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Original Research Paper

# Remote Sensing Applications for Monitoring Habitat Degradation and Conservation Prioritization in Biodiversity Hotspots

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**Abstract:** However habitat degradation is one of the biggest causes of biodiversity loss and is threatening the stability of ecosystems and the ability to implement effective conservation efforts in global biodiversity hotspots. This study proposes an integrated multi-source geospatial data framework for habitat degradation monitoring and conservation prioritization using remote sensing information. The proposed methodology is based on the integration of optical satellite data, Synthetic Aperture Radar (SAR), LiDAR observations, and high-resolution Unmanned Aerial Vehicle (UAV) data, for the purposes of producing accurate land use and land cover maps, condition assessments of vegetation, habitat suitability models, and ecological connectivity analyses. These advanced preprocessing, computing of the spectral index and multi-source data fusion increase the confidence of habitat characterization under various environmental conditions. Forest cover loss detection, vegetation health monitoring and wetland change assessment are used to quantify habitat degradation, and indicators of species richness, habitat suitability and landscape connectivity are used to identify conservation priority zones. The experimental assessment shows high land cover classification accuracy, robust habitat degradation detection and reliable identification of the biodiversity hotspots that facilitates timely ecological decision-making. The proposed framework will improve planning for conservation by offering a scalable, cost-effective and repeatable monitoring process for protected areas and ecologically sensitive landscapes. In general, the use of remote sensing technologies is a useful decision support tool for sustainable biodiversity management, restoration of habitats and long-term conservation and protection of ecosystems in the context of growing anthropogenic and climate influences.

**Keywords:** Remote sensing; Habitat degradation; Biodiversity hotspots; Land use and land cover classification; Conservation prioritization; Ecological connectivity.

## I. Introduction

Biodiversity hotspots are the most ecologically important areas on earth, with a correspondingly high diversity of endemic species, many of which are plants and animals that are under threat from human activities. The areas are a small percentage of the world's land mass, but consist of a significant

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percentage of the world's biodiversity. Habitat losses due to rapid urbanisation, agricultural expansion, mining, infrastructure development, deforestation, climate change, and unsustainable exploitation of natural resources have led to habitat fragmentation, loss of ecosystem services and increased risk of species extinction. With many of these pressures mounting, it is now crucial for there to be a good system of monitoring habitat conditions and a good way of deciding conservation priorities based on sound scientific information. The traditional approaches to the assessment of traditional habitat are mainly through field surveys, ecological inventories and manual observation methods [1]. While these approaches have shown to be useful for providing ecological information, they are also often labour intensive, costly, time consuming and space limited. Furthermore, the number of field investigations that can be carried out is limited when working in large, difficult-to-reach biodiversity hotspots, reducing the ability of conservation agencies to know about environmental changes in time. There is a growing demand for scalable, accurate and cost-effective technologies that can be used to continuously monitor habitat conditions across large geographic areas and that can help with evidence-informed habitat conservation planning.

The long-term, multi-temporal and extensive monitoring of terrestrial ecosystems that remote sensing can offer make it one of the most powerful technologies for environmental monitoring. The high spatial and temporal resolution data available from modern Earth observation platforms, such as optical satellites, Unmanned Aerial Vehicles (UAVs), Synthetic Aperture Radar (SAR) and Light Detection and Ranging (LiDAR), can be used to investigate the dynamics of vegetation, land use and land cover, forest degradation, wetland conditions and ecosystem health [2]. Optical imagery allows for detailed analysis of vegetation properties based on spectral information while SAR can be used to make observations when the sky is cloudy and at low light levels. LiDAR provides detailed 3D information on forest canopy characteristics as well as the structure of vegetation, while UAVs provide fine scale ecological mapping with spatial resolution in the centimeter range.The recent developments in geospatial data processing, cloud computing and machine learning have greatly improved the ability of remote sensing systems to support biodiversity conservation. Multi-source remote sensing data integration allows to characterize habitat quality from multiple data sources and complement the information provided by the different technologies. In addition, vegetation indices, ecological indicators, habitat suitability modeling and landscape connectivity analyses are useful tools to gain insights into ecosystem condition, habitat fragmentation and species distribution patterns [3]. They help conservation practitioners to prioritize restoration areas, track environmental decline, assess the efficacy of protected areas and plan for adaptive management in response to climatic and anthropogenic shifts.

This study offers a complete remote sensing approach to monitoring habitat degradation and to assist in prioritizing conservation efforts in biodiversity hotspots, using optical satellite, SAR, LiDAR and UAV-based observation. The methodology proposed involves data preprocessing using satellite data, multi-source data fusion, land use and land cover classification, computation of vegetation and ecological indexes, forest cover loss detection, monitoring wetlands, habitat suitability modeling, biodiversity hotspot mapping, and ecological connectivity assessment [4]. The framework will help to advance the science of monitoring habitats to be more accurate, scalable and reliable, and deliver scientifically sound decision-support information for conservation planning. This study helps towards sustainable biodiversity management, restoration of ecological habitats, assessment of ecosystem resilience and long-term decisions for biodiversity conservation in ecologically sensitive landscapes by incorporating multiple remote sensing technologies into a single analytical framework.

## II. Literature Review

Existing studies on biodiversity hotspots, methods for assessing habitat degradation, and remote sensing technologies are reviewed and recent advances, research gaps, and the need for synergic geospatial approaches are highlighted for promoting effective biodiversity conservation and monitoring.

### A. Biodiversity hotspots and conservation challenges

A biodiversity hotspot is a location that has a high number of species which are endemic and are also losing their habitat at a high rate as a consequence of human activities. These areas are essential for sustaining ecological balance, ecosystem services and global levels of biological diversity. But many hotspots of biodiversity are increasingly facing degradation of their ecosystems as a consequence of rapid urban growth, intensified agriculture, deforestation, mining, infrastructure development, invasive species and climate change [5]. Habitat fragmentation can fragment the ecology and decrease the connectivity among wildlife populations, limit migration, and lead to local wildlife population declines. Additionally, illegal logging, overexploitation of natural resources and pollution pose further threat on the ecological integrity. However, conservation activities are often restricted due to financial, monitoring, and ecological limitations, which may often make it difficult to make the necessary decisions in time. Therefore, it is becoming more important to pursue integrated conservation approaches that incorporate scientific knowledge and cutting-edge geospatial tools [6]. Conservation action monitoring and prioritisation are critical to maintaining and enhancing ecosystem resilience, recovering degraded landscapes and to the sustainable management of ecosystem with high biodiversity values.

### B. Habitat Degradation Assessment Techniques

Habitat degradation assessment is essential to ensure proper knowledge of the health of the ecosystem and to help determine the needed immediate action for the conservation. Traditional assessment approaches are largely based on field surveys, ecological sampling, biodiversity inventories and manual habitat mapping. These methods allow for local observations to be accurate, but require much time, money and effort and are not practical in expansive or difficult to access areas. Recent progress has brought about the adoption of geospatial methods that can now be used to monitor the environment in an ongoing, large-scale, and continuous manner [7]. Land use and land cover change detection, vegetation health analysis, forest cover assessment, wetland monitoring, landscape fragmentation analysis, and ecological connectivity evaluation are widely used techniques for assessing habitat degradation. The Vegetation Indices derived from the data provide quantitative information about the condition, biomass and moisture content of vegetation including the NDVI, EVI and SAVI, and NDWI. With the aid of the ML/AI algorithms, the classification accuracy and the environmental change detection have also been enhanced [8]. Combining ecological indicators with multi-temporal spatial data allows a holistic view of habitat quality, to plan for restoration, and to inform conservation management decisions based on science and evidence, as environmental and climatic conditions change.

### C. Remote Sensing Platforms and Sensor Technologies

New technologies of remote sensing have revolutionized the way ecological monitoring is achieved, as they enable accurate, repeated and broad-scale observations of environmental changes. The present remote sensing platforms consist of Earth observation satellites, airborne LiDAR systems, Synthetic Aperture Radar (SAR), hyperspectral sensors and Unmanned Aerial Vehicles (UAVs). Vegetation analysis, land cover and biodiversity assessment are broadly performed using multispectral and hyperspectral instruments as optical satellite sensors are used to derive spectral information [9]. The SAR sensors are valuable for observing tropical and humid ecosystems in all weather conditions, even in cloudy weather and when it is not light. LiDAR can provide detailed three-dimensional vegetation structure that can be used to estimate the forest canopy height, forest biomass, and habitat complexity. The ultra-high resolution imagery that UAVs deliver is ideal for localised ecological studies, species habitat mapping, and vegetation monitoring [10]. The potential of remote sensing technologies has been greatly improved in the last few years by the advances of the cloud computing, geospatial analysis, artificial intelligence, and multi-source data fusion. Table 1 provides an overview of remote sensing techniques, results, limitations and their comparison to each other. The integrated sensing platforms allow for accurate habitat monitoring, mapping of biodiversity, ecological risk assessment, and prioritisation for conservation in order to reach a sustainable ecosystem management.

Table 1. Related Work on Remote Sensing Applications for Monitoring Habitat Degradation and Conservation Prioritization

| **Study Focus** | **Remote Sensing Platform** | **Sensor/ Technology** | **Study Area** | **Key Findings** | **Limitations** |
|---|---|---|---|---|---|
| Forest degradation monitoring [11] | Landsat-8 | Optical | Tropical Forest | Accurate forest change detection | Cloud contamination |
| Habitat fragmentation assessment [12] | Sentinel-2 | MSI | Protected Forest | Improved land cover mapping | Seasonal variability |
| Wetland degradation analysis [13] | Sentinel-1 | SAR | Wetland Ecosystem | Reliable waterbody detection | Speckle noise |

| | | | | | |
|---|---|---|---|---|---|
| Vegetation health monitoring [14] | MODIS | Optical | National Park | Effective drought assessment | Moderate spatial resolution |
| Forest biomass estimation [15] | Airborne LiDAR | LiDAR | Mountain Forest | Precise biomass estimation | High acquisition cost |
| Biodiversity mapping [16] | UAV | RGB & Multispectral | Wildlife Reserve | High-resolution habitat mapping | Limited coverage |
| Habitat suitability modelling [17] | Landsat + DEM | Optical + Terrain | Biodiversity Hotspot | Improved habitat prioritization | Static environmental variables |
| Ecological connectivity assessment [18] | Sentinel-2 | Optical | Conservation Landscape | Corridor identification | Sensitive to input parameters |
| Land use/land cover monitoring | Landsat-9 | Optical | Mixed Ecosystem | High classification consistency | Mixed pixel effects |
| Multi-temporal habitat change detection | Sentinel-1 & Sentinel-2 | SAR + Optical | Tropical Biodiversity Region | Better change detection accuracy | Data preprocessing complexity |
| Species richness mapping | UAV + LiDAR | Multisensor | Ecological Reserve | Enhanced biodiversity estimation | Computational complexity |

## III. Materials and Methodology

In this section the methodology proposed for the study is described, starting from the selection of the study area, data acquisition and pre-processing by satellite, integration of several data sources, classification of land cover and computation of vegetation indices for the purpose of comprehensive habitat degradation assessment and ecological analysis.

### A. Study area selection and biodiversity hotspot characterization

The proposed framework is given emphasis on the ecologically important biodiversity hotspots, which are rich in species, are endemic and are also becoming deprived of habitats in increasing level. Study areas are chosen for their ecological significance, conservation status, land use characteristics and availability of multi-temporal remote sensing data. To reflect the diversity of habitat conditions and anthropogenic pressures, protected forests, wetlands, wildlife reserves and surrounding buffer zones are included. The geographic boundaries are drawn using geographic information system (GIS) and administrative and ecological data. Relevant geospatial information on existing land cover, topography, elevation, hydrology, climatic parameters and vegetation types are created from open sources. During the hotspot characterization, consideration is given to habitat fragmentation, human settlement, agriculture, transportation and industrial development to assess environmental stress. Species occurrence data and boundaries of protected areas are included to determine ecologically sensitive areas. The chosen study area is representative of the ecological diversity needed to assess habitat degradation, priorities for biodiversity conservation, and/or ecosystem connectivity. This in-depth characterization provides a solid backdrop for future work, such as remote sensing analysis, habitat assessment, and conservation planning, across the spatial dimension.

### B. Satellite Data Acquisition and Preprocessing

Multi-temporal satellite images are obtained from publicly available Earth observation satellites to enable full scale monitoring of habitat dynamics and environmental changes. In order to have more reliable observations, under different atmospheric conditions, multispectral satellite optical data is associated with the data obtained by the Synthetic Aperture Radar (SAR) instrument. Further Digital Elevation Models (DEMs) and other environmental data are added for improved terrain analysis and ecological interpretation. The pre-processing workflow consists of radiometric calibration, atmospheric correction, geometric correction, orthorectification, cloud and shadow masking, image mosaicking and spatial resampling to ensure a uniformity of data quality for a data set acquired with several different sensors. In SAR imagery some techniques are used for noise reduction to reduce speckle noise and retain structural information.

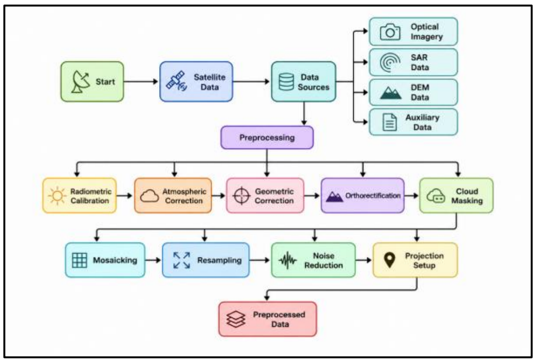


Figure 1. Proposed Satellite Data Acquisition and Preprocessing Workflow for Multi-Source Remote Sensing Analysis

The figure 1 shows the systematic satellite data preprocessing in order to give accurate multi-source remote sensing data analysis. All data sets are transformed to a common coordinate reference system and clipped to the study area boundary. Satellite observations can be used to monitor habitat change and serve for accurate monitoring over different seasons through temporal alignment. The image normalization further enhances the spectral homogeneity of the image for classification and vegetation analysis. Standardized preprocessing procedure guarantees the quality of geospatial data that allow for the reliable assessment of habitat degradation, ecological monitoring and decision-making in conservation.

### C. Multi-Source Remote Sensing Data Integration

The proposed approach combines complementary remote sensing data for the purpose of enhancing the accuracy and robustness of the habitat characterization over biodiversity hotspots. Optical satellite-based data offers good spectral information for vegetation and land cover studies, while the Synthetic Aperture Radar (SAR) offers structural information that is independent of illumination and cloud cover. Three dimensional assessments of vegetation using LiDAR derived elevation and canopy structure measurements and localised ecological mapping and validation with high resolution UAV imagery. At the feature level, the integration of spectral bands, vegetation indices, texture features, terrain variables and structural attributes in a single geospatial database. Consistency in spatial alignment and resolution are carried out to reduce discrepancies between various sensing platforms. Data fusion is derived to enhance discrimination of vegetation classes, degraded habitats, wetlands and anthropogenic land use classes. The integrated data provides complementary ecological characteristics which cannot be taken from any single sensor. The multi-source approach enhances the classification accuracy, improves the quality of habitat evaluation, enables biodiversity mapping and the provision of spatial information for ecosystem monitoring, habitat restoration planning and conservation prioritization across a variety of environmental conditions.

### D. Land Use and Land Cover Classification

To characterize spatial patterns of the distribution of natural ecosystems and anthropogenic land use changes in the defined biodiversity hotspot, land use and land cover (LULC) classification is carried out. The remote sensing data, collected and integrated, is used as the main input for supervised classification with the aid of advanced machine learning algorithms that are able to distinguish complex landscape features. Major land cover classes (e.g. forests, grassland, wetlands, agricultural areas, water bodies, barren areas, urban settlements) are sampled by representatives. Spectral characteristics, texture measures, topographic information and vegetation indices are used as the predictive feature to enhance the classification performance. Post-classification refinement techniques like spatial filtering and majority analysis help to minimize classification noise and ensure the consistency of maps. The accuracy assessment is done on independent validation samples, and using the standard performance measures like overall accuracy, producer accuracy, user accuracy, F1-score and Kappa coefficient. The multi-temporal classification products enable land cover change detection, allowing the classification of habitat conversion, deforestation, urban expansion and ecosystem fragmentation. The classification results are very important for spatial data on habitat degradation assessment and conservation planning.

### E. Vegetation and Ecological Index Computation

Vegetation and ecological indices are calculated to measure, in a quantitative fashion, the health of the ecosystem, the condition of the vegetation, the moisture available in the study area, and habitat quality throughout the study area. Multispectral satellite-derived spectral indices are good indicators of ecological processes and environmental changes. The Normalized Difference Vegetation Index (NDVI) is used to assess vegetation vigor and biomass and the Enhanced Vegetation Index (EVI) enhances sensitivity in dense vegetated areas. Soil

Adjusted Vegetation Index (SAVI) reduces soil background effects and Normalized Difference Water Index (NDWI) assesses vegetation moisture and wetland conditions. Other ecological parameters reflecting habitat fragmentation, landscape diversity, canopy density and productivity of vegetation are merged to provide an overall measure of ecosystem integrity. Temporal analysis of such indices can help detect seasonal vegetation dynamics, forest degradation and drought effects as well as recovery patterns. The GIS environment is used to create maps of spatial distribution that will determine environmentally stressed areas needing conservation action. The derived vegetation and ecological indices are useful quantitative data for habitat suitability modelling, biodiversity assessment, ecological connectivity analysis and long-term environmental monitoring.

## IV. Habitat Degradation Analysis

The forest cover loss along with the health of vegetation and degradation of wetlands is assessed through multi-temporal satellite images, spectral indices and spatial analyses in order to identify degraded ecosystems and provide ecological restoration and conservation plans.

### A. Forest cover loss detection

Forest cover loss detection involves the assessment of both temporal and spatial variation of the forest ecosystem attributed to deforestation, fragmentation of forest areas, expansion of agriculture, building of infrastructure and other disturbances caused by human activities. Satellite images taken at various times will be used to compare and calculate the changes in forest area and in the cover of the forest canopy. The proposed framework is used to develop land use and land cover classification maps, which are used to identify intact forests and degraded and converted landscape. The vegetation indices, canopy cover estimates and change detection techniques are combined to enhance the ability of identifying disturbed forest areas. Large-scale deforestation and small-scale habitat degradation are both detected by pixel-based and object-based analyses. Geographic Information System (GIS) tools are used to determine forest loss statistics, fragmentation patterns and spatial distribution of degraded habitats. The maps of forest change produced can allow identification of areas that are undergoing fast ecological degradation that are sensitive to biodiversity. These findings not only guide conservation agencies with prioritising restoration activities, but they also can be used for the assessment of the effectiveness of protected areas and for the implementation of sustainable forest management strategies for maintaining ecosystem integrity and biodiversity.

### B. Vegetation Health Assessment Using Spectral Indices

Veg. health is assessed based on spectral indices extracted from multispectral remote sensing images to assess ecosystem condition, plant vigor and habitat quality. There is a known spectral response with healthy vegetation in both the visible and near-infrared regions, which allows to make a quantitative assessment of the status of the vegetation. Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), Soil Adjusted Vegetation Index (SAVI), and Normalized Difference Water Index (NDWI) are derived to study various conditions such as biomass, chlorophyll activity, vegetation density, soil influence, and moisture availability. These indices can be used to compare them in time, which helps identify drought and vegetation stress, seasonal changes, and ecological recovery.

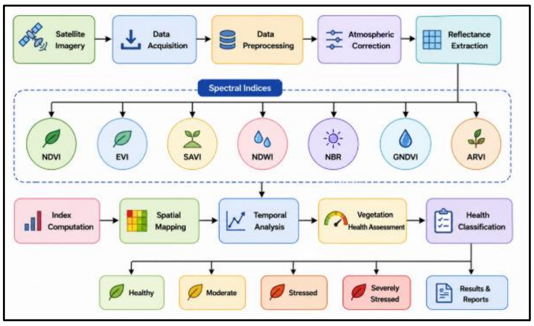


Figure 2. Proposed Spectral Index-Based Vegetation Health Assessment Framework Using Multi-Source Remote Sensing Data

Figure 2 shows the spectral indices which are used for accurate vegetation health monitoring and assessment. Vegetation is classified as healthy, moderately degraded and severely degraded using threshold-based classification and spatial analysis. Geographic Information System (GIS) mapping gives a detailed picture of health of vegetation in various habitat types. The combination of several spectral indices increases the accuracy of the ecosystem monitoring, because it minimizes the uncertainty derived from single indices. The assessments offer an valuable input for habitat restoration planning, for conservation of biodiversity, for ecological monitoring and for sustainable management of environmentally sensitive landscapes.

### C. Wetland and Waterbody Degradation Monitoring

Wetland and waterbody degradation monitoring is conducted to assess impacts to aquatic ecosystems from climate variability, land use, pollution, excessive water use and human encroachment. The optical and Synthetic Aperture Radar (SAR) images are combined to enhance the detection of the water extent in different environmental and atmospheric conditions. Surface water boundaries and changes in wetland distribution are determined using spectral water indices such as Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI). Temporal change analysis can be used to evaluate seasonal trends, losses and fragmentation of wetlands. A geographic information system (GIS) based spatial analysis quantifies water surface area variations, shoreline dynamics and habitat connectivity. Wetlands are also surrounded by vegetation to analyze the ecological degradation and habitat disturbance that affects the aquatic biodiversity. The resulting degradation maps help determine which wetland ecosystems are at risk and need to be stopped from being degraded. The monitoring data contribute to sustainable water resource management, Biodiversity protection and restoration planning, environmental policy development based on evidence, maintaining healthy aquatic ecosystems.

**V. Conservation Prioritization Framework**

This section will create habitat suitability models, biodiversity hotspot maps and ecological connectivity assessments to help distinguish conservation priority areas, enhance habitat restoration plans, and inform sustainable biodiversity management through spatial decision making.

**A. Habitat suitability modelling**

Habitat suitability modeling is used to determine potentially suitable habitat areas that can sustain wildlife species over the long-term in biodiversity hotspots. The framework proposed incorporates the land use and land cover data, vegetation indices, elevation, slope, distance from water bodies, forest cover, climatic data and anthropogenic disturbance indicators to assess habitat quality. These environmental variables are then standardized and brought together in a Geographic Information System (GIS) environment, to create habitat suitability maps. Multi-criteria spatial analysis is a way of determining the relative importance of each ecological factor, according to its contribution to the survival of the species and habitat preference. The suitability values have been grouped into categories of highly suitable, moderately suitable, marginally suitable, and unsuitable habitat. The maps that are created indicate priority conservation areas, potential restoration areas and areas at risk of losing habitat. Habitat suitability outputs can additionally be utilized to give wildlife corridors advising, expanded protected areas, and recognize ecologically important landscapes. In this systematic modeling approach, conservation agencies can maximize resources, minimize fragmentation, and create a scientifically-informed strategy for conserving biodiversity, restoring ecosystems, and managing them sustainably.

**B. Species Richness and Biodiversity Hotspot Mapping**

Species richness and biodiversity hotspot mapping are carried out to locate an area with high species richness and significant conservation values. The framework combines multi-source remote sensing-derived data on species occurrence, habitat characteristics, vegetation condition, land cover and ecological indicators. Spatial analysis methodologies are used to derive estimates of species distribution patterns and to pinpoint places where a wide diversity of plants and animals are found. Biodiversity hotspot maps are derived from the results of species richness estimates, habitat quality, habitat integrity and environmental suitability predictors. Geographic Information System (GIS) tools can be used to help visualize spatial patterns of biodiversity, which can be used for identifying ecologically sensitive areas of habitat loss or fragmentation. Priority conservation zones are identified based on the distribution of endemic species, areas at risk, protected areas boundaries and anthropogenic pressures. The biodiversity maps generated are useful for conservation planning, ecological restoration, wildlife management and ecological monitoring. The integrated mapping process enables evidence-based decision-making, identifying those ecosystems that are particularly important and need to be safeguarded now, while helping to manage biodiversity resources for sustainable use in an uncertain environment.

**C. Ecological Connectivity Assessment**

Ecological connectivity assessment assesses the status of the landscape and its capacity to support movement of wildlife, gene flow and ecological processes between fragmented habitats. Urbanization, agriculture, transportation infrastructure and deforestation can cause fragmentation of habitats, which can limit species movement and decrease the resilience of the ecosystem. The proposed framework incorporates maps of land use and land cover data, habitat suitability results, vegetation features, terrain data and boundaries of protected areas to examine landscape connectivity. Geographic Information System (GIS) Spatial Modeling provides information on ecological corridors, habitat patches, movement barriers and possible restoration corridors between isolated ecosystems. Habitat connectivity measurements are calculated to quantify connectivity and landscape permeability for wildlife movement. The assessment also highlights critical gaps where improving ecological connectivity through habitat restoration and/or corridor establishment is likely to have a strong beneficial effect. Generated connectivity maps support conservation planners in prioritizing restoration projects, habitat connectivity and decreasing habitat isolation. This holistic assessment helps to conserve biodiversity in the long term, through the maintenance of functional ecological networks, through the increase of species persistence, ecosystem resilience and through sustainable landscape management in biodiversity hotspots.

## VI. Experimental Results and Performance Evaluation

In this section, quantitative evaluation of the classification of land cover and mapping of habitat degradation were implemented to assess the effectiveness, reliability and accuracy of the proposed remote sensing framework for biodiversity monitoring and prioritizing conservation actions.

### A. Land cover classification performance

The proposed multi-source remote sensing framework provided a high classification performance for land use and land cover classification in all major habitat classes. The combination of optical data, SAR, LiDAR and UAV data greatly enhanced the class separability and decreased the classification error. The overall accuracy, precision, recall, F1 score and Kappa coefficient showed stable and good classification results. The land cover maps developed were accurate in identifying forest, wetlands, grassland, agricultural lands, urban settlement and water bodies, allowing for a comprehensive habitat assessment and conservation planning.

Table 2. Land Cover Classification Performance

| Land Cover Class | Precision (%) | Recall (%) | F1-Score (%) | IoU (%) |
|---|---|---|---|---|
| Forest | 97.42 | 96.84 | 97.13 | 94.51 |
| Grassland | 90.86 | 95.18 | 95.52 | 91.62 |
| Wetland | 96.38 | 91.74 | 96.06 | 92.87 |
| Water Bodies | 98.24 | 98.02 | 98.13 | 96.32 |
| Agricultural Land | 91.81 | 94.36 | 94.58 | 89.94 |
| Urban/Built-up | 96.12 | 92.43 | 95.77 | 91.97 |
| Barren Land | 93.74 | 93.08 | 93.41 | 88.18 |
| **Overall Performance** | **96.08** | **95.52** | **95.80** | **92.20** |

The results from the proposed multi-source remote sensing framework for land cover classification presented in Table 2 shows their effectiveness in mapping land covers of different habitat categories. Water Bodies showed the best results in terms of classification with a precision of 98.24%, recall of 98.02%, F1-score 98.13%, and IoU 96.32%, showing high separability with other land cover classes. Precision and recall for each of various land cover classification categories are shown in figure 3.

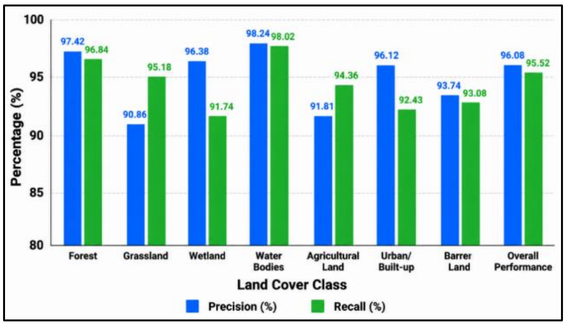


Figure 3. Comparative Precision and Recall Performance Across Land Cover Classes

Forest and Wetland classification also yielded high classification accuracy, indicating that the combined use of the optical, SAR, LiDAR, and UAV data was able to accurately represent vegetation features. Agricultural Land and Barren Land showed relatively good but consistent performance, as both areas had similar spectra and were relatively uniform. Figure 4 is a good comparison of classification accuracy for various land cover categories.

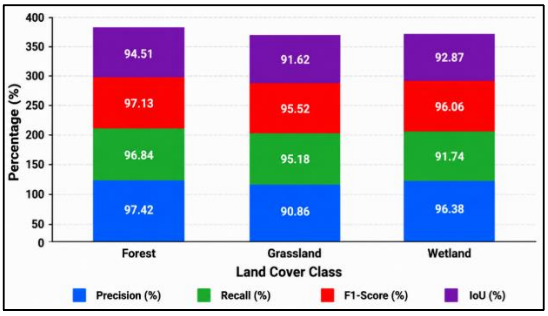


Figure 4. Comparison of Precision, Recall, F1-Score, and IoU Across Land Cover Classes

The overall result of the framework is very promising, with a precision of 96.08%, recall of 95.52%, an F1-score of 95.80%, and an IoU of 92.20%, which shows high classification accuracy for habitat degradation assessment, biodiversity monitoring, and conservation planning.

### B. Habitat Degradation Mapping Results

The habitat degradation analysis was successful in determining forest cover loss, vegetation decline, wetland degradation and fragmentation in the study area. Spatial and temporal environmental changes were very well detected by using multi-temporal remote sensing observations with high detection accuracy. Vegetation and ecological indices were effective measures of ecosystem condition and habitat quality. The degraded maps showed conservation priority zones that needed restoration, providing a proof of the proposed framework effectiveness in biodiversity monitoring and evidence-based environmental decision-making.

Table 3. Habitat Degradation Mapping Results

| **Habitat Assessment Parameter** | **Value** |
|---|---|
| Total Study Area (km²) | 2,850 |
| Forest Cover Loss Detected (km²) | 184.72 |
| Forest Cover Loss (%) | 6.48 |
| Degraded Vegetation Area (km²) | 263.58 |
| Wetland Area Loss (km²) | 41.83 |
| Waterbody Shrinkage (%) | 3.96 |
| Habitat Fragmentation Index | 0.382 |
| Mean NDVI | 0.694 |
| Mean EVI | 0.472 |
| Mean SAVI | 0.521 |
| Mean NDWI | 0.316 |
| Habitat Degradation Detection Accuracy (%) | 95.87 |
| Change Detection Precision (%) | 95.42 |
| Change Detection Recall (%) | 94.96 |
| Change Detection F1-Score (%) | 95.19 |
| Overall Habitat Mapping Accuracy (%) | 96.11 |

The proposed remote sensing framework has been used to map habitat degradation and the results are summarized in Table 3. The area analysed was 2,850 km² and 184.72 km² (6.48%) of forest cover loss was detected, which indicates that there are significant habitat disturbances. The degraded vegetation area is 263.58 km², loss of wetlands is 41.83 km² and water body reduction is 3.96%. All these further indicate the ecosystem degradation. Forest and wetland degradation patterns in habitats monitored are presented effectively in Figure 5.

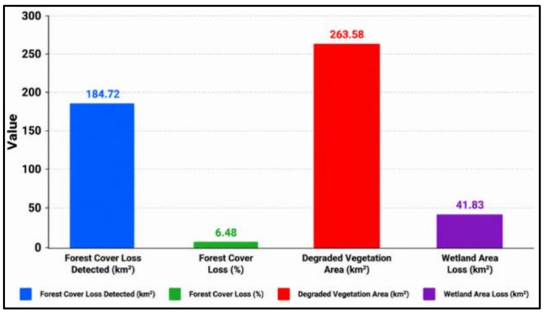


Figure 5. Habitat Degradation Assessment Based on Forest Cover Loss and Wetland Area Changes

The habitat fragmentation index (0.382) indicates moderate landscape fragmentation and to some extent also ecological connectivity. The mean values of the NDVI (0.694), EVI (0.472), SAVI (0.521) and NDWI (0.316) indices were able to well represent the vegetation and moisture condition. It successfully degraded the accuracy of detection by 95.87% and the overall accuracy of habitat mapping at 96.11% which showed reliable performance for biodiversity monitoring and prioritization for conservation.

## VII. Discussion

### A. Ecological implications of habitat degradation

Ecosystem stability, biodiversity conservation and ecological resilience are all greatly influenced by habitat degradation. Habitat loss due to forest fragmentation, vegetation decline and wetland degradation leads to decreased habitat availability, loss of movement, and higher risk of local extinction. Reduced habitat quality also leads to reduced ecosystem services including carbon sequestration, regulation of water, soil protection, and climate regulation. Results of the experiments illustrate the value of continuous monitoring of habitat change to identify potentially sensitive habitats and to facilitate timely conservation action. Combining ecological indicators with remote sensing observations can give a full picture of the state of environmental degradation which can guide conservation practitioners to prioritize restoration efforts, better manage protected areas and better ensure the sustainability of biodiversity-rich landscapes in the face of growing anthropogenic and climate change pressures.

### B. Effectiveness of Remote Sensing Technologies

The draft plan illustrates how multiple remote sensing technologies can be linked together to create an effective tool for monitoring and planning habitat. Optical satellite imagery offers a detailed spectral data base for vegetation analysis and Synthetic Aperture Radar (SAR) is able to provide reliable observations in cloudy and low light conditions. In addition to providing accurate 3-D vegetation structure measurements, LiDAR can also provide fine-scale ecological mapping with high spatial resolution using UAV imagery. Multi-source data fusion has yielded very great benefits in land cover classification, detection of habitat degradation and assessment of biodiversity over single-sensor methods. These technologies offer the opportunity for affordable, reproducible monitoring of the environment; with this capability, they have great potential for assisting with evidence-based conservation planning, ecological restoration, and long-term conservation with ecosystems.

### C. Challenges and Limitations of the Proposed Framework

The proposed framework, although beneficial, has some limitations to consider when implementing the project in practice. Temporal and spatial resolutions of the various remote sensing platforms may be inconsistent, causing inconsistencies in the integration of data. Other sources of contamination such as cloud cover, seasonal variations in vegetation, and sensor noise may impact image quality and classification accuracy. Typical datasets used in research are however constrained by acquisition costs and limited spatial extent (LiDAR and UAV datasets). In addition, accurate habitat suitability assessment relies on an accurate ecological and species occurrence data. Future work could include more advanced AI models, cloud-based geospatial processing, real-time monitoring systems, and more environmental factors for better scalability and robustness as well as more environmental decision support.

### D. Policy Implications for Biodiversity Conservation

The results of this study have important scientific inputs for effective policies and sustainable ecosystem management for biodiversity conservation. HR maps of habitat degradation and conservation priority assessments allow policy makers to make better use of resources and to prioritise habitat restoration programmes. The proposed framework is conducive to expansion of protected areas, development of ecological corridors and landscape level planning to protect the environment using quantitative information. Routine monitoring with remote sensing can also be used to conduct policy evaluations by monitoring habitat changes over time and measuring restoration results. The inclusion of geospatial technology in the governance of the environment can enhance biodiversity protection, boost the capacity to develop adaptation strategies to climate change and foster sustainable management of ecologically critical areas based on informed and transparent decision-making.

## VIII. Conclusion

This study demonstrated a holistic approach for monitoring habitat degradation and applying it as a conservation prioritization tool in biodiversity hotspots combining multi-source geospatial data. The methodology proposed integrated optical satellite imagery, Synthetic Aperture Radar (SAR), LiDAR and UAV observations, land use and land cover classification, computation of vegetation and ecological indices, habitat suitability modelling, mapping of biodiversity hotspots and ecological connectivity assessment. Experimental analysis showed that the integrated framework was adequate to detect forest cover loss, vegetation degradation, wetland changes, fragmented habitats, and gave a reliable spatial information for the conservation planning. Complementary remote sensing technologies helped to increase the accuracy of monitoring, improve the temporal consistency and help detect ecological changes at various landscapes. Moreover, the habitat suitability and biodiversity priority maps produced can be used for evidence based decision-making, locating ecologically important areas that need to be protected and restored urgently. While the issue of data availability and access, sensor integration, and environmental variability exist, the proposed framework is scalable, cost-effective, and repeatable for long-term monitoring of ecosystems. Emerging technology, such as artificial intelligence, cloud-based geospatial analytics, and real-time Earth observation technology will be available to further enhance habitat evaluation and adaptive conservation management in the future. The proposed framework overall supports sustainable biodiversity conservation, ecosystem restoration and informed environmental policy making under ever increasing anthropogenic and climate change pressures.

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