

Contribution Mining Activities and Vegetation Dynamics in Gishwati-Mukura National Park, Rwanda

KARANGWA Clement¹, Prof Mupenzi Christophe² *

¹Faculty of Environmental and Development Studies, Environmental Economics and Natural Resources Management, University of Lay Adventists of Kigali (UNILAK), Kigali, Rwanda, Karangwac349@gmail.com

²Faculty of Environmental and Development Studies, University of Lay Adventists of Kigali (UNILAK), Kigali, Rwanda

Corresponding Author : Mupenzi Christophe commupenzic@gmail.com



Abstract: Gishwati-Mukura National Park (GMNP) is a protected area of Afromontane Forest ecosystem in western part of Rwanda that serves purposes of biodiversity conservation and regulation of climate and watershed but mining has been noted to be one of the major pressures within the park. This study was carried out to investigate the impact of mining operations on the vegetation cover in GMNP and the surrounding areas through a mixed methodological approach of field surveys, questionnaires and interviews together with GIS and remote sensing technology. There were 106 valid respondents who participated in the survey data analyzed. They included the community members, local authorities, mineworkers and GMNP officers from the selected areas of Rutsiro and Ngororero districts. Deforestation and loss of vegetation cover emerged as the most commonly mentioned vegetation change (40 respondents), with the reduction of forest vegetation cover being the most commonly cited impact (34 respondents). Geospatial analysis revealed forest cover of 89.8%, 86.9%, and 98.7% in the years 2015, 2020, and 2025 respectively, revealing a temporary reduction but significant recovery of the landscape. Further, through change detection analysis, 3,059.2 ha of the land retained its forest cover, while 118.0 ha and 196.3 ha of the land, previously occupied by cropland and grassland respectively, converted into forests. All in all, the results indicate that landscape recovery and forest recovery may proceed hand in hand with mining disturbance in specific localities.

Keywords: Artisanal mining; Vegetation degradation; Gishwati-Mukura National Park; GIS; Remote Sensing; LULC and Restoration.

1. Introduction

Mining is an economically valuable industry; however, surface disruption, deforestation, waste dumping and access creation can result in long-lasting ecological impacts, particularly in conservation areas and forested areas [1] Research on mining-affected forests has shown that mining results in the reduction in the diversity of trees and shrubs, habitat fragmentation, soil disruption and delayed ecological restoration due to concentrated mining impact [2].

In sub-Saharan Africa, the tree cover loss from mining activities can be associated not only with the direct footprint of mining operations but also with the indirect pressures related to road construction, settlements [3]. Similar research in Tanzania, Uganda, and western Kenya showed transformation of forest and shrub-grassland ecosystems, destruction of riparian vegetation, erosion, and plant diversity loss. Remote sensing and GIS technologies are thus increasingly being employed along with the ground truth data to differentiate the local disturbances from larger landscape trajectories and measure changes in land cover through time.

An interesting example for the same is that of the Gishwati-Mukura National Park of Rwanda wherein the landscape has undergone degradation, conservation and restoration processes while impacts on the soil, water and vegetation have been

observed due to mining. [4]. Management strategies for protected areas must consider the importance of ecosystem integrity and the socio-economic context within which resource utilization takes place [5].

Study problem and objective. Though efforts towards conservation and restoration have made parts of the Gishwati-Mukura landscape in good conditions, mining that takes place in and outside the park remains an issue of worry due to vegetation clearing, soil disturbance, degradation of habitat, and regeneration impairment. The central evidence gap that this research addresses is the magnitude of vegetation change due to mining operations and whether perceptions on ground differ from spatial changes seen between 2015 and 2025. In this context, the research sought to investigate: (1) mining operations taking place in the study area; (2) vegetation cover changes in mining sites; and (3) the extent of vegetation cover changes due to mining operations in GMNP.

2. Literature Review and Analytical Foundation

2.1 Mining disturbance and vegetation response

Mining has impacts on vegetation through an interconnected series of direct and indirect effects. Direct effects consist of the removal of vegetation in order to create pits, haul roads, spoil heaps, and other operational zones. The indirect effects are created by increased susceptibility of the soil to erosion, run-off and sediment transport, as well as repeated disturbances leading to fragmentation of the habitat and reduced regrowth rate. These impacts are particularly relevant for a protected forest landscape due to the fact that its ecological significance lies not just in the quantity of hectares which are officially recognized as a forest, but also in canopy continuity and species diversity [6]. The results obtained in various African countries are uniform when it comes to the environmental impacts of mining. In particular, artisanal gold mining has been found to lead to lower woodland cover and less dense trees in Zimbabwe, while mining-associated loss of vegetation has been observed in Cameroon, Tanzania, Uganda and Kenya. All these studies indicate that many scattered extraction locations can create problems for the whole landscape when poorly restored or rehabilitated [7]. Therefore, the case of Gishwati-Mukura should be understood on multiple scales. While one may observe a particular mining location where the presence of vegetation has been disturbed and even soil erosion is visible, the landscape around can become reforested through restoration projects or due to the conversion of farmland. The contrast between the two types of impact forms the basis for the approach adopted in this.

2.2 Artisanal and small-scale mining in forest landscapes

Management of artisanal and small-scale mining is complicated by the nature of the activity, which is prone to being dispersed and mobile in space. In contrast to the concentrated activity of one large industrial facility, small facilities may be less conspicuous but create multiple points of interference. This type of activity is the most commonly reported form of mining in the study area identified by the thesis, and needs to be monitored and regulated as such [8]. Ecologically speaking, the impact of artisanal mining extends beyond the actual mine shaft. The removal of vegetation on the surface may lower the interception of rainfall, expose topsoil, cause slope instability and produce sediment that travels downslope. Where mining takes place in riparian areas or mountainous areas, these impacts could tie vegetation damage to water quality and erosion issues. The erosion and sedimentation findings of the thesis are thus ecologically linked to the destruction of forest vegetation cover, and not separate impacts [9].

2.3 Remote sensing and GIS for detecting vegetation change

Remote sensing allows observing land cover conditions repeatedly for large and inaccessible regions. Using the classification images taken at different points in time, one can evaluate changes from forest cover to croplands, grasslands or urban area, distinguish forest from forest regrowth. Then the land cover classes should be used for the further integration with mining site maps and field measurements using GIS methods [10]. The primary value of the change detection method lies in its capability to provide analysis that extends beyond the single-date maps. In such a case, the 2025 forest map will not reveal whether the area was continuously forest or was originally croplands or grasslands and was then restored. That is why the transition matrix is needed to indicate changes during the 2015-2025 timeframe. There are also some drawbacks of remote sensing. The land cover class of forest does not necessarily indicate the quality of the forest, types of trees, age and soil restoration. That is why the

current research uses spatial data together with the results of questionnaires and photos taken in the field. It is the right way to evaluate landscape improvements along with disturbances [11].

2.4 Ecological resilience and protected-area management

Furthermore, the study aligns with the concept of ecosystem resilience, which revolves around the ability of an ecosystem to absorb disturbance, reorganize, and retain its ability to function. Recovery of mapped forest cover may be viewed as a positive indication of landscape resilience; however, resilience is not equivalent to a lack of disturbances. Repeated mining could limit the ability to recover if the soil structure, seeds, and habitat connectivity are affected in ways that hinder natural regeneration. Management of protected areas should involve two strategies: avoidance of new disturbances and rehabilitation of disturbed areas. The IUCN guidelines recommend the maintenance of ecological integrity, whereas the literature on restoration highlights the importance of choosing appropriate methods based on the type and extent of disturbance. For GMNP, it implies that enforcement, rehabilitation, monitoring, and livelihood programs for the community need to be integrated into one management approach [12].

2.5 Conceptual interpretation

The study uses an impact pathway that is based on a straightforward sequence. The mining itself is viewed as a pressure; vegetation removal, soil disruption, and fragmentation are immediate ecological impacts; forest depletion, species reduction, erosion, and sedimentation are observed effects; and rehabilitation, restoration, and regulation are key management responses. Participant surveys indicate what they see as the pressures and effects, photographs depict the observable site conditions, and GIS/remote sensing data offer the geographical and chronological context for all of this. In this way, the findings can be understood without attributing every land-cover change to mining [13].

3. Materials and Methods

3.1 Study area

The Gishwati-Mukura National Park is an area of fragmented montane rainforest situated within the districts of Rutsiro and Ngororero in the Western Province of Rwanda. This dissertation outlines heights of around 2,000-2,700 m above sea level, as well as a landscape that is protected due to the two isolated forest areas of Gishwati and Mukura [14].

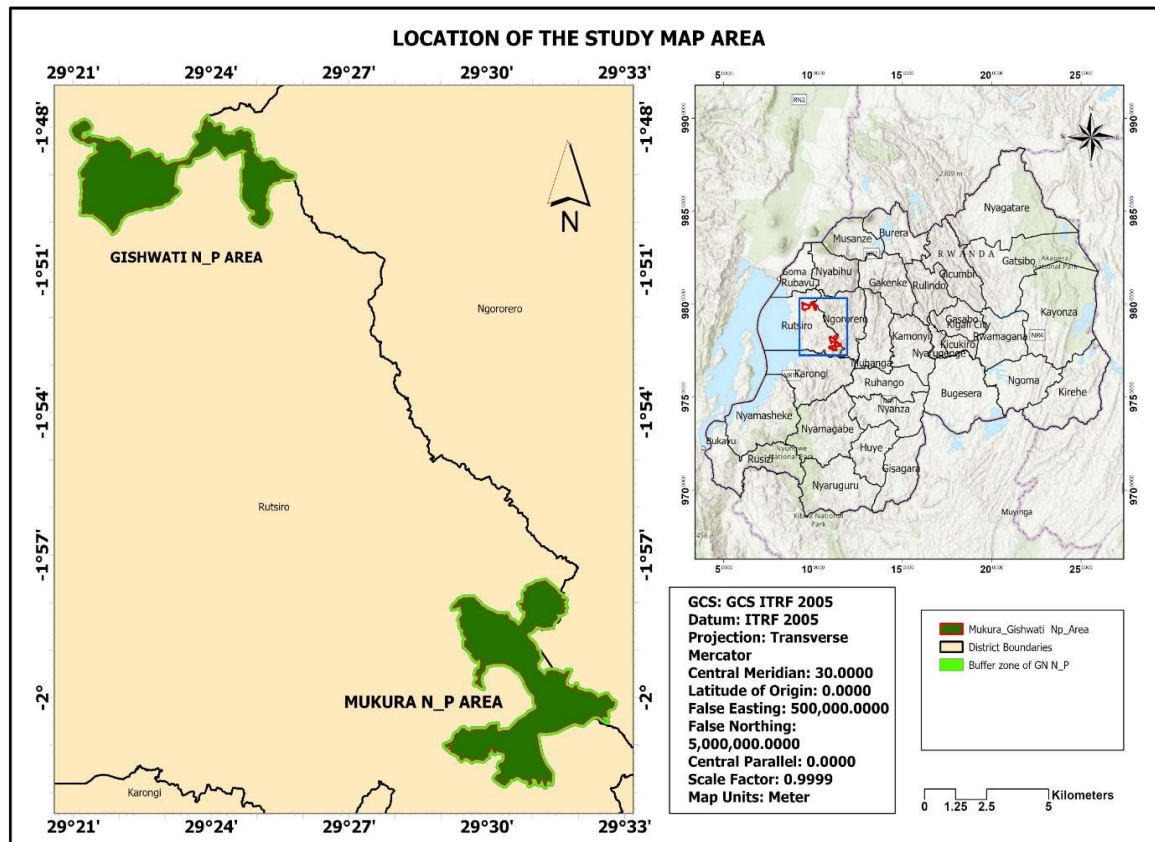


Figure 1. Location of the Gishwati-Mukura National Park study area. Source: GIS map reproduced from the thesis, 2026.

3.2 Research design, population and sampling

The methodology that used in this research is a mixed method that combines quantitative evidence from surveys, qualitative information from stakeholders and spatial analysis. The primary data was collected through surveys, interviews and observations and secondary data from documents, reports and previous researches [15]. Convenient sampling method was used to collect data from community members and leaders [16]. For people who have knowledge on the institutions and the mining industry, the researcher used purposive sampling method [17]. There are 106 valid observations in the analyzed survey tables which include 100 community members/local government leaders from selected cells in Rusebeya, Mukura and Muhanda sectors, 2 mineworkers and 4 park staff. This paper will use 106 as the analyzed total because that is what has been shown in all the result tables.

3.3 Data collection and processing

Observations related to the type of mining activity and the effect on vegetation were gathered through questionnaires. Information related to mining and the observation of disturbances were gained through semi-structured interviews and field observations. Procedure documentation and secondary data contributed to reproducibility and interpretation [18]. The GIS and Remote Sensing was employed to identify the location of mines, to classify LULC, and to detect LULC transitions from 2015, 2020 and 2025. The spatial analysis was done according to the general pattern of mapping observations, raster classification, and change detection to determine the area and percent of the major land-cover categories [19]. Data gathered using the survey method was summarized

using frequencies, mean, standard deviation, and z-scores, as presented in the thesis. The present paper concentrates on description since the tables showing the results in the thesis give frequencies and spatial areas for different categories but do not include a complete output of an inferential model for the mining-vegetation relationship [20].

3.4 Reliability, validity and research ethics

In this thesis, the issue of validity was taken care of through instrument review before fieldwork as well as through the correlation of questionnaire items with the research aims. Issues of reliability were taken care of in terms of consistency in measurement as well as repeated use of the data collection processes. In this paper, the statistical figures are shown just the way they are found in the thesis tables and are not re-estimated based on the raw data that are not available anymore [21]. From the ethical point of view, the subjects involved in the research were willing to be part of the research as a result of voluntary filling of questionnaires and conducting of interviews. In addition, the importance of safeguarding the participants as well as seeking of institutional approval for data collection was mentioned in the research.

3.5 Data analysis framework

The quantitative survey data analysis includes frequencies, percentages, means, deviations, variance, standard deviation and standardized scores stated in the thesis. These measures are useful to rank the prominence of mining activities and vegetation effects in the responses. However, the paper does not convert these descriptive measures to cause-and-effect measures. Rather, the data from survey is used to detect patterns which could be compared with mapping of land-cover change and field studies. In terms of the spatial analysis, the thesis made comparison of land-use/land-cover states in 2015, 2020 and 2025 years and then produced change-detection matrix of 2015-2025 years. The major classes identified were forest, cropland, grassland, built-up land and water. Interpretation takes into account both the percentage of landscape covered by each class and the direction of transitions between classes. The identification of three dates is significant since it is seen that the pattern of 2015-2025 is not monotonic as forests first decreased by 2020 and then significantly increased by 2025 [22].

4. Results and Discussion

4.1 Profile of respondents

Table 1. Demographic profile of the 106 analyzed respondents.

Characteristic	Category	Frequency	Percentage (%)
Gender	Male	58	54.7
Gender	Female	48	45.3
Education	Diploma	52	49.0
Education	Certificate	20	18.9
Education	Degree	34	32.1
Age	18-30 years	46	43.4
Age	31-45 years	30	28.3
Age	46-55 years	20	18.9
Age	56 years and over	10	9.4
Marital status	Single	46	43.4
Marital status	Married	60	56.6

In the respondent profile, it is seen that there was a presence of both men and women in the sample, with an average male domination. Diploma holders constituted the largest educational subgroup, at 49.0%, while those holding degrees comprised 32.1%, and certificate holders made up 18.9%. Respondents who were between the ages of 18-30 constituted the largest age subgroup, while 56.6% were married. This is important because in the study, the aim was to get information from people who have firsthand experience of the surroundings, mining, park, and local administration. However, this profile cannot be viewed as statistically representative because of the elements of convenience and purposive sampling.

4.2 Dominant mining activities

Table 2. Distribution of reported mining activities.

Mining activity	Frequency	Share of responses (%)
Small-scale and artisanal mining	56	52.8
Quarrying mining	28	26.4
Tantalum and wolfram mining	22	20.8
Total	106	100.0

Source: Primary data

Small-scale and artisanal mining made up over half of all of the mining that was reported (56 out of 106; 52.8%), and thus it became the leading pressure reported by survey respondents. Quarrying made up 26.4%, while the mining of tantalum and wolfram made up 20.8%. The dominance of small scale and artisanal mining is in line with the fact that this study had a focus on small localized mining sites, and also with studies conducted in other protected forests in Africa.

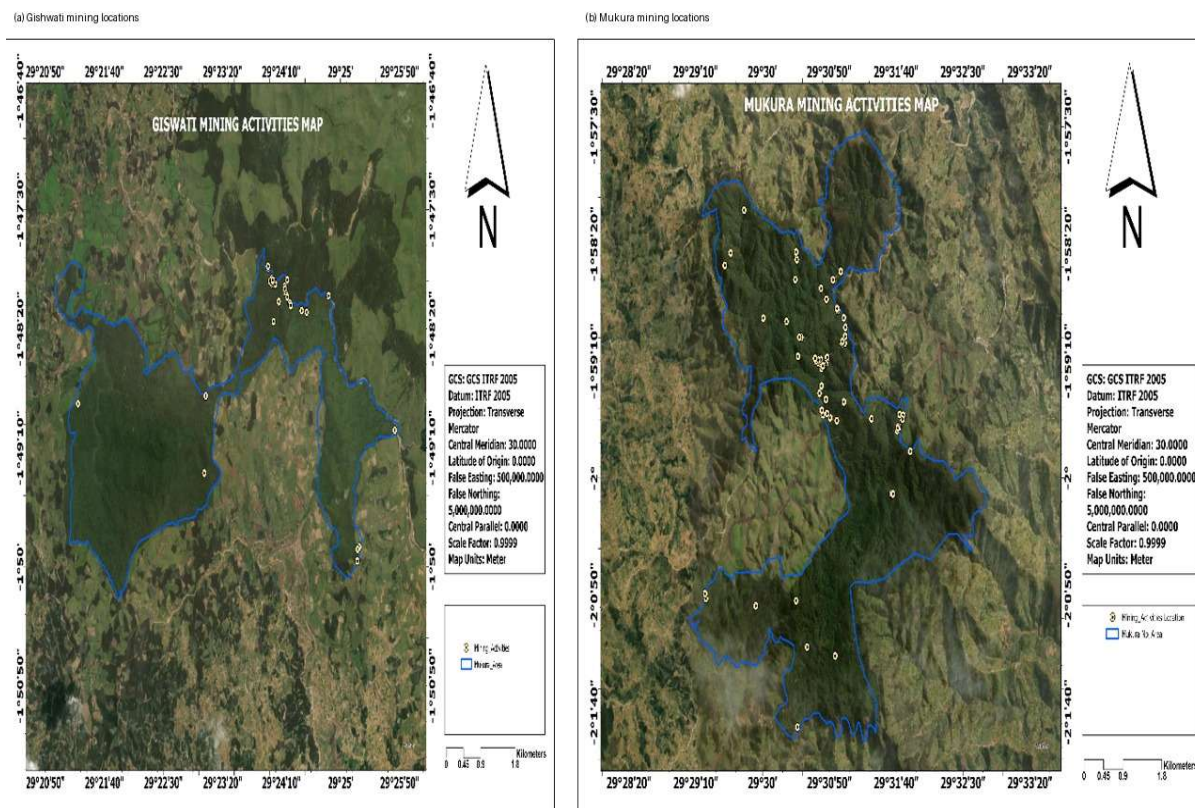


Figure 2. Mapped mining locations in the Gishwati and Mukura forest blocks (2015-2025).

4.3 Reported vegetation changes in mining-affected areas

Table 3. Main reported vegetation changes in mining-affected areas.

Observed change	Frequency	Z-score
Deforestation and vegetation loss	40	1.54
Increased soil erosion	25	0.31
Decline in plant species diversity	20	-0.10
Habitat fragmentation	11	-0.83
Soil degradation	10	-0.92

Deforestation and vegetation clearing was the most common change cited (40 citations) and scored highest on standardized scores (1.54), while an increase in soil erosion ranked second (25, $z = 0.31$). The loss of plant species diversity was just below the average number of citations, while habitat fragmentation and soil deterioration were noted fewer times. From these findings, it shows that participants were able to detect vegetation clearing most readily, but some secondary ecological impacts may not be as apparent or geographically localized. This trend is in line with disturbance ecology where vegetation clearance could be a fast-acting disturbance, while fragmentation, changes in soil processes and lack of regeneration might take longer periods [23].

4.4 Extent of mining-related vegetation impacts

Table 4. Reported extent and form of mining-related vegetation impacts.

Reported impact	Frequency	Share (%)
Reduction of forest vegetation cover	34	32.1
Loss of plant species	22	20.8
Vegetation degradation	19	17.9
Increased soil erosion	16	15.1
Sedimentation of water bodies	15	14.2

Loss of forest vegetation cover emerged as the most commonly cited effect (34 mentions), with other effects being the loss of plant species (22 mentions) and overall degradation of vegetation (19 mentions). Erosion and sedimentation also occurred, thereby establishing a relationship between disturbances in the vegetation and the soil and water pathway. This point is relevant since the clearing of vegetation may result in greater sedimentation [24].

4.5 Land-use/land-cover dynamics, 2015-2025

Table 5. LULC composition in 2015, 2020 and 2025.

LULC class	2015 area (ha)	2015 (%)	2020 area (ha)	2020 (%)	2025 area (ha)	2025 (%)
Forest	3,085.55	89.8	2,989.30	86.90	3,394.3	98.7
Cropland	147.51	4.3	369.78	10.75	3.4	0.1
Grassland	204.81	6.0	80.97	2.35	41.8	1.2
Built-up	0.00	0.0	0.06	0.00	0.6	0.0
Water bodies	-	-	-	-	0.1	0.0

The LULC findings demonstrate a non-linear change in the landscape. In 2015, forest was dominant at 89.8% of the mapped landscape, whereas in 2020, there was a decline to 86.9%, with an increase in cropland to 10.75%. However, there was a sharp rise in forest cover to 98.7% in 2025, with cropland dropping to 0.1% and grassland to 1.2%. This finding indicates significant forest restoration and regrowth in 2025. The findings from the survey relate to mining impacted regions, whereas the LULC findings reflect the larger mapped landscape; hence, the two sets of findings are not contradictory [25].

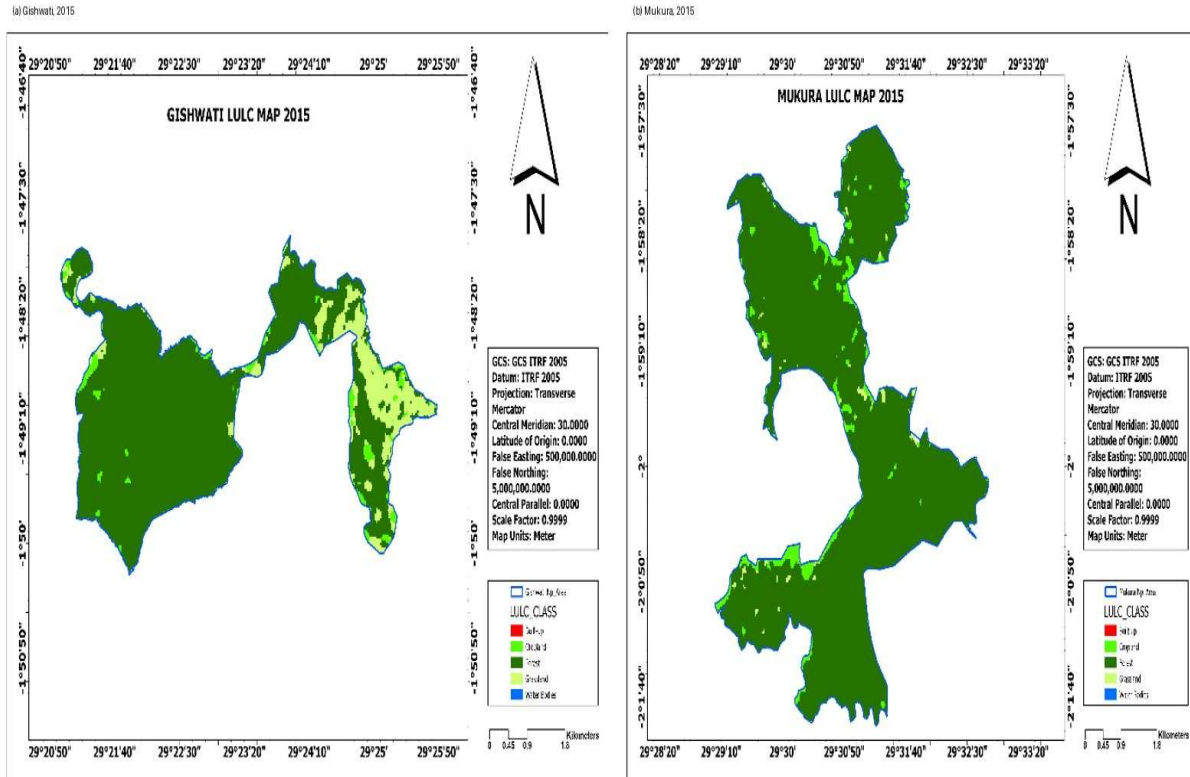


Figure 3. LULC maps for Gishwati and Mukura in 2015

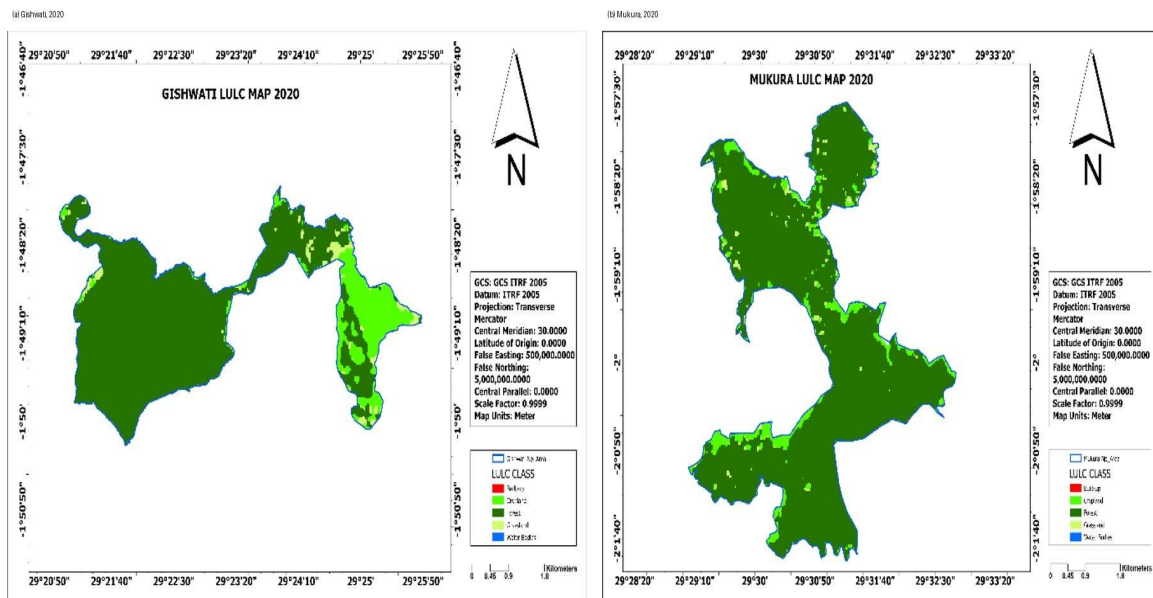


Figure 4. LULC maps for Gishwati and Mukura in 2020.

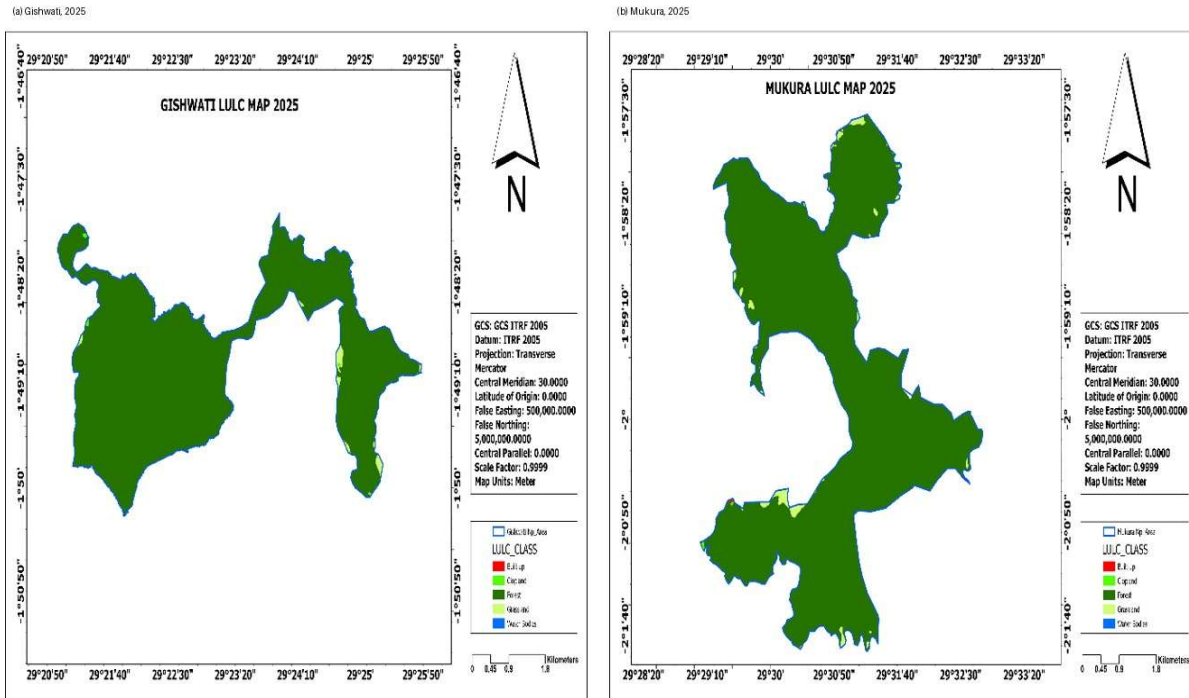


Figure 5. LULC maps for Gishwati and Mukura in 2025

4.6 Change detection and ecological interpretation

From the 2015-2025 change detection matrix, it can be seen that 3,059.2 ha (89.5%) continued to remain forest to forest. Some of the significant changes to forest were 118.0 ha (3.5%) from cropland to forest and 196.3 ha (5.7%) from grassland to forest. In addition, the transition from forest to cropland was only 0.8 ha according to the above matrix.

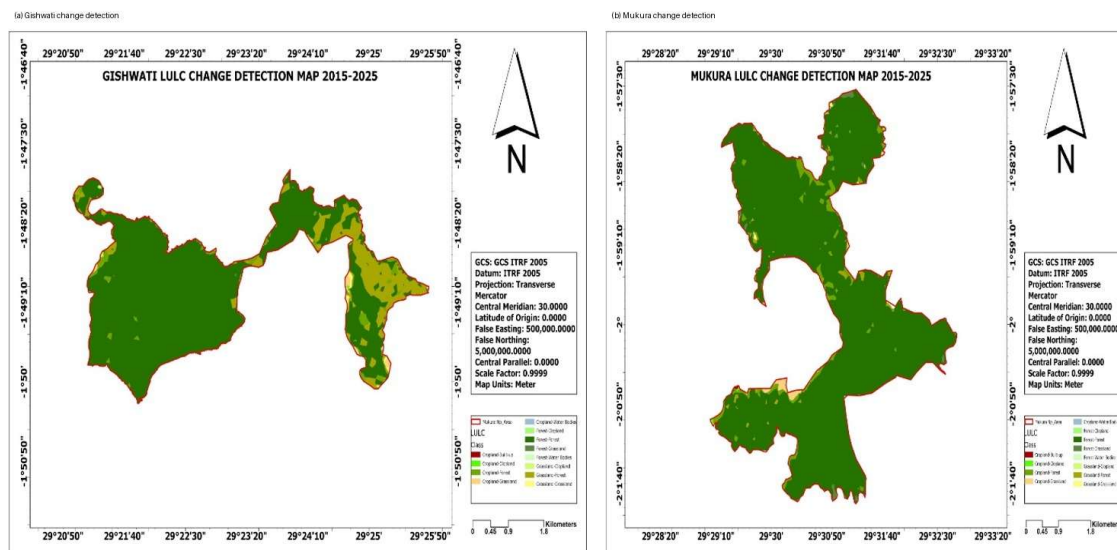


Figure 6. LULC change-detection maps for Gishwati and Mukura, 2015-2025.

The main interpretation of all the available information is scale-dependent. The field survey and observation reveal mining to be a significant cause of vegetation destruction, erosion, habitat disruption, and biodiversity stress, but remote sensing LULC suggests that there has been much restoration and regrowth of forests in the broader park landscape. Managers must not base their conclusion about the disappearance of mining impacts on total forest gains. Site-specific monitoring needs to locate disturbance hotspots and examine whether the recovered forest structure, species composition, and soil function are restoring at mine sites.



Figure 7. Examples of field-observed mining disturbance within the Gishwati-Mukura landscape.

Source: Field photographs reproduced from the thesis, 2026.

4.7 Integrated discussion of survey, field and spatial evidence

These three streams of evidence paint a cohesive, yet complex picture. The questionnaire provides data that mining causes observable vegetation damage, soil erosion, and species decline. Field photographs confirm visually that certain mining locations have damaged or bare soil, openings, and slopes. Yet, the analysis of land use and land cover proves that there was a significant increase of forest coverage in the park landscape by 2025. Thus, the proper approach is not to choose between datasets, but rather recognize the difference in measuring different landscape dimensions [26].

This is crucial in terms of policies. If managers take into account only the percentage of forest coverage in 2025, they risk underestimating ecological importance of mining hotspots that are small in area. In turn, if managers consider only the disturbed field sites, they might overlook successful reclamation and natural regeneration. Monitoring should therefore retain both scales of evidence – landscape-wide satellite indicators and specific field inspections of the ecological state of mining and reclamation sites. The timeline is also important. Forest cover was reduced between 2015 and 2020 and increased drastically between 2020 and 2025. Thus, there could be a phase of decline in between when just considering from the beginning to the end. Monitoring should therefore be done frequently enough so that temporary loss may not be overlooked as it will be masked by some gains in other parts of the area.

The ranking of the impact in the survey gives insight into what must be done in terms of restoration. Given that the problem was the reduction of forest vegetation cover and deforestation, restoration efforts should first stabilize the disturbed ground cover and plant indigenous plants and connect any fragments where possible. From the erosion and sedimentation response, restoration should involve stabilizing slopes, drainage and protecting water ways. Restoration is not only the planting of trees but must include erosion control, regeneration, plant diversity and connectivity [27].

4.8 Implications for management

These results indicate that an integrated management approach can include the following four related objectives. First, mining activities and informal mining in particular must be tightly regulated and monitored. Second, sites of past disturbances need to be restored using local plant species and slope stabilization. Third, satellite monitoring must be performed again, maintaining the same classifying techniques to prevent masking of local disturbances due to overall landscape recovery. Fourth, livelihood-based measures will help to eliminate socio-economic factors responsible for the maintenance of informal mining. All of these measures can be incorporated into the idea that protected area conservation necessitates ecological and social adaptation.

5. Conclusions and Recommendations

This research has highlighted how mining still continues to be one of the key localized threats to the vegetation in the Gishwati-Mukura National Park despite the general trend of landscape regeneration of forests. Mining activities involving small-scale and artisanal mining practices occurred more frequently, while mining practices were most commonly associated with deforestation and vegetation loss, as well as loss of forest coverage. The other secondary effects included erosion, plant species loss, vegetation degradation, and sedimentation.

The spatial information is supplemented with the time dimension. Forest coverage decreased from 89.8% in 2015 to 86.9% in 2020, yet rose up to 98.7% in 2025. Thus, based on change detection, extensive forest persistence, as well as cropland and grassland to forest conversions were identified. Therefore, the most accurate conclusion would be the coexistence of local mining threats and landscape-level forest regenerations.

The priority recommendations include: enforcement against mining in sensitive protected areas; identification and periodic surveying of mining “hot spots”; land rehabilitation using native vegetation and erosion control methods; maintenance of GIS/remote sensing monitoring; and development of alternative livelihood opportunities for those communities which depend on artisanal mining. Further studies should combine the high-resolution time series imagery and field plots, soil and biodiversity studies, so that recovery is evaluated not only in terms of forest coverage, but also in terms of ecological quality and functionality.

5.1 Conclusion by study objective

Concerning the first objective, the results indicate that small-scale and artisanal mining formed the most prevalent type of mining practiced in the study area. This is followed by quarrying and mining of tantalum/ wolfram. The high percentage of answers in the artisanal mining category implies that management needs to pay particular attention to dispersed mining practices.

As for the second objective, deforestation and vegetation depletion was the most common vegetation change associated with mining. Soil erosion and reduction in the number of plant species were other important vegetation changes caused by mining activities. The results therefore indicate that the impacts of mining on the ecology not only include deforestation but also other impacts such as soil erosion.

As for the third goal, deforestation was the most common effect observed, whereas the LULC study showed that there is a general trend towards a temporary drop followed by an active recovery. Overall, one can say that the protected area has gained considerable progress in its forestation, yet such progress does not mean that mining activities are not present locally. It is important to measure conservation effectiveness in both absolute numbers and ecological condition at the disturbed sites.

5.2 Recommendations for park management and government agencies

First, the surveillance of mining operations must be improved in and near forests of strategic importance. The database of mining operations should be kept operational and up-to-date with periodic field verification of mapped locations. Mining sites should be recorded by date, type of activity, footprint, state of vegetation, and rehabilitation state. It will allow the government to differentiate between historical disturbances and ongoing ones and allocate resources for law enforcement efforts [28].

Second, disturbed mining sites should be restored in situ with specific techniques. If slopes are unstable, then erosion and drainage should be controlled first before vegetation restoration can be done. Restoration should be conducted with indigenous species that fit into the local forest system and be followed by monitoring whether there is survival, regrowth, and decreased amount of bare soil [29]. Third, monitoring of land cover should be conducted periodically and with consistent classification technique. Repeatable procedure of GIS analysis will allow for quick detection of newly disturbed areas and confirmation of gradual recovery of the previously restored sites. High-resolution images should be used, if possible, in areas with high concentration of mining hotspots because small-scale disturbances can be overlooked in landscape classifications.

5.3 Recommendations for communities and mining stakeholders

The community involvement must center on viable options to activities that negatively impact the environment and early alert of any newly created disturbance. Given that artisanal mining can be linked with livelihoods, enforcement will move the activity elsewhere but not eliminate the motivation for such behavior. Livelihood assistance, environmental education, and involvement in restoration activities will help enhance the regulatory approach. Mine owners and miners must be made to reduce unnecessary deforestation, reduce disturbed areas to the minimum possible, control soil waste and runoff, and engage in progressive rehabilitation. Mining that is permitted by law within the defined buffer zones must be guided by environmental responsibilities prior to extraction and progressive rehabilitation after the activity has ended [30].

5.4 Recommendations for future research

Future studies can make use of high-resolution satellite or drone imagery together with vegetation plots set up on active mines, abandoned and rehabilitated mines to measure recovery and regeneration of canopy cover, species diversity, biomass, soil condition, etc., instead of making use of the land-cover class only. It will also help differentiate between seasonality and changes due to mining activities [31]. The next important step is related to improving the research design in order to create a more causal study. While the current thesis has made the effort to describe some patterns and to prove coexistence of mining activities and certain ecology features, future researchers may compare mining and non-mining areas with similar elevation and slope and land use in order to attribute certain differences to mining activities.

6. Study Limitations

There are certain limitations which need to be considered when interpreting the results. Firstly, the sampling method utilized is convenience and purposive and thus the 106 respondents used for analysis only present informed evidence but cannot be used as a probability sample of all households near the park. Secondly, the survey assesses the perceptions and observations of the respondents and not actual ecological measurements made at each mining location. Thirdly, the land cover classes indicate broad surface categories and not the quality of the forest, plant species and soil regeneration. Fourthly, there is a difference in the scale of the survey and spatial data as the former assesses the experiences of respondents in the mining locations while the latter gives a broader picture of the entire map. Finally, the thesis presents descriptive statistics and change detection results but lacks a full inferential model table to enable us quantify the causal effect size presented in this paper.

7. Practical Significance of the Study

The study offers an application framework for improving conservation decision-making within a landscape setting, where ecological conservation and mineral extraction livelihoods overlap. The most significant practical value of this study is represented by the integration of perceptual data, mapping of mining sites, land cover analysis and pictures taken during field work. Such integration will help to identify the difference between general reforestation and particular site disturbances. In turn, the results of the study may help park officials and environmental protection organizations to prioritize mining areas for inspections and rehabilitation. For local authorities and community organizations, such results explain why there is a need to combine erosion prevention and rehabilitation along with enforcement. In terms of future research, the land use and land cover maps of 2015, 2020 and 2025 will help to compare future changes in the area, if classification methods will remain the same [32].

Acknowledgements

The author acknowledges the University of Lay Adventists of Kigali (UNILAK), the research supervisor Prof. MUPENZI Christophe, PhD, the participating communities, mineworkers, local leaders and park staff who contributed to the original thesis research.

Data and Materials Statement

All of the surveys, GIS mapping, LULC tables, and pictures taken in the field, that have been used for this manuscript, were obtained from the author's final thesis data set and figures. The further availability of any information is dependent on the terms under which the original data was collected.

References

- [1] Maus.V, J. and S. , "Global forest loss from mining activities between 2001 and 2023," *Environmental Research Letters*, vol. 20, no. 1, 2025.
- [2] Yeboah.F, A. E. and B. , "Declines in tree and shrub diversity in forest reserves impacted by gold mining in Ghana," *Forest Ecology and Management*, 540.
- [3] Smith.P, A. A. and M. , "Tree cover loss near mining areas in sub-Saharan Africa: Direct and indirect deforestation effects," *Land Use Policy*, p. 120, 2025.
- [4] Muhire.I, N. and U. , "Impacts of mining activities on soil, water, and vegetation in Gishwati Forest, Rwanda," *African Journal of Ecology*, vol. 59, no. 4, pp. 564-577, 2021.
- [5] P. F.J.Eagles, S. and C. , *Sustainable Tourism in Protected Areas: Guidelines for Planning and Management*, IUCN-The World Conservation Union, 2002.

-
- [6] Xu,L, C. Y. and W. , "Surface coal mining and vegetation carbon sequestration capacity: Recovery challenges after reclamation," *Journal of Cleaner Production*, vol. 14, no. 1, p. 13479, 2024.
- [7] Mubvami.T, C. and M. , "Effects of artisanal gold mining on woodland structure in Mana Pools, Zimbabwe," *Forest Ecology and Management*, vol. 525, 2023.
- [8] Lameck.R, M. and K. , "Artisanal and small-scale gold mining impacts on forest and shrub-grassland systems in central Tanzania(1995-2023)," *African Journal of Ecology*, vol. 63, no. 2, pp. 210-225, 2025.
- [9] Nabaasa.A, K. and T. , "Sand mining impacts on riparian vegetation and soil erosion in Ugandan forest reserves.," *Environmental Monitoring and Assessment*, vol. 195, no. 9, p. 1123, 2023.
- [10] Boateng.P, A. and A. , "Remote sensing analysis of vegetation change due to mining activities in the Prestea Huni-Valley Municipality, Ghana," *Environmental Monitoring and Assessment*, vol. 194, no. 12, p. 895, 2022.
- [11] Xie.Y, W. and G. , "High-resolution remote sensing and machine learning applications in land use change detection," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 202, pp. 108-124., 2024.
- [12] IUCN, Guidelines for applying protected area management categories, International Union for Conservation of Nature, 2016.
- [13] Ahmed.S, "Documentation practices in environmental research: Ensuring transparency and reproducibility," *Journal of Research Methodology*, vol. 15, no. 2, pp. 45-59, 2024.
- [14] Arakwiye.R, N. and U. , "Forest degradation and restoration in Gishwati-Mukura National Park, Rwanda: Historical trends and management interventions. Rwanda," *Journal of Environmental Studies*, vol. 7, no. 1, pp. 33-50, 2021.
- [15] Casteel.C and B. , "Primary data collection methods in social and environmental research," *International Journal of Research Methods*, vol. 14, no. 3, pp. 201-218, 2021.
- [16] Meredith.C, "Convenience sampling and its applications in field research," *International Journal of Social Research Methodology*, vol. 21, no. 5, pp. 517-528, 2018.
- [17] Jodene.H., "Purposive sampling in qualitative research: Strategies and considerations," *Qualitative Research Journal*, vol. 18, no. 1, pp. 54-63, 2018.
- [18] Dziak.J, C. and L. , "Secondary data sources and their application in environmental research," *Research in Social and Environmental Sciences*, vol. 8, no. 2, pp. 112-128, 2020.
- [19] Longley.P, G. M. and R. , Geographic information science and systems (4th ed.), Wiley, 2015.
- [20] J.Veal.A., Research methods for leisure and tourism (5th ed.). Pearson Education, Veal.A. J, 2019.
- [21] Gravesande.M, J. and L. , "Assessing reliability in social science instruments using Cronbach's alpha," *Journal of Quantitative Methods*, vol. 12, no. 4, pp. 65-78., 2019.
- [22] Miller.H and S. , Geographic information systems for transportation: Principles and applications, Oxford University Press, 2017.
- [23] Were.M, O. and K. , "Gold mining impacts on woodland fragmentation and plant biodiversity in western Kenya," *Biodiversity and Conservation*, vol. 35, no. 5, pp. 1201-1219, 2024.
-

-
- [24] Ngounouno.I, F. and T. , "Vegetation cover changes in mining zones of northern Cameroon: 2015-2023," *African Journal of Environmental Science and Technology*, vol. 18, no. 3, p. 2024, 145-159.
- [25] Sharma.V, S. and K. , "Long-term vegetation dynamics in mining-affected regions of Jharkhand and Odisha, India," *Journal of Environmental Management*, vol. 315, 2022.
- [26] Agyeman.F, O. and M. , "Longitudinal assessment of gold mining impacts on forest cover and biodiversity in Ghana.," *Journal of Environmental Management*, p. 310, 2025.
- [27] Gough.L, V. and W. , "Disturbance ecology: Principles and applications for assessing human impacts on ecosystems," *Ecological Research*, vol. 39, no. 1, pp. 15-29, 2024).
- [28] Esri, GIS for environmental management: Applications and best practices, Esri Press, 2022.
- [29] Connell.J.H and S. , "Mechanisms of succession in natural communities and their application to post-disturbance recovery," *Ecology Letters*, vol. 22, no. 5, pp. 750-766, 2019.
- [30] Singh.R and S. , "Introduction to mining engineering," *Springer Nature*, 2022.
- [31] Kumar.S, P. and S. , "Vegetation phenology and spectral responses to mining disturbances in arid landscapes," *Remote Sensing of Environment*, vol. 300, p. 113586, 2024.
- [32] Goodchild.M.F, "GIS and the future of spatial data analysis," *International Journal of Geographical Information Science*, vol. 35, no. 7, pp. 1234-1248, 2021.
- [33] Li.S, Z. and C. , "Advances in satellite remote sensing for environmental monitoring," *Remote Sensing of Environment*, p. 291, 2023.
- [34] Li.S, Z. and C. , "Advances in satellite remote sensing for environmental monitoring," *Remote Sensing of Environment*, vol. 291, p. 113610, 2023.
- [35] Miller.H and S. , Geospatial technologies in environmental analysis: GIS and remote sensing integration, Guilford Press, 2017.