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Utilizing photogrammetry for forest rehabilitation assessment: Remote sensing techniques applied to Mt Rubavu in Rubavu District, Rwanda

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Abstract
Forest rehabilitation has gained popularity in an era of unprecedented rapid urban growth for sustainable development. Monitoring forest restoration using geospatial technologies has recently attracted many researchers' attention. In Rwanda, GIS and remote sensing have been proven to be useful tools in monitoring rehabilitated forest landscapes. The current work assumes to monitor the spatiotemporal change of the rehabilitated artificial forest of Mount Ruvubu near Rubavu city using advanced photogrammetric images and Geographic Information System (GIS) techniques across three distinct time periods: 2005, 2010, and 2015. The results revealed that forest encroachment increased from 23.5 hectares in 2005 to 23.9 in 2010, followed by a significant reversal of this trend in 2015. The NDVI imagery provides a visual representation of these changes, highlighting encroachment in the western and southwest parts of the forest in 2005 and 2010, and successful rehabilitation in the central and western regions in 2015. All in all, the study demonstrates the effectiveness of remote sensing and GIS in monitoring forest cover and rehabilitation efforts. These technologies are essential in sustainable forest management, offering valuable insights into areas that require immediate attention. GIS and remote sensing are crucial for protecting forest benefits for society and the environment.

1. Introduction

Globally, forests are vital natural assets that support biodiversity, provide food for the human population, and contribute to economic livelihoods(Kinoti & Mwende, 2019). Urban forests are often called "the green lungs" of city ecosystems, providing substantial social, economic, and environmental benefits to urban dwellers. However, rapid urbanization has led to the rapid decline of urban forests and environmental degradation in pursuing socio-economic growth(Kojo & Paschal, 2018).

In the early 21st century, forest conservation has gained substantial attention globally. The United Nations Millennium Development Goals and the United Nations Framework Convention on Climate Change (UNFCCC) have underlined the essential role of forest preservation in pursuing sustainable development. Moreover, introducing Sustainable Development Goals (SDGs), particularly Goal 15 and the Aichi targets, has reinforced the efforts (Duguma et al., 2019).

Recently, researchers have turned their attention to monitoring the dynamic of spatiotemporal land use and land cover (LULC) change using geospatial technology. Several studies have emphasized the essential role of GIS and Remote Sensing in monitoring forest rehabilitation programs to ensure their effectiveness. Geospatial data, GIS and Remote Sensing techniques create meaningful thematic forestry maps, yielding quantitative evidence on forest cover, deforestation, and biophysical aspects (Avtar et al., 2017).

In Rwanda, GIS and remote sensing have been useful in monitoring forest cover changes and restoration outcomes, specifically in Gishwati-Mukura National Park. However, no study has been done to monitor the artificial forest of Mt. Ruvavu adjacent to Rubavu City following the relocation of the encroached forest rehabilitation practices in 2010 for forest management. Therefore, this work aims to utilize photogrammetric images and GIS techniques to monitor forest cover change on Mount Rubavu in three-time series: 2005, 2010, and 2015.

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2. Method

2.1. The study area description

Rubavu District is situated within a high-altitude mountainous area, predominantly in volcanic terrains, and is a constituent part of the Western Province. It is located approximately 145 kilometers from Kigali, the primary gateway to the Democratic Republic of Congo(Kubwimana, 2020). The region encompasses a total land area of 388.3 square kilometers, comprising 12 sectors, 80 cells, and 525 villages. The population density is recorded at 1,614 individuals per square kilometer, with a population count of 546,683 as of 2022(NISR, 2023). The choice of Mountain Rubavu, situated within the Gisenyi sector, was deliberate, and its approximate boundary encompassing an area of 20 square kilometers was meticulously digitized.

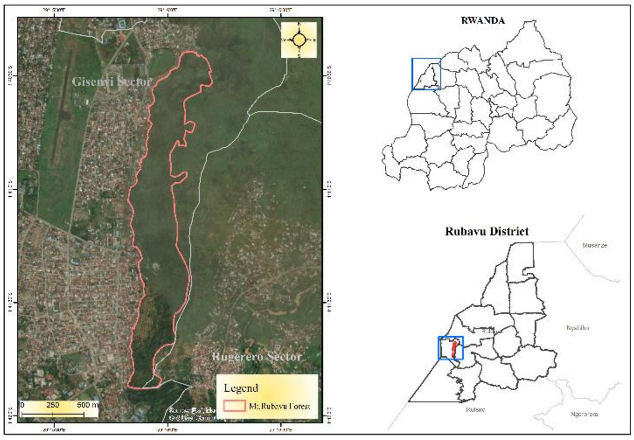

Figure 1. Location map of Mt Rubavu

2.2. Data source

The data employed in this work was meticulously acquired by integrating photogrammetric and remote sensing techniques facilitated by Google Earth Pro. These advanced methodologies were instrumental in bridging critical information gaps and enabling comprehensive geospatial analysis (NISR, 2023). Administrative shapefile data were sourced from DIVA-GIS, enriching the dataset with crucial administrative boundaries and geospatial information. This addition enhances the precision and contextual relevance of the dataset, ensuring a comprehensive understanding of Rubavu District's geographical and administrative landscape.

Figure 1. Data source table

Data	Time	Source
High-resolution images	2005, 2010, 2015	Google Earth Pro 7.3.6.9345 (64-bit)
NDVI	2005, 2010, 2015	https://ladsweb.modaps.eosdis.nasa.gov/
Administrative shapefiles	-	https://www.diva-gis.org/gdata

2.3. Data processing

The forest boundary on Mt. Rubavu was meticulously delineated through digitization using Google Earth Pro, ensuring precise demarcation. Additionally, the level of population encroachment onto the mountain was also digitized using the same tool, capturing data from three distinct time points: 2005, 2010, and 2015. Furthermore, Normalized Difference Vegetation Index (NDVI) values were derived by multiplying 0.0001 with the MOD13Q1 Vegetation Indices for each time frame. This NDVI data was subsequently compared with the encroachment levels to discern correlations or patterns. This comprehensive approach leverages advanced geospatial techniques to gain insights into forest cover dynamics and population impact on Mt. Rubavu over time.

3. Results

3.1. Forest encroachment results for 2005, 2010 and 2015

The forest encroachment rate increased from 2005 to 2010 but decreased significantly in 2015. In 2005, 23.5 hectares of forest were converted to other land uses, particularly informal residential, while 62 hectares remained unconverted. In 2010, the converted area increased to 23.9 hectares, while the unconverted area decreased to 61.6 hectares. However, in 2015, the converted area decreased sharply to 0 hectares, while the unconverted area increased to 85.5 hectares.

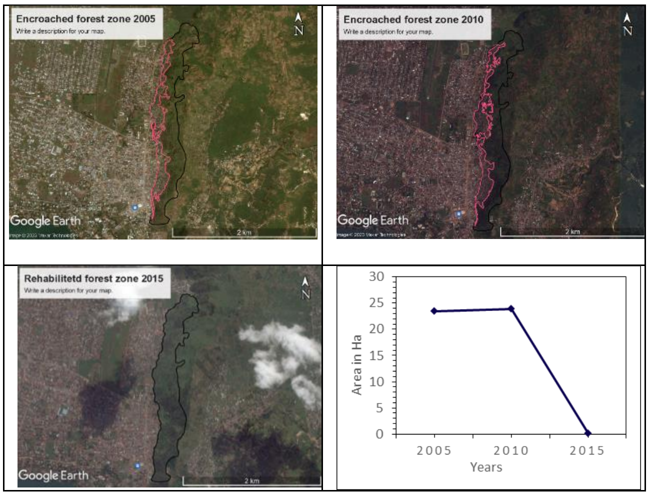

Figure 2. Forest encroachment level

3.2. NDVI change due to forest encroachment.

The NDVI image shows the study area in three different years: 2005, 2010, and 2015. The NDVI values range from -0.2 to 0.9995, with higher values indicating more vegetation cover. The NDVI image-based visualization is valuable for monitoring forest encroachment and rehabilitation. It can identify areas where the forest is at risk and where rehabilitation efforts are successful.

The following observations can be made from the NDVI image-based visualization: The encroachment in 2005 and 2010 is most evident in the western and southwest parts of the forest. However, the rehabilitation in 2015 is most evident in these parts of the forest where encroachment was prevalent. The rehabilitation efforts have restored the forest cover to its pre-encroachment levels.

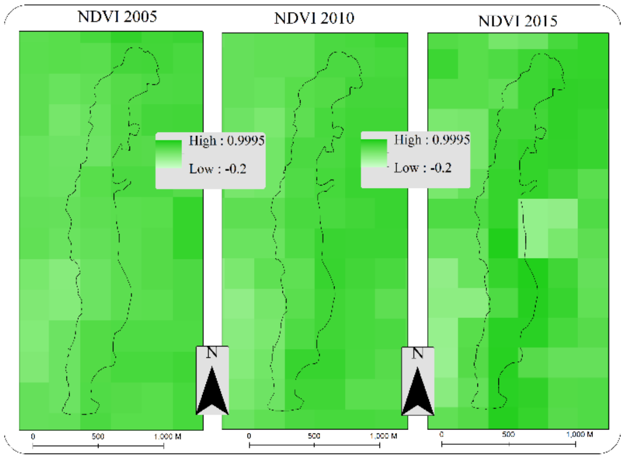

Figure 3. NDVI changes due to forest encroachment

4. Discussion

In the study area, the NDVI image-based visualization and accompanying table indicating forest encroachment trends point to a noteworthy shift toward sustainable forest management (Molnár & Király, 2023). The data emphasizes a substantial reduction in the rate of forest encroachment in recent years attributed to successful restoration initiatives. This positive trajectory indicates a shift towards a more environmentally sound management approach. Current monitoring and proactive measures to mitigate future encroachment are imperative to sustain this progress (Hallegatte et al., 2020). These may encompass heightened law enforcement, incentivizing conservation through economic means, and heightening awareness regarding the significance of sustainable forest management (Malik et al., 2020). By undertaking these measures, the stakeholders responsible for forest management can ensure its continued provision of societal and environmental benefits in the years ahead.

5. Conclusion

Remote sensing data can monitor changes in forest cover and tree health over time. This information can be used to identify areas where encroachment occurs and areas where rehabilitation efforts are needed. The successful implementation of sustainable forest management in the study area is a testament to the power of GIS and remote sensing. By integrating these technologies, forest managers have better understood the forest and make more informed decisions about managing it sustainably.

As we continue to face challenges such as climate change and population growth, the role of GIS and remote sensing in sustainable forest management will only become more important. By investing in these technologies and developing the skills to use them effectively, we can help ensure that our forests can provide their many benefits to society and the environment for generations to come.

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