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研究課題名（和文）インド・ウッタラカンド州における大規模なバイオガス導入が森林再生にもたらす効果

研究課題名（英文）Effects of Biogas Interventions on Forest Regeneration in Uttarakhand, India

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研究成果の概要（和文）：インドの農村部では、薪が手に入りやすいため、調理や熱エネルギーの主要な供給源となってきた。これは森林の劣化につながる。本研究の主な目的は、バイオガスに移行した村に隣接する森林において、バイオガスの大規模な導入が森林再生と炭素固定に及ぼす影響を調査することである。ランドサット画像を用いた森林被覆の変化の分析から、調査地内の森林減少率が減少していることがわかった。さらに、PALSARデータは、バイオマスの蓄積または森林再生に起因するHV偏光における後方散乱の増加を明らかにした。本研究の結果は、バイオガス設備の潜在的な利点と、森林の回復と持続可能な開発を促進する役割を強調するものである。

研究成果の学術的意義や社会的意義
この研究は、バイオガスの介入による潜在的な利益と持続可能な開発への貢献を提供するものである。さらに、現在のシナリオにおいて地元の利用者が直面している課題や、バイオガスを利用した調理による健康状態の改善についても明らかにすることができる。

研究成果の概要（英文）：Fuelwood has been a primary source of cooking and thermal energy in rural parts of India because of its accessibility. This leads to forest degradation. The primary objective of this study is to investigate the effects of extensive biogas deployment on forest regeneration and carbon sequestration in the forests adjacent to villages that have transitioned to biogas solutions. The analysis of forest cover changes, using Landsat imagery, indicates a reduction in deforestation rates within the study site. Furthermore, PALSAR data reveal an increase in backscattering in HV polarization, attributable to biomass accumulation or forest regeneration. The outcomes of this study underscore the potential advantages of biogas installations and their role in promoting forest recovery and sustainable development.

研究分野：Geospatial data

キーワード：Forest biomass　Biogas　REDD+

様　式　Ｃ－１９、Ｆ－１９－１（共通）

１．研究開始当初の背景

Research objective: Monitoring the impact of a large-scale biogas intervention on forest regeneration using Remote Sensing Technologies. Target area: Ram Nagar region, Uttarakhand, India. By replacing fuelwood with biogas digesters in villages as part of a low-carbon farming effort, the study aims to understand how this affects forest regrowth and carbon storage in surrounding areas. Monitoring forest cover changes using remote sensing technologies is key to ensuring the environmental sustainability of biogas plant installations. By analyzing satellite imagery and land use data, the study aimed to quantify alterations in forest cover and biomass over time near biogas facilities. This information can help evaluate the ecological footprint of biogas plants and develop strategies to minimize potential environmental impacts, contributing to forest conservation and climate change mitigation efforts. Utilizing such technologies can provide valuable insights into forest responses and facilitate informed decision-making for sustainable management practices, as well as help curb deforestation and contribute towards REDD+ and climate change mitigation. This study utilized advanced multi-sensor remote sensing to assess forest cover changes linked to biogas plant installations. By analyzing satellite imagery and land use land cover change (LULC) data, it aimed to quantify alterations in forest cover and biomass over time near biogas facilities.

２．研究の目的

In 2011, India's housing census revealed that roughly 49% of the population uses fuelwood for cooking, which poses health risks due to incomplete combustion. The Indian Government initiated the widespread installation of biogas digesters as a low-cost, sustainable energy alternative in rural areas. These units digest organic waste, human excreta and/or cattle dung to produce biogas, used for cooking. Figure 1 shows the biogas digester in Uttarakhand and its user. This can enable households to reduce reliance on fuelwood collection/consumption from forests as well as improve waste management and human health. The transition described in this study is expected to contribute to climate change mitigation by promoting forest regeneration and reducing greenhouse gas (GHG) emissions. The study hypothesized that the use of biogas units reduces the proportion of fuelwood consumption and helps in forest regeneration. This study evaluated the following: Quantitatively assess the extent to which forest regeneration is progressing in areas where biogas technology has reduced dependency on fuelwood and quantify changes in carbon sequestration in forests undergoing regeneration due to reduced fuelwood dependence. Henceforth, this research can help Japan to establish and

implement bilateral crediting schemes (JCM), and play an important role in realizing REDD+ through forest conservation.

Figure 1. A view of installed biogas digester and a user of biogas for cooking in the study site

3．研究の方法

The research employed varied methodologies to investigate the potential impact of the biogas plant on the deforestation pattern in the study area. The research used remote sensing image processing and analysis techniques to determine the changes in forest coverage and biomass and to quantify the alterations in forest biomass. Satellite imagery was acquired before and after the development of the biogas plant. The Hansen Global Forest Change data was also utilized to observe the changes in the forest after the installation of the biogas plants in the region. It performed Time series analysis using the ALOS-2/PALSAR-2 dataset, Google Earth Engine, and machine learning-based techniques to estimate the changes in forest biomass and HV and HH backscatter. Henceforth, land use land cover change analysis provided valuable insights into the changes in vegetation classes in the preceding decade. Furthermore, a field visit was conducted to validate the results. It helped the study to understand the intricate details related to alternate fuel consumption and the importance of biomass consumption and usage. It conducted focused group discussions (FGDs) that aided understanding the problems related to the erratic success of biogas in some areas and the probable solutions.

4．研究成果

In the study site, a 2 km buffer zone has been established around villages. Using Hansen Forest cover data, forested area changes within this zone were tracked. Figure 2 depicts deforestation trends: higher rates pre-2013, decreasing thereafter.

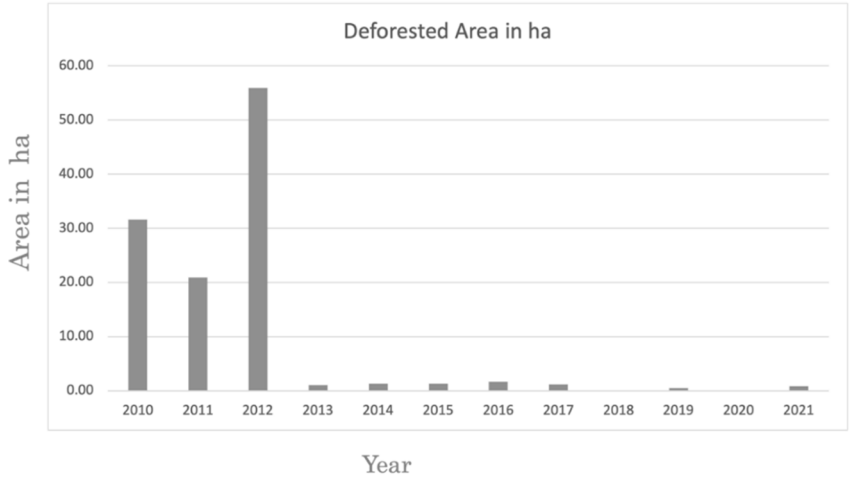

Figure 2. Temporal change of the deforested area.

However, since 2013, there has been a decrease in forest loss due to reduced demand for fuelwood after the installation of biogas plants in the region. Landsat satellite data has been used to monitor land use cover changes over the last decade. The vegetation cover has increased between 2014 and 2023. To investigate temporal changes in forest biomass, a random forest machine-learning approach was implemented using ALOS-2/PALSAR-2 data. After pre-processing, backscatter coefficients HH and HV were generated and used as predictive variables to estimate forest biomass. Figure 3 shows an increasing pattern of forest biomass. Analysis of satellite imagery revealed an increase in forest cover and biomass after the installation of the biogas digesters. The increment was observed across the study area but was particularly notable near the villages with biogas digesters. Temporal analysis indicated a steady decline in deforestation and a rise in forest biomass during the operational timeline of the biogas installation. Several factors may have contributed to the observed increase in forest biomass, including improved soil fertility, enhanced nutrient cycling, and potential afforestation efforts related to biogas plant development. According to this study, there is a positive relationship between the growth of biogas digesters and an increase in forest cover and biomass. Biogas digesters can contribute to the enrichment of forests by recycling organic waste, enhancing soil quality, and promoting afforestation. Increased forest biomass has significant implications for ecosystem health, carbon sequestration, and biodiversity conservation.

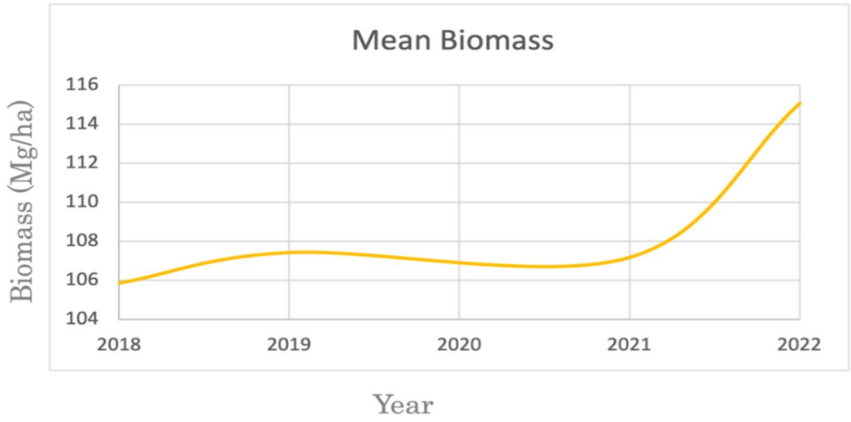

Figure 3. Temporal change in the forest biomass in the study area

During the fieldwork, respondents reported that biogas was not successful in some areas as an alternative energy source for various reasons due to reduction in the production of enough cattle dung because of a decrease in the number of animals, poor design/technology of biogas plants, poor training to run the plant, seasonality, and migration of people etc. We also interviewed households that were still collecting fuelwood from the forest. Seasonality significantly affected biogas use; when digesters were not operational, households reverted to collecting fuelwood from forests. These insights are crucial for scaling up biogas initiatives effectively.

Key Activities	Recommendations
Mapping of forest cover and analyzing satellite data	The research identified that increased forest cover due to biomass-related intervention. Henceforth, to reduce the community's dependence on fuelwood, community-centric biomass production units should be set up.
Fieldwork and Focused Group Discussions	Sustained biogas consumption requires better plant designs and community training. This also involves sensitizing the communities about local policies that will help them to set up biogas plants.
Recommendations	One of the major recommendations of the study is to enhance the usage and production of biomass systematically so that the community's dependence on fuel woods decreases uniformly.

In conclusion, the establishment of biogas plants can lead to a considerable increase in forest biomass. It highlights the potential environmental benefits of biogas plants and emphasizes the importance of combining renewable energy initiatives with conservation efforts. Monitoring and research are crucial to fully comprehend the long-term impacts of biogas plant development on forest ecosystems.

５．主な発表論文等

〔雑誌論文〕　計4件（うち査読付論文　2件／うち国際共著　2件／うちオープンアクセス　0件）

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３．雑誌名 Remote Sensing Applications: Society and Environment	６．最初と最後の頁 12
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.rsase.2022.100789	査読の有無 有
オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 該当する

１．著者名 Avtar, R., Rinamalo, A.V., Umarhadi, D.A., Gupta, A.; Khedher, K.M.,Yunus, A.P., Singh, B.P., Kumar, P., Sahu, N., Sakti, A.D.	４．巻 11
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オープンアクセス オープンアクセスではない、又はオープンアクセスが困難	国際共著 －

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２．出版社 Springer	５．総ページ数 573
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〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関