Rwanda national building codes during its periodic review • The district development plans for 2013-2018 during its mid-term evaluation	RNRA/LMD RHA MINECOFIN	MINIRENA MININFRA MIDIMAR MINALOC
	• Incorporate technical recommendations derived from the National Risk Atlas to inform decision making regarding investment planning and budget allocation for all key sectors	MINAGRI	MINECOFIN RAB

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Appendix A – National Hazard Profiles

			Drought										Landslide					Flood (25 year RP) per meter level					Earthquake				Windstorm									
			Season A					Season B															2475		475		10 year RP					5 year RP				
S/N	Province	District	VH	H	M	L	VL	VH	H	M	L	VL	VH	H	M	L	VL	>2	2-1.5	1.5-1	1-0.5	<0.5	VII	VI	VI	V	SG	G	MG	SB	FB	SG	G	MG	SB	FB
1	Est	Bugesera					*		*	*				*	*	*	*	*		*		*		*		*				*	*					*
2	North	Burera					*					*	*	*	*	*	*				*			*		*			*						*	
3	North	Gakenke					*					*	*	*	*	*	*	*	*	*		*		*		*			*	*					*	*
4	KC	Gasabo				*	*			*			*	*	*	*	*	*		*		*		*		*					*					*
5	KC	Gatsibo	*	*	*	*	*	*	*	*	*			*	*	*	*							*		*			*	*					*	*
6	North	Gicumbi					*			*	*	*		*	*	*	*							*		*			*	*	*				*	*
7	South	Gisagara					*			*	*	*		*	*	*	*							*		*					*					*
8	South	Huye					*				*	*		*	*	*	*						*	*	*	*					*					*
9	South	Kamonyi					*			*	*	*	*	*	*	*	*	*		*				*		*				*	*					*
10	West	Karongi					*				*	*	*	*	*	*	*						*		*	*			*	*	*				*	*
11	Est	Kayonza	*	*	*	*		*	*						*	*	*							*		*				*					*	*
12	KC	Kicukiro					*		*	*				*	*	*	*	*		*		*		*		*					*					*
13	Est	Kirehe	*	*	*	*	*	*	*	*					*	*	*							*		*				*						*
14	South	Muhanga					*				*	*	*	*	*	*	*	*	*		*		*	*	*	*				*	*				*	*
15	North	Musanze					*					*		*	*	*	*	*	*		*		*	*	*	*			*						*	
16	Est	Ngoma				*	*		*	*					*	*	*	*		*		*		*		*				*	*					*
17	West	Ngororero					*				*	*	*	*	*	*	*	*	*		*		*	*	*	*				*	*				*	*
18	West	Nyabihu					*					*	*	*	*	*	*	*	*		*		*	*	*	*			*	*					*	*
19	Est	Nyagatare		*	*	*	*		*	*	*			*	*	*	*	*		*		*		*		*			*	*				*	*	
20	South	Nyamagabe					*				*	*	*	*	*	*	*						*	*	*	*			*	*	*			*	*	*
21	West	Nyamasheke					*					*	*	*	*	*	*						*		*	*	*	*	*				*	*	*	
22	South	Nyanza					*			*	*		*	*	*	*	*	*	*		*		*	*	*	*					*					*
23	South	Nyaruguru					*					*	*	*	*	*	*						*	*	*	*			*	*	*				*	*
24	KC	Nyarugenge					*		*	*				*	*	*	*	*		*		*		*		*					*					*
25	West	Rubavu					*					*	*	*	*	*	*	*		*		*	*		*	*			*	*					*	*
26	South	Ruhango					*			*	*			*	*	*	*	*		*		*	*	*	*	*					*					*
27	North	Rulindo					*			*	*	*	*	*	*	*	*	*		*		*		*		*			*	*	*				*	*
28	West	Rusizi					*					*	*	*	*	*	*						*		*	*	*	*	*			*	*	*	*	
29	West	Rutsiro					*					*	*	*	*	*	*	*		*		*	*		*	*			*	*	*				*	*
30	Est	Rwamagana		*		*	*		*	*				*	*	*	*	*		*		*		*		*				*	*				*	*

Appendix B- National Exposure Profiles

National Exposure Profiles						
Elements at risk	Earthquake		Landslide	Storms	Drought	
	MMV II	MMI VI		10 years	Season A	Season B
Gender						
Female	1,690,000	3,759,000	2,023,000	1,484,000		
Male	1,522,800	3,591,410	2,182,300	1,357,000		
Level of poverty						
Severely poor	357,330	692,540	420,690	284,570		
Moderately poor	971,650	1,846,190	1,189,800	783,780		
Vulnerable to poverty	915,900	1,864,300	1,193,980	786,360		
Not poor	912,930	2,815,640	1,348,600	962,200		
Dependent age	484,130	1,061,390	609,390	398,550		
Working age	2,722,500	6,246,500	3,596,100	2,036,150		
Buildings (type of wall)						
Sun dried brick	799,300	1,882,750	125,570			
Wood and mud	491,400	1,233,600	59,740			
Wood and cement	27,260	169,850	16,800			
Timber	35,650	970	1,740			
Plastic	1,420	3,380	185			
Burnt brick	31,000	94,315	8,365			
Cement brick	3,600	32,500	3,065			
Stone	6,200	5,850	655			
Buildings (type of roof)						
Sun dried brick	799,300	1,882,750	125,570			
Wood and mud	491,400	1,233,600	59,740			
Wood and cement	27,260	169,850	16,800			
Timber	35,650	970	1,740			
Plastic	1,420	3,380	185			
Burnt brick	31,000	94,315	8,365			
Cement brick	3,600	32,500	3,065			
Stone	6,200	5,850	655			
Buildings (type of roof)						
Iron sheet				433,050		
Local tile				177,795		
Asbestos				455		
Concrete				60		
Industrial				2,860		
Agriculture (cultivated area in ha)						
Maize					6,320	22,370
Sorghum					7,715	29,845
Rice					1,205	4,175
Ordinary bean					13,965	47,700
Climbing bean					2,845	14,375
Banana					19,375	67,890
Irish potato					3,925	15,110
Cassava					3,880	23,235

National Exposure Profiles						
Elements at risk	**Earthquake**		**Landslide**	**Storms**	**Drought**	
	MMV II	**MMI VI**		**10 years**	**Season A**	**Season B**
Maize					18,735	28,975
Sorghum					21,490	35,105
Rice					16,770	24,070
Ordinary bean					11,355	17,425
Climbing bean					4,880	9,970
Banana					556,080	761,065
Irish potato					75,105	111,440
Cassava					192,020	414,410
Education facilities	**1,015**	**2,315**	**1,475**	**880**		
Health facilities	**170**	**370**	**235**	**150**		
Roads (length in km)						
National paved road	390	820	555			
National unpaved roads	570	970	690			
District roads	1,390	2,505	2,005			

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