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Remote Sensing Environmental Management Tool – Case of Landslides in the City of Kigali

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ABSTRACT
This study examines the impact of remote sensing in the management and monitoring of environmental problems, taking as an example the landslide in the city of Kigali, Rwanda. The aim of this study is to analyze how remote sensing technology can be used to map risk areas and monitor changes in the landscape, in order to predict landslide risks in advance.
The researchers used various remote sensing instruments including satellite imagery, aerial photographs, and drones, to remotely collect data on Kigali's land surface. The data collected was processed and analyzed through a combination of visual interpretation, image analysis, and GIS technology. They mapped areas with a high probability of landslides and used this data to inform planners, local officials and policy makers on measures to take to reduce existing risks.
The results of the analysis showed that remote sensing is a valuable technology for the management and monitoring of environmental problems of landslides by these strong capacity to detect and map landslides, by providing timely information through its methods of radar and drone images and plays a leading role in the formulation and implementation of landslide risk reduction strategies in Kigali.
In conclusion, the study recommends the use of remote sensing in its highest dimension for the management and monitoring of environmental problems such as landslides in Kigali city. Although measures have already been taken to reduce risks, the use of remote sensing would make it possible to assess risks more accurately, plan appropriate interventions and prevent potential negative consequences for local populations. In addition, it is also recommended to educate the local population about environmental risks and preventive measures to be taken, in order to further reduce the risk of landslides.

Key words : Remote Sensing, Landslide, Disaster Management

I. INTRODUCTION

In recent decades, remote sensing technology has emerged as a cornerstone in the field of environmental management, offering unparalleled capabilities in data collection, analysis, and monitoring. This technology utilizes sensors mounted on satellites, aircraft, drones, and ground-based platforms to capture information about the Earth's surface and atmosphere without direct physical contact. Remote sensing has proven invaluable in various environmental applications, including land cover mapping, vegetation monitoring, water quality assessment, and disaster management.

One critical area where remote sensing technology demonstrates its significance is in the management of landslides, a natural hazard with devastating consequences for human lives, infrastructure, and ecosystems. Landslides, characterized by the movement of soil, rock, and debris down a slope, are influenced by factors such as geological conditions, rainfall intensity, land use changes, and topographic features. In rapidly growing urban areas like the city of Kigali, situated amidst hilly terrain and experiencing frequent heavy rainfall, landslides pose significant threats to public safety and sustainable development.

Traditional methods of landslide management, relying on field surveys, manual mapping, and periodic inspections, are often limited in their spatial coverage, accuracy, and timeliness. According to Kirschbaum et al. (2016), remote sensing technology provides an effective way to map landslide hazards and assess their impact on the environment. Remote sensing technology addresses these limitations by providing a bird's-eye view of the landscape, enabling comprehensive monitoring and analysis of landslide-related parameters over large areas.

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In the case of Kigali, the capital city of Rwanda, the need for effective landslide management is paramount due to its geographical setting and rapid urbanization. Kigali is characterized by steep slopes, fragile soils, and intense rainfall patterns, making it highly susceptible to landslides, especially during the rainy season. As the city continues to expand and infrastructure development accelerates, understanding and mitigating landslide risks become imperative for sustainable urban planning and disaster resilience.

Against this backdrop, remote sensing technology emerges as a valuable tool for enhancing landslide management in Kigali. By providing detailed information on terrain morphology, land cover changes, precipitation dynamics, and other relevant factors. Moreover, remote sensing facilitates early warning systems, enabling timely responses to potential landslide threats and minimizing the impacts on lives and property.

In the subsequent sections of this research, we will delve deeper into the significance of remote sensing technology in landslide management, focusing specifically on its applications in the city of Kigali. Through a comprehensive analysis of remote sensing data, coupled with field observations and stakeholder consultations, we aim to contribute valuable insights and recommendations for enhancing the resilience of Kigali's urban environment to landslide hazards.

The utilization of remote sensing technology in environmental management, particularly in the context of landslide management, presents a critical avenue for enhancing disaster resilience and sustainable development. Rwanda is one of the developing countries that are making progress in the use of remote sensing technology in environmental management. However, several research gaps and challenges persist, precisely in the domain of remote sensing in landslide management.

The general objective of this research is to investigate the role and importance of remote sensing technology in landslide management within the context of environmental management in the city of Kigali.

The theoretical framework for understanding the importance of using remote sensing technology in landslide management in Kigali draws upon several key concepts and theories:

Systems theory posits that environmental systems, such as landscapes and ecosystems, are interconnected and dynamic, with various components influencing each other. In the context of landslide management in Kigali, remote sensing technology serves as a tool for observing and understanding these complex systems, allowing for the assessment of interrelated factors contributing to landslide susceptibility and impacts.

Risk assessment theory emphasizes the importance of systematically evaluating hazards, vulnerabilities, and exposure to determine the likelihood and potential consequences of adverse events, such as landslides. Remote sensing technology facilitates risk assessment in Kigali by providing spatial data on terrain characteristics, land cover changes, and environmental factors that influence landslide occurrences.

GIS theory underscores the role of spatial data analysis and visualization in understanding geographic phenomena and supporting decision-making processes. Remote sensing data, when integrated with GIS, enables the creation of spatial models and maps for identifying landslide-prone areas, assessing their vulnerability, and prioritizing mitigation efforts in Kigali.

The conceptual framework for analyzing the importance of remote sensing technology in landslide management in Kigali encompasses the following key components:

Remote sensing technology involves the collection of data from various sensors mounted on satellites, aircraft, drones, and ground-based platforms. This data encompasses optical imagery, radar data, and other remote sensing datasets, which provide valuable information on terrain morphology, land cover, precipitation patterns, and vegetation health relevant to landslide management in Kigali.

Once acquired, remote sensing data undergoes processing and analysis to extract meaningful information related to landslide hazards. This includes image classification, change detection, and spatial analysis techniques to identify landslide-prone areas, assess their vulnerability, and monitor changes over time in Kigali.

Remote sensing data is often integrated with other datasets, such as geological maps, topographic surveys, and meteorological data, to enhance the understanding of landslide processes and interactions with the environment in Kigali. This integration enables comprehensive risk assessment and mitigation planning strategies.

Overall, the theoretical and conceptual frameworks outlined above provide a structured approach for understanding and analyzing the importance of remote sensing technology in landslide management in the city of Kigali, guiding

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research efforts and informing practical applications in environmental management practices.

II. DATA AND METHODS

2.1. Description of the study air

The city of Kigali is the capital of Rwanda and is located in the geographical heart of Rwanda. Occupying an area of 730 km², the city is located at 10°58' south latitude and 30°07' east longitude. The average annual precipitation rate is approximatelyto 950 millimeters (37.4 inches) per year, with an average annual high temperature of 27°C and an average annual low temperature of 16°C.

Perched at an altitude of 1,400 meters, Kigali is made up of several hills and therefore has a very hilly terrain. It is bypassed by theNyabarongo River. Its population in the city of Kigali is 1,745,555 inhabitants according to the data source of the fifth population and housing census in Rwanda (RPHC5) of August 22, 2022.

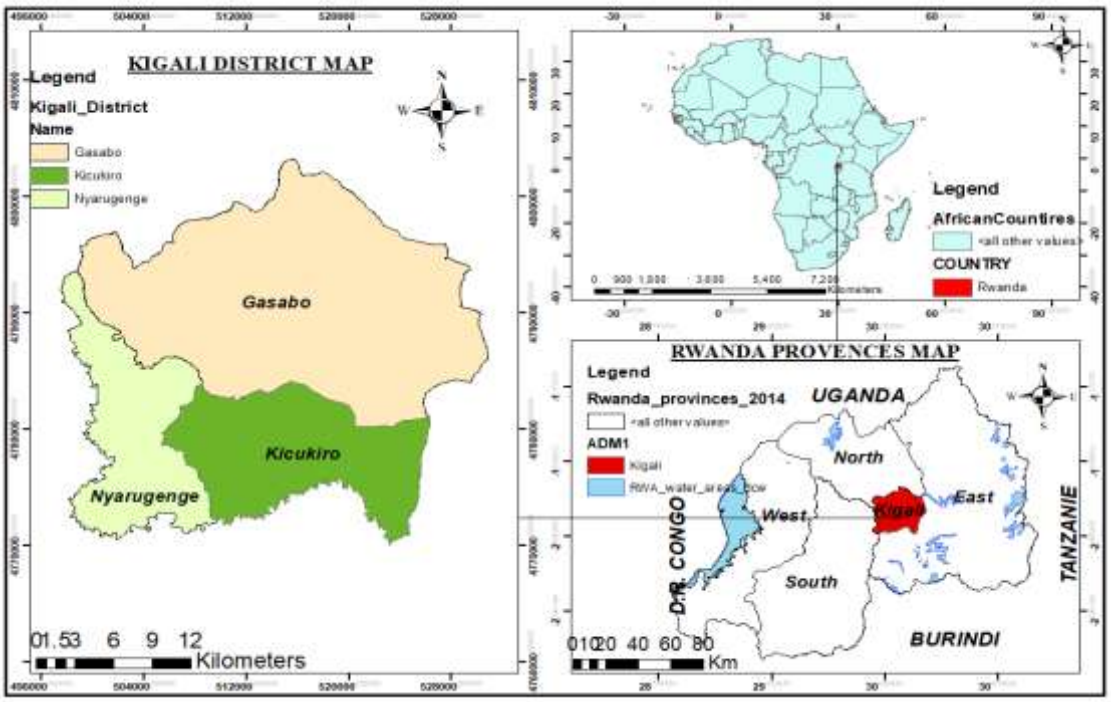

Figure 1: Location Map of the Study Area: a) a Map of Kigali City and they Districts; b) a Map of Africa for Rwanda localization; c) a Map of Rwanda with they 5 provinces.

2.2. Dataset

In Kigali city, landslides have occurred due to various factors such as heavy rainfall, steep topography, deforestation, and improper land management practices. These cases illustrate the importance of implementing effective landslide management practices in Kigali, particularly in areas with haphazard construction, inadequate drainage systems, and waste disposal practices that increase the risk of landslides. Here are some notable cases of landslides in Kigali:

History of Landslide in Kigali				
Time	District	Death	injured	House Dammage
Aug-22	Gasabo			houses destroyed
Jun-21	Gasabo			houses destroyed
Apr-21	Nyaruguengue	8	50	150 houses destroyed
May-20	Gasabo	12		4 houses destroyed
Apr-19	Nyaruguengue	1		12 houses destroyed
May-18	Nyaruguengue			houses destroyed

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Oct-17	Gasabo	9		4 houses destroyed
May-16	Gasabo			houses destroyed
Dec-16	Nyaruguengue			houses destroyed
Apr-13	Gasabo	3	7	56 houses destroyed
Mar-13	Nyaruguengue	4	3	87 houses destroyed
2012	Gasabo		6	houses destroyed
2012	Kicukiro	3		houses destroyed
2005	Kigali	2	3	houses destroyed
May-02	Kigali			houses destroyed

Table 1: History of Landslide in Kigali (Source:MINEMA)

2.3. Methodology

The research uses a combination of quantitative and qualitative methods, including data analysis of remote sensing results, stakeholder interviews and GIS-based spatial analysis.The researchUse of satellite images, aerial photographs, GIS software and ground sensors for data collection and analysis.

The research design for this study is a case study approach, focusing on the use of remote sensing technology in environmental management for landslide management in Kigali city. This design allowed for in-depth investigation of the topic while providing an in-depth understanding of how remote sensing technology can be integrated into current management practices.

The research takes a mixed methods approach, integrating both qualitative and quantitative methods. The qualitative research approach involves interviews and group discussions, while the quantitative approach involves satellite image analysis, statistical analysis, and GIS software.

The data is processed and analyzed by the weight overlay method below using ArcGIS. However, others benefit from the direct application of remote sensing using modeling methods. The findings are presented in a comprehensive report, including recommendations for integrating remote sensing technology in landslide management in Kigali.

III. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Detection and mapingLandslides in Kigali City

The study used a range of remote sensing tools, including satellite imagery, aerial photographs, and drones, to analyze the landscape of Kigali city. The data collected was processed and analyzed through a combination of visual interpretation, image analysis, and GIS technology.

Through satellite imagery, spatial data processing centers such as the National Aeronautics and Space Administration (NASA), the Tropical Applications of Meteorology using Satellite and ground-based data (TAMSAT), the United States Geological Survey (USGS), and the Climate Hazard Center (CHC) provide daily data on factors such as precipitation, soil moisture, and plant cover to national agencies and governments. This data enables the prevention and assessment of natural disasters like landslides and floods. Vulnerable areas can be detected by mapping the data digitally and facilitating risk monitoring.

The remote sensing data collected for this study highlights the conditioning factors of landslides in Kigali, as shown in the maps below. Using the weight overlay method, the analysis helps identify areas at risk of landslides. The data presented in Figures 5 and 6 were established using aerial models, including the Shuttle Radar Topography Mission (STRM) for digital elevation modeling (DEM), Landsat-8 for land use/land cover (LULC), the Moderate-Resolution Imaging Spectroradiometer (MODIS) for soil cover and type, rainfall, and more.

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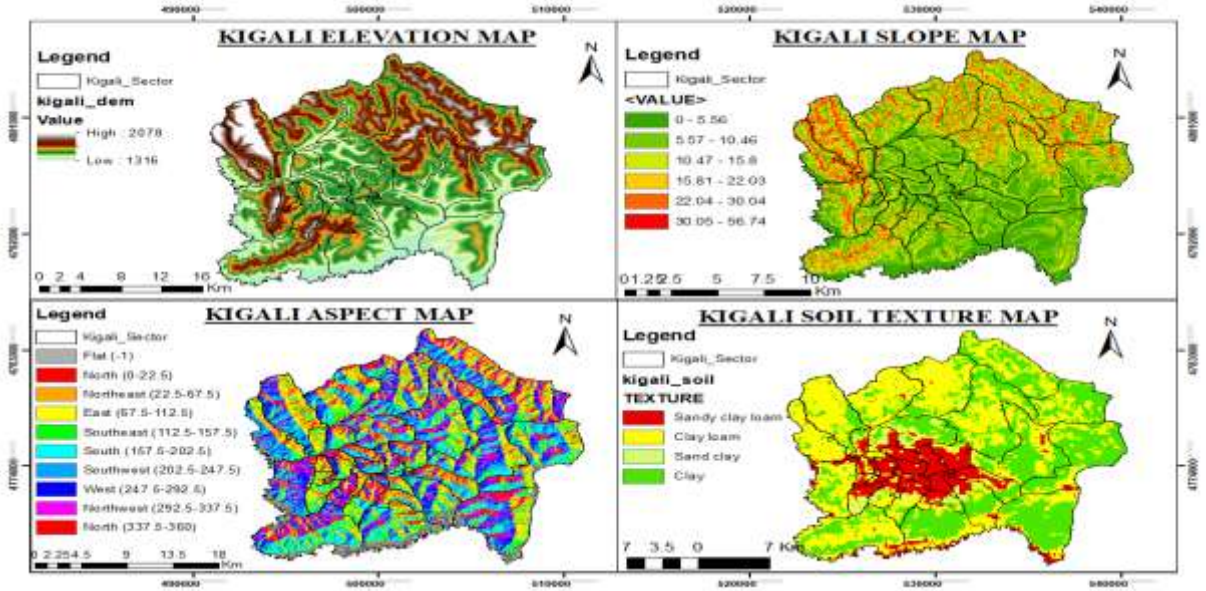

Figure3: Landslide conditioning factors in Kigali: a) a Map of Kigali Elevation; b) a Map of Kigali Slope; c) a Map of Kigali Aspect; d) a Map of Kigali Soil texture.

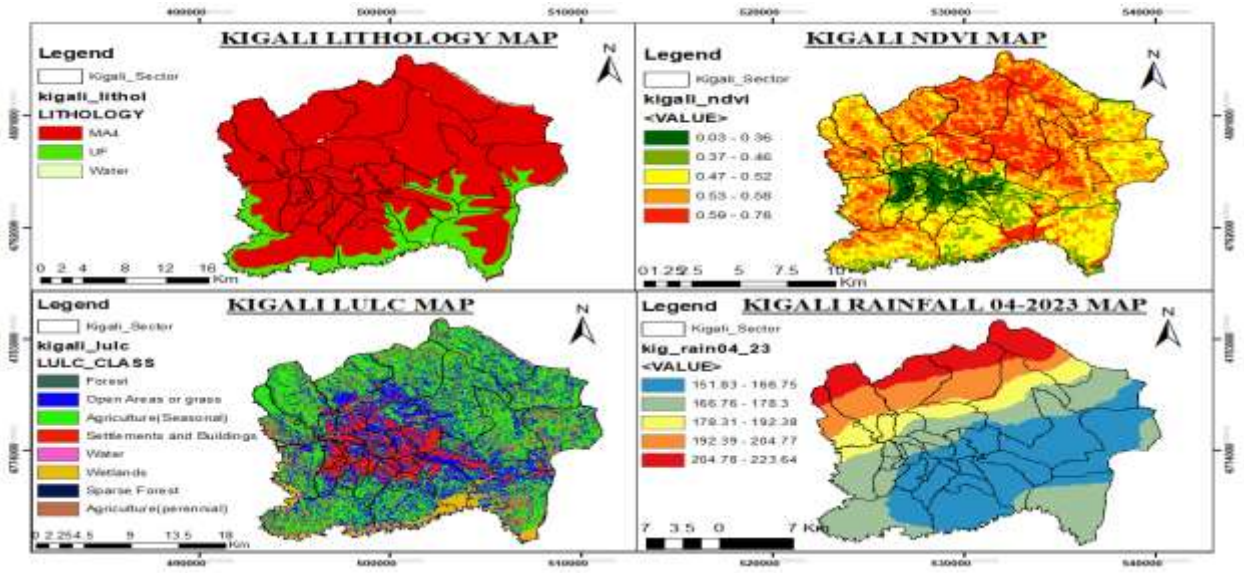

Figure4: Landslide Conditioning factors in Kigali: a) a Map of Kigali Lithology; b) a Map of Kigali NDVI; c) a Map of Kigali LULC;d) a Map of Kigali Rainfall.

The results showed that remote sensing technology was effective in identifying areas prone to landslides in Kigali City. The landslide susceptibility map showed that slopes with high susceptibility were mostly concentrated in the north and weastern part of the city. Several factors contributed to landslide susceptibility in these areas, including steep slopes, rainfall intensity, and soil type.

The map provided critical information necessary for decision making in infrastructural planning and emergency management. Authorities could use the map to identify areas that required slope stabilization, land use restrictions, or other preventive measures. This could potentially save lives and reduce the economic impact of landslides.

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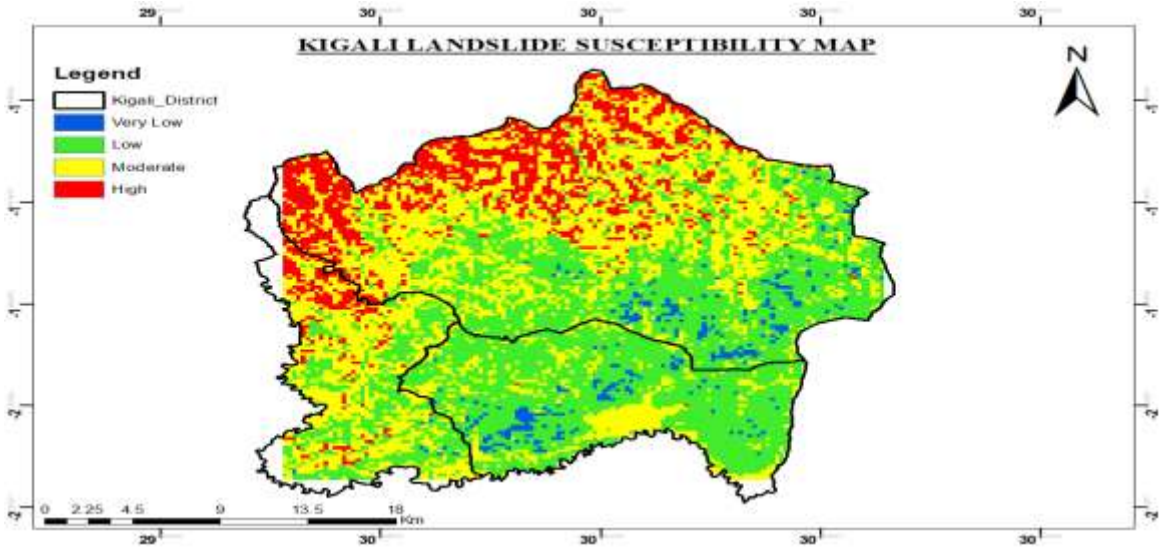

Figure5: Landslide Susceptibility in Kigali

The application of remote sensing to modeling methods helps us produce the maps below with certain data, including rainfall, which is often involved in triggering landslides in Kigali.

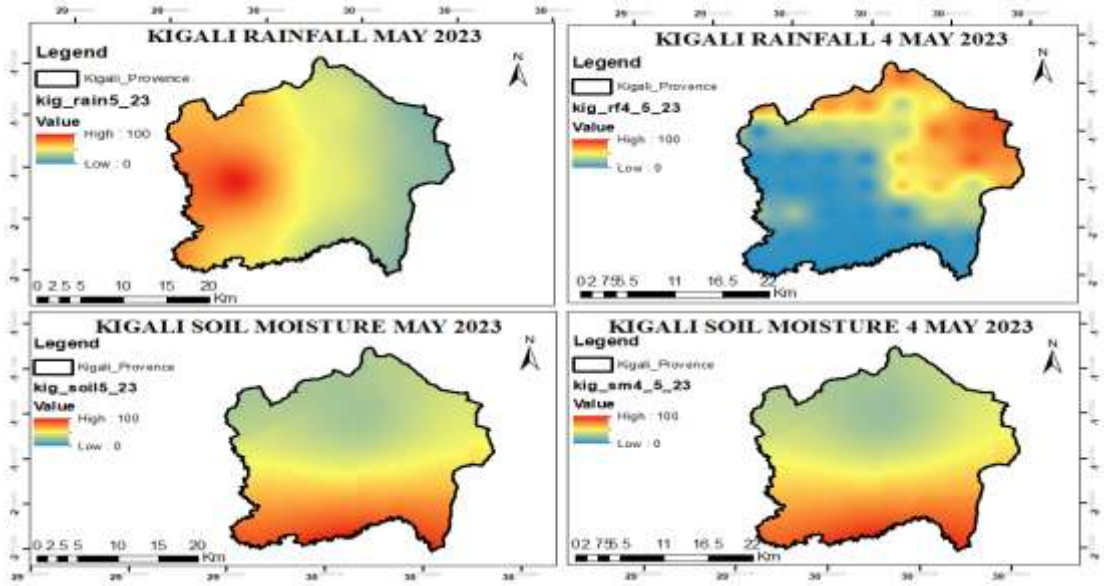

Figure6: Kigali Rainfall and Soil Moisture Map from May-2023: (Rainfall Source: My NASA data, Resolution: 0.5°); (Soil moisture Source: Tamsat, Resolution: 0.25°).

The two resolutions mentioned in the figure 6, like 0.5° for rainfall data from My NASA Data and 0.25° for soil moisture data from Tamsat, refer to the spatial resolution at which the data is sampled or recorded.

A resolution of 0.5° means that the data is recorded or sampled at intervals of half a degree of latitude or longitude on the Earth's surface. This would result in a coarser picture of rainfall distribution, with larger regions being grouped together and possibly missing finer details of rainfall amounts and spatial variability within those regions.

A resolution of 0.25° means that the data is recorded or sampled at intervals of a quarter of a degree of latitude or longitude on the Earth's surface, resulting in a higher resolution picture of soil moisture distribution. This would allow for a more detailed understanding of soil moisture patterns across smaller regions and more accurate identification of areas with high or low moisture content.

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Therefore, the main difference between the two resolutions is the level of detail provided in the data. A resolution of 0.25° is higher than a resolution of 0.5°, making the soil moisture data from Tamsat more detailed and potentially more useful for identifying fine-scale patterns and trends in soil moisture, while the rainfall data from My NASA Data provides a larger-scale view of rainfall distribution.

3.1.2. Landslides information and assess in Kigali City

The images below prove that remote sensing technology is capable of providing us with high-resolution images of areas affected by landslides. This was the case of the Myembe landslide in the Kimihurura sector. We respectively have an image of the place taken by satellite before, during and after the disaster, visualized using Google Earth Pro. In addition, we have a recent image of Myembe after remediation including the site of the previous disaster dating from July 17, 2023. This information can help local authorities develop mitigation strategies and reduce the risk of landslides in this area and in the city of Kigali.

Figure 7: Image of Myembe, in Kimihurura Sector,**Figure 8: Image of Landslide atMyembe**,in Gasabo District in Kigali City. At 01/03/2020 Kimihurura Sector,City at 29/06/2020. One Month Before Landslide (Source Google heart) after the landslide (Source Google heart)

Figure9: Myembe at 14/03/2021, After Landslide **Figure 10: Myembe** at 17/07/2023, after started remediation (Source Google heart)

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Figures 7, 8,9 and 10 illustrate the images taken from Myembe, in Kimihurura Sector, Gasabo District in Kigali City to different dates. We see that the place lost part of its homes during the landslide of May 2020 which cost the lives of 12 people. In addition, a hollow was left on the site,

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creating a break in the land between the inhabitants and the dumpsites until the government's full intervention in 2023 to begin making earth embankments to fill the void in order to to avoid a serious situation.

3.1.3. Findings

The study revealed the following key findings regarding the use of remote sensing technology for managing landslide risks in Kigali city:

The remote sensing technology used in the study was able to accurately identify areas that were prone to landslides based on changes in the landscape. These changes included alterations in the vegetation cover, the presence of cracks in the soil, and changes in the topography.

Remote sensing technology provided valuable information on the amount of rainfall in the area, as well as the resulting runoff. This information was critical for identifying areas that were at risk of landslides and for developing early warning systems for disaster risk management.

Remote sensing technology was able to detect changes in the vegetation cover, which can indicate changes in soil moisture and slope stability. This information was particularly useful for assessing the risk of landslides in areas where significant changes in the vegetation had occurred.

The use of remote sensing technology was critical for developing early warning systems for landslides in Kigali city. By analyzing data from satellite imagery and other sources, experts were able to detect signs of slope instability or changes in soil moisture and issue warnings to residents and officials in the area.

3.2. Discussion

Vulnerability analysis is an essential part of hazard assessment, which encounters complications, reasons for uncertainty and other characteristics. The total landslide exposure estimate for the study area results from the combination of triggering factors including slope, precipitation, soil depth and lithology. According to research as well as history, slope is the most triggering factor for landslides and represents 30% compared to other factors, soil types 20%, precipitation 15%, human activities 5% and the other factors remaining 30%. The landslide vulnerability map hasbeen classified into three classes: low, moderate and high landslides. To recognize landslide information, it is essential to illustrate landslide vulnerability analysis and landslide impact assessment.

This study demonstrates the feasibility of using remote sensing technology for landslide management in Kigali City. Remote sensing data can be used to detect and monitor factors that increase the susceptibility of an area to landslides. The data can be used to create landslide susceptibility maps that can aid in disaster risk reduction, infrastructural planning, and emergency management.

Moreover, the remote sensing-derived information has provided valuable insights into the factors contributing to landslide occurrence in Kigali, including steep slopes, land cover changes, rainfall patterns, and geological characteristics. By understanding these factors, policymakers can implement appropriate mitigation measures to reduce the vulnerability of communities to landslides and enhance their resilience to natural hazards. The Rwandan government and other relevant stakeholders should consider investing in remote sensing technology and collaborating to mitigate the threat of landslides in Kigali City. Then, the study highlight the need for investment in advanced technology infrastructure, in particular, high-resolution images, hardware and matrixes.

IV. CONCLUSION

In conclusion, Landslides have a significant impact on the environment and the people of Kigali. Landslides can cause significant damage to infrastructure, including homes, roads, and public utilities, which can result in loss of life and property. Landslides can also have a severe impact on the environment, leading to soil erosion, water pollution, and habitat destruction for wildlife.

Remote sensing offers numerous advantages across various fields. Some of the key advantages include global coverage, Temporal monitoring, Cost-effective, Repetitive observations, Multi-sensor integration and Non-invasive.

By using remote sensing technology, urban planners in Kigali can gather critical data and insights to help guide and sustainably manage urban growth. Improved understanding of the environment, infrastructure planning, and disaster risk management are all key aspects of urban planning, and remote sensing technology is a powerful tool for enhancing these capacities in Kigali.

Remote sensing technology can be applied to the management and monitoring of landslides in Kigali in several ways.The study recommends that Kigali city should take a number of actions to enhance the use of remote sensing technology for

landslide management. These recommendations include:

- Developing a clear policy framework for the use of remote sensing technology for landslide management, which includes guidance on the sharing of data and information and the coordination of efforts among stakeholders.
- Providing training and technical support to stakeholders on the use of remote sensing technology, including data processing, interpretation, and analysis.
- Establishing partnerships with international organizations and regional initiatives to improve access to data, knowledge transfer, and technology transfer.
- Improving communication, collaboration, and information sharing among different stakeholders, including government agencies, NGOs, academia, and the private sector.
- Encouraging the development of innovative approaches to using remote sensing technology for landslide management, including the integration of traditional knowledge, citizen science, and new technologies.

Overall, the recommendations outlined above can help to facilitate the efficient and effective use of remote sensing technology for landslide management in Kigali, Rwanda. By doing so, it will be possible to reduce the risks associated with landslides and enhance the overall resilience of the city to natural hazards.

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