Agricultural Plastic Waste Mapping in Rice Farms: A Geospatial Analysis Approach

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Agricultural Plastic Waste Mapping in Rice Farms: A Geospatial Analysis Approach

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Abstract: *With major effects on ecosystems, human health, and sustainable farming practices, agricultural plastic waste has become a pressing global concern. By employing mapping techniques and geospatial analysis, this study will model the agricultural plastic waste in rice-farming areas within Remedios T. Romualdez, Agusan del Norte, Philippines. The study intends to help optimize waste management strategies by identifying waste hotspots and quantifying the volumes and types of plastic waste. To do this, this study utilized Sentinel-1 and Sentinel-2 satellite imagery and field survey data. Rice field maps were generated using Random Forest classifiers with high accuracy (Kappa coefficient: 0.92; overall accuracy: 97.15%). Findings of the study showed that fertilizer sacks and pesticide containers like bottles, sachets, and gallons are the predominant sources of plastic waste in the area, with Basilisa recording the highest waste generation rates. Geospatial analysis showed that 742.289 kg of plastic sacks per hectare (ha) per year (yr) is generated in the area, followed by plastic bottles with a total volume of 135.271 kg/ha/year, gallons (93.980 kg/ha/year), and plastic sachets (27.225 kg/ha/year). This study further proves that geoinformatics-based identification of waste hotspots supports policy and community-based waste management strategies.*

Keywords: Agricultural plastic waste; geospatial analysis; rice farming;

1. INTRODUCTION

Plastic waste pollution is a significant environmental issue affecting the Philippines and nations around the world [1, 2, 3], posing serious risks to human health due to microplastic infiltration in food and water sources [4, 5] like the ocean [6], causing harm to marine ecosystems, while the rest obstructs waterways [7] or accumulates in landfills [8].

The Philippines is one of the largest contributors to global plastic pollution [9], generating approximately 2.7 million tons of plastic waste annually [6, 10]. In the agricultural sector, plastics like fertilizer sacks and pesticide containers are widely used [11]. These materials contribute to persistent waste, leading to soil degradation and water contamination.

The study's motivation to assess plastic waste within rice plantations was drawn from a prior Focus Group Discussion (FGD) with rice farmers at the Caraga State University. Based on the FGD, it was indicated that respondents still prefer traditional farming that use synthetic inputs over organic farming and modern techniques. The municipality of Remedios T. Romualdez (RTR), Agusan del Norte, Philippines, is known as the rice granary of the province. As the leading rice producer of the province, a geoinformatics-based analysis and mapping of its rice farms are essential to pinpoint the hotspots of agricultural plastic waste.

Geoinformatics provides a formal approach for managing geoinformation, integrating GIS, photogrammetry, remote sensing, and cartography into a unified framework [12, 13, 14]. Utilizing remote sensing imagery to generate maps and employing geospatial analysis can effectively illustrate potential patterns [15, 16] in the distribution of agricultural plastic waste. This approach facilitates an understanding of the extent of waste generation and its spatial distribution, providing crucial information to develop strategies to reduce waste, enhance resource efficiency, and improve the overall management of agricultural residues. Thus, this study aims to identify and quantify the agricultural plastic wastes in the rice plantations of RTR through the use of remote sensing and geospatial analysis techniques to generate plastic waste hotspots and evaluate their distribution.

2. METHODOLOGY

2.1 The Study Area

The study was conducted in RTR, Agusan del Norte, Philippines. RTR comprises eight sub-areas with a total rice area of 1,426.52 hectares as shown in Table 1. Seven sub-areas within the Municipality that practice rice farming are Balangbalang, Basilisa, Humilog, Panytayon, Poblacion I, Poblacion II, and Tagbongabong. The municipality of Remedios T. Romualdez (RTR) is primarily an agricultural area, with a large portion of its land dedicated to rice farming, as shown in Fig. 1.

Table 3. Rice Plantation Area in RTR sub-areas.

Sub-Area	Total Rice Plantation Area (ha)
Balangbang	162.58
Basilisa	314.60
Humilog	173.12
Poblacion 1	28.25
Poblacion 2	302.48
Panaytayon	175.93
Tagbongabong	269.56

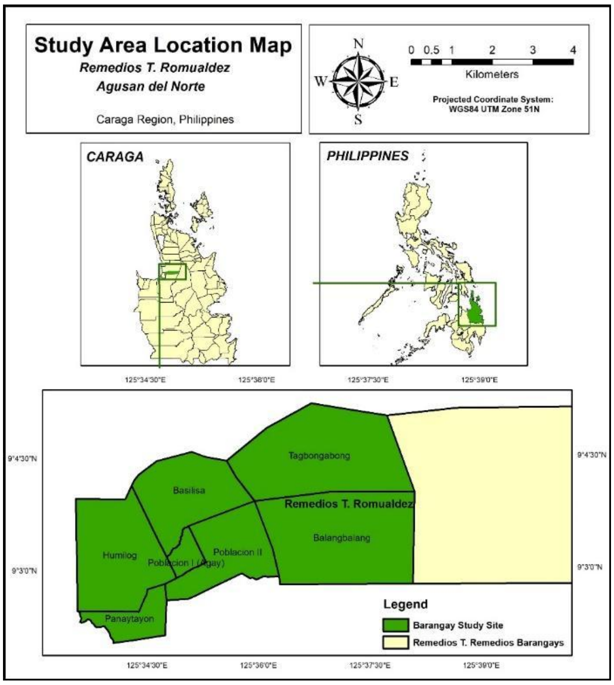

Fig. 1. Location of the study area.

2.2 The Methodological Flow

The study's methodological flow, shown in Fig. 2, was designed to achieve the research objectives. The research process consisted of: (1) data collection through field interviews and surveys; (2) rice mapping using Sentinel-1A SAR imagery and a Random Forest classifier; (3) thematic mapping of plastic waste using calculated plastic loading rates.

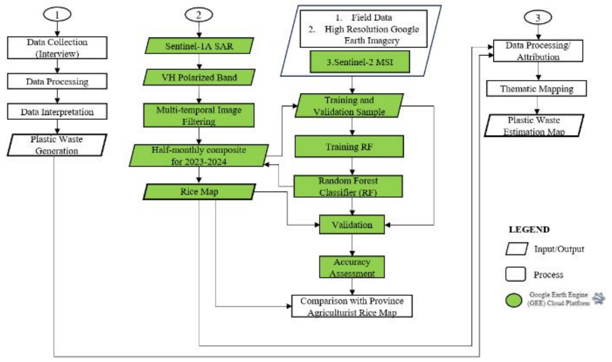

Fig. 2. The Flow Chart of the Study

2.3. Plastic Waste Generation

Field data from structured interviews identified key plastic types (sacks, bottles, sachets, gallons). Waste were quantified using the most common volumes used among farmers and calculated as plastic loading rates (kg/ha/year). To gather primary data on plastic consumption in agricultural activities, structured questionnaires were distributed, accompanied by direct interviews with the farmers. The data collected encompassed the following key parameters: farm size, methods used for planting rice, planting and harvest frequencies, and the types and quantities of fertilizers and pesticides applied. It was assumed that the respondents were homogeneous within each barangay, making them representative of their respective areas. The total plastic usage for each year was calculated by multiplying the quantity of each type of plastic used by the frequency of planting cycles per year and the weight of each plastic item (Equation 1). Subsequently, the plastic loading rate was calculated by dividing the total plastic usage by the plantation area in hectares (Equation 2). This rate, expressed in kilograms per hectare per year, served as an estimate of the amount of plastic waste generated annually for each hectare of rice plantation, providing crucial insights into the scale of plastic waste in agricultural practices.

$$\text{Total plastic (kg/yr)} = \text{plastic quantity} * \text{planting frequency (times/year)} * \text{plastic weight (kg)} \qquad \text{Equation 2}$$

$$\text{Plastic loading rate (kg/ha/yr)} = \text{Total plastic (kg/yr)} / \text{plantation area (ha)} \qquad \text{Equation 1}$$

2.4. Rice Mapping

The mapping process relied primarily on data from Sentinel-1A SAR, Sentinel-2 MSI, and field-based datasets to produce accurate and detailed maps of rice fields. The VH polarized band of Sentinel-1A SAR provides essential information on vegetation structure and moisture content. Noise reduction was implemented by employing multi-temporal filtering process. Bi-monthly composite images were generated for the 2023–2024 period to capture the temporal changes and seasonal patterns of rice fields. While, Sentinel-2 MSI's high-resolution added valuable spectral details that give more distinction in classifying rice fields from other land cover types.

Field data and high-resolution imagery from Google Earth were then integrated to prepare training and validation samples for rice and non-rice areas. A Random Forest (RF) classifier, a widely used machine learning tool [13], was employed for the classification of rice fields. The RF image classification was implemented both offline and in the online cloud platform of Google Earth Engine® (GEE). The classifier was trained using the prepared samples, enabling it to recognize patterns and characteristics specific to rice fields based on their spectral and temporal features. The RF classifier was utilized due to its robustness, accuracy, and efficiency when using high-dimensional datasets. RF excels in scenarios involving mixed data types and can effectively handle the erroneous data typically found in agricultural mapping. Unlike Support Vector Machines (SVM), which may require extensive parameter tuning and perform less effectively with large datasets, RF has built-in capabilities to prevent overfitting using multiple decision trees. Additionally, RF outperforms k-Nearest Neighbors (KNN) in terms of computational efficiency, particularly when processing large spatial datasets, as KNN's performance can degrade significantly with increasing data size due to its instance-based learning approach. Studies have also demonstrated that RF achieves comparable or superior accuracy in agricultural classification tasks compared to SVM and KNN, further supporting its suitability for this study.

After training, the classifier's performance was tested using independent validation data to ensure accuracy and reliability. Metrics such as overall accuracy and kappa coefficient were calculated to assess the quality of the rice field map, as shown in Table 2. Once the map was generated, it was compared with an existing rice map provided by the Provincial Agriculture Office. This comparison helped verify the consistency and accuracy of the newly produced map and identify any discrepancies between the two datasets. The integration of cloud-based tools like GEE with local processing facilitates efficient handling of large datasets and precise mapping.

Table 2. Accuracy Metrics for Rice Classification

Metric	Description	Standard Accuracy Range
Overall Accuracy	The percentage of correctly classified samples out of the total samples.	≥ 85%
User's Accuracy	The probability that a classified pixel represents that category on the ground (precision).	≥ 90%
Producer's Accuracy	The probability that a reference sample is correctly classified (recall).	≥ 80%
Kappa Coefficient	Measures agreement between classification and ground truth, adjusting for chance agreement.	≥ 0.75 (strong agreement), 0.4–0.75 (moderate agreement).
Confusion Matrix	A matrix showing true positives, true negatives, false positives, and false negatives for each class.	It should reflect minimal misclassification in key categories.

2.5. Thematic Mapping

The visualization of the distribution of plastic waste was represented through thematic maps generated using QGIS, which identified specific hotspots for different types of plastics in each sub-area. These thematic maps illustrated the varying levels of plastic waste accumulation, allowing identification of critical areas that require site-specific interventions.

3. RESULTS AND DISCUSSION

3.1. Data Collection

A total of fourteen (14) respondents were interviewed for the data collection, ranging from one to three respondents per sub-area. For each sub-area it was ensured during the selection of respondents that one of them serves as the sub-area President of their Rice Farmers' Association, alongside other rice farmers. The interviews with 14 farmers across seven sub-areas revealed that all farmers in RTR have full irrigation access and practice two-cropping seasons. Synthetic methods were preferred by the majority due to pest and disease concerns.

3.2. Rice Mapping

The rice field map produced, shown in Fig. 3 yielded high classification accuracy. VH polarization efficiently distinguished vegetated rice areas from other land uses. The accuracy assessment revealed a Kappa coefficient of 0.92 and an overall accuracy of 97.15%, shown in Table 3, indicating a high level of agreement and an accurate representation of rice field distribution.

3.3. Plastic Waste Estimation

The study identified fertilization and pesticide application as the primary activities contributing to agricultural plastic waste in rice cropping. Commonly used fertilizers include complete NPK fertilizers, urea, ammonium, and potash, with Urea as the most prevalent due to government subsidy [1].

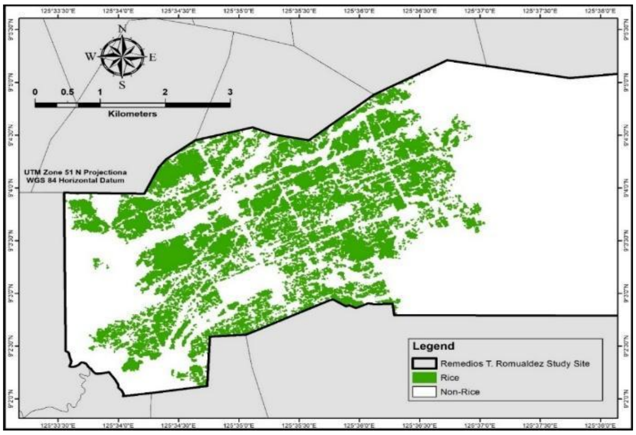

Fig. 3. Rice map of RTR study site based on VH polarization

Table 3. Performance Metrics of the Classification Method

Classes	PA	UA	Overall Accuracy	Kappa Coefficient
Rice	98.57	99.70		
Non-Rice	92.15	95.26		
Others	98.62	97.65		
			97.15	92.00

Legend: Producer's Accuracy (PA), User's Accuracy (UA).

Table 4. Average Waste Volumes of Fertilizer Sacks in RTR Sub-areas.

Sub-Area	Land Area	Volume of Wastes (Sacks)	
		kg/yr	kg/ha/yr
Balangbang	4.75	6	1.895
Basilisa	2	2.25	1.725
Humilog	4.5	4.75	1.656
Poblacion 1	3	3	1.500
Poblacion 2	6	6.75	1.725
Panaytayon	3	3	1.500
Tagbongabong	3.75	6.5	2.133

The plastic wastes generated by rice farming, including bottles, sachets, and sacks, are relatively uniform in volume, resulting in similar weights when emptied of their contents. To understand the extent of waste accumulated in a year, the total annual weights of each plastic waste type per sub-area were computed in kilogram per hectare per year (kg/ha/yr). To demonstrate this derivation, Table 4 is presented with the data for fertilizer sacks accumulated in the area. Among the sub-areas, Poblacion 2 recorded the highest total weight of sacks at 6.75 kg/year, while Basilisa had the lowest at 2.25 kg/year. When averaged by area, Tagbongabong also displayed the highest weight per hectare at 2.133 kg/ha/year, reflecting a significant reliance on fertilizer sacks.

The highest weight of bottle waste was observed in Balangbalang at 2.318 kg/year, with an average weight of 0.488 kg/ha/year, indicating frequent use of liquid pesticide containers. Conversely, Poblacion 2 had the lowest bottle waste weight average at 0.264 kg/ha/year. Balangbalang and Humilog produced the most sachet waste at 0.264 kg/year, while Basilisa recorded the least at 0.180 kg/year. Despite the small volumes, sachet waste is significant due to its non-biodegradable nature and small size, which complicate collection and disposal. The highest gallon waste weight was noted in Poblacion 2 at 1.572 kg/year, averaging 0.262 kg/ha/year, highlighting substantial herbicide usage. In contrast, Tagbongabong had the lowest gallon waste average of 0.140 kg/ha/year.

Table 5. Total Estimated Plastic Waste Volumes in RTR Sub-areas (kg/ha/yr).

Sub-Area	Sack	Bottle	Sachet	Gallon
Balangbang	64.85	13.79	1.57	6.23
Basilisa	271.34	57.04	14.03	40.83
Humilog	63.69	14.59	2.11	8.36
Poblacion 1	14.12	4.34	0.88	2.07
Poblacion 2	86.96	13.19	2.14	13.07
Panaytayon	3	13.39	3.29	14.38
Tagbongabong	153.35	18.93	3.21	9.03

3.4. Waste Hotspot Mapping

Using QGIS, thematic maps were successfully generated to model the waste from fertilizers, pesticides, and insecticides, quantified in kilograms per hectare per year. The thematic maps produced enabled determination of the total plastic waste generated per unit of cultivated land, measured in kilograms per hectare annually. Basilisa consistently had the highest waste, while Poblacion and Tagbongabong had varying levels depending on the plastic type. Socioeconomic and farming intensity factors influenced these trends. Fig. 4 shows the distribution of plastic sacks for each sub-area in Municipality of RTR. Humilog, Poblacion 1 and 2, and Balangbalang have the lowest volume of plastic sacks followed by Panaytayon and Tagbongabong based on the categorized interval.

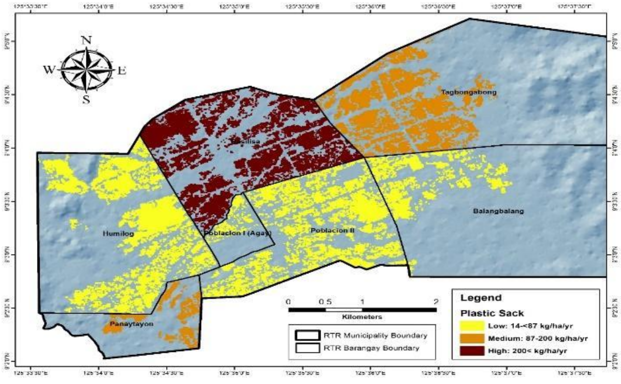

Fig. 4. Estimation of Sack each sub-area in Municipality of RTR

Fig. 5 illustrates the distribution of plastic bottles for each sub-area of RTR. Basilisa showed the highest volume of plastic bottles. Poblacion 1 has the lowest volume of plastic bottles, followed by the Humilog, Balangbalang, and Panaytayon. Fig. 6 and Fig. 7 shows the distribution of plastic sachets and plastic gallons, where Basilisa remains the highest producer of these plastic wastes.

In summary, Basilisa exhibits the highest levels of sack waste generation, exceeding 200 kg/ha/year, likely due to intensive farming practices and high fertilizer usage. Areas with moderate waste levels (87–200 kg/ha/year) include Tagbongabong and Panaytayon, while Balangbalang, Humilog, and portions of Poblacion show lower sack waste levels (14–87 kg/ha/year). In terms of plastic bottle waste, Basilisa exceeds the levels of 50 kg/ha/year, likely linked to frequent pesticide and herbicide applications. Tagbongabong and Poblacion II fall within the medium range (20–50 kg/ha/year), while Poblacion I (Agay) is the only sub-areas with low plastic bottle waste (<20 kg/ha/year). When it comes to plastic gallons, only Basilisa and Poblacion II are in the high and medium categories, respectively, with the rest of the sub-areas in the low range. Overall, the highest loading rate among agricultural plastic waste types is found in sacks, exceeding 700 kg/ha/year.

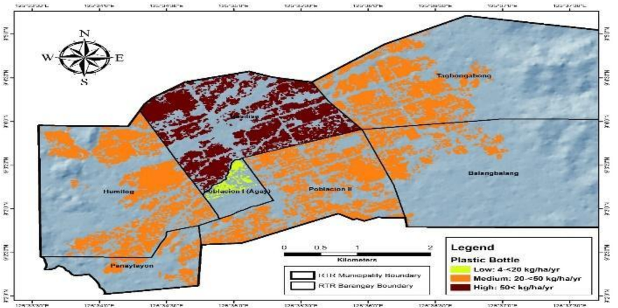

Fig. 5. Estimation of Plastic Bottles in each sub-area in the Municipality of RTR

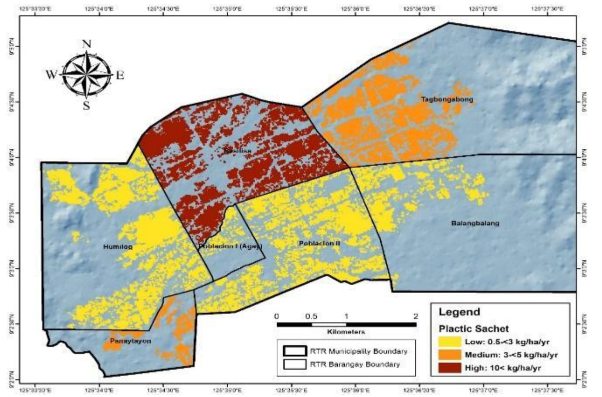

Fig. 6. Estimation of Plastic Sachets in each sub-area in the Municipality of RTR

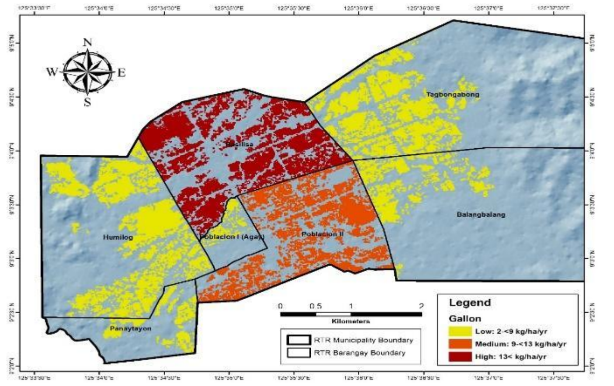

Fig.7. Estimation of Gallons in each sub-area in the Municipality of RTR

These thematic maps offered a comprehensive view of plastic waste distribution in an agricultural setting, which provided insights on waste management strategies in the area. The results of this study showed that the amount of plastic waste accumulation in the rice-producing regions could be accurately estimated using geoinformatics-based modeling of plastic waste. With the help of the resulting maps, the distribution of plastic waste was clearly understood, offering helpful direction for creating efficient waste management plans and encouraging more environmentally friendly farming methods in the area.

Figures 8 through 11 illustrate histograms showcasing the estimated plastic waste generated by rice farms in the respective sub-areas of RTR to provide a comprehensive comparison among the sub-areas. The results indicate significant variations in plastic waste generation among sub-areas, with Basilisa consistently producing the highest waste per hectare across all plastic types. While land area plays a critical role in overall waste generation, other factors such as farming intensity and socioeconomic variables likely contribute to these differences.

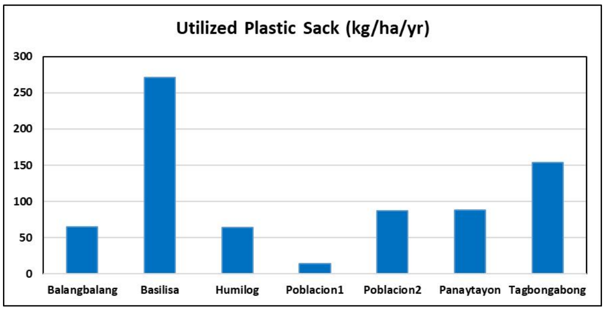

Figure 8. Comparison of different sub-areas of the estimated plastic sack

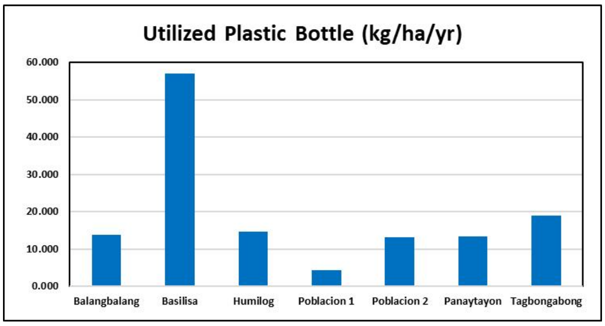

Figure 9. Comparison of different sub-areas of the estimated plastic bottle

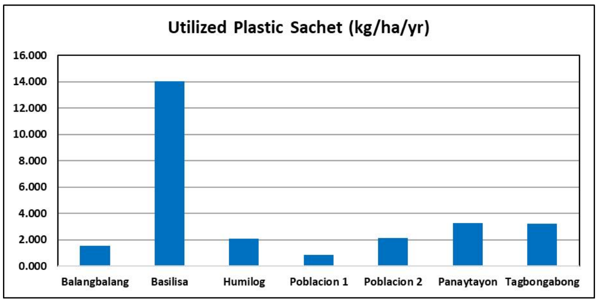

Figure 10. Comparison of different sub-areas of the estimated plastic sachet

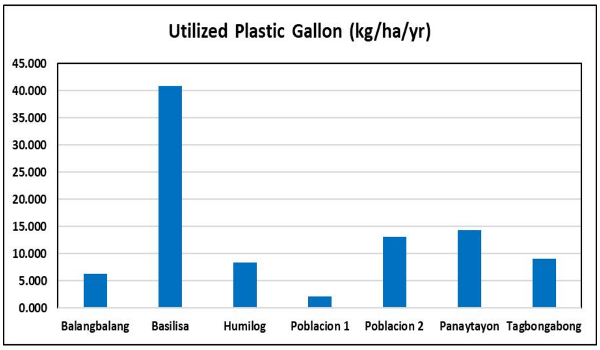

Figure 11. Comparison of different sub-areas of the estimated plastic gallon

4. CONCLUSIONS AND RECOMMENDATIONS

This study demonstrated the effective use of Sentinel-1 satellite data for estimating rice crop areas by employing Random Forest classifier. The classification with VH polarization yielded high accuracy values, Kappa Coefficient of 0.92 and an Overall Accuracy of 97.15%. This proved that the integration of SAR data in agricultural monitoring provides significant potential for optimizing crop management. In addition, the study quantified agricultural plastic waste generated in rice farming, identifying plastic sacks as the predominant waste type (742.289 kg/ha/year), followed by plastic bottles (135.271 kg/ha/year), gallons (93.980 kg/ha/year), and plastic sachets (27.225 kg/ha/year). Among the sub-areas of RTR, Basilisa exhibited the highest plastic waste generation, correlating directly with its extensive rice land area. These findings emphasized the need for sustainable waste management practices in rice farming to mitigate environmental impacts while maintaining agricultural productivity.

Based on the findings of this study, policymakers and stakeholders in RTR can formulate strategies for plastic waste management from rice farming.

It is also advised that future research investigate the temporal patterns of plastic waste accumulation and its spatial variability across different farming systems. Such insights will contribute to the development of tailored and sustainable waste management strategies. Additionally, the study highlights the potential of involving local communities and adopting technological innovations, such as mobile applications and remote sensing tools, to further improve waste management practices. This research emphasizes the value of geospatial analysis as a critical tool for addressing plastic waste challenges in agricultural systems. It provides a framework for other regions to adopt, promoting more sustainable and data-driven approaches to waste management.

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