RS-GIS based Rice Residue Energy Potential Assessment: A Case Study in Ubay, Bohol

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Abstract: Rice residue management is a critical aspect of sustainable agriculture and renewable energy development. This study explores the application of geospatial technology for assessing the energy potential of rice residues in Ubay, Bohol. Utilizing remote sensing (RS) and geographic information system (GIS), spatial distribution and biomass availability were analyzed to estimate the recoverable energy from rice husks and straw. The study highlighted the use of data collected from SENTINEL-2 satellite images that was customized for environmental monitoring depicting the province of Bohol vegetation index for the past five years. The satellite images was complemented by Unmanned Aerial Systems (UAS) equipped with multi-spectral sensors enabling the identification of vegetation and agricultural residues. As a result, it was found that the municipality of Ubay rice crop residue in the form of rice husk and rice straw theoretical potential in mass amounted to 2,584,433 metric tons and 3,022,729 metric tons annually. The majority of Ubay's rice plantations are concentrated in the northwest and central parts of the municipality, which aligns with the clustering of villages that ranked highest in bioenergy potential. The bioenergy potential estimates can reach up to 5,851,350 GJ for rice husk and 6,236,230 GJ for rice straw. Findings emphasized the potential of geospatial tools in identifying high-yield areas, optimizing collection strategies, and promoting sustainable energy solutions.

Keywords: Remote Sensing, GIS, Biomass, Waste-to-energy, Geospatial Technology

1. Introduction

Agricultural residues, as an example of biomass, have the potential to generate sustainable bioenergy from renewable fuels (Ginni , 2021). Agricultural residues, also called crop residues, are wastes created after the harvesting of crops. Biomass availability in Southeast Asia is primarily driven by extensive cropland area and high agricultural productivity, especially in countries such as Indonesia, Vietnam, and Thailand (Beňová, et al., 2021. Their vast agricultural landscapes allow for substantial biomass generation, making them key players in the transition toward bioenergy utilization.

In the Philippines, agriculture accounts for more than half of the land. The province of Bohol is a significant agricultural producer, particularly in the Central Visayas region. It has agricultural waste that can be used to generate energy. Agriculture remains the province's leading industry in terms of workforce and land use. Bohol, a rice-producing province, utilizes approximately 32% of its agricultural land for rice cultivation, with Ubay being the most consistently abundant in rice production (PPDO, 2024).

In agriculture, the remaining biomass residue on agricultural land may be estimated. A growing number of agricultural leftovers are left unused, which could be utilized to generate renewable energy. Satellite data can be utilized in conjunction with geospatial tools and analytics to examine the state and planning of the region's renewable energy assets, as well as to determine the most cost-effective utilization of these resources. Satellite images are products of remote sensing (RS) technologies using satellite-mounted sensors. RS technologies also include airborne cameras and unmanned aerial vehicles (UAVs). These technologies enable large-scale and high-precision agricultural monitoring. The use of remote sensing in determining crop activity and health is widely utilized because it can cover large geographical areas and is more cost-effective than ground-based surveys (Li &Kpienbaareh, 2024) and (Zhang, 2025).

In reference to satellite images, a widely used RS tool is the SENTINEL-2 Multispectral Instrument (MSI). This satellite image captures spatiotemporal data offering 13 spectral bands that include different bands at varying spatial resolutions. Specifically, it provides four bands at 10-meter, six bands at 20-meter, and three bands at 60-meter resolutions. Currently, the unmanned aerial system technology, commonly known as unmanned aerial vehicles (UAVs) or drones, integrates sensors to collect high-resolution data. This upgrade of technology enables increased flexibility in spatial and spectral resolution compared to the traditional RS methods (Aasen, 2023). The images obtained from remote sensing technology can be further evaluated using the capabilities of Geographic Information System (GIS) analysis tools, and the resulting information will aid in tracking and managing the use of natural resources to ensure their long-term viability through improved environmental planning.

2. Methodology

This study was conducted in Bohol, a province in the Central Visayas region of the Philippines. Bohol comprises 47 municipalities and one city, Tagbilaran City, which serves as the provincial capital. The province has a total land area of 411,726 hectares, and approximately 256,400 hectares of these areas are classified as arable land. Located in the northern part of the province is the second district, which includes the town of Ubay. The town is regarded as the "rice capital of the province," serving as one of the most important rice granaries in the region. It plays a vital role in ensuring food security and supporting the local economy. This town is a significant contributor to Bohol's overall rice production.

This study was initiated with data collected from the Sentinel-2 satellite images. Specifically, it examines the province of Bohol's satellite pictures, which have been utilized for vegetation index studies over the past five years, from 2017 to 2022. One of the most commonly used tools for tracking vegetation changes is the Normalized Difference Vegetation Index (NDVI). This study included images captured by multi-spectral Unmanned Aerial Systems (UAS), referred to as drones. The captures provide high-resolution images that confirm the presence of observable rice crop plantations in the municipality of Ubay. In particular, the site samples chosen to confirm the rice plantation areas using the satellite images' NDVI were three villages, in line with the project timeline. After capturing the image of the rice plantation in Ubay, geoprocessing follows to eliminate geometric distortions caused by sensor, platform, and terrain displacement. It was done by photogrammetrically correcting drone footage using GIS software, ArcGIS.

The energy potential of rice residues was estimated by combining statistical data on rice production from Ubay municipality with satellite imagery showing agricultural coverage from 2018 to 2023. The amount of rice residue available is calculated using annual rice production and the residue-to-product ratio (RPR), which determines the amount of waste produced per unit of rice harvested. Additionally, the potential energy from rice waste can be estimated by considering the amount of rice straw (the stalks and stems left after harvesting) and rice husk (the outer covering of the rice grain after milling), along with their calorific values (the amount of energy they can produce when used as fuel).

3. Results/Findings

As shown in Figure 1, the province of Bohol harvested rice over an area of 70,278 hectares, accumulating a total production of 212,719 metric tons, with an average yield of 3.03 metric tons per hectare.

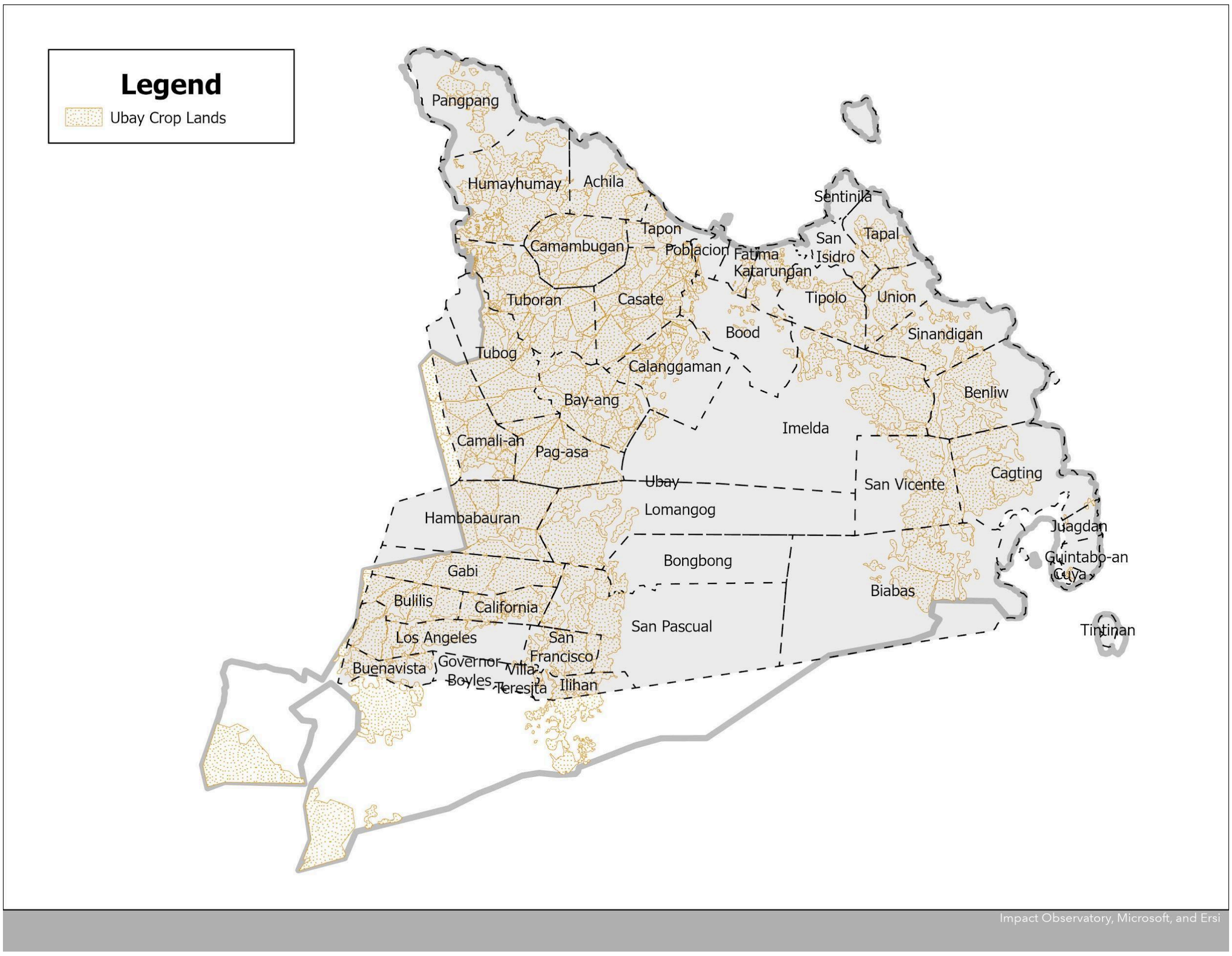

Figure 1: Ubay, Bohol geoprocessed agricultural crop coverage.

To validate the remote sensing data collected by the UAS, ground truth data were collected through detailed field surveys. This study employed a statistical metric, the Root Mean Square Error (RMSE), to quantify the difference between estimated values and actual observed values. In this particular study, the estimated values refer to the identified rice plantation areas based on satellite data, while the actual observed values are from ground truthing aided by multispectral surveying drone to cover images of large rice plantation areas. The results show RMSE values, ranging from 2.96 to 0.86, indicating that the estimation based on satellite images fits the data well and provides near-precise predictions of the actual rice plantation areas.

In the municipality of Ubay, a large amount of rice was produced from 2018 to 2023. Using satellite images and drone captures, this study estimated the residues from rice crops, where the theoretical potential in mass for rice husk amounted to 2,584,433.089 metric tons and 3,022,728.759 metric tons for rice straw. Figure 3 shows the theoretical potential in mass for all barangays in the municipality of Ubay.

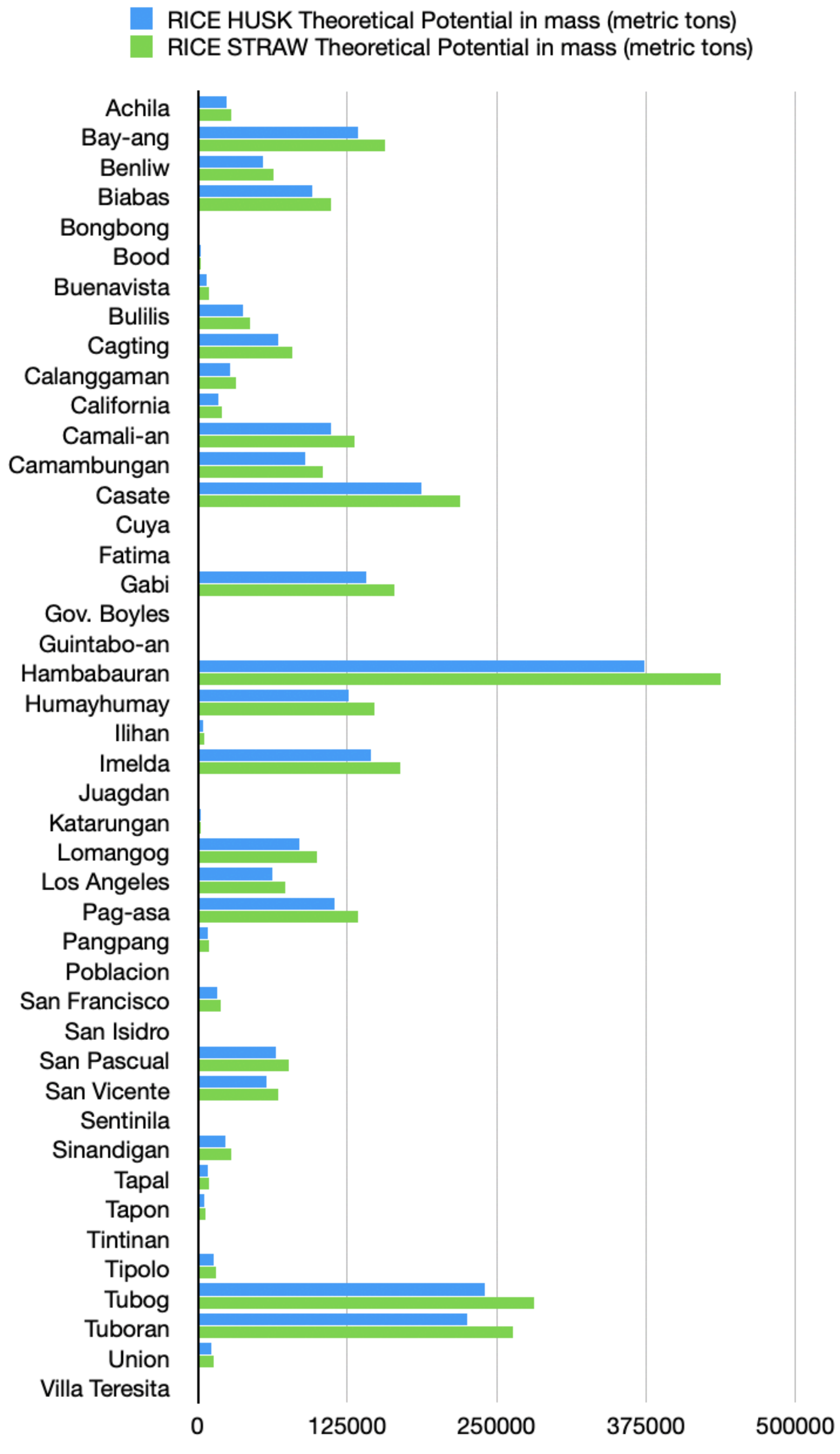

Figure 2: Barangay level rice husk and rice straw residue energy potential

4. Conclusion

The findings highlight the advantages of geospatial tools in identifying areas with sustainable biomass resources, such as rice crop residues. Through the application of Geographic Information Systems (GIS) and remote sensing, the spatial distribution and biomass availability of rice husks and straw were analyzed to estimate their recoverable energy potential. This study determined the theoretical annual biomass potential of Ubay from rice husks at 2,584,433 metric tons and rice straw at 3,022,729 metric tons. In barangays with a high concentration of recoverable residues, these biomass resources translate to an electrical energy potential of 1,625 GWh for rice husks and 1,732 GWh for rice straw. It is observed that the majority of Ubay's rice plantations are concentrated in the northwestern and central regions, exhibiting the highest bioenergy potential. The estimated bioenergy potential reaches up to 5,851,350 GJ for rice husks and 6,236,230 GJ for rice straw.

The current study is limited to a single season, which may not fully reflect the inter-seasonal variability in residue availability and quality. Future studies should adopt stratified sampling across multiple cropping cycles to enhance the reliability and generalizability of the results. Beyond technical estimations, integrating socio-economic factors is essential to ensure realistic and actionable assessments of rice residue bioenergy potential.

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