International Journal of
Environmental Science
(IJES)

Optimizing Farmer Managed Natural Regeneration Efforts Using Geospatial Technology

Charles Kigen, Janet Korir, Michael Aiyabei Chesire, Carol Munini Munyao and Prisca Tanui Too

Optimizing Farmer Managed Natural Regeneration Efforts Using Geospatial Technology

Charles Kigen[1], Janet Korir[1], Michael Aiyabei Chesire[2], Carol Munini Munyao[3] and Prisca Tanui Too[4]
[1]Department of Environmental Studies, Department of Geography and Environmental Studies, Moi University
[2]Department of Community Development, Sociology, Psychology and Anthropology Department, Moi University
[3]Department of Environmental Health and Disaster Risk Management, School of Public Health, Moi University
[4]Department of History, Political Science and Public Administration, School of Arts and Social Sciences, Moi University

Article History

Received 14th November 2024
Received in Revised Form 19th December 2024
Accepted 14th January 2025

How to cite in APA format:

Kigen, C., Korir, J., Chesire, M., Munyao, C., & Too, P. (2025). Optimizing Farmer Managed Natural Regeneration Efforts Using Geospatial Technology. *International Journal of Environmental Sciences*, *8*(Special Issue 1), 118–132. https://doi.org/10.47604/ijes.3165

Special Issue on Farm Managed Natural Regeneration (FMNR)
Vol 8, Special Issue 1, pp118-132, 2025

Abstract

Purpose: Farmer Managed Natural Regeneration (FMNR), holds immense potential for addressing land degradation and enhancing ecosystem services in the arid and semi-arid lands. However, decisions regarding where to prioritize FMNR efforts and effectively monitor adoption and impact require reliable data and objective analysis. Spatial technologies (ST) such as Remote Sensing (RS), Geographic Information Systems (GIS), and GPS play a crucial role in achieving these goals. This paper explores the application of ST in optimizing FMNR implementation in Kenya.

Methodology: It discusses how ST can be used to identify suitable areas for FMNR based on factors like land degradation severity, vegetation cover, and socio-economic characteristics. Additionally, the paper explores how ST can be utilized to monitor FMNR adoption by tracking changes in land cover over time and assess the impacts of FMNR on ecosystem services like carbon sequestration and biodiversity conservation. Finally, the paper highlights the challenges and opportunities associated with using ST for FMNR and proposes recommendations for its effective integration into FMNR programs.

Findings: Remote Sensing (RS) and Geographic Information Systems (GIS) provide powerful tools for landscape-level planning in FMNR, application of Geographical Positioning System (GPS) Unit in data collection plays a vital role in grounding those plans with real-world data at the field level. The GPS data collection contributes to the success of FMNR implementation through establishing baselines, monitoring changes at the field level and integration with remote sensing and GIS. Key challenges include limited technical expertise among stakeholders and the cost of geospatial data acquisition in low-resource settings.

Unique Contribution to Theory, Practice and Policy: Through building capacity, fostering collaboration, and tailoring ST applications to local contexts, FMNR initiatives can be targeted more effectively, interventions can be designed to address specific challenges, and restoration efforts can be monitored and evaluated at scale.

Keywords: *FMNR, Remote Sensing, Geographic Information Systems, Decision Making*

INTRODUCTION

The challenge of land degradation caused by deforestation, overgrazing, and unsustainable agricultural practices is increasingly becoming significant worldwide. This degradation leads to a vicious cycle of soil erosion, reduced water infiltration, and desertification (Smith et al., 2014). Several initiatives and efforts to reverse these trends and restore ecosystems' health have been recommended. One such initiative is Farmer Managed Natural Regeneration (FMNR). Within the realm of conservation and rehabilitation efforts, FMNR emerges as a particularly well-suited approach for the arid and semi-arid lands (ASALs) (Reij, Tappan, & Smale, 2009). The FMNR's low-cost and community-driven nature makes it an attractive option to drive ownership of the conservation efforts, thus ensuring sustainability (Garrity & Verchot, 2008). Farmers are empowered to regenerate existing trees and shrubs on their land by protecting natural regrowth instead of resorting to expensive tree planting initiatives.

Successful FMNR implementation yields several ecosystem-wide benefits to the environment and the people. Increased tree cover promotes the accumulation of soil organic matter, enhancing soil fertility and water retention (Lal, 2015). This improved soil health translates to better water security as regenerated landscapes enhance water infiltration, reducing surface runoff and increasing groundwater recharge (Mbow et al., 2014). Moreover, increased vegetation cover provides habitat for diverse flora and fauna, promoting biodiversity in the region (Garrity et al., 2010). FMNR also plays a crucial role in mitigating climate change by promoting the carbon sequestration by trees (Smith et al., 2014 and Bayala et al, 2019). Further, improved livelihoods can be achieved through FMNR as communities gain the ability to sustainably harvest wood products, pasture, herbal medicine, and non-timber forest products like fruits and nuts (Leakey, 2017).

While traditional methods have played a historical role in FMNR implementation, they often struggle to provide the robust data and analysis needed for optimal decision-making and effective monitoring, especially in large-scale areas. These limitations can significantly hinder the overall effectiveness of FMNR programs (Garrity & Verchot, 2008). One key challenge lies in the inherent subjectivity and limited scope of traditional approaches. Reliance on visual assessments and local knowledge, while valuable, can be subjective and lack the spatial detail required for large-scale planning (Bayala et al., 2012). This subjectivity can lead to the selection of unsuitable areas for FMNR or the neglect of areas with high potential for successful regeneration.

Obtaining comprehensive data in a standardized format on critical factors like land degradation severity, vegetation cover, carbon sequestration potential, and socio-economic conditions can be a significant challenge with traditional methods (Reij, Tappan, & Smale, 2009). This data scarcity hinders informed decision-making about where to prioritize FMNR efforts based on objective criteria. Moreover, traditional data collection methods can be inconsistent, making it difficult to track changes over time and compare results and benefits across different areas (Lal, 2015). Furthermore, monitoring the adoption of FMNR practices and their impact on the landscape is often inaccurate with traditional methods. Tracking changes in vegetation cover or soil health can be time-consuming and lack the precision needed to precisely assess the status of FMNR interventions (Bayala et al., 2012, Iiyama et al., 2017).

Remote sensing (RS) and Geographic Information Systems (GIS) have been widely applied in vegetation monitoring, carbon sequestration studies, and land-use planning. Technologies like Sentinel-2 and Landsat satellites provide high-resolution, temporal data ideal for FMNR evaluation. Spatial technologies offer a powerful solution by providing a more objective, data-driven approach to decision-making and monitoring. This allows for a more targeted and impactful implementation of FMNR efforts, ultimately leading to the successful restoration of degraded landscapes (Garrity et al., 2010). Remote Sensing (RS) data, collected by satellites and other airborne sensors, offers a powerful tool for assessing land degradation severity, vegetation cover, and biomass, which are crucial factors for effective FMNR planning. One way RS helps assess land degradation severity is through the use of Vegetation Indices (VIs). These indices, derived from specific combinations of satellite image bands, can reveal the health and density of vegetation. A popular VI is the Normalized Difference Vegetation Index (NDVI) (Smith et al., 2014). NDVI uses the difference between near-infrared and red reflectance to estimate vegetation greenness and ranges from -1 to 1. Degraded lands typically have lower NDVI values compared to healthy, well-vegetated areas (Garrity & Verchot, 2008). Areas of barren rock, sand, or snow have NDVI values less than 0.1, while sparse vegetation such as shrubs and grassland range from 0.1-0.5, and dense vegetation, including forests, have values more than 0.5 (Smith et al., 2014). Analyzing Land Surface Temperature (LST) data from thermal bands of satellite sensors supports identification of areas with severe degradation. Land degradation often leads to increased soil exposure and decreased vegetation cover, resulting in hotter land surfaces compared to the neighborhood. Areas with higher LST, as detected by RS data, can be indicative of severe degradation (Garrity et al., 2010).

In vegetation cover analysis, RS is the best in providing detailed information. The RS sensors capture data across various wavelengths of light, including visible, near-infrared, and shortwave infrared. Analyzing these bands allows for classification of different land cover types, such as forests, grasslands, and bare soils, among others, at different times (Smith et al., 2014). This information is key for determining the previous and the current vegetation cover and identifying areas with potential for FMNR. These areas would ideally have been covered or currently have natural regrowth that can be encouraged through FMNR practices (Reij, Tappan, & Smale, 2009).

Remote Sensing has the capability to estimate biomass, the total amount of organic matter stored in living plant parts, which is useful in carbon sequestration studies. Advanced techniques involving radar (Radio Detection and Ranging), LiDAR (Light Detection and Ranging), or a combination of multispectral and other data sources are used for biomass estimation (Lal, 2015). LiDAR data, for example, provides detailed three-dimensional information about the land surface, allowing for more accurate biomass estimates (Bayala et al., 2012).

Through analysis of these various forms of RS data, it is possible to create detailed maps that represent the severity of land degradation, existing vegetation cover, and estimate biomass across large-scale landscapes. This information is critical for selecting areas with high FMNR potential. It allows for prioritizing interventions in the most degraded areas where FMNR can have the most significant impact, ultimately leading to the successful restoration of these landscapes (Garrity et al., 2010).

Whereas RS provides valuable data on land degradation, vegetation cover, and biomass, Geographic Information Systems (GIS) unlock the true potential of this information for FMNR planning and execution. GIS is a powerful integration platform, allowing the combination of various spatial datasets and identifying areas with high FMNR potential by considering both biophysical and socio-economic factors (Mbow et al., 2014). The GIS can be considered a central hub where diverse spatial data is assembled, processed, analyzed, and interpreted. This includes not only the data on land degradation severity, vegetation cover, and biomass but also additional biophysical data layers like soil type, climate patterns, and slope, among others. Socio-economic data, such as population density, land tenure systems, and market access for potential FMNR products, can also be integrated into the GIS platform (Reij, Tappan, & Smale, 2009).

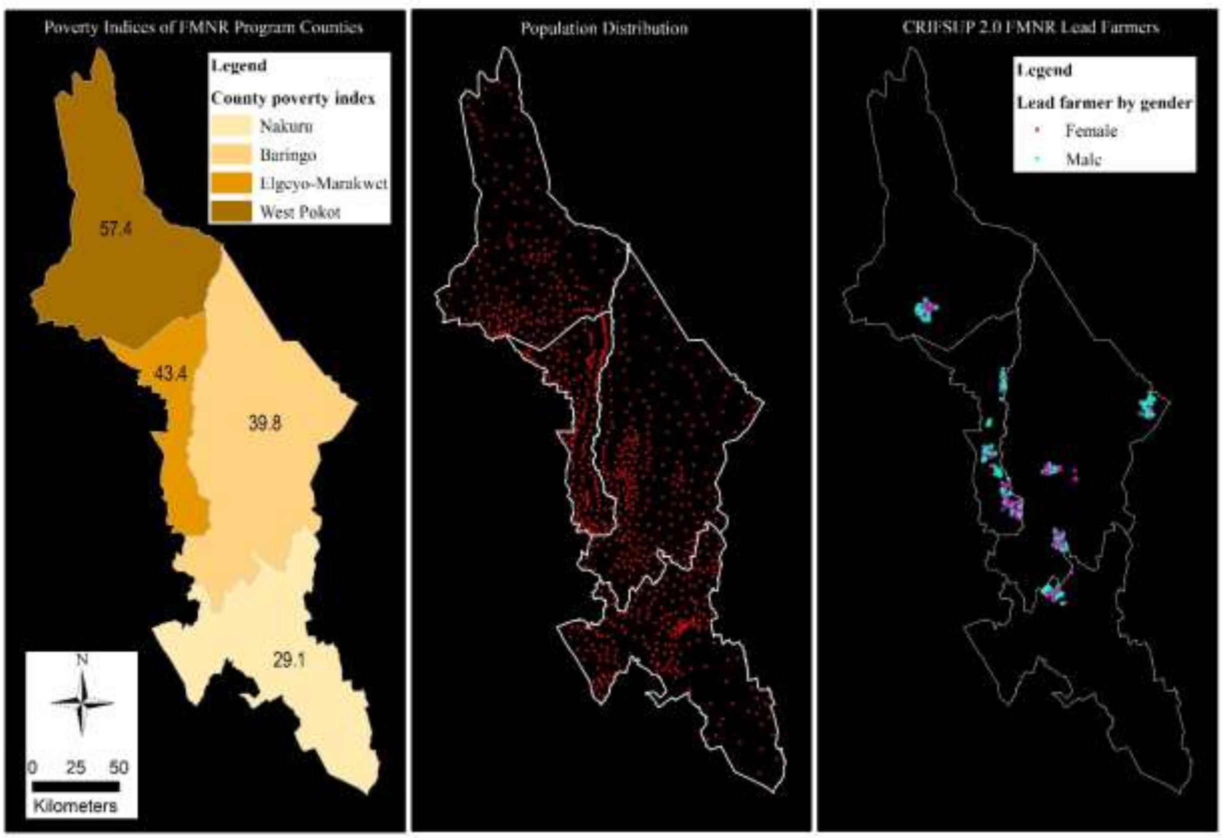

Figure 1: CRIFSUP Project Social-Economic Information

Once these datasets are brought together, GIS allows for complex spatial processing and analysis. It is possible to assign importance to different factors based on their influence on FMNR success (Garrity & Verchot, 2008 and Lohbeck et al., 2018). In this context, areas with moderately degraded lands, good soil quality, and adequate rainfall might receive a higher score compared to severely degraded lands with poor soil and low rainfall. Similarly, areas with secure land tenure and access to markets for FMNR products might be considered more favorable for adoption (Bayala et al., 2012). Through this spatial analysis, GIS can generate FMNR suitability maps

(Mbow et al., 2014). These maps depict areas with high, moderate, or low potential for successful FMNR implementation, considering the combined influence of biophysical and socio-economic factors. A suitability map provides a more comprehensive picture compared to using individual datasets only (Reij, Tappan, & Smale, 2009). In focusing on areas with high suitability scores, FMNR efforts can be targeted towards locations with the greatest chance of success, maximizing the impact of interventions (Smith et al., 2014).

Using suitability maps, decision-makers can objectively prioritize areas for FMNR implementation. They can target outreach programs and capacity-building initiatives towards communities residing in high-suitability areas. This targeted approach is best done through institutional collaboration (Binam et al., 2017) and allows for a more efficient allocation of resources ensuring FMNR efforts are directed towards areas with the greatest potential for positive environmental and socio-economic outcomes (Garrity et al., 2010).

Spatial Technology for FMNR Targeting

While Remote Sensing (RS) and Geographic Information Systems (GIS) provide powerful tools for landscape-level planning in FMNR, application of Geographical Positioning System (GPS) Unit in data collection plays a vital role in grounding those plans with real-world data at the field level. The GPS data collection contributes to the success of FMNR implementation through establishing baselines, monitoring changes at the field level and integration with remote sensing and GIS.

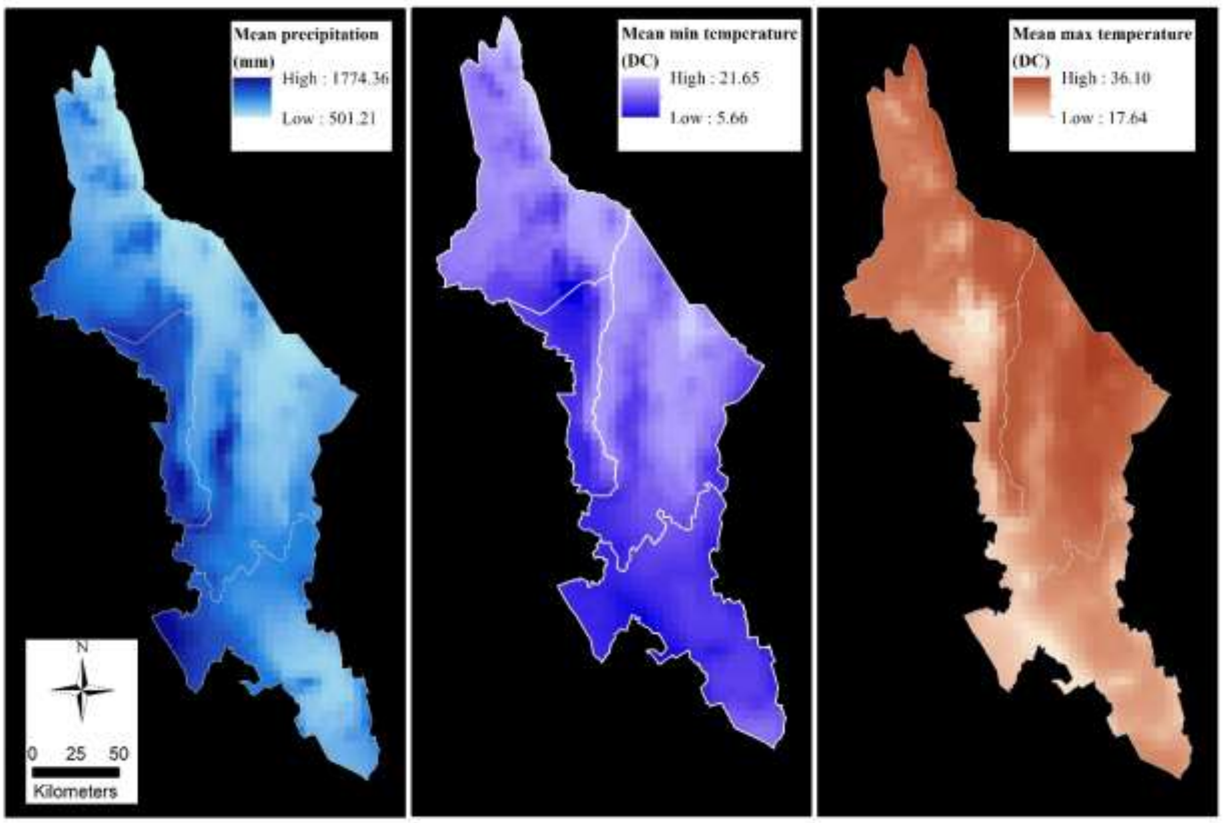

Figure 2: Mean Precipitation and Temperature in CRIFSUP Project Area

The first step in initiating FMNR interventions is collection of GPS data on key features within the target area to aid establish baseline information. This baseline data sets the stage for measuring progress over time. For instance, identifying and recording the GPS coordinates of existing trees and shrubs allows for monitoring their survival and growth over time. This data is essential for assessing the effectiveness of FMNR practices in promoting natural regeneration. Collecting GPS data along transects or at specific points within the landscape allows for recording observations on degradation severity, including factors like soil erosion levels, vegetation cover percentage, and presence of invasive species.

International Journal of Environmental Sciences
ISSN 2519-5549 (online)
Vol.8, Special Issue 1, pp 118-132, 2025

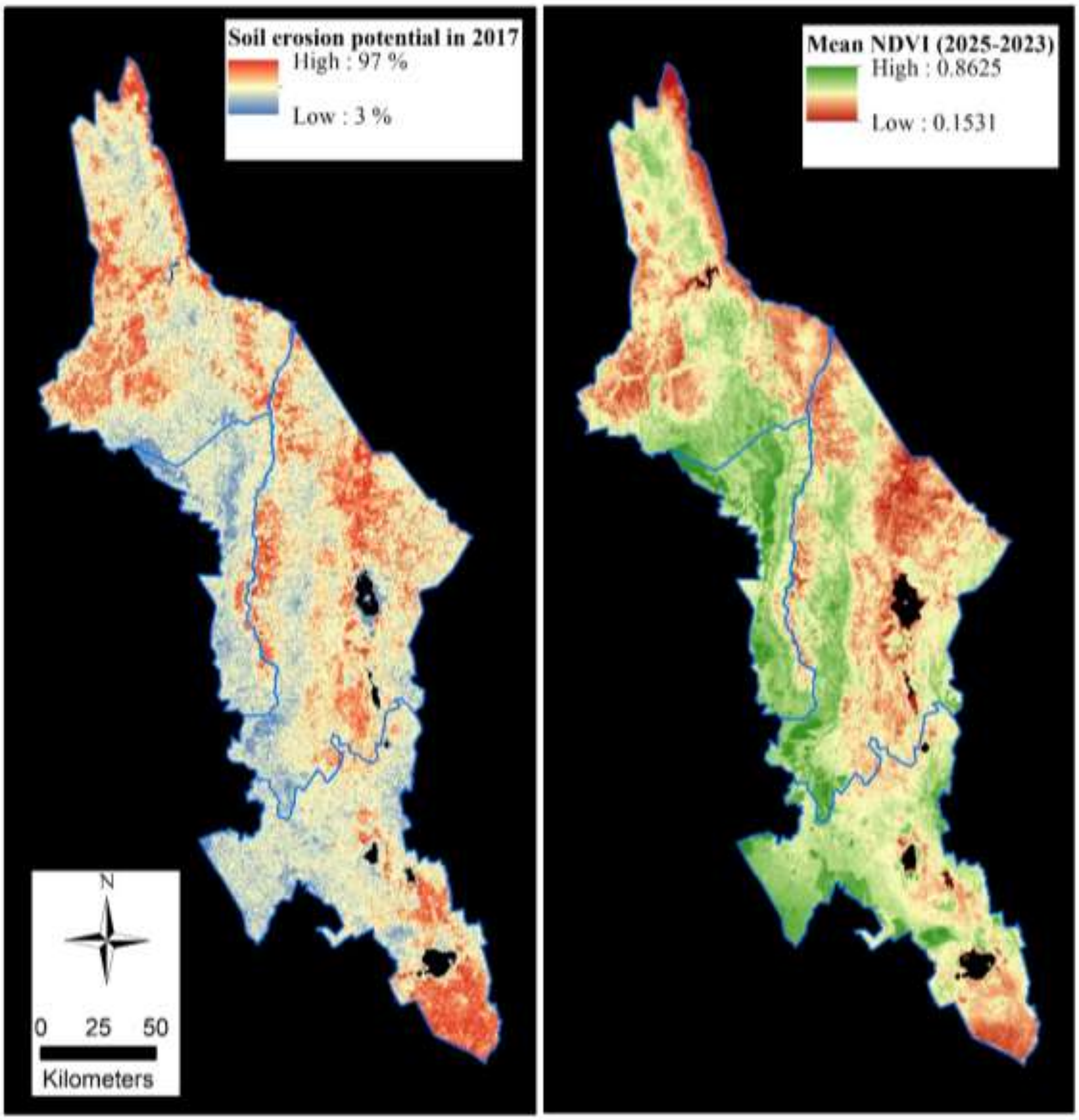

Figure 3: Average Soil Erosion Potential (2017) and NDVI (2023-2025) in CRIFSUP Project Area

This baseline data forms the benchmark for monitoring changes in degradation severity over time as FMNR interventions are implemented.

Regularly collecting GPS data after introducing FMNR allows for effective monitoring of changes at the field level. The data provides valuable insights into the program's effectiveness and appropriate action can be taken in time. Recording the GPS coordinates of newly emerging seedlings, it is possible to monitor the spatial distribution of trees regeneration and identify areas where natural regeneration is lagging. This information can be used to adapt FMNR practices and target specific areas for additional interventions like seed dispersal or controlled grazing management. Periodically revisiting previously recorded GPS points of existing trees and shrubs allows for measuring their growth parameters like crown diameter and height. This data is suitable in the assessment of the success of FMNR in promoting tree growth and improving vegetation cover.

The functionality of GPS data lies in its ability to bridge the gap between field-level observations and broader landscape patterns. GPS data collected at the field-level can be seamlessly integrated with RS and GIS data. This allows for a more comprehensive understanding of FMNR impacts. Through overlaying GPS data on vegetation cover maps derived from RS, one can visualize the spatial patterns of regeneration and identify areas showing the most significant positive changes due to FMNR practices. This combined analysis provides a powerful tool for guiding future interventions and maximizing the FMNR program impacts.

Spatial Technologies for FMNR Monitoring

One of the most powerful tools for monitoring FMNR lies in leveraging the power of time through RS data analysis. This technique, known as time series analysis, involves analyzing a sequence of satellite images captured over a period of time. The examination of these sequences, track changes in land cover and vegetation health, providing invaluable insights into FMNR adoption rates.

Tracking vegetation cover changes uses vegetation indices derived from multispectral satellite imagery processed into vegetation health indicators. The analysis of vegetation indices particularly the Normalized Difference Vegetation Index (NDVI), over time, can detect changes in land cover.

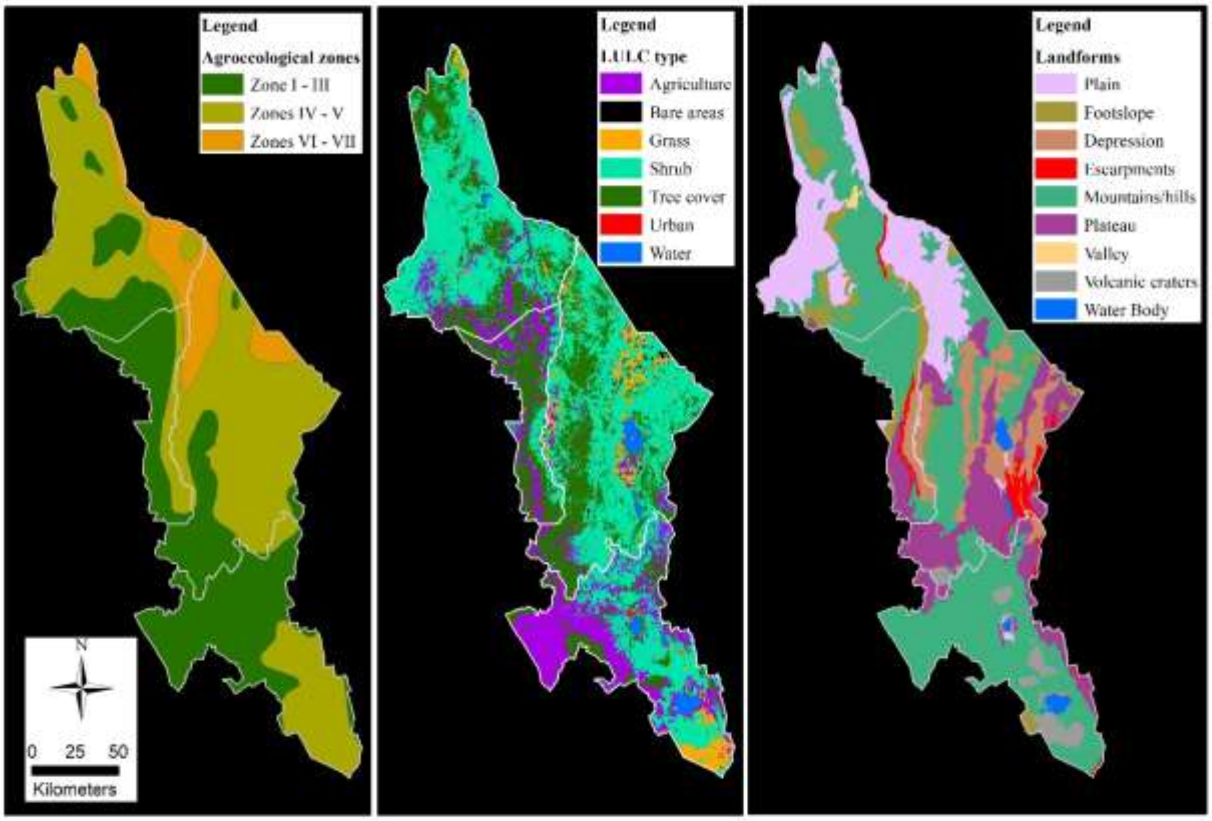

Figure 4: Agro-ecological Zones, LULC and Land Forms in CRIFSUP Project Area

An increase in NDVI over time suggests an increase in vegetation greenness, potentially indicating successful FMNR adoption. Conversely, stagnant or declining NDVI might suggest areas with slow regeneration or a lack of FMNR implementation or serious vegetation disturbance.

Time series analysis is more powerful when combined with land cover classification techniques as variabilities over time are detected. In classifying land cover types like forest, grassland, and bare soil in multiple satellite images acquired at different points in time, it is possible to identify areas undergoing significant transitions. A change from bare soil to grassland or from degraded forest to denser vegetation cover over time could be a strong indicator of successful FMNR practices. One of the best things about time series analysis lies in its ability to use freely available satellite data sources like Landsat and Sentinel which offer long time series archives. This allows change analysis in land cover over extended periods cost effectively. The extended view over time can reveal the adoption of FMNR practices even before significant vegetation change is visually apparent on the ground. Early detection of FMNR adoption allows for adjustments to the program if needed and for identifying areas where additional support or intervention might be crucial.

Several standardized techniques and software tools are available for time series analysis. These tools can automate the process of analyzing changes in VIs or land cover classifications across multiple images. This automation makes it significantly more efficient to monitor large areas for

FMNR adoption, allowing for a broader and more comprehensive assessment of the program's reach and impact.

The analysis of trends in vegetation cover and land cover changes over time and time series analysis of RS data provides insights into FMNR adoption rates across landscapes. This information is important in assessing FMNR effectiveness at a glance. It allows for identifying areas with high adoption, highlighting success stories, and targeting areas where FMNR practices might not be taking hold, ensuring the program's long-term success and maximizing its positive environmental impact.

Imagine GIS as a central hub where information from multiple sources come together. In the context of FMNR adoption analysis, GIS can combine land cover maps indicate areas with FMNR adoption. Additionally, socio-economic data on factors that might influence FMNR adoption can be included. The socio-economic data encompass population density, land tenure security, and market access for potential FMNR products.

Once these datasets are integrated, GIS allows for complex spatial analysis to generate simplified information using techniques like hotspot analysis. This helps identify areas with high concentrations of FMNR adoption, potentially representing successful implementation. Conversely, it can also reveal areas with low adoption rates, highlighting precisely where targeted interventions are most needed. Another powerful tool within GIS is geospatial regression analysis. This tool allows exploring the relationships between FMNR adoption (as indicated by land cover changes from RS data) and various socio-economic factors. These relationships analysis, can identify factors that might be hindering FMNR adoption in specific areas.

With outputs from spatial analysis techniques, GIS can generate maps that show areas with lagging FMNR adoption. These maps become even more informative when overlaid with additional data layers like infrastructure access or extension services coverage. This can point to the potential reasons for low FMNR adoption in specific areas. Using this spatially informative data on lagging adoption areas, stakeholders can design targeted interventions to support FMNR practices. This could involve focusing outreach programs and capacity building initiatives towards communities residing in these areas. In ensuring these communities have the necessary knowledge, skills and other support to implement FMNR effectively, the program adoption can increase. It is worth noting that, the geospatial analysis might reveal specific factors hindering adoption in certain areas, such as insecure land tenure or lack of access to markets. The identification of constraints enable stakeholders to develop targeted interventions to address them, paving the way for successful FMNR implementation.

While time series analysis of Landsat and Sentinel data provides valuable insights into FMNR adoption at a landscape level, some situations require more detailed monitoring of vegetation regeneration and ecosystem services. This is where high resolution satellite images and drone images come into play. With spatial resolutions of 30 m and 10 m for Landsat and Sentinel imageries respectively, they form powerful tools for landscape-level analysis but are insufficient for capturing the finer details of vegetation regeneration, particularly in the early stages. High-resolution satellite imagery with resolutions less than 5 m can provide much clearer images of seedling emergence, species composition, and changes in vegetation structure. This fine-scale data allows for more precise monitoring of regeneration success and identification of areas that might require additional interventions like targeted seeding or brush control.

The high-resolution imagery facilitates a more detailed assessment of ecosystem services improvement resulting from FMNR practices. The ability to distinguish between different tree species allows for a more accurate estimation of carbon sequestration potential and biodiversity impacts of FMNR. It can also capture changes in understory vegetation, providing insights into improved habitat quality for biodiversity or soil erosion control. Although high-resolution satellite imagery offers significant advantages, its revisit frequency might be limited. Drone surveys can address this gap by providing high-resolution data at more frequent intervals, allowing for more responsive monitoring of regeneration progress and ecosystem services improvement. Drones can be particularly useful for capturing detailed imagery of specific areas of interest or for monitoring during critical stages of regeneration.

Both high-resolution satellite imagery and drone surveys can be seamlessly integrated with other data sources within a GIS platform. This allows for a more holistic analysis and understanding of FMNR impacts. The high-resolution imagery data on vegetation cover changes can be overlaid with soil moisture data or rainfall data to identify relationships between regeneration success and environmental factors. It is however important to acknowledge limitations of the high-resolution satellite imagery and drone images which include higher costs and computationally intensive compared to Landsat and Sentinel data.

Challenges and Opportunities of Spatial Technology in FMNR

Spatial Technologies hold enormous promise for transforming FMNR planning, monitoring, and evaluation. However, their utilization has a number of challenges ranging from data availability to technical skills inadequacy. Key challenges include limited technical expertise among stakeholders and the cost of geospatial data acquisition in low-resource settings. Emerging open-access tools and capacity-building programs offer potential solutions (FAO, 2020).

Obtaining the right data can be a significant challenge, especially for organizations working in global south. Even though freely available data sources like Landsat and Sentinel exist, they might not provide the necessary detail for all monitoring needs. High-resolution satellite imagery or drone data, which offer a finer view, often come with licensing fees that are costly.

Successfully using ST requires a certain level of technical know-how. This includes skills like accessing and downloading data, processing the data with specialized software, and interpreting the results to translate them into actionable insights for FMNR interventions. The lack of readily available technical expertise within local communities or FMNR implementing organizations can be a significant barrier to widespread ST adoption. The power of ST relies heavily on robust internet connectivity for data download, processing, and analysis. Limited or unreliable internet access in remote areas can significantly hinder the use of ST for FMNR programs. Processing large datasets of high-resolution imagery or drone data can require powerful computers, which might not be readily available in resource-limited settings.

Even though there are challenges of ST application in FMNR, a number of prospects exist to address them and unlock the full potential at minimal cost. Capacity building programs are important to bridge the data access, technical expertise, and infrastructure gaps. These initiatives equip FMNR stakeholders with the skills and knowledge necessary to utilize ST effectively. This can involve hiring ST experts or training existing staff on data access procedures, basic image processing techniques, and interpreting ST outputs specifically for FMNR applications. The trainings can be tailor-made, cascading and knowledge exchange programs between staff members. Tailored-training programs should can be designed specifically for the needs of FMNR stakeholders, considering their existing knowledge base and technical skills levels. This could involve introductory modules on accessing and downloading satellite imagery or drone data, followed by training on basic image processing techniques using open-source software. More advanced training could cover interpretation of spatial data for FMNR applications, such as identifying areas with high FMNR adoption rates or analyzing changes in vegetation cover over time.

A cascading approach to training can be highly effective. The, FMNR practitioners or extension officers are trained first, equipping them with the skills to then train community members on basic ST concepts and data collection techniques using mobile apps or handheld GPS devices. This approach empowers local communities to actively participate in FMNR monitoring and data collection, fostering a sense of ownership and promoting the long-term sustainability of the program.

The knowledge exchange platforms are largely online and can provide ongoing support and resources for FMNR stakeholders. These platforms could host training modules, tutorials, and case studies showcasing successful applications of ST in FMNR projects around the world. The online forums can facilitate communication and knowledge sharing amongst FMNR practitioners, researchers, and community members.

A growing range of open-source geospatial tools for collecting, processing and analyzing geospatial data is increasingly becoming available. This reduces reliance on expensive proprietary software and makes ST more accessible. Through investing in capacity building initiatives, local communities and FMNR stakeholders can be empowered to utilize ST effectively. The free software and tools are supported by many free training courses available online mounted in different platforms by renown world class universities or the developers. The courses range from introductory to advance with self-paced options and materials can be downloaded for offline learning making the training very flexible and convenient for all. Open-source software like QGIS and GRASS GIS offer powerful functionalities for data processing, analysis, and visualization, all at no cost. These user-friendly platforms have intuitive interfaces and extensive online resources, making them accessible even for individuals with limited technical backgrounds. Other feely available to use geospatial tools are app-based connected to powerful servers that processed data as requested by the user. The Soltice/mWater is an operating system for digital governance used for data collection, summarize and display same in maps. It also allows for repeated FMNR practitioner data collection over time. Restor is a free digital platform that allows everyone, everywhere to access information about their landscape from soil moisture levels to rainfall levels to types of biodiversity. This provides the knowledge needed to plant and restore the species that will most likely survive.

Open-source software reduces dependence on expensive commercial software licenses, making ST a more financially viable option for resource-constrained FMNR programs. This opens doors for wider adoption of ST and empowers local communities to take ownership of their data and monitoring activities. The open-source nature of these tools fosters a collaborative development environment. Developers and users can contribute to the ongoing improvement of the software, leading to the creation of new features and functionalities specifically tailored for FMNR applications.

Collaboration between FMNR practitioners and research institutions can unlock significant opportunities for ST utilization in many ways. The research institutions can collaborate with FMNR programs to design and implement research projects that leverage ST for targeting, monitoring and evaluation. This can involve co-developing methodologies for analyzing spatial data and translating research findings into practical recommendations for improving FMNR practices.

The research institutions often have access to cutting-edge technologies like high-resolution satellite imagery or drone data, as well as advanced analytical tools and expertise. Collaboration allows FMNR programs to leverage these resources for more in-depth monitoring and evaluation activities. Collaboration can foster the development of standardized protocols and best practices for utilizing ST in FMNR monitoring and evaluation. This ensures consistency and comparability of data across different programs and regions, allowing for more robust assessments of FMNR impacts at a broader scale of different ecosystems.

CONCLUSION AND RECOMMENDATIONS

Spatial Technology has a big potential to enhance the FMNR efforts. It offers a powerful toolkit for optimizing implementation and maximizing on impact. From guiding strategic planning to enabling robust monitoring and evaluation, ST empowers stakeholders to make data-driven decisions and ensure the long-term success of FMNR programs. Through building capacity, fostering collaboration, and tailoring ST applications to local contexts, FMNR initiatives can be targeted more effectively, interventions can be designed to address specific challenges, and restoration efforts can be monitored and evaluated at scale. Ultimately, this translates to a future with healthier landscapes, enhanced ecosystem services, and thriving communities – a future where FMNR, guided by the power of ST, unlocks its full potential for landscape restoration and environmental sustainability. To fully harness potential of ST for FMNR efforts, the following recommendations are made; investing in capacity building of both FMNR trainers and practitioners; fostering collaboration between government agencies, NGOs and research institutions; and tailor ST applications to local context where FMNR is under implementation.

Acknowledgement

This research was conducted as part of the Central Rift FMNR Scale Up (CRIFSUP) Project, implemented by World Vision Kenya and funded by the Australian Department of Foreign Affairs and Trade (DFAT) through the Australian NGO Cooperation Program (ANCP) under World Vision Australia.

The authors gratefully acknowledge the critical support from World Vision Australia, World Vision Kenya, and Moi University. We extend our sincere appreciation to the County Governments of Elgeyo Marakwet, Baringo, and Nakuru, as well as to the community members, particularly the FMNR lead and replicate farmers, whose participation was essential to the success of this project.

We also wish to thank World Vision staff members Titus Kimono, Winnie Jeritoch, Betty Kandargor, Daniel Makana, Faith Milkah Muniale, Willis Okumu, Anthony Mativo, Caroline Maua, and Fredrick Kasiku for their invaluable contributions to this work.

REFERENCES

Bayala, J., et al. (2012). Cereal yield response to conservation agriculture practices in drylands of West Africa: a quantitative synthesis. Journal of Arid Environments, 78: 13-25.

Bayala, J., Sanou, J., Bazié, H. R., Coe, R., Kalinganire, A., and Sinclair, F. L. (2019). Regenerated trees in farmers' fields increase soil carbon across the Sahel. Agroforest. Syst. 94, 401–415. DOI: 10.1007/s10457-019-00403-6

Binam, J. N., Place, F., Djalal, A. A., and Kalinganire, A. (2017). Effects of local institutions on the adoption of agroforestry innovations: evidence of farmer managed natural regeneration and its implications for rural livelihoods in the Sahel. Agric. Food Econ. 5:2. doi: 10.1186/s40100-017-0072-2

Garrity, D.P., & Verchot, L.V. (2008). Rehabilitating Degraded Production Landscapes. Science, 321: 1211.

Garrity, D.P., et al. (2010). Evergreen Agriculture: a robust approach to sustainable food security in Africa. Food Security, 2: 197-214.

Iiyama, M., Derero, A., Kelemu, K., Muthuri, C., Kinuthia, R., Ayenkulu, E., et al. (2017). Understanding patterns of tree adoption on farms in semi-arid and sub-humid Ethiopia. Agroforest. Syst. 91, 271–293. doi: 10.1007/s10457-016-9926-y

Lal, R. (2015). Restoring Soil Quality to Mitigate Soil Degradation. Sustainability, 7: 5875-5895.

Lohbeck, M., Winowiecki, L., Aynekulu, E., Okia, C., and Vågen, T. G. (2018). Trait-based approaches for guiding the restoration of degraded agricultural landscapes in East Africa. J. Appl. Ecol. 55, 59–68. doi: 10.1111/1365-2664.13017

Mbow, C., et al. (2014). Achieving mitigation and adaptation to climate change through sustainable agroforestry practices in Africa. Current Opinion in Environmental Sustainability, 6: 8-14.

Reij, C., Tappan, G., & Smale, M. (2009). Agroenvironmental Transformation in the Sahel: Another Kind of Green Revolution. IFPRI Discussion Paper.

Smith, P., et al. (2014). Agriculture, Forestry and Other Land Use (AFOLU). In Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.