ASSESSING THE IMPACTS OF CLIMATE CHANGE ON FORESTS USING REMOTE SENSING AND GIS TECHNIQUES: A CASE OF KANONA NATIONAL FOREST, ZAMBIA

BY

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Introduction

- The report focused on studying the impacts of climate change on Kanona National Forest in the Chitambo District of Central Zambia.
- The primary objectives were to gain a deeper understanding of how climate change affects the forest and trees in the study area.
- Key aspects of investigation included:
  - Analyzing land use and land cover changes.
  - Exploring correlations between vegetation indices and land surface temperature.
  - Determining tradeoffs between livelihoods and forest/tree-based ecosystem services.
- Spatio-temporal changes in land use and land cover within Kanona National Forest were analyzed using remote sensing and GIS techniques.
- Remote sensing and GIS techniques helped in:
  - Mapping and monitoring changes in land use and land cover over time.
  - Providing valuable insights into the forest's response to climate change.
  - Providing information for effective sustainable forest management.

Study rationale

- Improve understanding of climate change impacts on African forest and tree-based ecosystems
- Identify and generate adaptation options for stakeholders
- Provide a comprehensive overview of research findings
- Guide future strategies for community resilience and forest management
- Support sustainable forest management by the Department of Forestry in Zambia

Objectives

- Detect and analyze Spatio-temporal changes in Land Use Land Cover (LULC) within the Kanona National Forest using satellite imagery and remote sensing techniques.
- Evaluate Spatio-temporal trends and establish the relationship between vegetation indices and land surface temperature (LST) within the study area.
- Investigate trade-offs between livelihoods and forests/tree-based ecosystem services in the Kanona National Forest.

Materials and methods

Description of the Study Site:

- Study Area: Kanona National Forest Area
- Latitude: 12°59'57.84"
- Longitude: 30°28'38.96"Terrain Elevation: Approximately 1543 meters above sea level
- Size: Approximately 28,640 hectares
- Location: Shared by Chitambo and Serenje Districts in Zambia

Data Collection/Sources of Data:

Objective 1:

Landsat 7 Enhanced Thematic Mapper Plus (ETM+):

- Years: 2004 and 2009
- Resolution: 30 meters
- Downloaded from Earth Explorer (http://earthexplorer.usgs.gov)

Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS):

    - Years: 2014 and 2019
    - Resolution: 30 meters
    - Downloaded from Earth Explorer (http://earthexplorer.usgs.gov)

Materials and methods Cont'd

Objective 2:

1. **MODIS NDVI/EVI data:**
   - Product: 16-Days MOD13Q1 L3 Global 1 Km SIN Grid V006
   - Source: USGS (United States Geological Survey)
   - Downloaded from: https:/modis.gsfc.nasa.gov/dataprod/mod13.php
2. **Land Surface Temperature (LST) data:**
   - Product: MOD11A2 16-Day L3 Global 1 Km SIN Grid V006
   - Source: NASA's MODIS (Moderate Resolution Imaging Spectroradiometer)
   - Downloaded from: https://modis.gsfc.nasa.gov/data/dataprod/mod11.php

Objective 3:

1) Focus Group Discussions (FGD)
2) Key Informants Interviews (KII)
3) Desk review of documents
   - Forest Management Plans
   - Integrated Land Use Assessment Phase II (ILUA II) Project report
   - "Promoting Climate-Resilient, Community-Based Regeneration of Indigenous Forests in Zambia's Central Province" Project report

Materials and methods Cont’d

Data analysis

Objective 1

Preprocessing and image preparation:

- The satellite images (Landsat 7 and 8) were already geometrically corrected from source.

Image classification:

- Supervised and unsupervised classification techniques were used to classify the land cover types within the study area.
- Maximum Likelihood (supervised) and iso-cluster Unspervised classification techniques

Change detection:

- Pixel-based or object-based change detection analysis was performed to identify areas of land use and land cover changes between different time periods.
- Techniques such as post-classification comparison or image differencing were used to detect and quantify the changes.

Cont'd

Data analysis

Objective 1

Accuracy assessment:

- The accuracy of the classified images was validated by comparing the results with reference data collected in the field or from reliable sources.
- Accuracy metrics such as overall accuracy and kappa coefficient were calculated to assess the quality of the classification.

Spatial analysis:

- Spatial analysis was conducted to analyze the spatial patterns and distribution of different land cover types.
- Land cover area calculations were used to assess the spatial distribution and composition of land cover within the study area.

Cont’d

Objective 2

Trend Analysis:

- **Examined Spatio-temporal trends in NDVI, EVI, and LST**
    - Mapped distribution of NDVI, EVI, and LST
    - Identified spatial clusters and gradients

Relationship Analysis:

- **Explored relationship between vegetation indices and LST**
- **Conducted statistical analysis:**
    - Correlation analysis
    - Regression analysis

Visualization:

- **Presented results using maps, charts, and graphs**

Cont'd

Data analysis
Objective 3

FGDs and KII were conducted to gather valuable insights from the communities.

The following steps were typically taken during the analysis:

- Transcription:
  - The data collected from the Focus Group Discussions (FGDs) was transcribed to create a written record.
  - Transcription involved either transcribing audio recordings or taking detailed notes during the discussions.
- Data Familiarization:
  - The transcribed data was thoroughly reviewed and familiarized.
  - The content was carefully read and re-read to gain a comprehensive understanding.
  - The g**oal** was to understand the participants' responses and perspectives
- Coding:
  - Codes or labels were assigned to specific sections or segments of the transcribed data.
  - The codes represented recurring patterns, themes, or categories identified during the analysis.
  - Coding was used to organize and categorize the information for further analysis.

Key findings and discussion

Objective 1

Class Name	2004		2009		2014		2019	
	Area	Percent	Area	Percent	Area	Percent	Area	Percent
Water body	704	2.49	73	0.26	38	0.13	210	0.74
Grass land	8,430	29.85	7,482	26.49	5,675	20.09	8,131	28.79
Forest land	9,714	34.39	4,349	15.40	6,773	23.98	2,513	8.89
Farm land	2,533	8.97	10,166	35.99	9,759	34.55	10,441	36.97
Bare land	6;098	21.59	5,518	19.54	5163.7858	18.28	5,510	19.51
Settlements	765	2.71	657	2.33	835.39836	2.958	1440	5.09
Totals	**28,244**	**100**	**28,244**	**100**	**28,244**	**100**	**28,244**	**100**

Key findings and discussion

Objective 1

Key findings and discussion

Objective 1

- Significant decrease in forest cover (from 9,714 ha in 2004 to 2,513 ha in 2023)
- Declines in water bodies, grassland, and bare land
- Notable increases in farm land and settlements (from 2,533 ha in 2004 to 10,441 ha in 2019)
- Indicates a significant landscape transformation
- Potential implications for biodiversity, ecosystem services, and water resource availability
- Highlights the importance of sustainable land management practices
- Emphasizes the need to balance development and conservation goals

Key findings and discussion

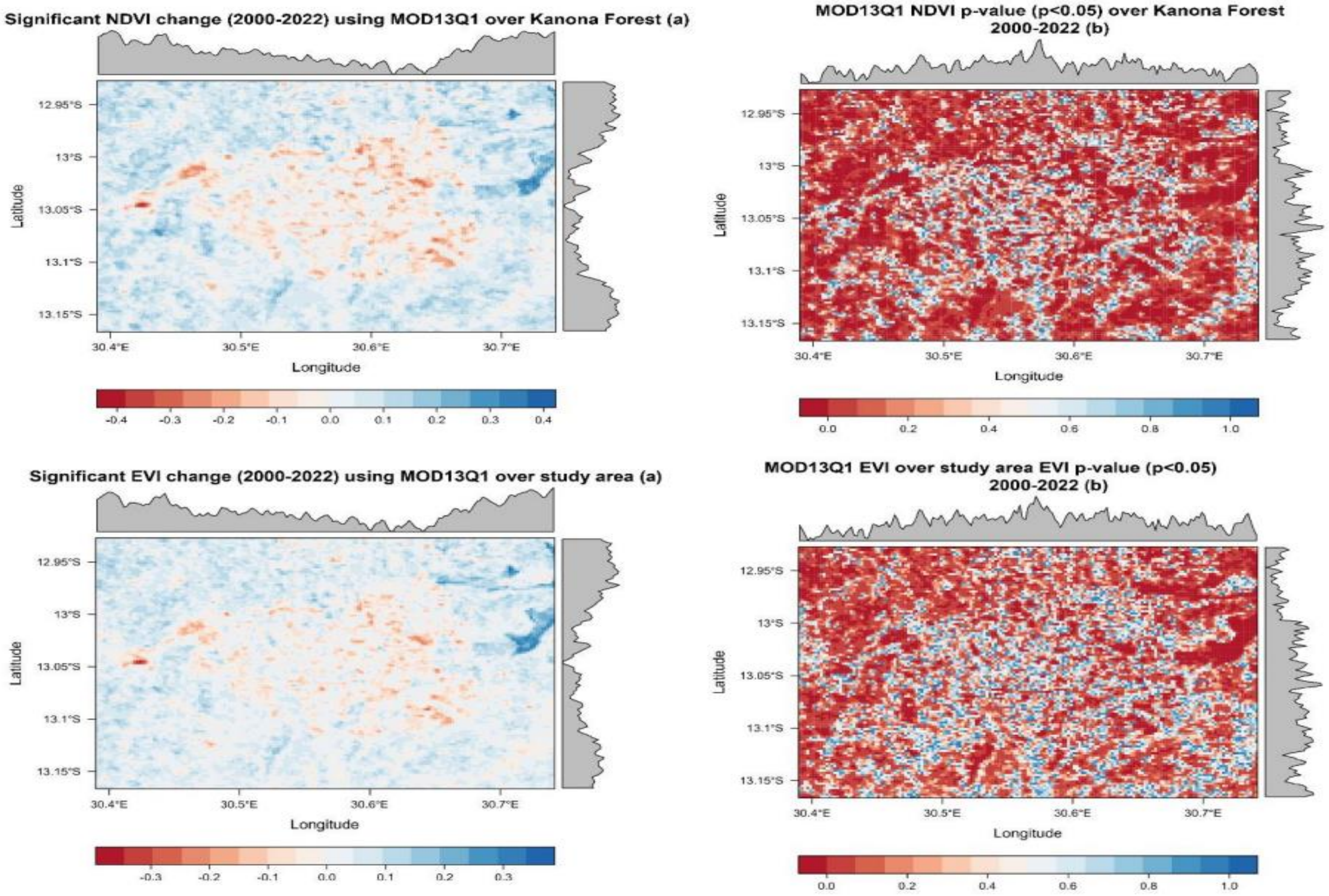
Objective 2

NDVI and EVI Values

- Outside the Forest Reserve:
  - NDVI values ranged from 0.5565 to 0.6890.
  - EVI values ranged from 0.2859 to 0.3968.
- Inside the Forest Reserve:
  - NDVI values ranged from 0.3503 to 0.6042.
  - EVI values ranged from 0.2572 to 0.3487.
- Outside the Forest Reserve, higher NDVI and EVI values were observed, indicating a healthier and denser vegetation canopy.
- Inside the Forest Reserve, lower NDVI and EVI values were recorded, suggesting weaker vegetation cover compared to areas outside.

Key findings and discussion

Objective 2



Key findings and discussion

Objective 2

- Decline in vegetation cover and health within the Kanona National Forest over the analyzed period.
- The forest reserve experienced more pronounced changes in NDVI and EVI compared to the surrounding areas.
- These findings highlight the urgency to implement proactive measures to address the declining vegetation health and protect the forest reserve from further degradation.

Key findings and discussions

Objective 2

The Daytime and Nighttime Land Surface Temperature (LST)

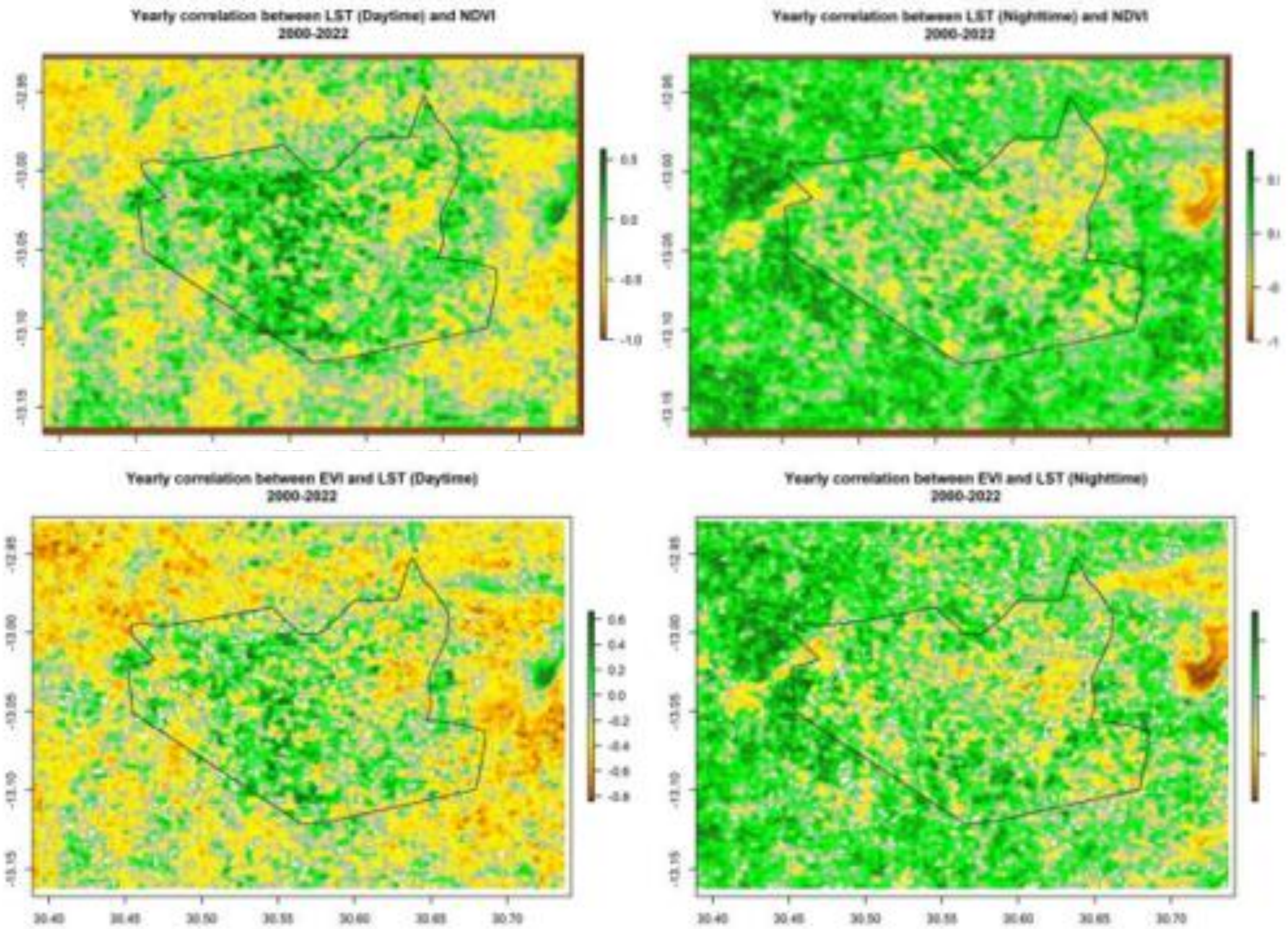
- Daytime LST inside the forest reserve ranged from 22.41°C to 48.35°C, higher than outside the forest.
- Nighttime LST inside the forest reserve ranged from 32.81°C to 39.07°C, also higher than outside the forest.
- Land cover changes, particularly deforestation activities, contribute to increased temperatures inside the forest area.
- Land use/land cover changes have a significant impact on LST, affecting local, regional, and global scales.
- **LST Trends:**
- Daytime LST Trends:
  - The forest reserve exhibited greater changes in daytime LST compared to areas outside the forest reserve.
  - The analysis showed a rate of change ranging from -0.08°C to 0.08°C.
- Nighttime LST Trends:
  - Deforested areas experienced a positive increase in nighttime LST.
  - Areas inside the forest reserve exhibited warmer temperatures, indicating higher deforestation activities.
  - Yearly trends in mean LST did not provide significant evidence of change, possibly due to small effect sizes.

Key findings and discussions

Objective 2

Correlation between LST and NDVI in Kanona Forest area:

- NDVI is negatively correlated with surface temperature, indicating that higher vegetation corresponds to lower LST.
- Areas with more vegetation cover experience lower LST, while areas with less or no vegetation experience higher LST.
- Loss of vegetation cover leads to increased LST and contributes to global warming .
- The understanding of the relationship between NDVI and LST helps guide forest management decisions.


Yearly correlation between LST (Daytime) and NDVI
2000-2022
Yearly correlation between LST (Nighttime) and NDVI
2000-2022
Yearly correlation between EVI and LST (Daytime)
2000-2022
Yearly correlation between EVI and LST (Nighttime)
2000-2022

Key findings and discussion

Objective 3

Identification of ecosystem services

- In Kanona National Forest Area, the identified ecosystem services were mainly classified as provisioning and regulatory services.
- Provisioning services, such as food, fibre, energy, water, agricultural land, medicine, and construction materials, were highly valued by the community members.
- Regulatory services, including pollination, soil fertility, rain cycle, and climate change mitigation, were recognized as crucial for maintaining the balance and functionality of the ecosystem.
- The community members acknowledged the importance of both provisioning and regulatory services in sustaining the ecosystem's well-being.

Key findings and discussion

Objective 3

Threats to ecosystem services in the forest area

Threats to the Forest	Impact	Impact scores out 10
Agriculture	Deforestation through land clearing	8.5
Wood-harvesting	Forest destruction	8
Climate change	Extreme weather	6.8
Fire	Destruction to forests and property	8
Water management and use	Water abstraction and damming	6
Hunting	Fire ignition	3
Fish harvesting	Over fishing and poisoning	6.5
Human disturbance	Forest destruction	5
Vehicular movements	Soil degradation and environmental pollution	4.8
Gathering plants (roots and fruits)	Forest destruction using unsustainable methods	6
Mining	Land degradation	8

Key findings and discussion

Objective 3

Conflicting priorities:

- Agriculture, forest management, and settlement development in Kanona Forest Area present conflicting priorities.

Conflicting features	Benefits
Agriculture production	Farm land and household food security
Forest management	Provisioning and regulatory Ecosystem services
Settlement development	Secure shelter and proximity to forest services

Key findings and discussion

Objective 3

Valuation of Ecosystem Services

- Efforts were made to quantify ecosystem services in monetary units in the Kanona National Forest Area.
- Forest-based services and agricultural-based services were categorized and assessed for their economic value.
- The valuation revealed the monetary worth of various forest-based and agricultural-based products, such as charcoal, firewood, fruits, mushrooms, honey, sand, maize, beans, soya beans, and cassava.
- The valuation matrix provided insights into the economic, ecological, and social values associated with each product.
- The findings emphasized the importance of considering multiple dimensions, including revenue, ecological sustainability, and social benefits, when assessing the value of ecosystem services.

Key findings and discussion

Objective 3

Valuation of forest-based products

Product	Measure	Per month	Per annum	Price	Total amount
Charcoal	Bags	50	600	80	48000
Firewood	M^3 Stack	3	36	45	1620
Fruits	Baskets	300	900	100	90000
Mushrooms	Buskets	300	1500	150	225000
Caterpillar	10 lt backet	60	180	240	43200
Honey	2.5lt containers	160	320	250	80000
Sand	trips/Truck	40	480	2500	1200000
					1687820

Valuation of agricultural-based products

Product	Measure	Per month	Per annum	Price	Total amount
Maize	Bags/ha	100	100	180	18000
Beans	Bags/lima	10	10	100	1000
Soya beans	bags/ha	50	50	600	30000
Cassava	Bags/lima	20	20	100	2000
					51000

Key findings and discussion

Objective 3

Economic, Ecological, and Social Value Assessment of Ecosystem Services

Product	Revenue per annum	Economic Value	Ecological Value	Social Value
Charcoal	48000	Medium	Low	Low
Firewood	1620	Low	Low	Low
Fruits	90000	High	Medium	Medium
Mushrooms	225000	High	High	High
Caterpillars	43200	Medium	Medium	High
Honey	12500	Medium	High	Medium
Sand	1200000	High	Low	Low
Maize	18000	Medium	Low	Medium
Beans	1000	Low	Low	Low
Soya beans	30000	Medium	Medium	Medium
Cassava	2000	Low	Low	Low

Key findings and discussion

Objective 3

Alternative scenarios:

- Different options were presented to address management and utilization challenges in the study area.
- Consistent results: Similar outcomes were obtained across all areas visited, including those outside the forest reserve.
- Options presented during FGDs:
    - Evict and leave the forest.
    - De-gazette the forest reserve.
    - Remain and conserve the forest.
    - Evict but find alternative land for communities.
    - Evict and compensate affected communities.

Key findings and discussion

Objective 3

Options	Evict and leave forest	De-gazette Forest Area	Remain and conserve	Evict but find alternative land	Evict and compensate	Totals	Ranking
Evict and leave forest		0	0	0	0	0	5
De-gazette Forest Area	1		0	1	1	3	2
Remain and conserve	1	1		1	1	4	1
Evict but find alternative land	1	0	0		0	1	4
Evict and compensate	1	0	0	1		2	3

- These scenarios highlight the range of factors to consider and trade-offs involved in decision-making.

Options	Ranking
Remain and conserve	1
De-gazette Forest Area	2
Evict and compensate	3
Evict but find alternative land	4
Evict and leave forest	5

- Community members expressed a strong preference for staying in the forest area and actively participating in its conservation and sustainable management.

Key findings and discussion

Objective 3

- **Differing views among stakeholders**:

  Government officials and some Key Informants outside the forest area expressed skepticism about allowing settlements in the forest and the feasibility of balancing settlements with effective forest management.

- **Conflicting perspectives**:

  The belief that settlements and forest management inherently conflict with each other was highlighted, posing challenges and potential trade-offs.

- **Community perspective vs. broader objectives**:

  Allowing settlers to remain and participate in forest management may align with community desires but may not align with broader objectives and policies of sustainable forest management according to some stakeholders.

- **Need for balancing community aspirations and broader goals**:

  Findings emphasize the importance of reconciling community aspirations with sustainable forest management objectives while addressing potential trade-offs.

Key messages and policy implications

Key messages

- Anthropogenic activities, such as deforestation and greenhouse gas emissions, have a significant impact on climate change and the well-being of forests and trees.
- Effective mitigation measures, including education, afforestation, and law enforcement, play a crucial role in addressing challenges and safeguarding forests against climate change.
- Achieving a balance between development and conservation goals necessitates careful consideration of trade-offs between various services provided by forests, along with active involvement of stakeholders.
- Through the implementation of appropriate measures and fostering stakeholder participation, sustainable practices can be promoted to protect the Kanona National Forest, mitigate climate change impacts, and support local livelihoods.

Key messages and policy implications

Policy implications

1. Regular monitoring and land use planning:
   - Establish a regular monitoring and assessment system for land use and land cover changes.
   - Develop and implement land use planning strategies to mitigate negative impacts such as deforestation and urbanization.
   - Strengthen policies and regulations related to land management and conservation.
2. Sustainable land management and collaboration:
   - Promote sustainable land management practices, including reforestation and afforestation initiatives.
   - Foster collaboration between government agencies, local communities, and stakeholders to develop and implement effective policies and conservation strategies.
3. Understanding vegetation indices and land surface temperatures:
   - Support further research on the relationship between vegetation indices and land surface temperatures.
   - Investigate the drivers of land surface temperature trends, such as land cover changes, climate change, and urban heat island effects.
   - Develop early warning systems and adaptive strategies to cope with extreme heat events.

Key messages and policy implications Cont'd

4. Sustainable land management practices:
    - Promote sustainable land management practices that regulate surface temperatures, such as preserving and restoring natural vegetation cover and minimizing impervious surfaces.
    - Utilize findings to improve vegetation monitoring and land surface temperature modeling techniques.
5. Trade-offs between livelihoods and ecosystem services:
    - Conduct socio-economic assessments to understand the trade-offs between livelihoods, forest conservation, and ecosystem services.
    - Promote sustainable livelihood options that align with forest conservation objectives, such as agroforestry and sustainable harvesting practices.
    - Involve local communities and stakeholders in decision-making processes to ensure equitable distribution of benefits and foster community ownership of forest resources.
    - Implement payment for ecosystem services schemes or other incentive mechanisms to recognize and reward contributions to conservation efforts.

Conclusion and Recommendations

Conclusion

- Climate change impacts on forests in the Kanona National Forest were assessed using remote sensing and GIS techniques.
- Significant decreases in forest cover and changes in land use were observed, with implications for biodiversity, ecosystem services, and water resources.
- Weaker vegetation cover and higher land surface temperatures indicated potential forest degradation, emphasizing the need for conservation measures.
- Correlations between vegetation indices (NDVI, EVI) and land surface temperature highlight the role of vegetation cover in regulating surface temperatures.
- Trade-offs between livelihoods and forest/tree-based ecosystem services were identified, emphasizing the importance of sustainable land management.
- Community involvement in forest conservation is crucial, with community preferences supporting the "Remain and conserve" approach.

Conclusion and Recommendations

Recommendations

Objective 1:

1. Regular monitoring and assessment of LULC changes
2. Implement land use planning strategies
3. Promote sustainable land management practices
4. Enhance collaboration between government agencies, local communities, and stakeholders

Objective 2:

1. Explore the relationship between vegetation indices and land surface temperatures
2. Conduct further research to identify underlying mechanisms
3. Develop early warning systems and adaptive strategies
4. Promote sustainable land management practices to regulate surface temperatures
5. Improve vegetation monitoring and land surface temperature modeling techniques
6. Apply knowledge to inform land management decisions

Objective 3:

1. Conduct comprehensive socio-economic assessments
2. Promote sustainable livelihood options compatible with forest conservation
3. Develop participatory approaches involving local communities and stakeholders
4. Implement payment for ecosystem services schemes or incentive mechanisms
5. Strengthen policies and governance frameworks