Disaster Risk Management of Land and Water-related Natural Hazards for Africa's Central Highlands: Rwanda, Burundi, and the Democratic Republic of Congo

A Review Report

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

AASWDA	Ahafo Ano Southwest District Assembly
AFR100	African Forest Landscape Restoration Initiative
BMUV	Federal Environment Ministry of Germany
CGIAR	Consultative Group on International Agricultural Research
CREWS	Climate Risk Early Warning Systems
DRM	Disaster Risk Management
DRR	Disaster Risk Reduction
EM- DAT	Emergency Events Database
EW4A	Early Warnings for All
EWS	Early Warning Systems
IFRC	International Federation of Red Cross and Red Crescent Societies
IGEBU	Geographic Institute of Burundi
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
IWMI	International Water Management Institute
MEDD	Ministry of Environment and Sustainable Development (DRC)
MINEAGRIE	Ministry of Environment, Agriculture, and Livestock (Burundi)
MINEMA	Ministry in Charge of Emergency Management (Rwanda)
NAP	National Action Plan
NAP	National Adaptation Plan
NSIR	National Institute of Statistics of Rwanda
PDP	Provincial Development Plans
PRRPB	Landscape Restoration and Resilience Project in Burundi
RWB	Rwanda Water Board
TAFS- WCA	West and Central African Food Systems Transformation
UNDP	United Nations Development Programme
UNDRR	United Nations Office for Disaster Risk Reduction
WMO	World Meteorological Organization

ABSTRACT

As a consequence of climate change, changes in land use, and land management—especially in densely populated areas—numerous natural disasters, such as floods, storms, heatwaves, landslides, and droughts, are becoming increasingly frequent, with severe impacts on living conditions. This is the case for Rwanda, Burundi, and the Democratic Republic of Congo (DRC). At the same time, intense farming practices (particularly on sloped land), deforestation activities, mining extraction operations, challenges in agriculture water management, and soil erosion all contribute to increased land vulnerability. The purpose of this study was to review how the risks of natural disasters related to flooding, landslides, and soil erosion are assessed, measured, managed, and mitigated in the central highlands of Africa, specifically in Rwanda, Burundi, and the DRC. In this process, the risks and the current status of disaster risk management, early warning systems, soil and land conservation practices, and risk mapping were investigated for the three countries.

The literature review revealed a high risk for landslides, flooding, and soil erosion in the region. Risk maps covered the potential risks and helped identify the vulnerable areas. Most of them vary in spatial data, methods, and classifications. They rely on input data on elevation, slope, rainfall, lithology, soil texture, land use, land cover, and the normalized difference vegetation index (NDVI). The use of heterogeneous data sets and geographical regions in these risk maps may lead to diverging interpretations of potential risks and 'hot spots' in spatial terms and the underlying drivers of those risks. None of the risk maps take into account existing population vulnerabilities such as social protection, income levels, or readiness to act in an emergency, such as hospital access in an emergency. Risk maps could be an effective tool for supporting disaster risk management policies and implementations if they are nationally based and built on comprehensive, comparable, and reliable data.

With the rise of climate change-related risks, the need for expended risk mapping is expected to grow. Vegetation cover, deep-rooted vegetation, and soil management practices such as terraces, green barriers, drainage systems for overflows, or similar physical structures are useful land management practices that can reduce risks. Such practices, however, are not in place to the necessary extent in the region. In the case of disaster risk management, although strategies and action plans do exist, the study faced significant constraints in verifying their implementation and therefore, their effectiveness. This assessment is also valid for the prevailing obstacles related to accessing accurate and quality data in general. It is recommended that this desk study be supplemented with interviews and local data collection to address the identified information gaps.

Keywords: Susceptibility of Natural Hazards, Sendai Framework for disaster risk reduction, disaster risk management, soil and land conservation, soil and water management, floods, flooding, soil erosion, landslides, African Eastern Highlands, Rwanda, Burundi, Democratic Republic of Congo, DRC

RESUME

En raison du changement climatique, des mutations dans l'utilisation des terres, en particulier dans les zones densément peuplées, de nombreuses catastrophes naturelles, telles que les inondations, les tempêtes, les vagues de chaleur, les glissements de terrain et les sécheresses se produisent de plus en plus souvent. Elles ont davantage d'incidences sur les conditions de vie. C'est le cas du Rwanda, du Burundi et de la République démocratique du Congo (RDC). Simultanément, les pratiques agricoles intenses, souvent sur des terres en pente, les activités de déforestation, les opérations d'extraction minière et les défis liés à la gestion de l'eau en agriculture et à l'érosion des sols, contribuent tous à la vulnérabilité des terres. Le but de l'étude était d'examiner la manière dont les risques de catastrophes naturelles liés aux inondations, aux glissements de terrain et à l'érosion des sols sont évalués, mesurés, gérés et atténués dans les hauts plateaux du centre de l'Afrique : le Rwanda, le Burundi et la RDC. Ce faisant, les risques et l'état actuel de la gestion des risques de catastrophes, des systèmes d'alerte précoce, des pratiques de conservation des sols et des terres, ainsi que la cartographie des risques ont été étudiés pour les trois pays. Sur la base de la littérature examinée, les résultats ont démontré un risque élevé de glissements de terrain, d'inondations et d'érosion des sols dans la région. Les cartes de risques établies couvrent les risques potentiels et servent à localiser les vulnérabilités. La plupart d'entre elles varient en termes de détails spatiaux, de méthodes et de classifications. Elles s'appuient sur les données saisies relatives à l'altitude, à l'inclinaison des terrains, aux précipitations, à la lithologie, à la texture du sol, à l'utilisation des terres, au degré de couverture des terres et à l'indice de végétation différentiel normalisé. Le fait que ces cartes de risques couvrent des groupes de données et des régions géographiques hétérogènes peut conduire à des appréciations divergentes des risques potentiels et des « points chauds » du point de vue spatial. De telles appréciations divergentes peuvent également s'appliquer aux facteurs sous-jacents à ces risques. Aucune carte des risques ne prend en compte les vulnérabilités existantes de la population telles que la protection sociale, les niveaux de revenus ni le degré de préparation à agir en cas d'urgence, par exemple en matière d'accès aux hôpitaux d'urgence. Cependant, les cartes des risques pourraient constituer un outil efficace en soutien aux politiques et aux mises en œuvre de gestion des risques de catastrophes si ces cartes étaient fondées sur une base nationale et sur des données complètes, comparables et fiables. Avec l'augmentation des risques liés au changement climatique, on s'attend à ce que la cartographie des risques de développement devienne davantage utile. La couverture végétale, la végétation à racines profondes et la gestion des sols comme c'est le cas pour l'aménagement des terrasses, les barrières vertes et les systèmes de drainage pour les trop-pleins ou d'autres structures physiques, sont toutes des pratiques de gestion des terres valables et qui peuvent réduire les risques. De telles pratiques ne sont toutefois pas suffisamment mises en place. Concernant la gestion des risques de catastrophes, il apparaît que, même si des stratégies et des plans d'action existent, l'étude s'est heurtée à d'importantes contraintes pour vérifier leur mise en œuvre et donc leur degré d'efficacité. Cette appréciation vaut également pour les obstacles majeurs auxquels se heurte généralement l'accès à des données pertinentes, précises et de qualité. Il est recommandé que cette étude documentaire soit complétée par des entretiens et par une collecte de données locales dans le but de combler les lacunes d'informations identifiées.

Mots clés : Susceptibilité de risques naturels, Cadre de Sendai pour la réduction des risques de catastrophes, Gestion des risques de catastrophes, Conservation des sols et des terres, Gestion des sols et de l'eau, Inondations, Érosion des sols, Glissements de terrains, Hauts plateaux de l'Est de l'Afrique, Rwanda, Burundi, République démocratique du Congo, RDC

1. INTRODUCTION

As a consequence of climate change, changes in land use and land management—especially in densely populated areas—numerous natural disasters, such as floods, storms, heatwaves, landslides, and droughts are becoming more frequent (CRED 2022, 2023, 2024; WMO 2023; UN et al. 2023). This situation affects today's ecosystems and livelihoods, and even leads to loss of life. It is also a contributing factor to the increased costs of disaster action, insurance, and reconstruction globally (WMO 2024b). Natural hazards result in the destruction of homes, loss of livelihoods, displacement of people, deterioration of soil and water quality, and, in the long-term, the loss of agricultural productivity (Vodacek 2021).

In East Africa, floods, landslides, and droughts have been recorded over the last several years (Ritchie et al. 2024b). As climate change continues, such occurrences are expected to increase, and have more severe impacts particularly in densely populated zones. This is a tangible concern in Rwanda, Burundi, and the Democratic Republic of the Congo (DRC). The three countries are collectively referred to herein as the 'the Study Area'. The Study Area is among the most densely populated regions, concentrated in the highlands of Eastern Africa.

In this region, which features steep slopes, factors such as intense farming activities, mining extraction operations and their ensuing deforestation, have significantly augmented the risk of natural hazards related to rainfall and land use. Such natural hazards include floods, occasional droughts, landslides, and loss of productive land through soil erosion. Flooding is reported as the most common natural disaster, with the highest frequency on record (97 out of 227 records between 2000 and 2024). This is followed by landslides (19/227) and droughts (7/227) (The International Disaster Database 2024).

The increasing risks of natural hazards necessitate a deeper understanding of these risks and the capacity to mitigate them. This can be achieved through various mechanisms, including local land management, enhanced knowledge of natural hazards, risk monitoring, early warning systems, and emergency assistance.

1.1 Objective and research questions

The purpose of this study is to review how the risks of natural disasters are assessed, measured, managed, and mitigated, with a focus on land and water-related hazards, such as floods, landslides, and soil erosion in Africa's central highlands covering Rwanda, Burundi, and the DRC, with a particular focus on the eastern parts.

Three research questions were formulated as:

1. What is the current evidence of *risks of natural disasters* in Africa's central highlands?
2. Which type of measures are in place for *disaster risk management?*
3. What measures are used across national to sub-national *early warning systems*?

1.2 Method and Scope

For this desk study, a qualitative literature review was conducted. Relevant scientific literature was identified by searching the Web of Science (WoS) and the International Disaster Database (EM-DAT).

Additionally, information was collected from the UN system, in particular the World Bank Climate Change Knowledge Portal and the Intergovernmental Panel on Climate Change (IPCC), as well as through governmental documents from individual countries. Lastly, Google Scholar was leveraged due to the relatively poor quality content of French-language publications in WoS.

While the present report covers the three national entities selected as the Study Area, in certain instances, a particular focus may be applied either to a specific zone within a given country (e.g., eastern DRC) or a region extending beyond a given country (e.g., Africa's eastern highlands).

Reviewing the literature on soil and landslide risks and flood risks in Rwanda, Burundi, and the DRC, the following observations are raised:

i) The three countries are in geographic proximity and share similar topographic and geological features. Their proximity to the Albertine Rift, the western branch of the East African Rift Valley System, justifies a common study and examination. The landscape is characterized by highlands, sizeable lakes, and significant biodiversity, which add to the physical similarity of the terrain in the three countries.
ii) By contrast, the three countries present significant differences with regard to their sizes, geopolitical security settings, level of stability and security, as well as the nature of their governance and political and bureaucratic systems. The disparity in data quality and availability makes the comparative analysis challenging and, in some cases, inconclusive. Additionally, the fact that Burundi and the DRC are French-speaking, while Rwanda is primarily English speaking creates an additional divide in the Study Area.
iii) A regional approach that considers topographic and geological features beyond geopolitical boundaries may yield additional relevant findings for the study.

2. OUTLINE OF CONCEPTS

Natural hazard risks proceed from a combination of elements: the incidence and exposure to the hazard, the ability to reduce the risk with accurate and timely warning systems, and the recovery process after being exposed. Three relevant concepts for researching the current risks are: (I) resilience, (II) disaster risk management, and (III) early warning systems.

This chapter will present the three concepts and follow them with an outline of the internationally adopted disaster risk framework: the Sendai Framework for Disaster Risk Reduction. In addition, regarding measures applied either for disaster management or early warning systems, a distinction is commonly made between 'structural' and 'non-structural' measures. These will be addressed in this chapter under 2.5.

2.1 Resilience

Disasters such as floods, storms, heatwaves, and droughts have occurred and continue to occur around the world. In 2023, 399 disasters were recorded around the globe (EM-DAT 2023). These disasters are caused by climate change and unsustainable human actions. They impact today's livelihoods, ecosystems, and infrastructure. Resilience becomes relevant when facing the risks of such natural disasters.

Defining resilience has gone through a series of stages. It may generally be defined as the dynamic capacity to continue despite disturbances and shocks (Tendall et al. 2015). Alternatively, the resilience concept describes the system's ability to cope with shocks and stresses, to re-organize, and to continue a set pathway of development. In the case of a disaster, resilience may mean either that the system absorbs the disaster while retaining its functions, adapts and goes back to its original state after the shock, or that it transforms into a new state (Douxchamps et al. 2017).

Resilience is a crucial concept but remains challenging to measure (Cabell and Oelofse 2012; Douxchamps et al. 2017). Cumming et al. (2005) explains that resilience is complex to operationalize due to its multi-dimensional nature. The fact that a system is resilient today does not mean it will be tomorrow. Indeed, the broader dynamic system in which it is incorporated may change. Further study reveals that disaster occurrences are often an opportunity to shift a social-ecological system into a more resilient pathway (Folke 2006). Resilience may be seen as the opposite of vulnerability and defined as *"the ability to resist, bounce back, cope with, and recover quickly from the impacts of hazards"* (Graveline & Germain 2022).

2.2 Disaster Risk Management

While resilience is the system's capacity to cope with risks and shocks, disaster risk management refers to the actions taken to increase resilience. Disaster Risk Management (DRM) is defined as, *"The organization, planning, and application of measures preparing for, responding to and recovering from disasters."* (UNDRR 2017). DRM can be pursued as a prospective, corrective, or compensatory management strategy, alternatively or in combination. Furthermore, the United Nations Office for Disaster Risk Reduction (UNDRR) (2017) identifies actions taken by local communities as part of a community management strategy. The specific use of traditional, indigenous, and local knowledge and practices qualify as a local and indigenous peoples' approach to disaster risk management. Disaster risk management may be carried out at various levels, including multilateral, national or local.

Unlike DRM, disaster risk *reduction* (DRR) is a preventive strategy. It consists of a set of approaches to reduce existing disaster risks while altogether preventing new risks from arising. As mentioned in the United Nations International Strategy for Disaster Reduction (UNDRR) (2017) DRR measures to strengthen resilience. They are the policy objectives for DRM (Šakić Trogrlić et al. 2022).

In the context of this report, disaster risk *management* includes disaster risk *reduction* as well. The reviewed literature qualifies all measures used to manage and reduce disaster risks under DRM. However, most, if not all, literature and documents reviewed in the context of this study address risk *management* rather than risk *reduction*. Moreover, both notions seem to be used interchangeably, with little or no focus on the difference between them in policies and scientific literature. Even the adopted global framework to guide *disaster risk management* actions is named Sendai Framework for *Disaster Risk Reduction*. (See Chapter 2, Section 2.4 below.)

2.3 Early Warning Systems

Currently, there is no universal definition of an early warning system (EWS). This is due to the complexity of the measurements and the required conceptual adjustments to relevant and current Risks (Šakić Trogrlić et al. 2022). Although several definitions are available, the one selected by UNDRR will be used in this report. It defines EWS as:

> *"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".* (UNDRR 2017)

These social-centered actions in an EWS range from local initiatives in rural villages to formal global United Nations (UN) actions working with governments (Kelman & Glantz 2014). A well-established and globally recognized checklist to map the components and main elements of an EWS has been established by the World Meteorological Organization (WMO) and UNDRR (UNDRR 2007a; WMO 2017).

The two organizations, in cooperation with the International Federation of Red Cross and Red Crescent Societies (IFRC) and the International Telecommunication Union (ITU), have subsequently implemented the United Nations Early Warnings for All (EW4A) initiative with WMO. The Initiative aims to ensure that every person on Earth is covered by early warning services by 2027 (WMO 2023).

Building on the Early Warning System, a more refined concept of Multi-Hazard Early Warning Systems has been developed to integrate the increasing complexity of multiple, inter-related hazard situations (UNDRR 2023).

2.4 Sendai Framework for Disaster Risk Reduction

The Sendai agreement is a framework for Disaster Risk Reduction (Sendai Framework). It was established in 2015 at the Third UN World Conference on Disaster Risk Reduction held in Sendai, Japan. The Sendai Framework is considered the most comprehensive accord on risk reduction, guiding countries in disaster risk management policies and strategies. The Sendai Framework aims to: "*Guide the multi-hazard management of disaster risk in development at all levels as well as within and across all sectors.*" (UNDRR 2015).

Understanding and accressing underlying risk factors, including socioeconomic, environmental, and cultural aspects, are central to the entire Sendai approach. The initiative recognizes the implementation of the Sendai Framework and DRR as a public responsibility of states and other stakeholders. It encourages the coordination of national and local frameworks.

The Sendai Framework, as shown in figure 1 (UNDRR 2015) identifies four priority areas: (I) Understanding disaster risk, (II) Strengthening disaster risk governance, (III) Investing in disaster risk reduction for resilience, and (IV) Enhancing disaster preparedness for effective response.

Figure 1. Chart of the Sendai Framework for Disaster Risk Reduction.
Source: UNDRR (2015)

2.5 Structural and Non-structural Measures

Structural measures refer to physical undertakings such as dams, drainage or flood levies. In contrast, non-structural measures refer to knowledge transfer, capacity strengthening and adopting and implementing regulatory measures to scale adoption of disaster management or early warning systems.

According to UNDRR, structural measures are *"any physical construction to reduce or avoid possible impacts of hazards, or the application of engineering techniques or technology to achieve hazard resistance and resilience in structures or systems"*. As to non-structural measures; these are defined as *"measures not involving physical construction which use knowledge, practice or agreement to reduce disaster risks and impacts, in particular through policies and laws, public awareness raising, training, and education."* (UNDRR 2007b).

This study reflects the non-structural measures, as opposed to structural ones.

3. EVIDENCE OF RISKS

3.1 Background

This section discusses the background and the drivers behind the risks of natural disasters in the Study Area.

Rwanda, Burundi, and eastern DRC are situated in the Great Lakes region of East Africa, an area characterized by diverse ecosystems, varied land use, and complex geographical features (topography), including steep slopes.

The area covers a major rift zone called the Albertine Rift, part of the Western branch of the East African Rift. Due to its geographic location, topography, and climate patterns, the rift is susceptible to various natural hazards. The area is prone to landslides. The triggering factors are high population density, land use changes, rainfall intensities, and high annual rainfall totals, moderate to high seismicity, high weathering, and steep landscapes (Ellis et al. 2010; Nyandwi et al. 2016; Depicker et al. 2020, 2021; Dewitte et al. 2021; Uwihirwe 2023).

The geography of the Study Area is defined in particular by high plateaus and significant differences in altitudes. In Rwanda, the minimum altitude is 835 m, and the highest is 4,334 m. In Burundi, the minimum altitude is 761, and the highest is 3,275 m. In DRC, the same conditions can be seen; the minimum altitude in the country is measured at 215 m and the maximum at 4,273 m. The steepest slopes are identified in the eastern region (Topographic maps 2024) as shown in Figure 2.

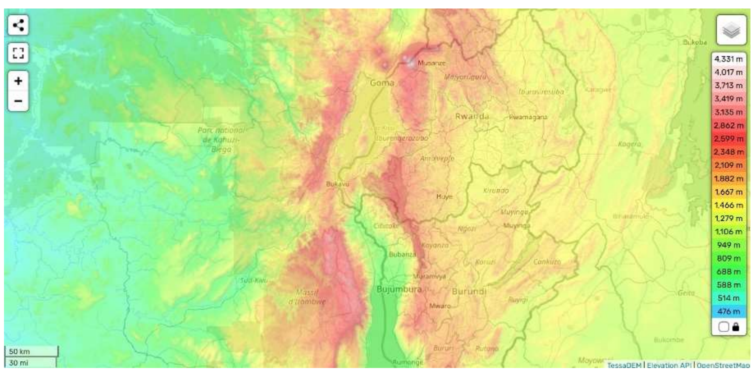

Figure 2. Topography map for western Rwanda, Northern Burundi and Eastern DRC (Topographic maps 2024)

The global average population density in 2024 is 62 people per km^2. Among all countries globally larger than 10,000 km^2, Rwanda was ranked as the second most densely populated country, with 584 people per km^2, followed by Burundi in fifth place with 584. The DRC measured 46.6 people per km^2 on average (Ritchie et al. 2024a). Eastern DRC measured 137 people per km^2 in the Northern Kivu region respectively, and 109 people per km^2 in the Southern Kivu region (Geo-Ref 2020). The population density map of the region is shown in Figure 3.

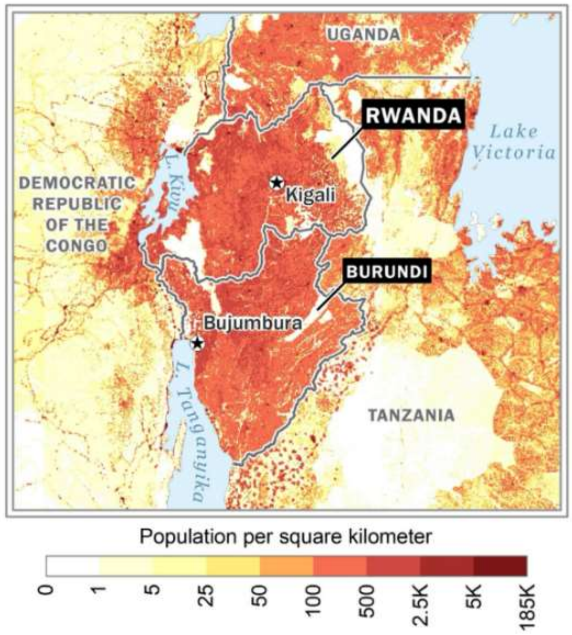

Figure 3. Population density map for Rwanda, Burundi and Eastern DRC.
Source: CIA (2021)

Land use changes in the area can be explained by major changes in farming activities, triggered by population growth, changes in agricultural systems such as terracing, and political and economic drivers. In the Study Area, agricultural land constitutes a significant share of the total land. In Burundi, 81,9 % of the total land is agricultural, compared to 81.3 % in Rwanda and 15 % in the DRC on average (World Bank 2021c). Figure 4 gives the land use in the three countries around the Albertine Rift.

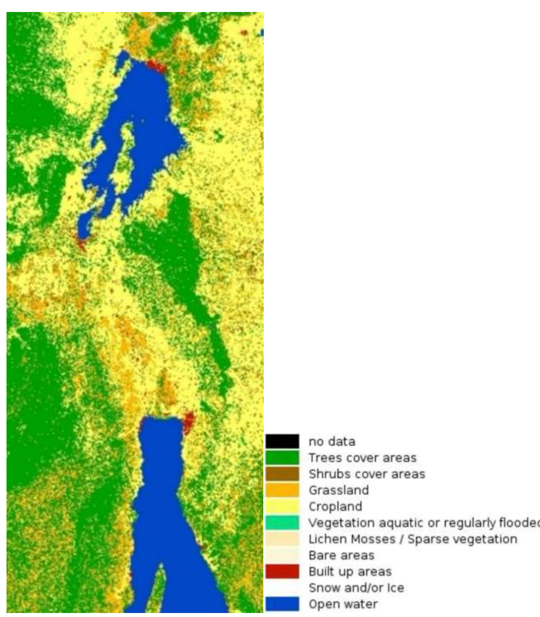

Figure 4. Land-use in Western Rwanda, Northern Burundi and Eastern DRC in 2016.
Source: ESA (2016)

Land use in the Study Area is extensively cropland (ESA 2016). When assessing risks from natural hazards, two considerations are of special relevance. These are: (I) understanding the dynamic nature of land cover change and human settlements; and (II) recognizing that landslide susceptibility is an evolving phenomenon (Vodacek 2021).

Since 2000, the use of land in the area has changed significantly. In-between 2000 and 2021, agricultural lands and croplands have increased in all three countries as a trend. In Rwanda and Burundi both the agricultural land and cropland have increased equally by 2.5 million ha. In the DRC, the same measure shows an increase of 10,000 ha for both agricultural land and cropland.

Forest regions are reported to have remained stable in Rwanda during this time-period. In Burundi forest cover increased from 2020 to 2015 by 125,000 ha, which remained stable until 2021. In the DRC forest area decreased by 20 million ha in-between 2000 and 2021 (Our World in Data 2024).

Major farming activities, including road and rail infrastructure development, accelerated the changes in the hydrology of the region. River patterns changed, bringing changes to the hillslope characteristics. Steep slope and proximity to the drainage and road networks have also been identified as one of the key geomorphological variables influencing landslide occurrences (Uwihirwe 2023).

Prior to the twentieth century, most of the Albertine Rift was covered by forests. However, over time, the area experienced large-scale deforestation. Between 2001 and 2023, Rwanda lost 9.3%, DRC 9.9%, and Burundi 6.6% of their tree cover, respectively (Global Forest Watch 2023).

Deforestation increases the risk of landslides. When the land, previously made up of forests, is left bare or converted into arable land, landslides pose an emerging hazard (Depicker et al. 2021). The increased expansion of agricultural practices remains the main driver of deforestation in the Study Area. Furthermore, armed conflicts, mining activities, and population growth have also led their populations to clear more hillside forests for subsistence farming (Vodacek 2021).

All these changes and movements exacerbate the impact of floods and droughts. In the Study Area, heavy rainfalls—whether reflecting the average normal records, extreme precipitations, or flash floods—contribute to floods and droughts (World Bank 2024). Figure 5 presents the annual precipitation between 1991 and 2020, showing the rainfall distribution across the three countries. Table 1 summarizes the mean temperature and precipitation for the three countries.

Table 1. Climate variables in-between 1901 and 2020 for DRC, Rwanda and Burundi, respectively

Climate Variables- 1901-2020	**DRC**	**Rwanda**	**Burundi**
Mean Annual Temperature (°C)	24.1	19.4	20
Mean Annual Precipitation (mm)	1,508	1,178	1,200
Mean Maximum Annual Temperature (°C)	29.7	25.5	24.7 to 26.8
Mean Minimum Annual Temperature (°C)	18.5	13.3	14.8

Source: World Bank Climate Change knowledge Portal

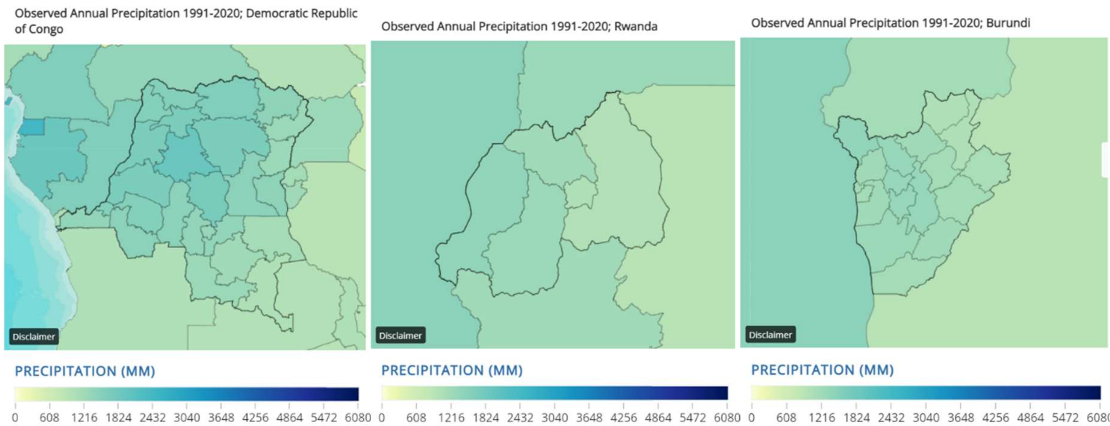

Figure 5. Annual precipitation across the country areal 1991-2020 for DRC, Rwanda, and Burundi, respectively. *Sources*: World Bank Climate Change knowledge Portal

While these figures represent averages, extreme precipitation can significantly exacerbate the occurance of floods. Increased greenhouse gas emissions have led to growing disparities in precipitation amounts, relative to seasons as well as in-between the rainfall occurrences. This trend is particularly evident in tropical regions and the northern high latitudes (IPCC 2023).

In Rwanda, the frequency of extreme rainfall events has been increasing since 1960, and this pattern is expected to continue in the coming years. From 1960 to 2020, the eastern region has experienced frequent droughts, followed by heavy rainfalls that has resulted in excesses precipitation. In the northern and western provinces, the rainy seasons are getting shorter and more intense, increasing the risk of natural hazards. Extreme rainfalls have also increased the risk of erosion in the mountainous areas. (World Bank 2021b).

In the DRC, rainfall varies significantly across the country's vast and diverse regions. Since the 1960, no major changes in the rainfall patterns have been identified. However, the annual precipitation amounts are predicted to increase in the coming years (World Bank 2021a).

Burundi has also experienced increased variability in rainfall with increased occurrences of extreme rainy seasons, resulting in droughts as well as flooding (African Development Bank 2018).

As is the case with floods and landslides, a major natural hazard risk illustrates the direct connection between heavy rainfall and episodes of extreme precipitation on the one hand, and the conditions discussed above in this section (topography, deforestation, population density, land use) on the other. Heavy rain is usually directly responsible for initiating landslides and mudslides (Uwihirwe 2023).

Heavy rainfalls and excess precipitation effect the soil and, consequently, its mass movement. Uwihirwe (2023) states that in Rwanda, landslides occur during the wettest period when soil moisture is close to saturation and the groundwater levels are high. The infiltration rate depends not only on the amount of water to which soils are exposed to, but also on the type of soils themselves (Bizimana and Sonmez 2015) As rainfalls intensify, the ability of the soil to absorb water reaches its climax resulting in water stagnation and very high soil pressure. This in turn causes slope failure (Bizimana and Sonmez 2015). A thinner and weaker soil layer, as a result of soil erosion, might therefore be a trigger for slope failure (Walraven 2018)

Because of tectonic uplift, mountain ranges have evolved in the Study Area, and it is now identified as a global hotspot of landslide risk (Depicker et al. 2021). Figure 6 shows a landslide inventory containing more than 8,000 occurrences. The following abreviations were used indicate different locations in the Study Area: VPP (Virunga Volcanic Province), SKVP (South Kivu Volcanic Province), NYAM

(Nyamulagira volcano), NYIR (Nyiragongo volcano), BUJ (Bujumbura), BUK (Bukavu), GM (Goma), KAL (Kalehe), UV (Uvira), IK (Ikoma landslide), and FU (Funu landslide).

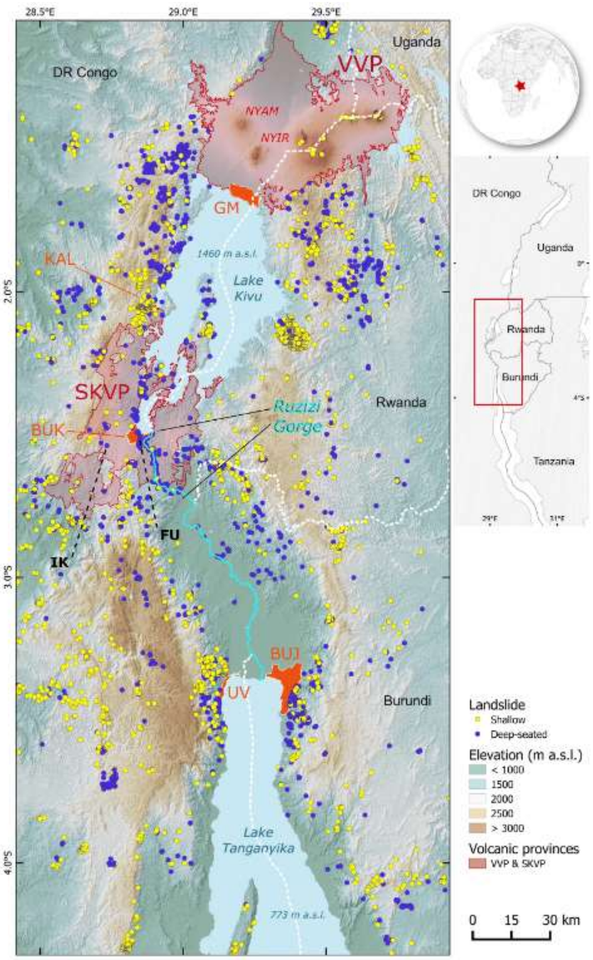

Figure 6. A map of the Study Area.
Source: The map shows a landslide inventory based of dataset from Depicker et al. (2020) and updated by Dewitte et al. (2021). The data was interpreted from Google Earth imagery between 2000 & 2018

Understanding when landslides occur and how they evolve is fundamental to predicting and mitigating the risks of such occurrences. The timing of landslides remains understudied mainly in most parts of the world (Jones et al. 2023). This is particularly the case for vulnerable regions, where information and communication infrastructures are *"weak or absent and where data scarcity is the norm"* (Dewitte et al. 2021).

The individual experiences of the three countries in the Study Area differs depending on their historical trajectories. This fact should be taken into consideration while evaluating landslide evolution. Depicker et al (2021) demonstrate that the risk in eastern DRC is twice as high as in neighbouring Rwanda and Burundi. The DRC features a more hazardous terrain. One of the causes most likely causes relate to geopolitical and governance considerations, such as conflicts. In such contexts, little or no conservation actions may be implemented. Other activities, such as mining, hamper conservation efforts and accelerate vulnerability (Debroux et al. 2007; Hanson 2018; Depicker et al. 2021). Simultaneously, large-scale deforestation has exacerbated the landslide risk in eastern DRC.

3.2 Identifying and mapping areas of risk for natural hazard

To better assess areas of risk, several efforts have been undertaken to map potential hazards. These maps help to raise awareness by highlighting the susceptibility to natural hazards. They are based either on statistical analyses or physical processes (Uwihirwe 2023).

The quality of data has a significant impact on the availability and accuracy of maps. The methodology used in gathering and processing the relevant data, their temporal and spatial resolution, consistency, technological limitations, and other limitations affect the accuracy and relevance of such maps. It is because of these limitations that risk maps , especially for large larger spatial areas scale and entire countries, is rare for the study area (Jones et al. 2023).

A difference between inventory and susceptibility maps should be noted. An inventory map presents current hazards, while a susceptibility map presents *potential* hazards. A 6-grade scale is used to classify susceptibility occurrences into different risk categories: very low, low, moderate, high, very high, and extremely high. This scale is applied across different variables, parameters, and units, impacting comparative analyses.

The next chapter focuses on identifying and mapping areas of risks with reference to this classification. However, several studies have modified the classification slightly in different ways.

3.2.1 Rwanda

The Government of Rwanda has mapped potential soil erosion risks, and generated an erosion risk map of Rwanda using the GIS-based Decision Support System spatial model Catchment Restoration Opportunity Mapping (CROM) (Rwanda Water Resources Portal 2022). This model is in turn based on the Universal Soil Loss Equation (USLE model) developed by Wischimeier and Smith in 1978. The USLE model counts five input parameters derivable from Rainfall (R), Soils (K), Topography/ Relief (LS), Land cover and crop management (C), and conservation practices (P), each having a multiplier effect as follows: $A=R\times K\times LS\times C\times P$ (FAO n.d.)

The following measurements were used to classify the soil erosion risks (Table 2).

Table 2. Risk severity levels classification for soil loss (t/ha/y)

Risk severity	**Very low**	**Low**	**Moderate**	**High**	**Very high**	**Extremely high**
Soil loss (t/ha/y)	<5	5–10	10–25	25–50	50–100	>100

Source: Majoro et al. (2023)

Using World View images from 2019, the Government of Rwanda developed detailed soil erosion maps, reporting that 45% of the total country's total land is at risk of soil erosion. Out of the total area at risk, 7% is estimated to be at extremely high risk, 1% very high risk, 28 % high risk, and 48% at moderate risk. The highest risk is faced in the Northern Province, followed by the Southern, and the capital, Kigali. The least susceptible region was the Eastern Province (Figure 7).

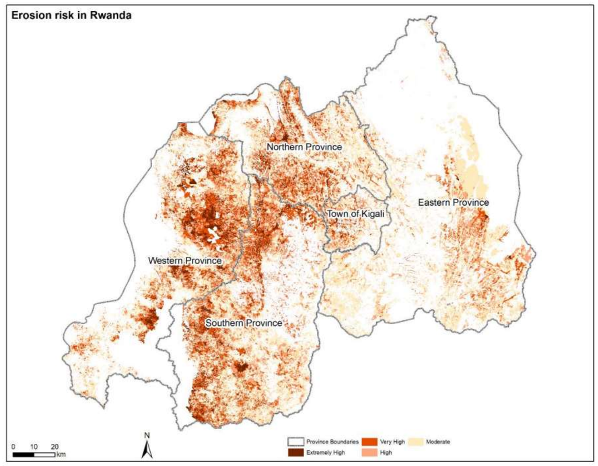

Figure 1: Erosion risk in Rwanda

Figure 7. Soil erosion risk map for Rwanda 2022.
Source: Rwanda Water Resources Portal (2022)

A shortcomings in the map are this explained by the authors: “The erosion risk map shows only the potential soil erosion risk, but fails to show areas already protected against erosion or erosive features proofing the risk.”(Rwanda Water Resources Portal 2022).

Conversely another study (Karamage et al. 2016) also using USLE, indicated that 78% of total land was at risk of being potentially exposed to soil erosion. In contrast to the previous report, the study submits that 78% of the total land had soil erosion rates ranging from 0–100 $t{\cdot}ha^{-1}{\cdot}a^{-1}$. Using the same classification system as earlier, 78% of the total land in Rwanda is at a very low to very high risk of potential soil erosion. Further on, the study presents that 4% of the land had erosion ranging from 100 to 200 $t{\cdot}ha^{-1}{\cdot}a^{-1}$, 3% of the land area from 200 to 300 $t{\cdot}ha^{-1}{\cdot}a^{-1}$ and 15% of the total national land was exposed to an estimated erosion rate of ≥300 $t{\cdot}ha^{-1}{\cdot}a^{-1}$. Presenting this data set in the risk classes, 22% of total land in Rwanda is exposed to extremely high risk.

Regarding landslides, Nsengiyumva et al. (2018) used the Spatial Multi-Criteria Evaluation module in ILWIS-GIS, considering factors such as land cover, lithology, soil texture, soil depth, precipitation, slope, altitude, and distance to roads. The result is based on how susceptibility is distributed by the percentage area, by causal factor weighting through SMCE Modeling. The result indicated that 42.3% of the total land area is at risk of landslides (ranging from moderate to very high susceptibility). The highest risk was found in the Western Province, where 40% of the total land area was exposed to potential risk, followed by the Northern (23%), Southern (12%, Kigali (8%), and Eastern (0.9%), as per Figure 8. The study concluded a landslide high zone in the western part and a landslide stable zone the eastern part.

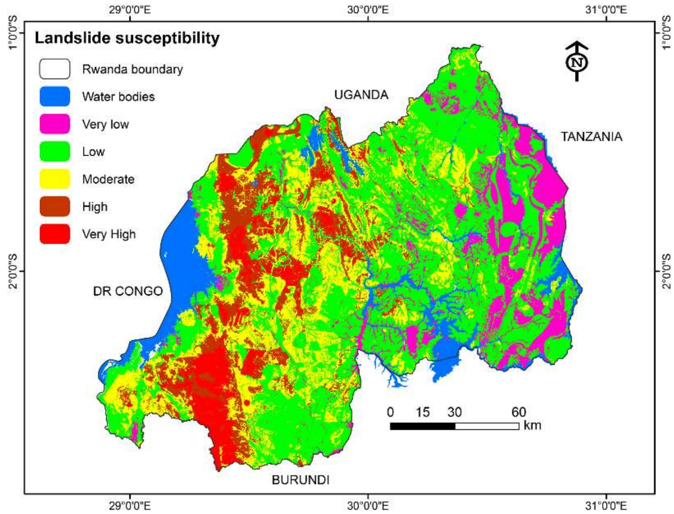

Figure 8. Landslide susceptibility for Rwanda.
Source: Nsengiyumva et al. (2018)

A different study, by Nahayo et al. (2019a) applied Geographic Information Systems and statistical index methods, considering factors such as elevation, slope, rainfall, lithology, soil texture, land use and land cover, normalized difference vegetation index, distance to rivers, distance to roads, aspects, and statistical index. Its results demonstrated, based on a 5-grade scale (very low, low, moderate, high, very high), that 85% of the total land area was at risk of landslides (ranging from moderate to very high susceptibility). The highest risk was found in Northern Province, where 90% of the total region area was under risk, followed by the Western Province (86.8%), Southern Province (29.2%), Kigali (6.3%), and Eastern Province (0.38%), as depicted in Figure 9.

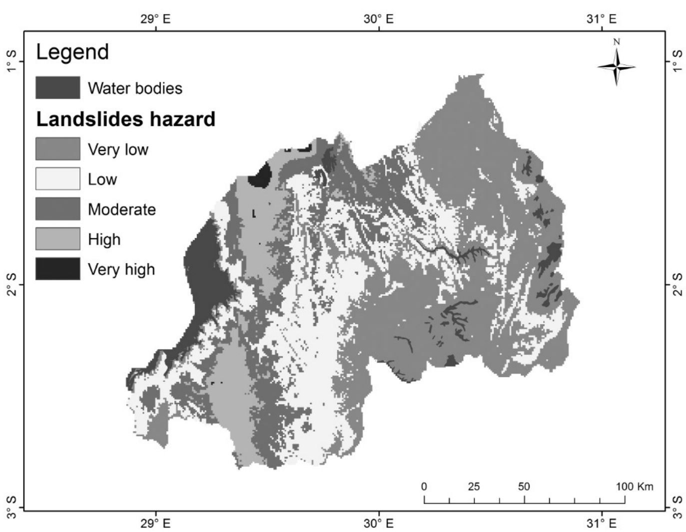

Figure 9. Landslide hazard in Rwanda.
Source: Nahayo et al. (2019a)

According to data from the Government of Rwanda (MIDIMAR 2015), 42% of the country is exposed to potential landslide susceptibility. The report does not include the methodology used, nor does it provide data for each separate province.

With regard to flood susceptibility, Mind'je et al. (2019) studied and mapped flood susceptibility using a regression model based on a dataset covering the following eight factors: elevation, slope, aspect, profile curvature, distance from rivers, distance from roads, NDSI, NDVI, mean annual rainfall and topographic Wetness Index (TWI). The result shown in Figure 10 indicate that the Eastern Province has low vulnerability to flood susceptibility, while the urban areas range from moderate to high susceptibility. The most vulnerable provinces were the Northern, Western, and Southern provinces, all of which demonstrate levels of high susceptibility to floods. These findings align with previous findings (Nahayo et al. 2019b) and (MIDIMAR 2015).

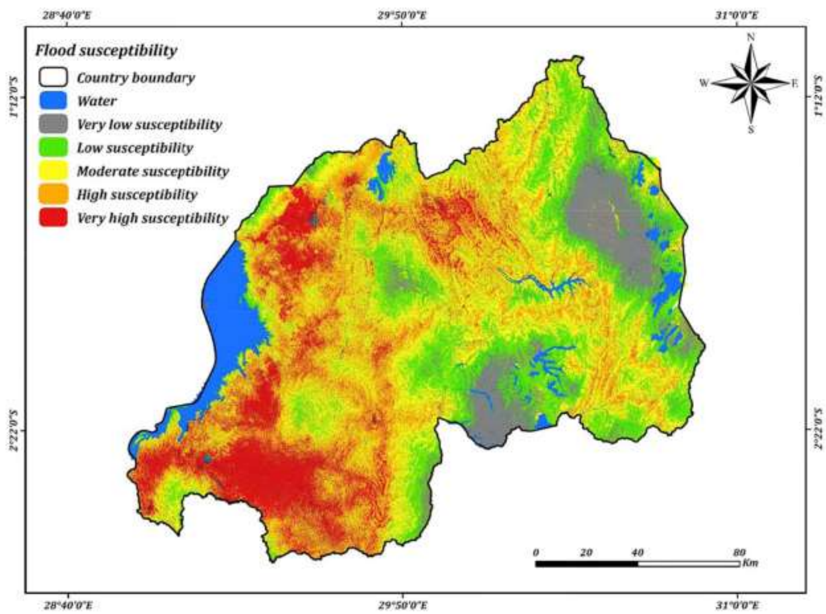

Figure 10. Flood Susceptibility for Rwanda.
Source: Nsengiyumva et al. (2018)

Based on this study, it can be concluded that the risk areas of flood, landslide, and soil erosion susceptibility are all located along the Kivu Rift in the southern, western, and northern parts of the country.

The value of risk maps for droughts, floods, and landslides is clearly recognized in the National Global Risk Atlas of Rwanda (MIDIMAR 2015). This government publication highlights the usefulness of risk maps in planning for and implementing natural hazard mitigation measures. They assist local authorities to undertake necessary measures to coping with the hazard at hand. They also support decision makers in detecting the areas that may potentially be affected and in adapting their activities accordingly. However, no concrete implementation examples or measures were presented.

3.2.2 Burundi

In 2020, the government of Burundi, in collaboration with the International Organization for Migration (IOM), initiated a project to design a multi-hazard map covering five hazards in successive layers: heavy rains, floods, earthquakes, landslides, and storms. This multi-hazard map elaborated by the Burundian government enables a multi-risk analysis covering all 18 provinces and 119 communes. (RTNB 2021; BCG 2022; IOM 2023a).

The fact that this multi-hazard map is accessible online, (Republique du Burundi n.d.) indicates an effort on the part of the government to reach out to stakeholders, to disseminate and facilitate risk information and assessment.

A more detailed multi-hazard map for the most vulnerable areas in Burundi has also been created, however there is no data confirming its implementation. It should be noted that the layers are available as integrative maps and as static maps (République du Burundi 2024a; b).

This study unable to access any data from the available maps on the online platform nor coule it identify any scientific publications with similar objectives, such as those related to the national action plan.

3.2.3 DRC

No national initiative could be identified for the DRC to map their current risks. However, several publications addressing soil erosion and landslide susceptibility were found (Mushi et al. 2019; Depicker et al. 2020; Nacishali Nteranya 2021; Chuma et al. 2023; Cimusa Kulimushi et al. 2023; Maki Mateso et al. 2023).

National risk assessment was the subject matter of only one of these studies. Cimusa Kulimushi et al. (2023) studied soil erosion susceptibility in the DRC-based on predictive machine learning algorithms (ML-ALs). In order to do so, 500 erosion sites were identified by the RUSLE model and Google Earth historical maps (Figure 11). The factors included were: Topographic factors (elevation, slope (°), slope aspect, drainage density, Terrain Ruggedness Index, Slope length and steepness, Sediment Transport Index, Topographic Wetness Index, profile curvature), climatic factor (rainfall), land cover factors (NDVI, LULC), and soil factors (soil type, soil texture, and lithology).

The result showed that 77% of the total land was at potential risk of soil erosion (Figure 11), with 7.28% were categorized as very high risk, 9.76% as high risk, 55.37% as moderate risk, and 27.57% as low risk.

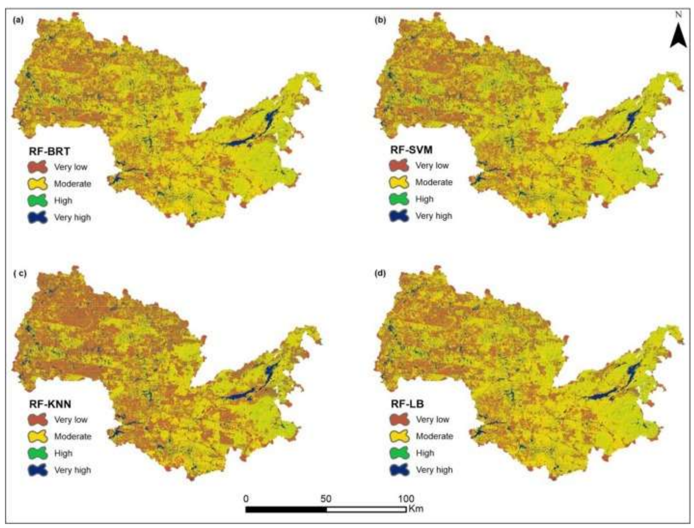

Figure 11. Soil Erosion hazard map for DRC based on four different models
Source: Cimusa Kulimushi et al. (2023)

Although Dewitte et al (2021) have elaborated on some inventory data, no map of the country's current hazards of the country is presented.

3.3 Conclusion

Rwanda, Burundi, and eastern DRC share their proximity to the Albertine Rift, the western branch of the East African Rift Valley system. The landscape is characterized by highlands, several large lakes and active land plate tectonics. The three countries face significant risks from natural hazards, stemming from various drivers. These include high population density, land use changes, moderate to high seismicity, high weathering and steep landscapes. Some drivers, such as rainfall intensities and high annual rainfall quantities, are specifically linked to climate change.

Other drivers such as hydrology patterns and soil structure seem to have been overlooked in literature, in spite of their significant role as risk factors. These drivers are crucial to soil stability. To better understand landslides and flooding, there is a clear need for further studies of soil types, pore pressure, high saturation, and runoffs.

Risk maps have been identified for the three countries. Most of these maps vary in spatial data, methods, risks covered and classifications. No implementation of these maps have been identified at national levels could be identified although, the Government of Rwanda has expressed the value and potential of such an undertaking.

4. NATIONAL DISASTER RISK MANAGEMENT RESPONSE SYSTEMS

The second research question in this study concentrates on what type of measures are in place for *disaster risk management.* This chapter aims to investigate the current National Disaster Risk Management Response System and to better understand how today's systems are governed and systemized.

4.1 Rwanda

The commitment to a national disaster risk management response system in Rwanda may be traced to 2010, when the Ministry of Disaster Management and Refugee Affairs (MIDIMAR, renamed the Ministry in Charge of Emergency Management—or MINEMA) was formed. A national platform for disaster management (NPDM) was created to exchange knowledge and information, and to review policies and plans.

The NPDM involves government institutions, UN agencies, NGOs, the private sector, academia and CSOs (MINEMA 2024). Their work is carried out in line with the Sendai Framework, focusing on five strategic focus areas. These are (I) establishing a professional disaster risk management system; (II) Integrating risk reduction into national development policy and plans, (III) enhancing capacities of institutions and human resources, (IV) promoting knowledge and innovations for empowering communities at risk, and (V) expanding risk reduction programming through public and private investments.

The implementation strategy in Rwanda is governed by the Disaster Management Law (IFRC 2015). This act determines the roles and responsibilities of government actors dealing with disaster management. The Law outlines procedures, roles, and responsibilities related to DRM, both within the country and in the regional context.

Along with this document, Rwanda has established a National Contingency Plan ("NCP") and a National Disaster Risk Management Plan ("NDRMP"). MINEMA is responsible for the coordination of these policies' objectives (Republic of Rwanda 2023).

4.2 Burundi

In Burundi, the government has integrated its disaster risk management strategies and policies in its National Development Plan 2018–2027 (NDP) (République du Burundi 2018) and the National Strategy for Disaster Risk Reduction 2018–2025 (NSFDRR) (ABP 2018). In line with the Sendai framework, the NSFDRR regulates risk prevention and disaster management to strengthen institutional and community resilience to disaster risks.

In the NDP, a plan for contingency is presented, "*Plan National de Contingence 2020-2021*". It includes the planning and undertakings for increased preparedness for natural hazards. Preparedness for landslides is specifically mentioned. Although no copy of the plan was available for the purposes of this study, the literature review highlights the four observations:

- (I) Although the plan title covers 2020–2021 it entered into operation in Mars 2021 as stated in the report,
- (II) It is uncertain if the document has been updated or is currently being implemented, and
- (III) No governmental body such as a ministry, directorate, section or service has been so far appointed responsible for the execution of the plan (République du Burundi 2023).

The IOM supports the government in preparing for, responding to, and reducing disaster risks through various programs, and initiatives. The recently published strategy "Burundi Crisis Response Plan 2024-2026" (IOM 2024a) is currently in force, and guides IOM actions.

As a member of the Humanitarian Country Team and the United Nations Country Team, IOM coordinates the implementation of its activities with other UN agencies and partners. IOM has forged strong links with national and local authorities. Its initiatives are aligned with the needs of the government as outlined in the above-mentioned steering documents.

The fact that IOM has established a Displacement Tracking Matrix (DTM) to track and monitor the displacement and population mobility (IOM 2024a) is of relevance. IOM's DTM products are disseminated to other agencies and partners, as well as to local authorities. DTM products serve to structure and provide evidence to inform appropriate humanitarian responses in the country. Their measures indicates among others, displacement of people due to natural hazards, among other things.

One report from the IOM, (IOM 2023b), indicated a displacement of 9,818 people caused by natural disasters between January and May 2023. The highest displacement numbers were reported in the Northern Province. In total, 158,939 people were affected by natural hazards, with floods and torrential rain being the major ones. The highest vulnerability was indicated in the Western Province.

Another important actor working for disaster risk reduction is the Burundian Red Cross. While it primerily focuses on emergency response, its activities also extend to data collection for humanitarian response, including response to natural hazards.

4.3 DRC

In DRC, the main instrument for implementing the country's vision and objectives for disaster risk management is the 2017–2023 National Strategy for Disaster Risk Reduction and Prevention (UNISDR) (World Bank 2023). The government undertook the National Adaptation Plan to Climate Change (NAP) (2022–2026) and is meant to complement the UNISDR, since many intervention areas are linked to climate change.

The National Adaptation Plan addresses the need to improve the prevention of extreme weather events and floods through EWS (The Democratic Republique of Congo & UNDP 2021). It covers nine objectives for adaptation and climate change resilience of which four are of interest to the current study. These are (I) Managing Forest ecosystems and biodiversity; (II) Strengthening the agriculture sector's resilience; (III) Managing climate risks in smallholder farming and (IV) Reducing the risk of disasters. They are included in Provincial Development Plans (PDPs) and for the implementation of SDGs (World Bank 2023).

Environment, water resources, forestry and environmental sanitation, are placed under the attributes of the Ministry of Environment and Sustainable Development (MEDD). Under MEDD, the Directorate of Sustainable Development (DDD) promotes environmental services and green economy. It also coordinates and implements the actions related to the Rio Convention.

The vulnerability assessment and associated measures are based on data collected from various national institutions; National Agency for Metreology and Remote Sensing (using satellite data), National Institute for Agronomic Studies and Research, the ministerial departments responsible for agriculture, energy, rural and urban development and regional planning as well as scientific research entities, NGOs, and the public and private sectors.

The current national framework for vulnerability assessment reveals significant governance challenges.There appears to be no established protocol to facilitate and coordinate the relationship between the organisations responsible for collecting valuable data for public administrations and the central state institutions.

In order to enable proper implementation of the plan, the roles and responsibilities in the NAP seem to require clearer definitions (UNDP 2021).

A new disaster risk management plan is anticipated, building on the previously mentioned documents. However, the country has not conducted coherent risk and vulnerability assessments related to DRM

(World Bank 2023; IOM 2024b). One reason for this shortcoming is the fragmented responsibility of disaster DRM among three ministries: the ministries of the Interior, Defense, and Environment. According to the World Bank (2023), another reason for the deficit is the cross-cutting challenges, including technical coordination and working protocols, data availability and ownership, and discrepancies in analytical models and reporting requirements.

At the local community level, IOM collaborates with civil society organizations, local NGOs, and community groups, mainly through local dialogue and inclusive and participatory governance processes.

4.4 Conclusion

In conclusion, Rwanda, Burundi, and DRC demonstrate gains in terms of understanding disaster risk and investing in disaster risk management at the national level. It is unclear how implementation is done at local and sub-national levels, through only a literature review. In assessing the literature for Disaster Risk Management, it appears that although strategies and action plans exist, results from their implementations could not be identified and evaluated. This situation may be explained by a lack of reporting on the actions taken, or by actual gaps in actions or implementation.

It is important to note that the policy documents guiding these actions, particularly the Sendai Framework, are relatively recent, and may not have been fully assessed for their implementation results.

5. THE CASE OF SOIL AND WATER CONSERVATION

Soil and water conservation can act together to stabilize soils on sloping agricultural land and hence is one important measure to contribute to disaster risk management (DRM) in the Study Area. A conservation management system serves to save a sustainable ecosystem that preserves biodiversity and its natural balance (Sale 2002). More specifically, soil and water conservation ("SWC") pertains to the practices for the sustainable use and conservation of soil and water (Bizoza 2014).

Soil erosion, floods, and landslides pose significant challenges to the resilience of ecosystems and livelihoods in the Study Area. Several conservation management practices are being undertaken to mitigate the Risks and to strengthen resilience. The practices identified in this study are the following: (I) Reforestation, (II) Agroforestry, (III) Terracing, (IV) Soil conservation structures, and (V) Land rehabilitation. Risk mitigation and soil conservation should also consider soil types, hillslope hydrology and drainage structures to avoid flooding and excess runoff events. For instance, Ojara et al. (2021) writes:

> *"In light of the highly variable trends of extreme rainfall events, we recommend planning adaptation and mitigation measures that consider the occurrence of such high variability. Measures such as rainwater harvesting, storage, and use during needs, planned settlement, and improved drainage systems management supported by accurate climate and weather forecasts are highly advised."* (Ojara et al. 2021)

Albeit, the need for drainage as a measure to cope with the most frequent risk—flooding—is often overlooked in literature.

There are several global initiatives contributing to the land, soil and forest conservation. One example is the "Bonn Challenge" aiming to restore forests across the globe. This initiative was launched in Bonn 2011 by the Government of Germany and the International Union for Conservation of Nature (IUCN). Today, the Bonn Challenge is a global goal supported by a large number of governments, private sector entities, and civil society organisations. By 2020, up to more than 210 million hectares were restored as a result of this initiative.

Rwanda, Burundi and DRC are part of the Bonn Challenge (BMUV 2020).

5.1 Rwanda

In Rwanda, the government has implemented various conservation measures to address agricultural production and sustainable soil and land management challenges, including terracing, agroforestry; and reforestation initiatives (Nahayo et al. 2017; IUCN & RWB 2022).

Regarding soil erosion, the government (Rwanda Water Resources Portal 2022) has identified the above-mentioned practices with the help of high-resolution images. Remotely sensed high-resolution data and high-quality World View images have become more accessible in Rwanda through a memorandum of understanding between the Government of Rwanda and Digital Globe facilitated by the National Institute of Statistics of Rwanda (NSIR), and later extended to the Rwanda Water Board (RWB) (Rwanda Water Resources Portal 2022). With this data, generated and validated in 2018, the maps show that only 26% of the land is protected, while 74% is unprotected. Of the total of 282 352 hectares of protected area, 67% were covered by forest, 15% is used for terracing practices related to soil conservation and land rehabilitation, 15% consists of bamboo plantations, 4% is scrubland, and 3% is part of the Savannah.

By contrast, another source indicates that in January 2023, the forest cover constituted 30.4% of the country (AFR100 2023c). Most of the soil erosion control measures currently in place by the Rwandan government, is located in the Northern Province, where 34% is protected per ha at risk, followed by the

Southern Province with 31%, Western Province with 24%, Eastern Province with 18%, and Kigali City with 15% erosion control per ha at risk (Rwanda Water Resources Portal 2022).

The country has established the Catchment Restoration and Erosion Control Division at the RWB, which is responsible for institutional efforts in soil and land conservation. Their responsibilities include identification of areas with soil erosion risks, deciding on soil erosion prevention measures, and developing catchment management plans based on detailedmanalysis of current catchment management interventions. Their aim is to: *"address root causes of water resources issues"* (RWB 2024)

5.2 Burundi

Similar data could not be identified for Burundi, nor for DRC in this study. However, Burundi has implemented conservation measures such as reforestation, soil conservation structures, and land use planning (Vervisch et al. 2013; Depicker et al. 2021). The Government of Burundi has implemented a Landscape Restoration and Resilience Project (PRRPB) with the goal of restoring land productivity in targeted degraded landscapes. Moreover, in the event of a crisis or eligible emergency, PRRPB aims to provide an immediate and effective response to crisis or eligible emergency (PRRPB 2024). The Burundian government and international donors have initiated programs to plant trees and implement trenches along the contour lines. In May 2023, it was indicated that 6.7% of the country is covered by forests (AFR100 2023a). Burundi is, as stated previously, a part of the "Bonn Challenge" and also a part of the African Resilient Landscapes Initiative. While the Bonn Challenge aims to restore forests, the African Resilient Landscapes Initiative focuses not only on forest cover, ecosystem restoration, and biodiversity conservation, but also on smart agriculture and pasture management. The PRRPB initiative has committed to restoring one million hectares of land by 2030 (PRRPB 2024).

Encouraged by the Paris Agreement, the Government of Burundi has developed a national action plan to present their national vision and mission for climate actions (République du Burundi 2023). The Burundian Ministry of Environment, Agriculture and Livestock (MINEAGRIE) is in charge of environment, forest, agriculture, and water strategies.

5.3 DRC

In DRC, the government has implemented conservation measures to mitigate the disaster risks, including reforestation; agroforestry; and land rehabilitation programs (République Democratique Du Congo 2002; République Democratique Du Congo 2018). Reforestation initiatives focus on restoring forest cover, rehabilitating degraded landscapes, and promoting sustainable land use practices (Megevand et al. 2013). Data from May 2023 indicates that DRC is 59% covered by forests (AFR100 2023b).

Nonetheless, these reforestation and land rehabilitation programs are being disrupted by conflicts and political instability in the country.

Institutional efforts are guided by the National Adaptation Plan (NAP). In the plan, several priority adaptation programs are outlined where land and forest conservation as well as water management measures are listed. These adaption programs are considered as priorities in the National Climate Change Policy, Strategy and Action Plan, nationally determined contributions. They are also included in two plans: Plan of action for integration climate change adaptation in the planning process, and the plan of action for integrating the adaptation priorities of indigenous people into the National Agricultural Investment Plan.

No specific Ministry could be found responsible for the implementations of these two plans (UNDP 2021).

5.4 The case of AFR100

The African Initiative (AFR100) is a multi-country landscape restoration initiative launched during COP21 in Paris in December 2015. It is a regionally initiated program within the Bonn Challenge. The target was to restore 100 million ha, but as it has been exceeded, the new commitment is to restore 108 million ha by 2030. The project indicated that Burundi committed to restore 72% of the country's area, DRC 3% and Rwanda 76%, as shown in Table 3.

Table 3. Commitments of Rwanda, Burundi, and DRC to AFR100

	Commitments to AFR100 (in million ha)	**Area of the country (in million ha)**	**% of landscapes to be restored to area of the country**
Rwanda	2.0	2.6	76
Burundi	2.0	2.8	72
DRC	8.0	234.5	3

5.5 Conclusion

Some initiatives and efforts related to soil and land conservation were identified in the study. Reforestation programs seem to be the most widely adopted conservation initiatives in the Study Area.

Other types of soil and land conservation management can help reduce risks. However, based on the findings, such practices are not sufficiently implemented. These practices include vegetation cover, deep-rooted vegetation, and soil management techniques such as terraces, green barriers, drainage systems for overflows, and other physical structures.

6. EXISTING EARLY WARNING SYSTEMS

This chapter discusses the current early warning systems (EWS) for natural hazards such as landslides, flooding and soil erosion, country-wise, within the Study Area.

At COP27 in March 2022, the UN Secretary-General launched an Executive Action Plan (UN et al. 2023) in collaboration with the World Meteorological Organization (WMO) and UNDRR. The plan's purpose is to apply EWS to the entire world population by 2027, to reduce hazard risks and increase resilience. This plan states that 60% of Africa's population does not benefit from EWS. Africa, therefore, stands to gain significantly from the plan's action and implementation.

It must be noted that no scientific publications could be found to support the study of current EWS structures and their functions in the three countries of interest. Additionally, in assessing the current EWS actions and implementation, only fragmented information could be gathered from non-peer-reviewed sources such as websites and reports from multilateral organisations and NGO's. Consequently, the majority of the references in the following chapter originate from the above-stated sources, many of which are outdated.

6.1 Rwanda

Rwanda has deployed concrete efforts in establishing EWS to mitigate the impact of natural hazards such as floods and landslides (Finnish Meteorological Institute 2023). Improving the EWS is one of the objectives of the National Contingency Plan (MINEMA 2018).

Monitoring and forecasting weather-related hazards are an essential action in the national EWS. To this end, the Rwanda Meteorology Agency (Meteo Rwanda) relies on a network of 183 meteorological stations that record rainfall, temperature, evapotranspiration and relative humidity (Nyandwi et al. 2016). Along with these meteorological stations, radar systems and satellite imagery are also used to monitor weather patterns and issue timely warnings to at-risk communities (The Rwanda Meteorology Agency 2024).

In the National Contingency Plan, MINEMA outlines the roles of each actor involved in the actions related to EWS. It states that the Ministry of Local Government is responsible for mitigation, response, and recovery. Each district, through the Ministry and Rwanda Red Cross, is responsible for raising community disaster awareness and for their EWS. As stated above, Meteo Rwanda, which reports to the Ministry of the Environment, oversees weather forecasts and EWS.

In addition, community-based early warning systems are implemented to strengthen local community resilience. Local radio and television channels designed locally adapted EWS content along with regular weather station bulletins to provide timely information (Nahayo et al. 2017). In Rwanda, radio broadcasting has been identified as the most effective communication tool for disseminating information about EWS. The reason is that most communities have radio access and the information is delivered in the local language. And radio sets do not necessarily require electricity, which is often unavailable in rural areas, especially those areas experiencing natural disasters (Nahayo et al. 2017).

In June 2023, an new initiative was launched under the auspices of the World Meteorological Organisation (WMO), the UN Office for Disaster Risk Reduction (UNDRR), and the World Bank's Climate Risk Early Warning Systems (CREWS). It involves six countries, including Rwanda and Burundi (WMO 2024a). CREWS is a citizen science initiative, with participatory and community-focused prediction and early warning system for floods, landslides, and other severe weather events. CREWS extends over 4 years from 2023 to 2027.

6.2 Burundi

The Burundi Directorate of Meteorology and Climate is responsible for monitoring and forecasting weather-related hazards. International partners such as WMO and the United Nations Development Programme (UNDP) support the authorities in this task.

This study could not identify an effective EWS for Burundi. Although numerous forecasting measures, as mentioned above, are put in place in preparation for upcoming disasters, there is no comprehensive systems clearly allocating roles and responsibilities for various institutions and organizations.

The existing forecasting measures are generated by the government, the Geographic Institute of Burundi (Institut Géographique du Burundi—IGEBU), multilateral organisations such as UNDP, IOM, and the World Food Program (WFP), and NGO's such as the Burundi Red Cross.

Various actors and sectors play different roles in the EWS in Burundi. Regarding natural hazards, the IGEBU plays a crucial role in collecting and disseminating data, including meteorological forecasts. Forecast information is assessed and shared via the Burundi National Radio and TV system (*Radio Télévision Nationale du Burundi*) and via IGEBU's Facebook page. According to the National Strategy for Disaster Risk Reduction from 2018 to 2025, the data is disseminated to government representatives, journalists, UN agencies, and NGO's (IFRC 2023). As reported by the Burundi Red Cross (IFRC 2023) The IGEBU successfully delivers seasonal forecasts, although its actions are constrained by a lack of investment and resources.

In addition, to centrally coordinated actions, community engagement is structured and coordinated at the local level. Effectively, WFP and the Burundi Red Cross seem to play key roles in preparatory actions for disasters (IFRC 2023; WFP 2023 a; b). In fact, the transmission of the relevant information to the communities is essentially secured by the Burundi Red Cross and WFP. This is due to these two actors' ability to reach to the population rapidly, relying on their collective, extensive networks. The knowledge collected and the experience accumulated from earlier situations are consigned in an Early Warning Protocol (EAP).

Since 2020, WFP has supported the Burundi Red Cross and the IGEBU in developing an Anticipatory Action Plan for floods (WFP 2023a). Through their collaborative effort, a trigger-based data set was established in order to strengthen the EWS with anticipatory actions. The trigger data set is paired with the forecast data.

Despite progress in developing EWS, Burundi continues to face challenges related to data availability, institutional capacity, and socioeconomic vulnerabilities. Strengthening partnerships among government agencies, NGOs, and communities, as well as investing in infrastructure and technology, are both essential measures for enhancing the resilience of Burundi's EWS.

6.3 DRC

In the case of the DRC, particularly in eastern DRC, the lack of data and reporting hinders the ability to create a comprehensive picture of the country's situation. Despite the absence of an adequate EWS, however, there seems to be fragmented action put in place regarding risk preparedness.

One of the reasons for the absence of an integrated and efficient EWS in the country is the lack of funding. It must be noted that at present, the country relies on only 13 operational hydrological monitoring stations for weather prediction. In 1995, there were 80 (ReliefWeb 2024).

In addition to a lack of funding, DRC experiences a lack of communication technology and a solid institutional structure supporting a preparedness system. This problem is compounded by the absence of community involvement. These weaknesses justified the 2010 initiative that was led by UNICEF and Catholic Relief Services (CRS), to compensate for these failures. UNICEF and CRS first identified the challenges related to early preparedness and the circulation of information. They, together with the social service organisation Caritas, decided to implement an EWS in certain areas in the DRC (CRS 2015).

The EWS they envisaged was built in different steps. The first step involved the trainings of community leaders. In the second step, the focus was on passing the information individually to communication tool equipped local parishes and Caritas contacts to share the information. The information was transmitted via cellphones and even by people on bicycles, who in turn passed it on to the regional hubs. This information was then taken to the Caritas' national offices, CRS and the UNICEF. Lastly, these three actors reported the information to the relevant United Nations clusters and government agencies.

Other than the above information related to the design and planning of the 2010 UNICEF and CRS initiative for an EWS, no analysis could be found or gathered regarding this initiative. Another initiative documented in 2016, is a joint effort to develop an early response and a set of appropriate measures. This undertaking was led by the DRC Red Cross, with support from the French Red Cross. (Croix Rouge RD Congo 2016; Anticipation Hub 2024; Croix Rouge Francaise 2024). No reports on the follow-up or implementation of this undertaking were found.

6.4 Conclusion

According to this review, the information on EWS implementation for Rwanda, Burundi, and DRC is sketchy. This appears to be due to a lack of capacity in national monitoring, such as observation of meteorology, as well as a lack of documents outlining official versus community and NGO roles and responsibilities in early warning systems. This study identified limitations in accessible and timely data, as well as in reporting on the current elements of the EWS available and their effectiveness.

Based on this study it was shown that the government of Rwanda has deployed significant efforts in designing and incorporating EWS in policies. Monitoring and forecasting are essential undertakings is presented in their National Contingency Plan.

Burundi has received major support from international partners in designing and establishing EWS for risk preparedness. The main activities centre on data collection and monitoring including weather forecasting. Actions are taken to transmit the forecasted information through radio and national TV.

In DRC it was found that no adequate EWS is currently in place. The reasons observed were the Lack of funding, lack of tools and technologies combined with the lack of good institutional governance practices supporting a preparedness system.

What was observed in all three countries was the lack of data and absence of measures regarding what is being implemented in times of crisis. No evaluation reports, nor scientific papers, could be identified in this review to analyse the success rate of implementing these strategy goals. This finding highlights the need for future research and support to data collection, particularly in the DRC.

7. GENERAL CONCLUSIONS

Rwanda, Burundi, and DRC face significant risks of natural hazards. These risks stem from various drivers, including geological, hydro-meteorological, socio-economic, and geo-political factors. Effective risk assessment, preparedness, and mitigation strategies are essential for enhancing resilience and reducing the impact of disasters on communities and ecosystems in these countries. In this context, the priorities set in the Sendai Framework prove valuable.

Answering the research questions in this study led to the conclusion that the evolving threat of floods, soil erosion, and landslides is well recognized in the studied countries. However, capacity is nonetheless lacking with regard to data collection, effective information systems, and coordination between structural and non-structural measures.

This study, which was carried out as a desk review, identified some national risk maps and national policies for risk mitigation, especially for EWS, that were recently put into place. The maps found cover the potential risks and serve to locate the vulnerabilities. Most of them vary in their spatial detail, methods, and classifications. They rely on input data on elevation, slope, rainfall, lithology, soil texture, land use, land cover, and the normalized difference vegetation index.

These maps cover heterogeneous data sets and geographical regions. This may lead to varying interpretations of potential risks, spatial hot spots, and the underlying drivers of said risks. No risk maps consider existing population vulnerabilities, such as social protection and income levels, or readiness to respond, for example, in accessing emergency hospital services. In addition, they fail to consider soil type and hillslope hydrology which provides valuable insights for relevant interventions.

Risk maps could be an effective tool to support disaster risk management policies and implementations if they were national-based and based on comprehensive, comparable, and reliable data.

Vegetation cover, deep-rooted vegetation, and soil management techniques such as terraces, green barriers, and drainage systems for overflows are all valid land management practices. They can reduce risks. However, such practices—which are to be encouraged—are not in place to the required extent.

It is difficult to study and evaluate the implementations of actions or possible structural and non-structural measures in a literature review for countries with poor access to data. Therefore, it is recommended that deeper field research and investigation be conducted into existing national disaster risk management practices in these countries. Locally generated and implemented practices and solutions, particularly in the case of EWS, call for greater focus and more research on their effectiveness.

Regarding disaster risk management, although strategies and action plans do exist, the study faced significant constraints in verifying their implementation, and therefore, their effectiveness. There is a pressing need to strengthen coordination and governance structures towards systematized national disaster risk management practices, including EWS. This assessment also applies to the existing obstacles hindering access to accurate and high-quality quality data.

To complement national initiatives and provide a more comprehensive assessment of the risks under study in the three countries, it is recommended that this review be enriched with on-the-ground expert interviews to verify and supplement the literature reviewed, with the trifold objectives of (I) understanding the local EWS, (II) conducting further research on national risk maps, and (III) reviewing possibilities for bottom-up initiatives for disaster risk management and EWS.

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