Technical Note on Steps in Baseline Quantification for ARR Carbon Finance Projects using Remote Sensing and GIS

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Abstract— *This technical note outlines a systematic approach to baseline quantification for ARR (Afforestation, Reforestation, and Revegetation) carbon finance projects using advanced remote sensing (RS) and GIS methodologies. This approach particularly addresses India's fragmented landscapes, aiming to integrate small and marginal farmers into carbon finance markets, thus enhancing agroforestry potential and providing additional income generation. The challenges in meeting common practice criteria and additionality, as per VERRA/Gold Standard methodologies, are also discussed, offering recommendations to improve inclusivity and applicability.*

Keywords— Baseline, Carbon Finance, Remote Sensing, GIS, LULC, Afforestation.

I. INTRODUCTION

The increasing emphasis on climate change mitigation has brought afforestation, reforestation, and revegetation (ARR) projects to the forefront as effective tools for sequestering atmospheric carbon dioxide. These projects form a crucial part of global and national climate action strategies. However, ensuring their success requires robust methodologies for baseline quantification and eligibility assessment, particularly in countries like India, where the landscape is highly fragmented, and smallholder participation is key. India's agricultural landscape is characterized by over 86.1% small and marginal landholdings, making it one of the most fragmented in the world. While this fragmentation poses challenges in scaling carbon finance projects, it also presents an opportunity to integrate millions of small and marginal farmers into these initiatives. Existing methodologies, such as those by VERRA and the Gold Standard, provide a strong framework for ARR projects but often fall short in addressing the complexities of fragmented landscapes and ensuring additionality and inclusivity. This technical note proposes a systematic approach to baseline quantification, leveraging high-resolution RS-GIS tools to overcome these challenges. By tailoring the methodology to India's unique landscape, this work highlights how agroforestry potential can be utilized not just for environmental benefits but also for generating additional income for smallholders. Furthermore, the methodology addresses critical gaps in existing frameworks, such as the common practice criteria and additionality, ensuring that projects are both credible and scalable. The revised approach aims to bridge the gap between existing standards and the practical realities of fragmented agricultural landscapes. It emphasizes the role of data-driven models and spatial analyses in creating transparent, scalable, and inclusive ARR carbon finance projects that align with national and international goals.

II. BASELINE QUANTIFICATION IN ARR PROJECTS: CURRENT PRACTICES AND LIMITATIONS

In carbon finance, the baseline serves as a critical benchmark, representing the carbon stock that would naturally exist in the absence of the project. This reference is essential for calculating the additional carbon sequestered due to project activities (Zomer et al., 2007). Traditional methods for baseline estimation predominantly rely on field measurements. While field-based approaches provide ground-truth data, they are labor-intensive, prone to human error, and prohibitively expensive when applied across large and fragmented landscapes, such as those prevalent in India (Pandit & Behera, 2021). Eligibility criteria for ARR projects add further complexity to baseline determination. Standards like the Verified Carbon Standard (VCS) and Gold Standard mandate that ARR projects must be implemented on degraded or non-forest lands. Moreover, to meet additionality requirements, a plot must not have been classified as forest land—based on canopy cover thresholds—at least 10 years prior to the project start date. These stipulations are designed to prevent the displacement of native ecosystems and ensure genuine carbon sequestration (Verra, 2024). In the Indian context, these criteria are further refined. Non-forest land is defined as having a canopy cover below 15%, adding a region-specific layer of specificity to baseline assessments (Government of India, 2023). Meeting these standards necessitates a retrospective analysis of historical land conditions, which is challenging without the integration of advanced technological tools. This is where remote sensing (RS) and geographic information system (GIS) technologies become indispensable. By leveraging high-resolution satellite imagery and geospatial analyses, RS-GIS offers a scalable, accurate, and cost-effective solution for baseline quantification. These tools enable the retrospective evaluation of land use and canopy cover, ensuring compliance with eligibility criteria while reducing the reliance on labor-intensive field surveys. Furthermore, RS-GIS methodologies are particularly suited to fragmented landscapes, allowing for the aggregation and analysis of smallholder plots, which are common in India's agricultural system. This integration of advanced geospatial technologies not only addresses the limitations of traditional methods but also enhances the credibility and scalability of ARR carbon finance projects, aligning them with both national and international standards.

2.1 Leveraging Remote Sensing and GIS for Robust Baseline Quantification:

By employing RS-GIS technology, particularly through high-resolution satellite imagery and linear regression modeling, we propose a method that not only enhances the accuracy of baseline quantification but also verifies the land's eligibility (Roy et al., 2020). This method integrates historical satellite data from at least two to three years before project initiation to capture the baseline carbon stock and extend the analysis back 10 years for compliance with eligibility criteria (Jain & Kumar, 2022).

In this approach, linear regression models are established between remote-sensing-derived predictor variables—such as Leaf Area Index, Fractional Vegetation Cover, Forest Canopy Density, and other vegetation indices—and observed biomass values from field monitoring plots. High correlations between these predictor variables and field biomass data allow for reliable biomass estimations across large areas. This not only facilitates the initial baseline quantification but also enables ongoing assessments of carbon sequestration over time, providing a transparent and credible foundation for carbon credit claims (Nair et al., 2018). This methodology ensures accurate, transparent, and scalable baseline quantification for ARR projects, providing both regulatory confidence and increased potential for smallholder inclusion in carbon finance markets (Ghosh & Sharma, 2024).

2.2 Steps in Baseline Quantification Using RS-GIS and Regression Modeling:

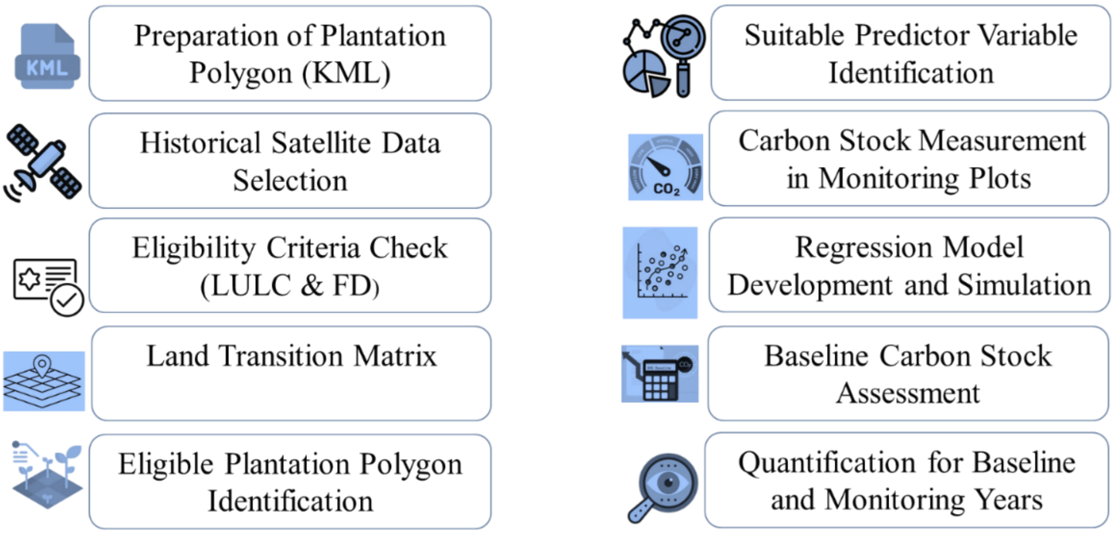

FIGURE 1: Steps in Proposed Baseline Quantification

1. **Preparation of Plantation Polygon (KML)**: Generate project-specific KML files defining the geographic boundaries of the plantation areas. These boundaries guide the spatial analysis and serve as the foundation for subsequent RS-GIS assessments.

2. **Historical Satellite Data Selection**: Historical Satellite Data Selection: Select historical satellite images, ideally dating 10+ years before the project start date, to evaluate prior land conditions and ensure compliance with common practice criteria. High-resolution imagery (e.g., LISS-IV, Sentinel-2) is used to analyze canopy density and land transitions in fragmented landscapes. Cluster-based analysis is applied to aggregate small plots for comprehensive assessments.

3. **Eligibility Criteria Check (LULC and Forest Canopy Density Mapping)**:
    - **Land Use and Land Cover (LULC) Assessment**: Classify historical land use patterns to ensure the project land qualifies as non-forest or degraded land according to project standards.
    - **Forest Canopy Density/Fractional Vegetation Cover (FVC) Mapping**: Conduct canopy density or FVC mapping to confirm that canopy cover was below required thresholds (e.g., <15%) a decade prior to project initiation, as per host-country or national definitions.
4. **Land Transition Matrix**: Use a land transition matrix to analyze historical changes in land use (e.g., non-forest to forest), ensuring that the project complies with the required standards regarding land conversion history.
5. **Eligible Plantation Polygon Identification**: Identify eligible polygons within the project area that meet baseline eligibility requirements, marking them for inclusion in the carbon quantification analysis.
6. **Socio-Economic Integration:** Incorporate socio-economic data of small and marginal farmers to ensure equitable distribution of carbon finance benefits. Data on land ownership, crop patterns, and socio-economic status is integrated with spatial data to design farmer-centric project models.
7. **Suitable Predictor Variable Identification**: Select predictor variables from satellite data, such as Leaf Area Index (LAI), Fractional Vegetation Cover (FVC), and Forest Canopy Density, that correlate well with carbon stock or biomass data observed in the field.
8. **Challenges Addressed in Existing Frameworks:**
    - **Common Practice Criteria:** Traditional approaches often fail to distinguish between historical and new agroforestry activities. This methodology uses retrospective high-resolution analyses to accurately identify additionality.
    - **Fragmented Landscapes:** By clustering smallholder plots and leveraging advanced GIS tools, this approach ensures scalability and compliance with VERRA/Gold Standard frameworks.
    - **Farmer Inclusivity:** The methodology incorporates socio-economic data to ensure that smallholders benefit from carbon finance projects.
9. **Carbon Stock Measurement in Monitoring Plots**: Establish monitoring plots within eligible areas and collect field data on carbon stock or biomass. This data will serve as observed values in the regression model, enhancing model accuracy and validation.
10. **Regression Model Development and Simulation**: Develop a regression model correlating the selected RS-derived predictor variables with field-measured biomass or carbon stock. Simulate the model to confirm a high correlation, ensuring that it can be reliably applied to baseline and monitoring years.
11. **Baseline Carbon Stock Assessment**: Apply the regression model to predict baseline carbon stock across the eligible land area. This quantification establishes the reference carbon stock against which future sequestration will be measured.
12. **Carbon Sequestration Quantification for Baseline and Monitoring Years**:

    Using the model, calculate the carbon sequestration achieved through ARR activities, comparing baseline and monitoring year values. This quantification provides the basis for carbon credit claims, enhancing transparency and reliability.

2.3 Benefits of RS-GIS and Machine Learning for ARR Baselines:

Implementing RS-GIS-based baseline quantification offers several advantages:

- **Scalability**: This approach supports large-scale analysis across fragmented plots typical of Indian landscapes, enabling coverage of regions with multiple small and marginal landholders (Zomer et al., 2007).
- **Accuracy and Reliability**: High-resolution imagery combined with machine learning and regression modeling enhances the accuracy of biomass estimates, bolstering confidence in the baseline quantification (Singh et al., 2023).
- **Transparency**: By archiving historical data and offering reproducible models, this approach provides a transparent baseline that meets the rigor demanded by carbon markets (Pandit & Behera, 2021).

- **Cost-effectiveness**: Remote sensing reduces the need for labor-intensive field measurements, making the monitoring process economically feasible for smallholder-inclusive ARR projects (Roy et al., 2020).

III. APPLICATION TO INDIA'S FRAGMENTED LANDSCAPE AND MEETING CARBON MARKET REQUIREMENTS

International standards require ARR and agroforestry projects to meet criteria for additionality and eligibility to avoid “business-as-usual” scenarios. The RS-GIS-based approach enables retrospective assessments that verify the land’s degraded status and non-forest classification 10 years prior to project start (Verra, 2024). By ensuring compliance with these conditions through objective, data-driven models, this methodology enhances the legitimacy and marketability of such projects. High-confidence baseline estimation builds a credible foundation for claiming carbon credits and ensures additionality by rigorously quantifying the impact of new plantation activities on carbon sequestration (Nair et al., 2018; Ghosh & Sharma, 2024). India’s agroforestry potential is closely tied to its small and fragmented landholdings, which account for 86.1% of agricultural land (Government of India, 2023). The baseline quantification approach, integrating high-resolution RS-GIS and regression modeling, enables precise assessments of small, scattered plots, thus broadening smallholder participation in carbon finance projects. This inclusion not only ensures equitable distribution of benefits but also expands the total area under agroforestry, enhancing carbon sequestration potential. Furthermore, the transparency, scalability, and affordability of this approach make it particularly suited for attracting greater investment in agroforestry carbon finance initiatives, especially in the Indian context.

IV. CONCLUSION

Integrating RS-GIS with linear regression and machine learning enhances baseline quantification for ARR projects in India. This method aligns with eligibility and additionality requirements by providing precise, retrospective carbon stock assessments and enabling continuous monitoring. For India’s agroforestry landscape, where fragmented holdings and smallholder participation are prevalent, this approach offers a practical, transparent, and scalable solution that could significantly improve the confidence of carbon markets. By adopting RS-GIS-based baseline quantification, India can facilitate access to carbon finance for a larger pool of smallholders, transforming agroforestry into a viable tool for sustainable development and climate mitigation. Our enhanced methodology not only addresses the limitations of existing frameworks but also ensures that India’s small and marginal farmers are integral beneficiaries of carbon finance projects. By tailoring the approach to fragmented landscapes, this work contributes to both sustainable development and equitable growth.

REFERENCES

[1] Ghosh, S., & Sharma, J. V. (2024). Enhancing baseline quantification and eligibility assessment for ARR carbon finance projects through remote sensing and GIS. Agri Articles, 4(6), 87-90.

[2] Government of India. (2023). Forest Canopy Density Standards and Definitions. Ministry of Environment, Forest and Climate Change.

[3] Gold Standard. (2023). ARR Project Requirements and Guidelines. Gold Standard Foundation.

[4] Jain, A., & Kumar, R. (2022). Applications of remote sensing in carbon finance: Methodologies and models. Journal of Environmental Science and Policy, 25(3), 110–123.

[5] Nair, R., & Kumar, A. (2018). Carbon stock assessment through remote sensing for ARR projects. International Journal of Climate Action, 7(2), 150–163.

[6] Pandit, R., & Behera, M. (2021). Remote sensing techniques in agroforestry and carbon sequestration projects. Forest Ecology and Management, 306, 10–20.

[7] Roy, P., & Singh, M. (2020). Remote sensing data and carbon baseline quantification in ARR projects. Asian Journal of Geospatial Science, 14(2), 55–72.

[8] Singh, S., Kumar, N., & Sharma, V. (2023). Utilizing high-resolution satellite imagery for land cover analysis in carbon finance projects. Remote Sensing Applications in Ecology, 29, 120–134.

[9] Verra. (2024). Verified Carbon Standard Program Guide: Agriculture, Forestry, and Other Land Use Requirements. https://verra.org/project/vcs-program/

[10] Zomer, R. J., Bossio, D. A., Trabucco, A., Yuanjie, L., Gupta, D. C., & Singh, V. P. (2007). Trees and water: Smallholder agroforestry on irrigated lands in Northern India. International Water Management Institute.