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Evaluating buffer zones' efficiency for conservation and restoration of Gishwati forest reserve in Rwanda

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ABSTRACT
The conservation and restoration of degraded ecosystems, exemplified by Rwanda's Gishwati Forest, are vital for preserving biodiversity, maintaining ecological balance, and ensuring sustainable resource utilization. This study aims to evaluate the impact of buffer zone implementation on the restoration and conservation of Gishwati Forest Reserve, comparing its status before and after buffer zone establishment. Employing a mixed-methods approach, the research combined Geographic Information System (GIS) analysis of land use/land cover (LULC) changes with questionnaires (360 respondents) and interviews (40 respondents) of local community members, capturing their targeted responses, aimed at gathering data to answer the research questions. It was found that before buffer zone implementation, the Gishwati Forest suffered severe change due to agricultural encroachment, deforestation, Nonetheless, the GIS technique analysis revealed a significant reduction in agricultural area, where Forestland experienced a substantial gain, increasing by 268.6 hectares over the 20-year period, with Cropland experiencing a significant decrease, hovering to the other side, with a total loss of 422.02 hectares, indicating successful restoration efforts. Moreover, survey results show a marked improvement in community perceptions of the forest post-implementation, with 94% of respondents describing it as "very degraded" or "degraded" before the intervention, and 74% ascertain observing improvements afterward. A buffer zone design that integrates concentric rings reflecting increasing ecological protection, stakeholder involvement in planning and robust monitoring and evaluation frameworks, aiming to enhance sustainability and ensure the long-term protection of Gishwati Forest was proposed. The study concludes that buffer zones are instrumental in reversing forest degradation and fostering ecological resilience in Gishwati Forest. To enhance the sustainability of conservation efforts, the study recommends adopting comprehensive buffer zone designs that include continuous community engagement, strict enforcement of conservation regulations, and adaptive management practices informed by regular monitoring and evaluation.

Keywords: Buffer zone, GIS analysis, Gishwati Forest Reserve, Restoration, Rwanda

I. INTRODUCTION

For numerous decades, human activities have exerted a profound and far-reaching impact on global ecosystems, leading to significant transformations in forests, grasslands, and woodlands, largely driven by the expansion of agricultural and permanent pasturelands [1]. This expansive alteration of land use patterns has been exacerbated by the substantial growth of the human population and the escalating demand for forestry and agricultural services, posing substantial challenges to the sustainability of Earth's natural resources [2]. The intricate interconnection between humans and forests underscores the critical importance of forests in fostering economic development and sustaining societal livelihoods, making it imperative to address the fundamental question of whether the Earth's resources can withstand the rapid expansion of the global population [3]. In Africa, forest degradation presents a significant environmental challenge with multifaceted implications, driven by rapid population growth and escalating demands for agricultural expansion, logging, and fuelwood extraction [4]. In the specific context of Rwanda, the management of natural forests has become increasingly complex, particularly in the aftermath of the genocide against the Tutsi, which led to

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significant resettlement efforts with discernible impacts on forest cover, notably in Gishwati Forest [5,6]. The mounting population density in the vicinity of Gishwati Forest, combined with a myriad of anthropogenic factors such as deforestation, agricultural expansion, and illegal logging, have collectively accelerated the degradation of this once-thriving ecosystem[7]. One restorative intervention is the establishment of buffer zones around protected areas, which aims to mitigate human-wildlife conflicts, regulate resource utilization, and facilitate ecosystem restoration [8]. However, uncertainties persist regarding the effectiveness of buffer zone strategies, with challenges such as inadequate enforcement, limited community engagement, and conflicting land-use demands potentially undermining their success [9]. Additionally, empirical data on the ecological and socio-economic impacts of buffer zones within the specific context of Gishwati Forest and Rwanda's environmental and cultural landscape remain limited [10].Despite efforts to conserve its biological diversity, including its designation as a national park, the current status as natural park is Gishwati-Mukura National Park in 2019 [11], the effectiveness of conservation strategies in Gishwati Forest has been limited [8].Through concerted action and continuous learning, it is possible to navigate the complexities of buffer zone governance and realize their potential as a pragmatic conservation tool in safeguarding biodiversity and supporting sustainable development objectives [9,10]. Integrating findings from this evaluation into conservation planning processes will facilitate adaptive management strategies that can address emerging challenges and opportunities in buffer zone governance.

II. METHODOLOGY

2.1. Study area description

The history of Gishwati Forest in western Rwanda reflects a trajectory of environmental degradation and subsequent restoration efforts. Once a thriving tropical rainforest teeming with biodiversity, Gishwati faced extensive deforestation and habitat loss due to population growth, agriculture expansion, and logging activities throughout the 20th century [12]. However, in recent years, concerted efforts, such as the Gishwati-Mukura Landscape Restoration Project, have been underway to rehabilitate the forest ecosystem through reforestation, community-based conservation, and sustainable livelihood programs. While challenges persist, the restoration of Gishwati Forest represents a beacon of hope for biodiversity conservation, ecosystem restoration, and sustainable development in the region [13]. The area of study currently takes part on the administrative District of Rubavu, Nyabihu, Ngororero and Rutsiro where Gishwati natural forest is located. The total number of human populations of these 4 Districts is estimated to about 1.6 million [14]. The community residing near Gishwati Forest sustains itself primarily through subsistence farming, with nearly half of the farmers engaging in agricultural practices on land plots that are less than or equal to 0.5 hectares in size [15].

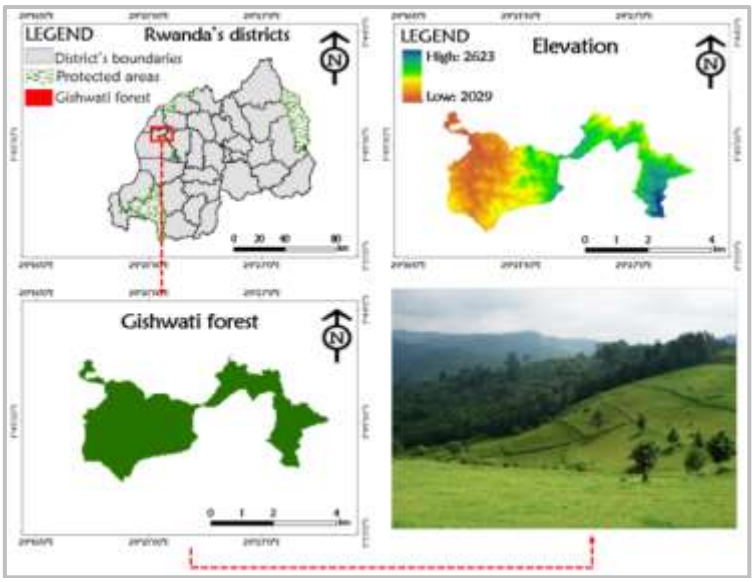

Figure1: Map of the Study Area

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2.3. Data Collection and analysis

The study employed a mixed-methods research design to comprehensively investigate the effectiveness of buffer zones in Gishwati Forest Reserve. The quantitative aspect involved a comparative analysis of ecosystem status before and after buffer zone determination through geospatial data analysis, aerial photos, and documentary analysis. Additionally, community perceptions and experiences regarding the ecosystem pre and post-buffer zone implementation were assessed qualitatively through interviews and questionnaires. Both quantitative and qualitative data were analyzed using appropriate statistical techniques and thematic analysis, respectively. Moreover, the utilization of Geographic Information Systems (GIS) and remote sensing technologies enhanced the accuracy and reliability of spatial data analysis, contributing to the methodological rigor of the study. This research design was carefully crafted to facilitate a comprehensive investigation into the effectiveness of buffer zones in Gishwati Forest Reserve while ensuring methodological rigor and validity of findings.In the 3 districts, Rubavu, Nyabihu, Ngororero, and Rutsiro, bordering the Gishwati forest, a simple random sampling (SRS) method was employed to select a representative population. Ten sectors fulfilling this criterion were selected as the focus for collecting quantitative data. These sectors are namely Kigeyo, Ruhango, and Nyabirasi in Rutsiro, Nyakiliba, Kanzenze, Kanama in Rubavu district. Bigogwe and Jenda Sector in Nyabihu and Muhanda sector in Ngororero district. To determine the sample size, the Cochran's sample size formula[16]. The sample size has used 360 respondents for questionnaires; with 40 respondents answering by interview Adult participants [aged 18 and above] for the questionnaire and interviews were selected. The respondents for questionnaires were selected ensuring representation from all the administrative sectors surrounding Gishwati Forest. For the interviews, purposive sampling was employed to target specific key stakeholders, including government officials and business representatives, to capture their special insights, as they were directly or indirectly involved in the management of the Forest reserve. Twenty government representatives (two from each sector) who had been in administration before and after buffer zone establishment were interviewed to capture their important insights. In addition, twenty businessperson representatives were interviewed]. Choosing business representatives was important since the overexploitation of Gishwati forest ecosystem was mainly for livestock farming and business reasons. These individuals provided valuable insights into the business situation before and after buffer zone establishment.

Secondary data was obtained using GIS and remote sensing techniques. Spatial data was sourced from satellite imagery and field surveys. GIS software was employed to facilitate the organization and analysis of the spatial data. Moreover, these data were also obtained from established literature, reports, and studies providing valuable insights into the investigated topic. Municipal records, existing GIS databases, and published maps also served as secondary sources for spatial data, complementing and validating the results from remote sensing data. The inclusion of only reputable and peer-reviewed sources ensured the reliability of the secondary data.

It is important to note that in the data analysis phase, satellite images were processed and analyzed using Geographic Information Systems (GIS) software to classify land use and cover types and detect changes over the considered period (2000-2020) within the Gishwati forest area. This analysis involves interpreting spectral signatures and applying image classification algorithms to categorize pixels into different land cover classes. The analysis of map data involved a comprehensive examination of spatial information related to Gishwati Forest and its buffer zone. Geographic Information System (GIS) tools were employed to process and analyze the map data, allowing for the identification of key spatial patterns and relationships. This analysis includes cross-referencing the collected map data with primary map sources to validate accuracy and completeness. By leveraging GIS technology, the study aimed to extract valuable insights into the ecological landscape and spatial dynamics of the Natural Forest. To address validity, ground truth data were collected through extensive field surveys across representative locations within the study area. These ground truth observations served as reference points to calculate accuracy metrics, such as overall accuracy, producer's accuracy, and user's accuracy, by comparing them with the classified LULC map through a confusion matrix. This approach ensured that the map accurately represented the true LULC conditions on the ground.Additionally, the Statistical Package for Social Sciences (SPSS) software was employed to perform quantitative analyses on survey data, community experience and perceptions, and other

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relevant variables, allowing for statistical comparisons and correlations.

III. RESULTS

3.1. Status of Gishwati forest reserve before and after buffer zone implementation

The comparison of Gishwati forest land cover before and after the implementation of the buffer zone strategy reveals compelling insights into the effectiveness of restoration efforts. Prior to restoration, the eastern part of Gishwati Forest experienced significant deforestation, with forest cover being converted to other land uses, predominantly crop cultivation (Figure 2). This conversion not only threatened biodiversity but also undermined the ecosystem services provided by the forest, such as carbon sequestration, water regulation, and soil conservation.

In 2015, the implementation of the buffer zone strategy marked the beginning of a concerted effort to halt and reverse these detrimental changes. Buffer zones were strategically placed to reconnect fragmented forest patches, particularly focusing on the eastern section which had undergone severe degradation. The primary goal was to create a continuous corridor of forested land that would facilitate wildlife movement, enhance genetic flow, and improve ecological resilience. GIS-generated figures below offer a good graphical and numerical representation of the outcome.

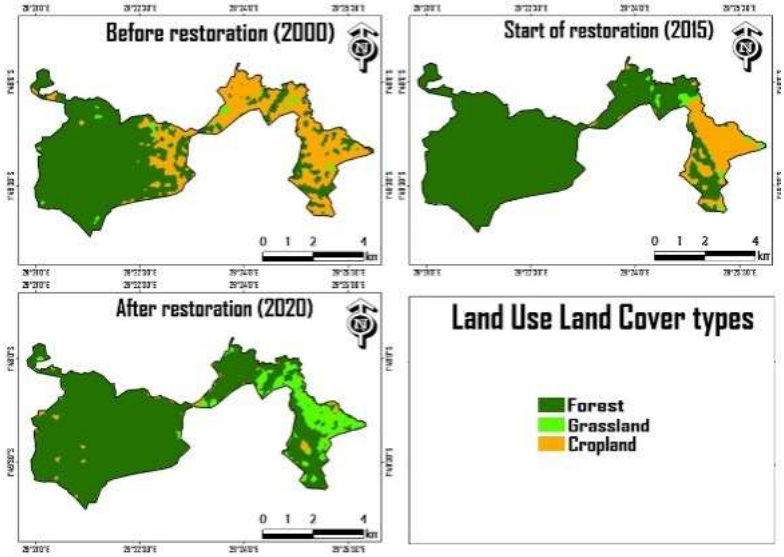

Figure 2: Gishwati forest cover before and after buffer zone establishment

Table 1: Quantitative analysis of forest cover change process (2000 - 2020)

Area in hectares						
Classes	**2000 Before rest.**	**2015 Start of rest.**	**2020 After rest.**	**Change 2000 - 2015**	**Change 2015 - 2020**	**Change 2015 - 2020**
Forestland	1011.5	1272.26	1280.1	260.76	7.84	268.6
Grassland	60	70.85	215.48	10.85	144.63	155.48
Cropland	496.5	226.98	74.48	-269.52	-152.5	-422.02
Total	1568	1568	1568			

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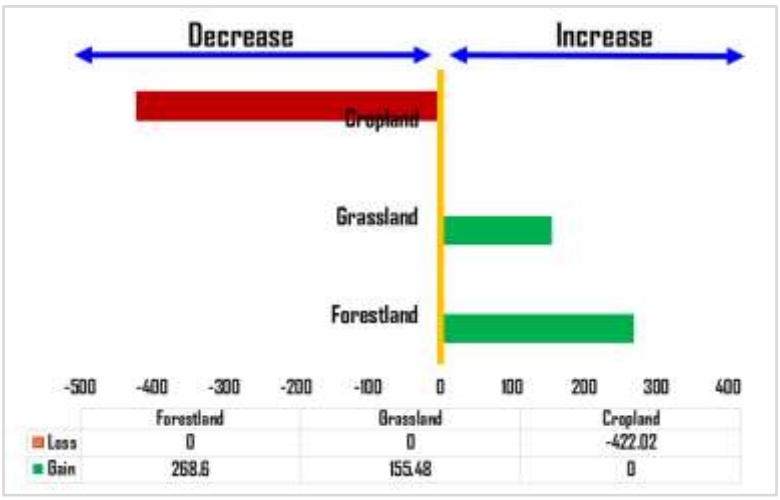

Figure 3: Forest cover change in terms of gains and losses (2000 - 2020)

Quantitatively, the analysis of forest cover changes in Gishwati Forest from 2000 to 2020 reveals significant transformations across various land use classes. According to Table 1, in the year 2000, before the restoration efforts began, forestland covered 1,011.5 ha. By the start of the restoration process in 2015, forestland had increased to 1,272.26 ha, showing a gain of 260.76 ha. This positive trend continued, and by 2020, after five years of restoration activities, forestland further expanded to 1,280.1 ha, marking an additional increase of 7.84 hectares from 2015 to 2020, climaxing in a total increase of 268.6 ha over the 20-year period. Grassland areas also experienced a noticeable change. Initially, grassland covered 60 hectares in 2000. This increased slightly to 70.85 ha by 2015, indicating a growth of 10.85 ha. The most substantial change occurred between 2015 and 2020, where grassland expanded dramatically to 215.48 ha, an increase of 144.63 ha, totaling a significant growth of 155.48 ha over the entire period. On the other hand, cropland saw a marked decline over the same timeframe. In 2000, cropland occupied 496.5 ha. By 2015, this area had decreased significantly to 226.98 ha, a reduction of 269.52 ha. The decline continued more sharply between 2015 and 2020, with cropland reducing further to 74.48 ha, representing a decrease of 152.5 ha during this period. Overall, cropland diminished by 422.02 ha from 2000 to 2020.

These quantitative changes emphasize the effectiveness of the buffer zone strategy and restoration efforts in Gishwati Forest. The increase in forestland and grassland, coupled with the significant reduction in cropland, highlights the successful reforestation and land rehabilitation, as implemented through the LAFREC project.

Furthermore, the analysis of land use/land cover (LULC) changes in Gishwati Forest, as illustrated in Figure 3, also reveals analogous significant shifts between 2000 and 2020. The figure clearly indicates the extent of change across different land use categories: forestland, grassland, and cropland. Forestland experienced a substantial gain, increasing by 268.6 ha over the 20-year period. This positive change underscores the success of the buffer zone strategy and reforestation efforts aimed at restoring the forest ecosystem. The increase in forestland reflects targeted interventions to halt deforestation and promote forest regeneration, particularly in previously degraded areas. Grassland also saw a considerable increase, with a gain of 155.48 ha. This transformation highlights the intermediate step of converting cropland into grassland as part of the broader restoration strategy. Grasslands serve as a critical transitional phase in ecological restoration, providing necessary habitat for various species and stabilizing the soil, which further facilitates the re-establishment of native forest vegetation. In plain contrast, only cropland experienced a significant decrease, hovering to the other side, with a total loss of 422.02 ha. This reduction indicates a successful reduction in agricultural encroachment within the forest reserve, which was a requisite if the restoration effort was to succeed. The decrease in cropland is a direct result of implementing the buffer zone, which helped to curb unsustainable agricultural practices and prioritize land for ecological restoration.

The contrasting trends depicted in Figure 3 clearly highlight the dynamic landscape changes

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driven by restoration effort in Gishwati Forest. These quantitative shifts demonstrate the effectiveness of the buffer zone strategy in reversing deforestation trends and promoting sustainable land use. By converting cropland into grassland and eventually into forestland, the restoration activities have enhanced the ecological integrity and resilience of the Gishwati Forest Reserve. In addition, the cessation of crop establishment within the buffer zones played a pivotal role in this transformation. By preventing further agricultural encroachment, the buffer zones allowed for natural regeneration processes to take hold. Additionally, active reforestation efforts, such as planting native tree species, further accelerated the restoration of forest cover. This dual approach of protecting existing forest areas while rehabilitating degraded lands underscores the importance of comprehensive restoration strategies.

3.2. Community perceptions on the Gishwati forest change before and after buffer zone implementation

Table 2 below serves as a pivotal illustration in capturing the nuanced shifts in community perceptions surrounding Gishwati Forest, delineating perceptions before and after the implementation of buffer zones. These perceptions stand as a testament to the intricate interplay between conservation interventions and local attitudes, shedding light on the efficiency of buffer zone initiatives in mitigating deforestation and fostering sustainable forest management practices. By delving into these perceptions, this study aims to unravel the underlying dynamics shaping community responses to conservation efforts, providing critical insights for refining future strategies; referring on the case of Gishwati forest reserve. The comprehensive analysis of pre- and post-implementation perceptions offers a holistic understanding of the multifaceted challenges and opportunities inherent in forest conservation endeavors, guiding policymakers and stakeholders towards more informed decision-making processes aimed at fostering resilience and harmony between human communities and forest ecosystems.

The statistics presented in Table 2 illustrate a significant shift in community perceptions regarding Gishwati Forest's condition before and after buffer zone implementation. Before the establishment of buffer zones, approximately 17% of respondents perceived the forest as "very degraded," while around 55% considered it "degraded," reflecting widespread concerns about the deteriorating state of the forest. Moreover, roughly 22% of respondents viewed the forest as "moderately degraded," with an additional 6% perceiving it as "slightly degraded." These perceptions align with documented challenges such as deforestation and habitat fragmentation resulting from human activities like agriculture and logging.

Following the implementation of buffer zones, however, there has been a marked improvement in community perceptions. None of the respondents reported the forest as "very degraded," "degraded," "moderately degraded," or "slightly degraded" after buffer zone implementation, indicating a significant reduction in negative perceptions. Instead, approximately 74% of respondents described the forest as "improved," reflecting a more optimistic outlook on its condition. This positive shift is corroborated by qualitative insights from community members, such as a local farmer who described the forest as "bare and lifeless" before buffer zones but now perceives it as "greener and more vibrant." Additionally, around 26% of respondents noted that the forest condition had "stayed the same" post-implementation, indicating stabilization and halting further degradation.

Table 2: Community perceptions on Gishwati forest condition before and after buffer zone implementation

Perception on forest condition	Before buffer zone implementation (%)	After buffer zone implementation (%)
Very degraded	17	0
Degraded	55	0
Moderately degraded	22	0
Slightly degraded	6	0
Improved	0	74
Stayed the same	0	26

These findings underscore the effectiveness of buffer zone measures in mitigating forest degradation and fostering ecosystem recovery. By regulating resource utilization and mitigating human-wildlife conflicts, buffer zones have contributed to tangible improvements in forest

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health and ecosystem resilience. Moreover, the stabilization of forest conditions post-implementation highlights the importance of halting further environmental decline, laying the groundwork for long-term conservation efforts. In fact, the comparison of perceptions before and after buffer zone implementation reveals a significant positive shift in attitudes towards Gishwati Forest's condition, matching the results obtained using GIS previously in this chapter. These findings emphasize the importance of community engagement and perception in conservation efforts and underscore the success of collaborative approaches that prioritize local knowledge and participation. By actively involving communities in conservation decision-making and fostering a sense of ownership over natural resources, buffer zones have not only improved forest health but also strengthened community support for conservation initiatives.

Additionally, research participants presented a diverse array of perspectives regarding the mitigation of concerns surrounding Gishwati Forest degradation after the establishment of the buffer zone. While a majority expressed optimism, noting observable improvements and affirming that their apprehensions had been effectively assuaged, a minority remained uncertain or voiced persisting challenges. Among those who perceived their concerns as addressed, there was acknowledgment of specific positive changes, such as a reduction in habitat destruction and enhanced management of wildlife displacement. Conversely, participants who felt their concerns had not been adequately resolved underscored ongoing issues such as habitat fragmentation and shortcomings in enforcing buffer zone regulations. These divergent viewpoints underscore the nuanced nature of conservation efforts and highlight the imperative for tailored strategies to tackle the multifaceted challenges confronting Gishwati Forest. Moreover, the variation in responses underscores the importance of ongoing monitoring and adaptive management to address evolving conservation needs and ensure the long-term sustainability of buffer zone initiatives.

3.3. Effective buffer zone designs for local environmental and community needs that maximize restoration and conservation

Surveyed participants contributed a diversity of recommendations aimed at encouraging buffer zone efficacy. Suggestions encompassed augmenting community engagement in conservation actions, instituting more stringent enforcement protocols, and implementing targeted interventions to tackle environmental concerns systematically. The range of proposals highlights the necessity for continuous stakeholder involvement and adaptive management strategies to maximize conservation outcomes within Gishwati Forest. This stresses the significance of more promotion of collaborative partnerships and flexibility in adapting to dynamic environmental circumstances, ensuring the sustained effectiveness of buffer zone initiatives in safeguarding the forest ecosystem.

The third objective of this study aims to determine effective buffer zone designs that are appropriate for the local environmental and community needs, maximizing restoration and conservation efforts. Drawing from the data and insights gathered from the community surrounding Gishwati Forest, it is essential to propose buffer zone designs that integrate ecological, social, and economic considerations.

3.3.1. Ecological considerations

To maximize restoration and conservation, buffer zones around Gishwati Forest should incorporate the following ecological elements:

- ✓ **Corridor connectivity:** As evidenced by the successful re-establishment of native vegetation and the transformation from crop-dominated land to grassland, it is crucial to enhance wildlife corridors. These corridors connect fragmented forest patches, facilitating wildlife movement and genetic flow, which are vital for maintaining biodiversity and ecological resilience.
- ✓ **Native species planting:** Active reforestation efforts with native tree species should continue to accelerate the restoration process. This approach has already shown success in re-establishing forest cover and should be a cornerstone of buffer zone design.
- ✓ **Water management:** The buffer zones should include riparian buffers along water bodies to prevent soil erosion, improve water quality, and support aquatic ecosystems. Effective water management practices will enhance the overall health of the forest ecosystem.

3.3.2. Social considerations

The involvement and support of local communities are critical to the success of buffer zone initiatives. Based on community feedback, the following social considerations should be integrated into buffer zone designs:

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- ✓ **Community Engagement:** Active participation of local communities in planning and implementing buffer zones is essential. This includes involving community members in decision-making processes and conservation activities, ensuring their knowledge and needs are considered.
- ✓ **Alternative Livelihoods:** To reduce dependency on forest resources, buffer zones should provide alternative livelihood opportunities. Eco-tourism, sustainable agroforestry, and community-based conservation projects can offer economic benefits while promoting conservation.
- ✓ **Educational Programs:** Enhancing awareness and education about the importance of buffer zones and conservation can foster community support. Educational programs targeting different age groups can leverage the innovative ideas of younger individuals and the traditional knowledge of older community members.

3.3.3. Economic considerations

Ensuring that buffer zone designs are economically viable and beneficial for local communities can enhance their sustainability through:

- ✓ **Sustainable resource use:** Buffer zones should incorporate sustainable harvesting practices for non-timber forest products. This can provide economic benefits to local communities without compromising conservation goals.
- ✓ **Incentive programs:** Financial incentives, such as payments for ecosystem services (PES), can encourage local communities to engage in and support conservation activities.
- ✓ **Collaborative partnerships:** Establishing partnerships with local businesses, government agencies, and non-profit organizations can provide financial and technical support for buffer zone management.

3.3.4. Proposed buffer zone design

Based on the pre-discussed considerations, an effective buffer zone design for Gishwati Forest (Figure 4-3) should include the following components:

- ✓ **Strictly protected area:** Strictly protected area within the forest where no human activities are allowed to ensure maximum ecological preservation.
- ✓ **A conventional buffer zone:** Surrounding the core zone, this area would allow controlled activities such as eco-tourism, sustainable agroforestry, and the collection of non-timber forest products. It would also serve as a corridor for wildlife movement.
- ✓ **Transition zone:** The outermost layer where more intensive land uses such as agriculture and settlement are managed sustainably to reduce their impact on the forest. This zone includes community engagement initiatives and educational programs.
- ✓ **Monitoring and Evaluation:** As an overarching necessity, this should involve the incorporation of GIS technology for continuous monitoring and adaptive management, ensuring real-time data-driven decisions. Monitoring Stations are Specific points within each zone (Core, Buffer, and Transition), marked by a house icon; these stations should collect daily data on biodiversity, forest health, water quality, and community engagement.

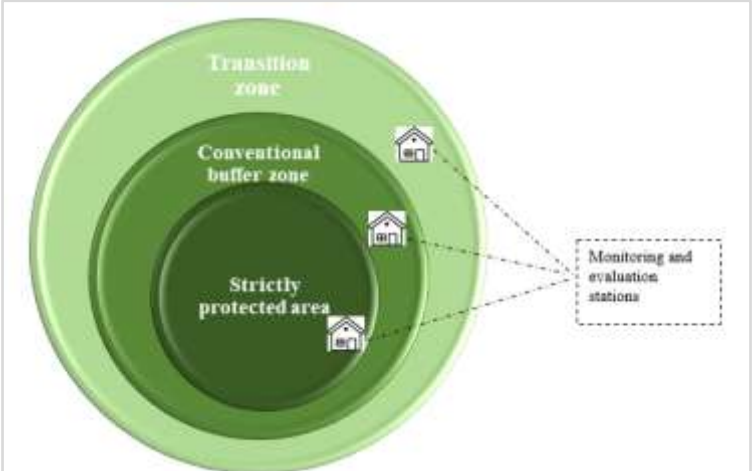

Figure 4: Proposed Effective buffer zone design. Source: Author's compilation

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IV. DISCUSSION

The implementation of strategically designed buffer zones within the Gishwati Forest Reserve has yielded remarkably positive outcomes, both ecologically and socially, emphasizing the profound impact of this conservation approach. The observed significant increase in forest cover and the encouraging conversion of previously cultivated areas to grasslands and native vegetation serve as tangible indicators of the success of natural regeneration and active reforestation efforts facilitated by the establishment of these protective zones [17]. This resurgence of vegetation not only enhances the aesthetic appeal of the landscape but also contributes to the restoration of crucial ecological functions and services provided by the forest ecosystem as also found by previous studies [18]. Crucially, the establishment of buffer zones has proven to be an instrumental force in mitigating the pervasive threat of deforestation [19], which had previously plagued the integrity of the Gishwati Forest Reserve. By creating a strategic protective barrier around the core reserve area, these zones have effectively curbed the encroachment of agricultural activities and reduced the intense human pressure on the forest's finite resources. This finding resonates with a growing body of scientific literature that has consistently demonstrated the remarkable ability of well-designed buffer zones to safeguard protected areas from external anthropogenic disturbances, such as illegal logging, poaching, and unsustainable resource extraction [20]. The positive transformation witnessed in the Gishwati Forest Reserve serves as a compelling case study, further solidifying the significance of buffer zones as a vital component of conservation strategies aimed at preserving biodiversity hotspots and ecological sanctuaries.

The comprehensive analysis of LULC changes before and after the intervention provides compelling empirical evidence that validates the effectiveness of buffer zones as a conservation strategy [21]. The positive impacts of the buffer zone implementation in the Gishwati Forest Reserve may extend beyond the realm of ecological restoration and preservation. The insightful analysis of community perceptions reveals a profound shift in attitudes towards the condition of the forest, presenting the profound social implications of this conservation initiative [22]. Prior to the intervention, the prevailing perception among respondents was one of concern and dejection, with the majority describing the forest as severely degraded, reflecting the widespread apprehension about rampant deforestation and the consequent loss of vital habitats. However, in the post-implementation phase, the community's perceptions have undergone a remarkable transformation, with a considerable proportion of respondents acknowledging the discernible improvements in the forest's health and resilience [23]. This striking change in perception highlights the critical importance of actively engaging local stakeholders in conservation efforts, as it fosters a sense of ownership, pride, and long-term commitment to the preservation of natural resources [24]. When communities witness tangible positive changes and experience the direct benefits of conservation initiatives, they become invested partners in the endeavor, further amplifying the likelihood of sustained success.

The study's findings on the design elements of effective buffer zones offer invaluable insights for maximizing the outcomes of restoration and conservation efforts while ensuring that local environmental and community needs are holistically addressed. The establishment of a comprehensive zoning system, comprising core zones for strict protection, buffer zones for sustainable use and facilitation of wildlife corridors, and transition zones for sustainable agriculture and human settlements, provides a robust and integrated framework for ecosystem management [25]. This strategic strategy not only enhances the protection of the most ecologically sensitive areas but also creates opportunities for sustainable resource utilization and economic activities in designated zones, thereby promoting harmony between conservation goals and community livelihoods. Furthermore, the incorporation of riparian buffers along water bodies serves as an additional layer of ecological reinforcement, contributing to the stabilization of aquatic ecosystems and the maintenance of crucial hydrological processes [26].

Perhaps one of the most outstanding lessons derived from this study is the paramount importance of continuous monitoring and evaluation across all zones within the buffer zone system. Such vigilant oversight facilitates adaptive management strategies and ensures the long-term effectiveness of the conservation efforts[27]. As environmental conditions and community dynamics evolve over time, the ability to make informed adjustments to buffer zone management practices becomes critical to sustaining the positive impacts achieved. Additionally, the integration of community engagement initiatives and the promotion of alternative livelihood opportunities,

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such as eco-tourism and sustainable agroforestry practices, emerge as essential components for ensuring that the buffer zones meet both conservation and socio-economic objectives [28]. By addressing the economic needs and aspirations of local communities while simultaneously providing sustainable income streams, the long-term viability and success of conservation efforts are greatly enhanced, as communities become vested partners in the preservation of their natural heritage.

In a nutshell, the findings from this comprehensive study serve as a resounding testament to the significant contributions of strategically designed and implemented buffer zones in catalyzing the restoration and conservation of the Gishwati Forest Reserve in Rwanda. The positive ecological impacts, manifested in the recovery of forest cover and the revival of native vegetation, coupled with the profound shift in community perceptions towards a more favorable outlook on the forest's condition, underscore the multifaceted benefits of this approach. Moreover, the insights gleaned from this study offer a valuable blueprint for crafting effective buffer zone designs that harmoniously reconcile conservation goals with the unique environmental and socio-economic contexts of local communities. By embracing an inclusive and holistic approach to conservation, one that actively involves stakeholders and addresses their needs, the long-term sustainability and success of such initiatives are greatly amplified, paving the way for a future where the preservation of natural treasures and the well-being of human communities are inextricably intertwined.

V. CONCLUSION AND RECOMMENDATIONS

In conclusion, this research underscores the significant impact of buffer zone implementation on the restoration and conservation of the Gishwati Forest Reserve. The study reveals that strategic buffer zones have effectively reversed deforestation trends, and restored essential ecosystem services. Community perceptions have shifted positively, reflecting increased local support and engagement in conservation efforts. The findings also highlight the importance of designing buffer zones that address both environmental and community needs, incorporating continuous monitoring and adaptive management. Overall, the successful case of Gishwati Forest demonstrates the critical role of buffer zones in achieving sustainable forest management and ecological resilience, offering valuable insights for similar conservation initiatives worldwide.

Several recommendations emerge, with key among them outlined below:

✓ **To the government and policy makers**

The findings of this research permit to recommend the government to put more investment in developing a GIS approach that monitors environmental status on a daily basis. This research has proven how this technology is efficient in analyzing LULC change and therefore taking appropriate measures in case of need. In addition, the government should invest its efforts in involving the community around the areas under conservation since the local community is the driving force towards knowing the major causes of degradation and enhancing conservation efforts.

✓ **To the local community**

The local community is the primary beneficiary of a conserved natural area through ecological benefits but also coupled economic benefits. The local community should take responsibility of keeping the continuity of the conservation measures set in place, acknowledging that the degradation that had occurred was due to human activities. In addition, the community should participate in developing eco-friendly business ideas instead of environmentally-harmful activities.

✓ **To investors**

Investing in research using GIS technology would be a sustainable idea. Such a protected area would give a good ground for the experimentation of various environmental phenomena. Secondly, there is opportunity for investment in the community in Gishwati buffer zones since this community needs alternative sources of income to stay away from the protected area.

✓ **To Future research directions**

Based on the study's conclusions, I strongly recommend research on the restored ecosystem services. That could imply similar research to assess the trend in the variability form the period spanning the pre-restoration period to the present day. This research would be a good input in enhancing Gishwati natural reserve value since income to the local community and the government would be generated. In addition, further research is needed to assess the interplay between different social parameters such as

employment rate on the success of restoration initiatives.

VI. ACKNOWLEDGMENTS

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