学 位 論 文 内 容 の 要 旨/Dissertation Abstract

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学 位 論 文 題 名/Title of Dissertation

Assessment of the effects of anthropogenic activities on forest resources using remote sensing and GIS : A case study of the Atewa Range Forest Reserve in Ghana
（リモートセンシングとGISを用いた森林資源に対する人為的活動の影響の評価：
ガーナ・アテワ森林保護区を例に）

The Atewa Range Forest Reserve (ARFR), located in southeastern Ghana, is recognized as a key biodiversity hotspot and an essential part of the country's ecological and hydrological systems. Despite its ecological importance, the ARFR is under increasing threat from human activities, notably farming, small-scale logging, and alluvial gold mining. These pressures have significantly impacted the forest's biodiversity and ecosystem services. This research combines multiple remote sensing approaches to monitor and assess the effects of these disturbances on the forest's structure, function, and carbon storage capacity over time. To assess the spatial and temporal dynamics of mining activities and land use changes in the Atewa landscape (Chapter 2), high-resolution PlanetScope satellite imagery (2018–2023) was analyzed using Geographic Object-Based Image Analysis (GEOBIA), which is ideal for reducing misclassifications resulting from the characteristic high spectral variability of high-resolution satellite images. Post-classification change detection was conducted to identify transitions in land use and land cover (LULC), particularly areas that were converted to alluvial mining sites. Additionally, post-mining vegetation recovery was evaluated to assess how long it took for the degraded sites to recover from vegetation loss. Buffer analysis was then applied to determine the proximity of mining sites to river channels and forest boundaries. This was crucial in assessing how mining activities affected the river channels in the area, as well as the effects on the edge of the ARFR. Results showed an annual increase in mining activities at a rate of 12.3% between 2018 and 2023. Notably, the ARFR recorded a decreasing trend in mining activity within its bounds, with a rate of change of -21.4%, indicating irregular mining patterns in the reserve compared to the broader landscape. Critically, a significant portion of mining, at least 49.7% annually, occurred within 100 meters of river channels, highlighting severe risks to aquatic ecosystems. Additionally, 0.7% of mining activities occurred within the 100 m buffer around the ARFR, emphasizing encroaching threats.

While Chapter 2 focused on large-scale disturbance activities in the Atewa landscape, the third chapter sought to fill the knowledge gap in small-scale canopy disturbance dynamics, which often precede permanent forest loss. Sentinel-2 satellite imagery was utilized to map small-scale canopy gaps using Linear Spectral

Mixture Analysis (LSMA) and GIS. Annual change detection within 100 m × 100 m grids tracked canopy disturbances and assessed their spatial correlation with topographical and geospatial variables. Disturbances within the grids were identified through the annual changes that occurred in the soil fraction image derived from the LSMA. Findings revealed consistent deforestation trends and increasing canopy gaps over time, except in 2024, which showed a decrease in gap coverage, a possible indication of forest regeneration. Canopy gaps exhibited rapid transitions from low to high disturbance annually and were predominantly located near forest edges and river channels. Disturbance levels showed a non-linear relationship with elevation and slope (increase followed by decrease), and most disturbances occurred on west-facing slopes, suggesting the possibility of strong anthropogenic drivers such as selective logging and small-scale resource extraction. These findings underscore the need for targeted monitoring strategies focusing on low-scale, progressive degradation activities.

In addition to monitoring disturbances, the study addressed the estimation of above-ground biomass (AGB) and carbon accumulation (CAc) in the ARFR (Chapter 4), an essential component for climate change mitigation. Due to the lack of comprehensive National Forest Inventory (NFI) data in Ghana, remotely sensed Sentinel-2 data were coupled with field-measured AGB to generate accurate biomass estimates. Ten vegetation indices and biophysical variables were tested as predictors in a stepwise linear regression model. Among these, the Normalized Difference Vegetation Index (NDVI; $r = 0.76$; $R^2 = 0.57$) and canopy chlorophyll content (LAI_CAB; $r = 0.42$; $R^2 = 0.17$) emerged as the most effective predictors. The resulting model yielded an R^2 value of 0.84 and a Root Mean Square Error (RMSE) of 28.17 $Mgha^{-1}$, with a statistically significant p-value (0.00016), indicating strong model performance. The final AGB and carbon accumulation (CAc) maps recorded mean values of 124.49 $Mgha^{-1}$ and 92.25 $Mgha^{-1}$, respectively. Comparisons between measured and predicted AGB produced an RMSE of 41.02 $Mgha^{-1}$ and an R^2 value of 0.51, validating the reliability of Sentinel-2 indices in estimating forest biomass.

Collectively, this research demonstrates the potential of integrating high-resolution satellite data, object-based image analysis, spectral unmixing techniques, and topographic variables in monitoring environmental changes in tropical forest reserves. It provides robust evidence of the growing anthropogenic pressures on the ARFR, notably from mining and small-scale forest degradation, and highlights the forest's role in carbon sequestration. The findings advocate enhanced surveillance, enforcement of buffer zone regulations, and strategic reforestation to protect the integrity of the ARFR and its surrounding ecosystems.