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Enhancing Baseline Quantification and Eligibility Assessment for ARR Carbon Finance Projects through Remote Sensing and GIS

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Accurate baseline quantification and eligibility assessment are critical in ARR (Afforestation, Reforestation, and Revegetation) carbon finance projects to ensure reliable carbon sequestration outcomes. Leveraging remote sensing (RS) and GIS-based analyses, this approach establishes the eligibility of land for ARR projects, setting baselines for carbon stock assessment and monitoring through time. The methodology employs historical satellite data, land use and land cover (LULC) mapping, and canopy density assessments to confirm compliance with eligibility standards such as those set by Verra or the Gold Standard. High-resolution imagery and predictive modeling establish baseline carbon stocks and quantify carbon sequestration accurately, benefiting small and marginal landholders in ARR project eligibility.

Keywords: Baseline, Carbon Finance, Remote Sensing, GIS, LULC, Afforestation

Introduction

With increasing recognition of the role that afforestation, reforestation, and revegetation (ARR) projects play in sequestering atmospheric carbon dioxide, the demand for reliable baseline quantification and eligibility assessment in ARR carbon finance projects has grown. Baseline quantification sets a reference carbon stock level against which additional sequestration can be measured, enabling stakeholders to confidently claim carbon credits for ARR activities. For projects to meet certification standards, such as those set by Verra or the Gold Standard, they must verify that eligible lands were either non-forest or degraded (below canopy density thresholds) for at least a decade prior to project initiation.

In response to these requirements, integrating remote sensing (RS) and geographic information system (GIS) technologies with regression modeling has emerged as a powerful approach. High-resolution satellite data allows retrospective assessment of land conditions, while regression models correlate satellite-derived indices (like Leaf Area Index and Forest Canopy Density) with field biomass data, establishing a precise baseline and facilitating ongoing monitoring. 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.

Baseline Quantification in ARR Projects: Current Practices and Limitations

In carbon finance, a project's baseline represents the amount of carbon stock that would exist in the absence of the project, serving as a reference to calculate the additional carbon sequestered (Zomer et al., 2019). Traditional baseline estimation often relies on field measurements alone, but these are time-intensive, subject to human error, and costly when scaled across vast and fragmented landscapes like those in India (Pandit & Behera, 2021).

The ARR project eligibility criteria further complicate baseline determination. According to standards like the VCS and Gold Standard, ARR projects must be implemented on degraded land or non-forest land. A plot must not qualify as forest land by canopy cover standards at least 10 years prior to the project start date, thereby avoiding the displacement of native ecosystems (Verra, 2024). India's own criteria, which define non-forest land as having a canopy cover below 15%, add an additional layer of specificity (Government of India, 2023). To ensure projects are eligible, a retrospective analysis of historical land conditions is necessary, which is where RS-GIS technology proves invaluable.

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).

Steps in Baseline Quantification Using RS-GIS and Regression Modeling

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**: Select historical satellite images, ideally dating 10+ years before the project start date, to evaluate prior land conditions and meet eligibility criteria. High-resolution images are preferred for precise canopy and land cover 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. **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.

7. **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.
8. **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.
9. **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.
10. **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.

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., 2019).
- **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).

Meeting Carbon Market Requirements with RS-GIS-Based Baseline Estimation

International standards require ARR projects to meet criteria for additionality and eligibility to avoid “business-as-usual” scenarios. This 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). Meeting these conditions through objective, data-driven models adds to the legitimacy and marketability of ARR projects.

The high-confidence baseline estimation achievable through RS-GIS builds a credible foundation for claiming carbon credits and ensures additionality by rigorously quantifying the impact of new plantation activities on carbon sequestration. Given the transparency, scalability, and affordability of RS-GIS methods, this approach is particularly well-suited to the Indian context, where numerous smallholder farmers are potential participants in ARR projects (Nair et al., 2018).

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.

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