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GUIDELINES ON DISASTER AND CLIMATE RESILIENT ROAD INFRASTRUCTURE & DISASTER MANAGEMENT

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I. INTRODUCTION

I.1 Background of climate change in Rwanda and impact of disasters on road infrastructure

Rwanda, a country in the central part of Africa with tropical climate and high altitude, is among most vulnerable countries to climate change and disasters for most of its socio-economic sectors. Landslide, flooding, erosion, earthquakes and prolonged droughts are the key disasters impacts that affect Rwandan socio-economy. These impacts have devastating effects on transport infrastructure components such as embankment, slopes, bridges and pavement, causing damages and service interruption.

In May 2023, heavy rain caused the losses of life and damages of the infrastructure due to flooding and landslides especially in Northern, Western and Southern provinces of the country. The road transport infrastructures affected are: 20 national roads, 21 District roads and 47 bridges.¹

In May 2021, the eruption of Nyiragongo Volcano and seismic activities caused damages to various infrastructures in Rubavu District (roads, schools, hotels, shops, hospital, water supply system, etc.), affected local communities, interrupted businesses and affected environment. The Roads in Rubavu especially urban roads were highly affected affected by the earthquakes and road infrastructure losses were estimated at 1,779,559,165 Frw while the required recovery cost was estimated at 19,745,000,000 Frw².

In 2020, heavy rains caused severe flooding and landslides in the Northern and Western Provinces. Roads were washed away, houses destroyed, and over 100 people lost their lives.³ In particular, the Nyabihu District suffered extensive damage to road infrastructure, disrupting access to Kigali and other regions. Bridges collapsed, and agricultural land was destroyed, impacting local food security.

In 2018, during the rainy season, roads in the Musanze District in Northern Province suffered extensive damage, with landslides blocking key routes to Kigali and disrupting the flow of goods and services. The increased cost of maintaining and repairing roads damaged by heavy rains has put additional financial strain on the Government.

To understand the problem and the requirements of resilient road infrastructure in Rwanda, a vulnerability assessment and mapping study was conducted on road network in August 2022. This study revealed that the road network is highly vulnerable to

¹ Rwanda 2023 Floods and Landslides Rapid Damage and Needs Assessment (MINEMA, May 2023)

² Post disaster need assessment recovery plan, May 2021 Rubavu District Seismic Disasters (MINEMA, July 2021)

³ www.gov.rw/blog-detail/government-steps-up-response-to-flood-disasters#:~:text=President%20Kagame%20expressed%20his%20solidarity,about%20the%20Government%20response%20here.

climate change with most effects in western, northern, and southern provinces of the country. This study identified 776 hotspots that were also analyzed according to their level of vulnerability: 8.2% were classified as very high; 17.8% as high; 72.7% as moderately vulnerable; and 1.4% with low vulnerability.

I.2 How Rwanda's climate has changed over the years

- 1. Temperature Increase:** Over the past decades, Rwanda has experienced a gradual increase in average temperatures. According to historical data, the average temperature in Rwanda has experienced a temperature increase of 1.4°C since 1970, higher than the global average, and can expect an increase in temperature of up to 2.0°C by the 2030s from 1970⁴. This rise is consistent with broader global warming trends and contributes to hotter days and warmer nights.
- 2. Rainfall Variability:** Rainfall patterns have become increasingly erratic, with longer dry spells and more intense rainy seasons. The country typically experiences two main rainy seasons (March to May and September to December), but recent years have seen disruptions in these patterns. Extended dry periods and sudden, heavy rains during the wet season have become more common.
- 3. Increased frequency of extreme weather events:** Rwanda has seen a rise in extreme weather events like floods, landslides, and droughts. These events often affect vulnerable areas, particularly in the northern and western regions where hilly terrain makes road infrastructure susceptible to landslides.

I.3 Climate condition forecast for Rwanda

Looking forward, Rwanda's climate is expected to continue changing, with key projections indicating:

- 1. Temperature increases:** By 2050, average temperatures in Rwanda are projected to rise by 1.5–2.5°C.⁵ This increase will lead to more frequent and intense heatwaves, which could worsen drought conditions and affect water resources.
- 2. Increased rainfall variability and intensity:** Rainfall is likely to become even more erratic, with intense rains interspersed with prolonged dry spells. The rainy seasons may see an increase in total rainfall, heightening the risk of flash floods and landslides. Regarding the modeling of future climate change scenarios, several studies have been conducted since 2009 to determine projections for Rwanda; and

⁴ <https://climatechange.gov.rw/index.php?id=2#:~:text=Rwanda%20has%20experienced%20a%20temperature,by%20the%202030s%20from%201970>.

⁵ Green Growth and Climate Resilience (Government of Rwanda 2011)

show an increase in mean annual rainfall of up to 20% (100–400 mm) by 2050 and 30% by 2080.⁶

3. **Rising frequency of extreme weather events:** Extreme weather events are expected to become more common. Flooding, landslides, and droughts will likely pose an even greater risk, impacting vulnerable communities and putting further strain on infrastructure like roads, bridges, and drainage systems.

I.4 Disaster and climate resilient road infrastructure in Rwandan context

Disaster and climate resilient road infrastructure in Rwandan context means road infrastructure that withstand disasters namely; Landslides, Floodings, Erosion and Earthquakes.

In this respect, development of disaster and climate resilient road infrastructure considers the designs adapted to climatic, topographic and soil conditions, quality control and assurance during road construction, monitoring and inspection of road condition as well as proper maintenance. The important road components that are given consideration in the construction of climate resilient infrastructure are:

1. Slopes,
2. Embankments,
3. Drainage Systems
4. Structures (bridges, culverts);
5. Road pavement (paved & unpaved roads);

It is believed that if those components are constructed in full consideration of the potential disasters in the area of application, by the use of appropriate designs standards that are monitored throughout construction, the resulting infrastructure would be enough resilient to these disasters.

On the other hand, it happens that disasters seriously affect road infrastructure and effective emergency response should be envisaged to quickly restore the operation but also protect the safety and health of users. In this regard, these guidelines provide a clear way of responding to emergencies in case disasters such as Landslides, Floodings, Erosion and earthquakes strike road infrastructure.

II. DEVELOPMENT OF DISASTER AND CLIMATE RESILIENT INFRASTRUCTURE

Building disaster and climate resilient road infrastructure requires a combination of strategic planning, engineering adaptations, and material choices tailored to withstand various disaster or climate related stresses, such as extreme weather events, increased temperatures, landslides, floodings, erosion and earthquakes. The section below

⁶ Downscaled Climate Projections for National Adaptation Plan in Rwanda (Rwanda Meteorology Agency, REMA 2022)

includes key practices and considerations for constructing disaster and climate resilient roads, focusing on design, materials, and site-specific adaptations:

II.1 Integration of disaster and climate data into design

- **Modeling and projections:** Use of historical disaster or climate data to model weather extremes like rainfall intensity, temperature variations, flood risks and disasters such as earthquake. Incorporate these projections into road design to anticipate and prepare for future conditions.
- **Site-specific risk assessment:** Analyze the geographic and climatic characteristics of the area, including flood zones, landslide-prone areas, temperature ranges, erosion risks and seismic zones. This informs design choices like road alignment, elevation, and materials.

II. 2 Enhanced drainage design

- **Effective water management systems:** Design robust drainage systems, including larger culverts, ditches, and side channels to handle heavy rainfall and flash floods. Ensure drainage infrastructure is easy to maintain and resilient to blockages.
- **Permeable surfaces and stormwater management:** In urban areas, permeable pavement and infiltration basins reduce surface runoff, preventing road flooding and supporting groundwater recharge.
- **Redundant drainage paths:** Incorporate multiple drainage paths so that if one drainage route is blocked, others can prevent flooding, especially in high-rainfall regions.
- **Sustainable Urban Drainage Systems (SUDS):** In urban areas, SUDS integrate road design with natural landscapes to absorb runoff, recharge groundwater, and prevent floods. This can include permeable pavements, bioswales, and retention basins.

II.3 Elevated Road design and structural adaptations

- **Raised embankments:** In flood-prone areas, building elevated embankments and multiple crossings (where possible) to keep road surfaces above anticipated flood levels, reducing the chance of submersion. Design embankments with materials that resist erosion and consider soil reinforcement for added stability.
- **Reinforced bridge:** Ensure bridge piers, abutments, and culverts are reinforced to withstand increased water flow and debris impacts from flash floods and storms. This is done by elevating the drainage capacity to accommodate heavy rainfall and sudden surges in water flow.

- **Culverts and ditches:** Installing culverts, side drains, and channels to divert water away from the road surface prevents waterlogging, erosion, and flooding. Ditches should be designed to handle higher-than-normal rainfall volumes and placed strategically along sloped terrain. The road side ditches should preferably be earthen with grass along gentle sloping and/or flat road sections or constructed with concrete/masonry along steep sections (See Manual developed by RTDA on best practices for the right of way erosion control measures).
- **Resilient Foundation:** Foundation that incorporates gravel or other permeable materials are more resistant to water damage. Strengthening the subgrade with materials such as cement-treated base layers can provide additional stability.

II. 4 Slope Stabilization and Erosion Control

- **Slope stabilization techniques:** Use retaining walls, gabions, bioengineering techniques, shotcretes, anchoring and terracing to stabilize slopes and prevent or reduce landslide risks depending on the site characteristics.
- **Erosion control: Bioengineering techniques** such as planting grasses, plants with strong root systems, shrubs, or trees along embankments provide natural reinforcement to slopes and reduces erosion by stabilizing the soil. Employ also other erosion control measures on road slopes like **compacted soil and soil reinforcement** to protect slopes from runoff water damage.
- **Rockfall Barriers:** In areas prone to landslides, rockfall barriers and nets help contain loose debris and protect the road surface.
- **Catch-water drains:** Use catch-water drains effectively in order to stop or slow down rainwater runoff from hillsides and hilltops before reaching the road surfaces. These drains should be preferably earthen lined with designated grass to reinforce it.
- **Groundwater draining:** Some landslides are caused by groundwater logging across the susceptible cut slopes; therefore, it is paramount to provide the groundwater appropriate management measures to the predetermined spots and establish automated water level meter to the dedicated spots to monitor the rise of water table.

Details are provided by the Manual on best practices for the right of way erosion control measures, by RTDA.

II. 5 Use of adapted crops and trees to protect road embankments and slopes

Depending on the soil structure of embankments and slopes, there is a need to investigate suitable trees and crops which can retain the soil in addition to analysis normally done during the confection of the Environment Impact Assessment (EIA). To

this end, the bidding documents for road construction works shall incorporate a thorough investigation of adapted crops adequate for the protection of embankments and slope found along the road in consideration and bills of quantities include quantity of adapted vegetation that will be needed.

II.6 Selection of disaster and/or climate resilient and durable pavement materials

- **Durable and temperature-resistant materials:** Use materials that can tolerate seismic vibrations, extreme temperature and heavy rainfall, such as polymer-modified asphalt or fiber-reinforced concrete, which can withstand extreme temperature changes and resist cracking and deformation, is essential.
- **Flexible pavement structures:** Incorporating flexible pavement designs that can accommodate expansion and contraction caused by vibrations and temperature changes, minimizes cracking and road failure. Using jointed concrete slabs, for instance, allows for controlled movement in response to temperature changes.
- **Permeable pavement:** In areas prone to heavy rainfall, permeable pavements reduce runoff by allowing water to pass through the surface, reducing runoff and improving water management on roads, particularly in urban areas, preventing therefore surface flooding.
- **Concrete pavements in high-temperature areas:** Concrete, which can tolerate high temperatures better than traditional asphalt, may be a better option in areas experiencing temperature spikes. However, it is crucial to consider the specific cost and sustainability aspects.

Details are provided by the Manual on sealing technology on road pavement by RTDA.

II.7 Enhanced Road design for flexibility

- **Multi-functional infrastructure:** Integrate design features that enable roads to serve additional functions, such as stormwater management or emergency access routes, in case of natural disasters.
- **Wider shoulders and turnouts:** Providing wide shoulders and turnouts along roads can mitigate landslide risks and reduce road edge erosion. They also offer safer zones for vehicles in the event of road blockages.

Details are provided by the Manual on road pavement design by RTDA.

II.8 Community and ecosystem considerations

- **Community engagement in design:** Engage local communities early in the design process to understand local knowledge and concerns about climate risks, incorporating community input into infrastructure planning. Integrating

community knowledge into planning can enhance resilience and reduce the environmental impact.

- **Gender inclusivity:** include gender-sensitivity in road infrastructure development to ensure the infrastructure meets the needs of all community members and recognizes the different impacts climate and disasters may have on diverse groups.
- **Ecosystem conservation and/or restoration:** Maintaining or restoring nearby ecosystem such as wetlands and forests, restoration of the borrow pits and quarry, dumping sites is critical in road infrastructure as it provides natural based measures against flooding and erosion. For instance, wetland conservation near roadways helps absorb excess rainwater, reducing flood risks.

Details are provided by the Manual on quarry and borrow pit exploitation and restoration for road project, by RTDA.

II. 9 Maintainability of the road infrastructure

- **Design for optimized longevity:** Consider accessibility and ease of repair when designing drainage systems, slopes, bridges, embankments and pavements. Design roads to accommodate routine inspections and quick repairs to mitigate climate impacts.
- **Real-time monitoring systems:** Install monitoring technology to monitor changes in temperature, moisture levels, temperature, rainfall, ground movement or behavior, soil stability, and road surface condition can provide early warnings, reducing maintenance costs and preventing sudden failures. Early detection of damage helps manage repair schedules and prevent larger failures.
- **Routine inspections:** Establishing a schedule for inspecting culverts, drainage systems, slopes, bridges, embankments is crucial. Early detection of erosion, cracks and drainage issues allows for timely repairs before significant damage occurs.

Details are provided by the Manual on road inspection and maintenance, by RTDA.

II.10 Incorporation of Redundancy and Fail-Safe Features

- **Redundant Structural Elements:** Design bridges, culverts, and slopes with redundancy in areas highly vulnerable to disasters and climatic impacts, so that if one element fails, other components can serve and maintain road functionality.
- **Alternative Transport Routes:** Consider designing additional, parallel routes or bypasses, especially in areas prone to frequent flooding, landslides, or other disruptions, to ensure continuity in road networks.

II.11 Climate Resilience Standards

- **Adherence to Climate-Resilient Design Standards:** Develop or use existing climate-resilient road design standards that incorporate thresholds for weather events, load-bearing capacities, and resilience measures based on predicted climate risks.

II.12 Prioritizing funding for resilience

- Prioritize disaster and climate resilience aspect in fund mobilization for road infrastructure development and maintenance.

Details are provided by the Manual on road material recycling, stabilization improvement, by RTDA.

By applying the above considerations, road infrastructure can be designed to withstand disaster and/or climate variability and extreme weather, ensuring durability, accessibility, and safety across various scenarios. This approach not only preserves infrastructure integrity but also minimizes future repair and replacement costs associated with climate and disaster impacts.

III. EMERGENCY RESPONSE TO DISASTERS

In general, activities of emergency response to disasters are governed by the law N°41/2015 of 29/08/2015 relating to disaster management.

However, there are some emergency response activities that are specific to road infrastructure including provision of alternative solutions in case of failed infrastructure to ensure service continuity and restoration of the same in a resilient manner.

In order to respond to emergencies, an emergency response plan is essential, providing for:

- Safety plan to protect the community and road users against incidents of further using the failed infrastructure;
- Plan to restore connectivity and transport services to minimize the impact of the failure on the socio-economic activities in the area;
- Plan to restore the failed infrastructure in sustainable and resilient manner.

Details are provided by the Manual on emergency response and build back better, by RTDA.

IV. MANAGEMENT OF SOCIAL ECONOMIC ACTIVITIES THAT AFFECT THE ROAD INFRASTRUCTURE

The socio-economic activities can accelerate infrastructure degradation, increase vulnerability to climate impacts, and intensify disaster risks. Integrating sustainable

practices within economic activities around road networks can enhance resilience and attention needs to be exercised to consider the provisions of the law n° 042/2023 of 02/08/2023 governing road and waterways transport that provides dimension of road reserves and acceptable activities to be conducted in road reserves as well as restrictions. Below are key areas to consider for that matter:

IV.1 Mining and Quarrying Activities

Mining and quarrying, often located near road infrastructure, can lead to soil destabilization, landslides, and increased erosion, especially during heavy rains. These activities can weaken road foundations and increase sediment runoff onto roadways.

Relevant mining authorities should establish buffer zones around roads and implement erosion control measures in mining sites. They should also encourage sustainable mining practices, requiring operators to restore land and manage runoff.

IV.2 Agricultural Practices

Agriculture, especially hillside farming, can contribute to soil erosion, sedimentation, and landslides, which damage roads. This is particularly a concern in Rwanda's mountainous regions where intense rainfall can lead to quick deterioration. Again, poorly managed irrigation systems near roads can lead to waterlogging and seepage under the road foundation, weakening the structure and causing cracking or subsidence.

Relevant agriculture authorities should:

- promote climate resilient agriculture and conservation practices, by cultivating adaptive crops capable to retain soil, agroforestry and cover cropping.
- limit farming too close to roads, especially on steep slopes. The institutions in charge of agriculture will determine additional buffer to the road reserve to be respected to avoid any negative impact to the road infrastructure.
- ensure proper water drainage systems for irrigation projects near road networks.
- educate local farmers and communities on managing water flow to avoid unintended road damage.

IV.3 Logging and Deforestation

Deforestation near road networks can reduce natural barriers to water flow, increasing erosion, landslide risks, and exposure to extreme weather impacts. Roads in deforested areas are more vulnerable to flooding and landslides.

Relevant authorities including local government should enforce reforestation and afforestation programs near roadways to stabilize soils. They should also introduce

policies that restrict deforestation in the road buffer and encourage sustainable forestry practices.

IV.4 Heavy Freight and Transportation Activities

High levels of freight transportation, especially with overloaded trucks, can cause significant road wear, leading to cracking, potholes, and quicker deterioration of the pavement structure. This accelerates the need for repairs, which is costly and unsustainable.

Relevant authorities should implement strict weight regulations for freight vehicles, enforce regular vehicle inspections and ensure strict measures for overloading. They should also enforce the use of dedicated freight routes with more resilient road structures or materials.

IV.5 Urbanization and Construction Activities

Urban expansion and construction increase impervious surfaces, leading to greater stormwater runoff. Without proper drainage, this can cause flooding and water accumulation on roads, accelerating deterioration.

Relevant authorities should integrate stormwater management systems into urban planning to control runoff and ensure that urban developments do not interfere with road infrastructure stability.

IV.6 Water Resource Management and Irrigation

Poorly managed irrigation systems near roads can lead to waterlogging and seepage under the road foundation, weakening the structure and causing cracking or subsidence.

Relevant authorities require proper water drainage systems for irrigation projects near road networks. Educate local farmers and communities on managing water flow to avoid unintended road damage.

By addressing these economic activities in the guidelines, Rwanda can proactively manage and mitigate the adverse effects of economic practices on road infrastructure, ensuring that roads remain resilient and sustainable in the face of climate challenges.

V. PUBLIC AWARENESS

Road authority and local government entities to educate the community on:

- **Preservation of the road infrastructure:** Focus should put on urging the community to implement measures of protecting road infrastructure against disasters and climate risks, namely erosion and land slide by planting trees and/or

preserving of vegetation, avoiding activities in the road proximity that impact roads such as agriculture, mining, deforestation, quarries, etc.

- **Safeguard and safety precautions:** the awareness should focus on educating the community on respecting the safety measures in case of a disaster strike and the risks of violating these measures.

VI. CAPACITY DEVELOPMENT IN CLIMATE RESILIENT ROAD INFRASTRUCTURE

Building capacity in Climate Resilient Road Transport Infrastructure and Disaster Management in Rwanda involves establishing the technical, organizational, and regulatory frameworks that enable engineers, policymakers, and stakeholders to design, build, and maintain road transport infrastructure resilient to climate impacts.

Relevant Agencies (central and local), High Learning institutions should plan and implement regular capacity building for climate resilient infrastructure to ensure available capacities to maintain the resilience aspect in the infrastructure development and management.

VII. CONCLUSION

These Guidelines on disaster and climate resilient road infrastructure and disaster management are critical for safeguarding the country's road network against the increasing impacts of disaster and climate change. Given Rwanda's unique topography, characterized by mountainous terrain and high rainfall, the development of disaster and climate resilient roads is essential to ensure the safety, connectivity, and durability of its transport infrastructure. These guidelines help in shaping a future where roads are designed not only to withstand disaster and climate extremes but also to promote sustainable development and disaster preparedness across the country.

Done at Kigali, on 10th Jan 2025



Digitally
signed by
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