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Research Article

Evaluation of Land Use and Land Cover Changes and the Reduction of Sugarcane Farming in Bombali Through GIS and Remote Sensing

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Abstract

The study evaluates land use and land cover changes in Bombali District, Sierra Leone, with a particular focus on the decline of sugarcane farming the research creates detailed maps to envision current land use patterns, highlighting areas of sugarcane cultivation and shifts to alternative agricultural practices. The objectives of this research are to create detailed maps showing current land use and land cover, highlighting areas of sugarcane cultivation as farm bush, quantify and analyze Land Use and Land Cover Changes in the study area over stated periods, focusing on the dynamics of sugarcane farming, identify and assess the socio-economic and environmental factors contributing to the deterioration in sugarcane farming within the context of competing land uses. To demonstrate our idea effectively, the researchers used a Geographical information system and remote sensing technique to quantify and map the changes in each Land Use and Land Cover Changes category. Employing an error matrix table and estimator of Kappa statistics (Khat), we were able to achieve overall accuracy, and Khat greater than 80% for class-level accuracies which were also achieved as greater than 80%. Findings indicate that rising population density and economic incentives for diversifying crops have led to a notable shift away from sugarcane cultivation. To address these tasks and invigorate the sugarcane sector, the study recommends promoting sustainable agricultural practices, supporting crop diversification, enhancing market access and infrastructure, implementing effective environmental management policies, and encouraging ongoing research and development. By implementing these approaches, Bombali District can foster agricultural resilience, improve local livelihoods, and ensure sustainable land use practices that benefit both farmers and the environment.

Keywords: Land Use, Land Change, Sugarcane, Farming, Geographic Information System and Remote Sensing, Sustainable Agriculture, and Socio-Economic Factors.

Abstract

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sector, the study recommends promoting sustainable agricultural practices, supporting crop diversification, enhancing market access and infrastructure, implementing effective environmental management policies, and encouraging ongoing research and development. By implementing these approaches, Bombali District can foster agricultural resilience, improve local livelihoods, and ensure sustainable land use practices that benefit both farmers and the environment.
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Introduction

Land use and land cover (LULC) changes are critical indicators of environmental dynamics, reflecting human activities and natural processes that shape landscapes over time (Kidane, Stahlmann, & Beierkuhnlein, 2012). These changes can result from urbanization, agricultural expansion, deforestation, and climate change, impacting ecosystems and biodiversity. Understanding LULC transformations is indispensable for active resource management and sustainable development, particularly in regions where agriculture is crucial to the economy. The assessment of these changes not only aids in monitoring environmental health but also informs policymakers about the implications of land management decisions.

Geographic Information Systems (GIS) and remote sensing technologies have revolutionized how researchers analyze LULC changes. These tools allow for the collection, analysis, and visualization of spatial data, enabling a comprehensive understanding of how land use evolves (Bey et al., 2016). Remote sensing, in particular, can capture large areas with high precision, allowing for regular monitoring of land cover changes without the need for extensive field surveys. By integrating GIS with remote sensing, researchers can assess patterns, trends, and the underlying drivers of LULC change, facilitating a more informed Sugarcane farming is a significant agricultural activity in many countries, contributing to local economies and global sugar supply chains. However, this sector faces numerous challenges, including land degradation, water scarcity, and competition for land from other agricultural uses and urban development. As demands for land and resources intensify, understanding the dynamics of sugarcane farming and its associated land cover changes becomes increasingly important. Analyzing the decline in sugarcane farming can provide insights into broader agricultural trends, environmental impacts, and socio-economic factors influencing land use decisions. Approach to land use planning and resource allocation.

This study aims to evaluate LULC changes and reduced sugarcane farming using advanced GIS and remote sensing methodologies. By analyzing data from various time points, the research will uncover trends and patterns that characterize the evolution of land use in the study area. The findings will contribute to a deeper understanding of agricultural land use's complexities and provide valuable recommendations for sustainable practices. Ultimately, this study seeks to inform policymakers and stakeholders about the importance of preserving agrarian landscapes, ensuring food security, and promoting sustainable land management practices in the face of ongoing environmental challenges.

Sugarcane farming is a vital agricultural sector in many countries, contributing significantly to local economies and global sugar production. In regions where sugarcane is cultivated, it serves as a primary source of income for farmers and contributes to food security. However, the sector faces numerous challenges, including land degradation, market fluctuations, and competition from other agricultural practices. These factors, combined with increasing urbanization and environmental changes, threaten the sustainability of sugarcane farming. As a result, there is a pressing need to understand the dynamics of land use and land cover (LULC) changes that affect sugarcane cultivation and to assess the underlying reasons for its decline.

Land use and land cover changes are crucial pointers of environmental and economic trends, reflecting the connections between human activities and natural processes. Recently, significant transformations have been observed in agricultural landscapes, often driven by factors such as population growth, urban expansion, and changing agricultural practices. In the context of sugarcane farming, these changes can manifest as the conversion of arable land to non-agricultural uses, such as residential or commercial developments. This shift can lead to a reduction in available land for cultivation, ultimately impacting sugarcane production and farmers' livelihoods. Understanding these changes is essential for identifying the extent of the problem and developing strategies to mitigate negative impacts.

Several socio-economic and environmental factors contribute to the decline of sugarcane farming. Economic pressures, such as fluctuating sugar prices and increased production costs, can lead farmers to abandon sugarcane cultivation in favor of more profitable crops. Additionally, the encroachment of urban areas and industrial development often leads to the loss of valuable agricultural land. Environmental factors, including climate change, soil degradation, and water scarcity, further exacerbate the challenges faced by sugarcane farmers. These interconnected factors create a complex landscape that makes it difficult for farmers to sustain their operations, leading to a decline in sugarcane farming that must despite the challenges facing sugarcane farming, there is a notable lack of comprehensive assessments that analyze the interplay between LULC changes and the decline of this critical agricultural sector. Current literature often addresses either land use dynamics or the socio-economic aspects of sugarcane farming in isolation, resulting in a fragmented understanding of the problem. To effectively address the decline in sugarcane farming, a holistic approach is needed that integrates geographic information systems (GIS) and remote sensing techniques with socio-economic analyses. Such an assessment would provide a clearer picture of how land use changes impact sugarcane cultivation, offering insights that can inform targeted interventions and policies aimed at revitalizing the sector. This would be thoroughly scrutinized and understood.

The decline in sugarcane farming and the associated changes in land use have significant implications for policy and future research. Policymakers must understand the complex factors driving these changes to develop effective strategies that support sustainable agricultural practices. Additionally, further research is needed to explore innovative solutions that can enhance the resilience of sugarcane farming in the face of ongoing environmental and economic challenges. By addressing the underlying issues contributing to the decline of this vital sector, stakeholders can work collaboratively to promote sustainable land management practices, ensure food security, and support the livelihoods of farmers reliant on sugarcane cultivation. Ultimately, a comprehensive understanding of these dynamics is essential for fostering a sustainable future for both the agricultural sector and the communities it supports.

Aim and objectives of the study

Aim of the study

This study aims to evaluate land use and land cover changes and the reduction of sugarcane farming in Bombali District through GIS and Remote Sensing.

Objective of the study

The specific objective is to identify and evaluate socio-economic and environmental factors contributing to the decline of sugarcane cultivation in the context of competing land uses.

Study Area

This study was conducted in the Mara, Bombali Sebura, and Makarie Gbonty chiefdoms within the Bombali District of Sierra Leone's Northern Region (see Fig. 1 and Fig. 2). These three chiefdoms are neighboring and easily accessible by road, facilitating the collection of ancillary records for land use/land cover (LULC) taxonomy and simplifying non-spatial data collection. The area is situated between latitudes 7°30' N and 7°10' N and extends from longitudes 13°20' W to 10°00' W. It is located within Sierra Leone's coastal lowland region, characterized by a landscape primarily above 700 meters in elevation (Gwynne-Jones et al., 1978), with prominent undulating hills. The predominant vegetation forms in the study area are grassland savanna farm bush, with patches of Boli land savanna and various water bodies. The region's edaphic characteristics are mainly defined by black loamy soils, although sandy and alluvial soils can also be found due to deep tropical weathering and depositional processes. The majority of residents in these chiefdoms are from the Temne ethnic group, with most engaged in farming activities. Landsat images for the study area from 2010 and 2020 were obtained free of cost from the United States Geological Survey (USGS) Earth Explorer website (https://earthexplorer.usgs.gov). These specific time points allowed for the utilization of the three most recent Landsat sensors: Landsat-7 Enhanced Thematic Mapper Plus (ETM+) for 2010 and Landsat-8 Operational Land Imager (OLI) for 2020. The 2010 data offers insights into land use and land cover changes (LULCC) during their operational period at Addax, Sunbird Bioenergy, while the 2020 data reflects the current LULC status after two decades of Sunbird Bioenergy's operations. For each year, two scene footprints were acquired to ensure complete coverage of the study area, with the temporal Landsat images obtained close to their anniversary dates. Here, only images with less than 10% cloud cover were selected.

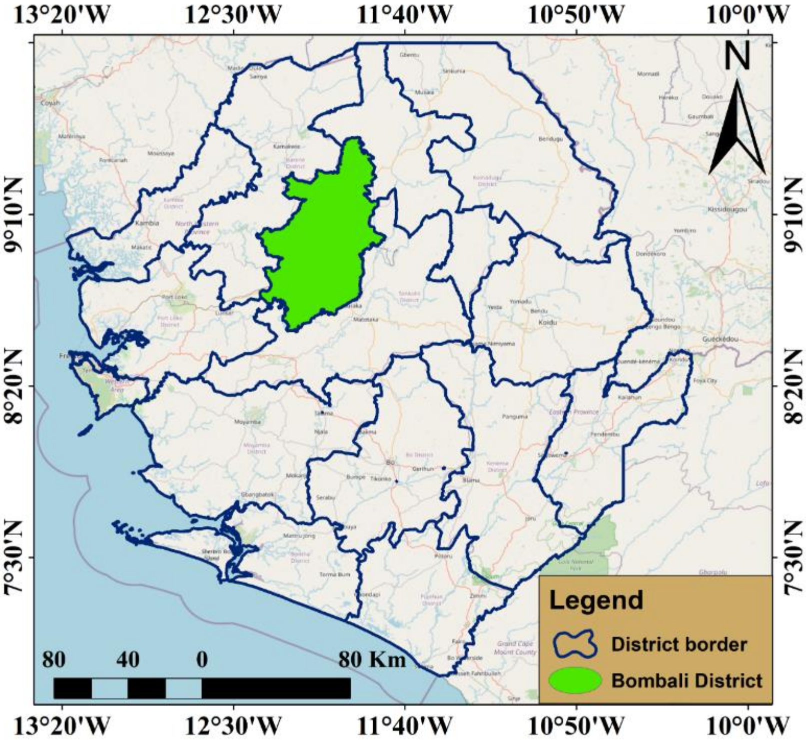

Figure 1: Location map of the study area showing the Bombali district

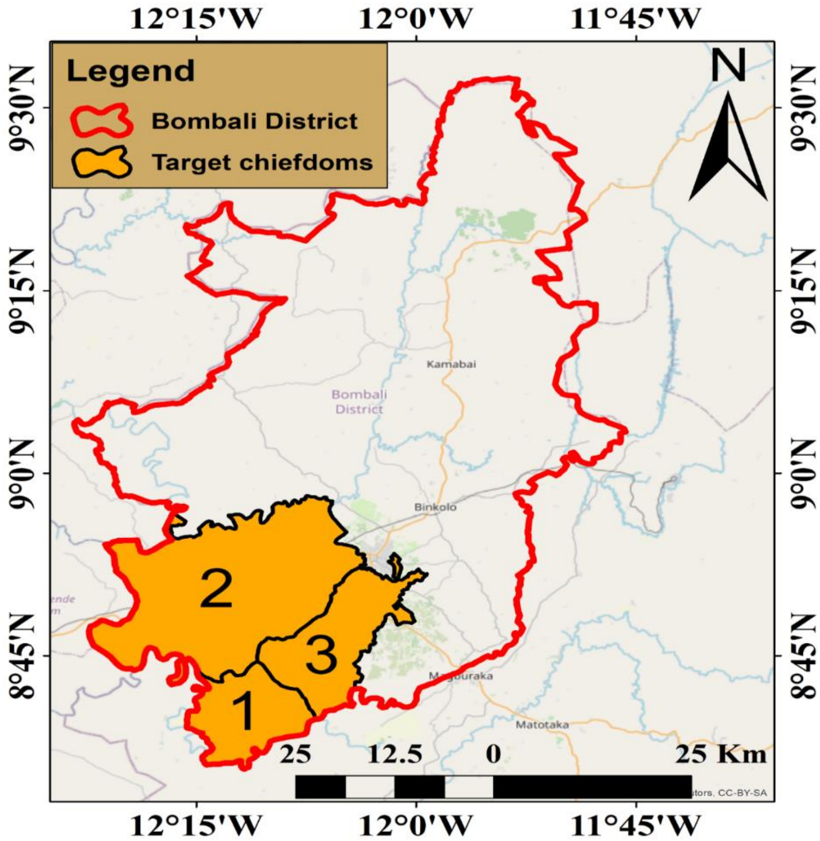

Figure 2: Map showing the targeted chiefdoms

Satellite image preprocessing

Satellite image processing is a powerful computational method that catches application in agriculture, natural disaster prevention, natural resource documentation, and so forth. Nevertheless, satellite image processing is too complicated due to the large scope of the satellite images. Remote sensing images have a huge amount of

information. If the image quality is not good or if the image analysis does not use the optimum feature set, then the impact of the remote sensing application for which the technique used may not be fully utilized.
In this research, all satellite images acquired from the Earth Resources Observation and Science (EROS) data center were already geometrically corrected, followed by the global geographic coordinate system (WGS 1984), and further geo-rectifications of all three images of each year were accomplished using the country-specific projection system. All ground control points (GCPs) were taken from global 30-meter SRTM topographic data for geo-rectification.

Image preprocessing of optical bands

These images were taken from diverse months of the year based on cloud-free data availability, they might be subjective to seasonal disturbances and atmospheric effects like aerosols, dust particles, clouds, and changing sun angles. Also, data sounds result from restrictions in sensing by the sensor, signal digitization, or data recording process. These noises from different sources significantly degrade the radiometric information of the image (P. Chavez, 1975). So, these images were exposed to severe atmospheric and radiometric correction to decrease the impact of clouds, atmosphere, and sunrise angle. Several atmospheric correction methods have been established, such as; the empirical dark object subtraction (DOS) technique (Gilabert, Conese, & Maselli, 1994), modified DOS method (P. S. Chavez, 1996), cosine estimation of atmospheric transmittance (COST) (Lillesand, Kiefer, & Chipman, 2015), moderate resolution atmospheric transmission (MODTRAN) model developed by the United States Air Force and the Spectral Science, Atmospheric Correction (ATCOR) developed by German Aerospace Center (DLR) and the Fast Line-of-sight Atmospheric Analysis of Spectral Hypercube (FLAASH) incorporated in ENVI software. Here, the FLAASH segment of ENVI-5.3 was used to conduct the atmospheric correction process. Numerous standardization parameters (image acquisition data, sensor type (TM/ETM/OLI), sensor-specific concise standardization file, solar peak angle, projected scene visibility, aerosol model, etc. will need to be conventional before running the process.

Fundamental information about the scene such as Image acquisition date, time, sun elevation angle, the spectral radiance (LMin) scaled to the lowest quantized standardized pixel value (QCalMin) in watt m-2sr-1μm-1. The spectral radiance (LMax) scaled to the maximum quantized calibrated pixel value (QCalMax) in wattm-2sr-1μm-1 is recovered unswervingly from the image metadata file. Furthermore, reducing atmospheric effects, FLAASH converts the digital numbers (DNs) of each pixel of each scene to sensor spectral radiance (L) in mWcm-2sr-1μm-1 and finally to surface reflectance (ρ) using the following equation (2.1). The resultant scene's pixel contained reflectance values ranging from 0 to 1.

$$L = \left(\frac{A_{\rho}}{1-\rho_e s} \right) + \left(\frac{B\rho_e}{1-\rho_e s} \right) + La \qquad (3.1)$$

L represents the at-sensor spectral radiance, ρ represents the surface reflectance, ρe represents the average surface reflectance of a pixel and surrounding region, S represents the spherical albedo of the atmosphere, La represents the backscattered radiance by the atmosphere, A and B are coefficients that depend upon air and geometric conditions however not at the surface.

Once atmospherically corrected, every year's image was mosaicked using a seam line to formulate a single scene of each study year. Therefore, one scene was generated, which was clipped to the study area's boundary using a region of concentration (ROI) resulting from the study area's vector file (ESRI shape file).

Image classification and LULC extraction

Landsat imagery (TM, ETM, and OLI) were processed separately, at first the modified Anderson Level I classification Scheme (Anderson, 1976), which is worldwide accepted was used. A widely used LULC ordering scheme was chosen to use in this study to realize anticipated LULC categories from satellite imagery. According to this organization scheme, we recognised five key classes (Table 2.1) built-up areas vegetation dense vegetation, low vegetation), bare land, water body, and farm bush. We extracted the LULC categories from satellite imagery, by using the support vector machine-supervised ordering method.
The Optimum Index Factor (OIF) was calculated for each set of 3 band combinations in a Landsat scene to investigate the optimum informative band composite with minimum correlation among spectral bands from where training sites for classification were compiled proficiently, using those spectral bands, false-color composite images were organized for each study year. A total of 200 signatures for each LULC class were extracted accidentally, covering the whole study area. The accuracy of those marks was evaluated utilizing the Transform Divergence (TD) values. Finally, Support vector Supervised classification is applied based on those spectral signatures to get the desired LULC categories. To connect remotely sensed longitudinal and temporal

style in land use and land cover (LULC) with population growth, census data from 1963, 1974, 1985, 2004, and 2015 were employed. While the study was focused on the period from 1998 to 2015, including data from as far back as 1963 allowed for a more comprehensive analysis of population dynamics and a clearer understanding of trends in the area.

Table 1: Analysis of the land cover types.

LULC Classification	Explanations
Thick Vegetation	Evergreen and semi-evergreen forest covers, commercially planted forests with large canopy covers
Farm Bush	Farmland, gardens, grassland and vegetable lands.
Built up Areas	All residential, transportation, commercial, industrial area villages
Water bodies	Perennial water body, lakes, ponds and other water reservoirs
Naked land	Open fields, uncovered lands, mining and sand fill areas

Post-classification refinement & accuracy assessment of the LULC classification

The classification procedure always leaves misclassified or poorly classified pixels in each image, commonly known as the salt and pepper effect (Congalton & Green, 1993). It mainly happens owing to similar spectral features of some pixels in two dissimilar categories. The wrong classification occurs along the border of each category. Several isolated pixels of dissimilar classes may be found to be produced within the other classes. Hence, a post-classification modification is desired to minimize misclassification. We made use of a 3x3-pixel window median filtering to reduce the number of quarantined pixels and assign the isolated pixels to the surrounding dominant class (Table 1). These may be furthermore reduced using contemporary high-resolution satellite images and secondary maps.

To measure the correctness of the classification, an accuracy assessment process must be applied. Among the different accuracy assessment models, the error matrix (confusion matrix or a contingency table) has become the most efficient method of reporting the accuracy of classification obtained from remotely sensed data (Congalton, 1991). The accuracy of each classified area (user accuracy and producer accuracy) is estimated along with the errors of inclusion (commission error), errors of exclusion (omission error) as well as the overall accuracy of the classification (Cohen, 1960; Congalton & Mead, 1983). Another estimator of accuracy is the Kappa statistics, a non-parametric discrete multivariate technique developed by Cohen (Cohen, 1960), which measures the overall agreement. For the accuracy assessment, 350 sample pixels (70 per category) were generated using the stratified random sampling method over the study area for all periods of LULC maps. Secondary spatial data, reference maps, and contemporary high-resolution satellite images were used to collect ground truth data for those pixels. Finally, the classification accuracy assessment procedure was performed using the class values and the ground truth values, generating the error matrix containing different measurement statistics. A rigorous Kappa statistic for the stratified random sampling method will also be used using the following equation (2.2) (Muller & Middleton, 1994) to check its accuracy.

$$k = \frac{N \sum_{j-1}^{r} X_{jj} - \sum_{i=1}^{r} \left(x_{i+}\right)\left(x_{+i}\right)}{N^2 - \sum_{i-1}^{r} \left(x_{i+}\right)\left(x_{+i}\right)} \qquad (3.2)$$

Where k represents the number of rows in the matrix, is the number of observations in row-i and column-i (the diagonal elements), and are the marginal totals of row-r and column-i, respectively. N represents the real number of observations.

Discussion

The use of Geographic Information Systems (GIS) and remote sensing technologies have become even more key in evaluating Land Use and Land Cover (LULC) changes, particularly in trendy regions like Bombali District in Sierra Leone. Recent studies indicate a significant reduction in farm bush areas, especially those dedicated to sugarcane farming. This discussion evaluates the results of LULC changes in Bombali, compares them with findings from other related works, and highlights the implications for agricultural practices and environmental management.

Using GIS and remote sensing data, recent analyses of Bombali District reveal a marked decline in farm bush areas, with a specific focus on sugarcane cultivation. Over the past years, the entire area dedicated to farm bush has fluctuated, showing an increase from 78.9 km^2 in 2010 to 85.4 km^2 in 2020, but the specific piece for sugarcane farming has contracted significantly. This reduction can be ascribed to various socio-economic factors, including market dynamics, land competition, and shifts in agricultural practices. The decline in sugarcane farming may also reflect changes in local and regional demand for sugar products, as well as a potential pivot toward other crops that are perceived as more productive or bearable (Martínez et al., 2013). The combination of remote sensing data aimed at precisely tracking these changes facilitates a deeper understanding of land management practices and trends in the region.

When comparing the findings from Bombali with other studies, it becomes clear that LULC changes are a common phenomenon in many regions experiencing agricultural intensification and urban expansion. For instance, a study by (Van Vliet et al., 2012) on land use changes in West Africa highlighted similar trends, where traditional farming practices were increasingly supplanted by more commercial agriculture. This trend aligns with the changes observed in Bombali, where traditional sugarcane farming is being challenged by economic pressures and the advent of alternative agricultural ventures. Furthermore, remote sensing studies in other parts of Sierra Leone, such as the work by (Van Vliet et al., 2012), indicate a trend of declining forest cover, exacerbated by agricultural expansion. This broader perspective recommends that the decline of sugarcane farming in Bombali is part of a larger narrative of land change driven by socio-economic pressures and environmental changes.

The reduction of sugarcane farming in Bombali can be further understood through an examination of socio-economic factors. Market fluctuations, access to resources, and changing consumer preferences play significant roles in shaping agricultural practices. A shift toward crops that require less input or offer quicker returns on investment may be influencing farmers to move away from sugarcane cultivation Additionally, the increasing competition for land due to urbanization and population growth can lead to the repurposing of agricultural land for residential or commercial uses, further impacting farm bush areas. The dynamics of land tenure, where land ownership and access rights influence cultivation choices, also play a critical role in determining which crops are prioritized (Holden & Otsuka, 2014). The integration of these socio-economic factors highlights the complexity of agricultural decision-making in Bombali and underscores the importance of adaptive land management strategies.

The decline of sugarcane farming in Bombali has significant environmental implications, particularly concerning biodiversity and ecosystem health. Sugarcane, like many monoculture crops, can lead to soil degradation and loss of nutrients when grown extensively without sustainable practices (Garside, Bell, Robotham, Magarey, & Stirling, 2005)The shift away from sugarcane could provide opportunities to adopt more diverse and sustainable agricultural practices, fostering better soil health and enhanced biodiversity. However, the transition must be managed carefully to avoid adverse environmental impacts associated with the expansion of other types of agriculture. Studies in similar contexts emphasize the need for integrated land management practices that balance economic viability with environmental sustainability (Pretty et al., 2018). This balance is crucial for ensuring long-term agriculture..

Conclusion.

The evaluation of Land Use and Land Cover Changes within Bombali District reveals a significant decline in sugarcane farming, primarily driven by socio-economic and environmental factors. Utilizing GIS and remote sensing technologies has permitted an in-depth analysis of land use dynamics, highlighting shifts from sugarcane cultivation to alternative agricultural practices and urban development. Key findings indicate that increasing population pressures, changing market demands, and environmental challenges have collectively influenced land use decisions among local farmers. The transition away from sugarcane cultivation reflects a broader trend of agricultural diversification aimed at enhancing economic resilience.

To mitigate the decline of sugarcane farming and promote sustainable agricultural practices, it is crucial to implement targeted strategies that support farmers in adapting to these changes. This includes promoting sustainable farming techniques, improving market access for sugarcane, and improving the overall resilience of agricultural systems in the region.

Recommendations for Policy Making

i. Promote agro ecological practices that enhance soil health and minimize dependency on sugarcane.
ii. Provide financial incentives for farmers to diversify their crops to mitigate economic risks.
iii. Develop integrated land use plans that balance agricultural, environmental, and urban development needs.
iv. Foster local community involvement in decision-making processes to ensure policies reflect their needs.

v. Establish ongoing monitoring programs using Geographic Information Systems and remote sensing to track land use changes policy effectiveness.

Recommendations for Further Research

i. Conduct studies to assess the socio-economic impacts of transitioning away from sugarcane farming.
ii. Investigate how land cover changes affect local biodiversity and ecosystem services.
iii. Research the weakness of agricultural practices to climate variation and identify adaptive strategies.
iv. Compare yields and profitability of alternative crops to sugarcane for informed decision-making.
v. Analyze longstanding land use and cover changes to identify trends and driving factors.

Declarations

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