ANALYSIS OF NOVASAR-1 S-BAND DATA IN DEVELOPING AN ALTERNATIVE LAND COVER MAPPING

K. L. S. Mariano[1,2] *, J. B. L. C. Dumalag[1,2], N. R. R. Cadiz[1,2]

[1] Synthethic Aperture Radar and Automatic Identification System for Innovative Terrestrial Monitoring and Maritime Surveillance (SARwAIS) Project, ASTI Building, C.P. Garcia Avenue, Diliman, Quezon City, Philippines – (karllouie.mariano, johnbartlovern.dumalag, neyzielle.cadiz)@asti.dost.gov.ph

[2] Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI), ASTI Building, C.P. Garcia Avenue, Diliman, Quezon City, Philippines

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ABSTRACT:

The Advanced Science and Technology Institute of the Department of Science and Technology (DOST-ASTI), through its Synthetic Aperture Radar and Automatic Identification System (SARwAIS) Project, has gained access to S-Band SAR images acquired by the NovaSAR-1 satellite of UK's Surrey Satellite Technology Ltd. (SSTL) To help maximize the utility of these images especially in the aspect of terrain-related applications, their viability as potential alternatives to datasets like optical satellite images and other SAR images in characterizing land cover types was evaluated. Statistical analyses on the backscatter values from the tri-polarization ScanSAR datasets using Multivariate Analysis of Variance (MANOVA) and its corresponding post-hoc tests showed that there is a significant difference on the mean backscatter values at 0.05 level of significance. Moreover, Tukey's honestly significant difference (Tukey's HSD) test determined which pairs contribute to the significant difference. Using the Random Forest algorithm resulted in an accuracy of 66.93% without further optimization and/or reduction in the number of land covers being classified. Despite the relatively unremarkable accuracy score, it still showed potential for data augmentation with optical satellites for land cover mapping and other terrain-related applications.

1. INTRODUCTION

1.1 Background of the Study

The NovaSAR-1 satellite is a joint technology demonstration mission of SSTL (Surrey Satellite Technology Ltd.), United Kingdom, and Airbus Defence and Space Ltd., partly funded by the UK Government (Cohen et al., 2017), that launched on September 16, 2018. It is a low-cost satellite that utilizes Synthetic Aperture Radar (SAR) technology, operating on the S-band microwave frequency range to provide images of Earth from space. With the SAR technology, the NovaSAR-1 satellite can operate in all types of weather conditions; hence, it can take images of Earth through clouds, or even during nighttime. It is also equipped with an Automatic Identification System (AIS) that can be used together with its maritime surveillance mode for ship detection and identification.

The Department of Science and Technology – Advanced Science and Technology Institute (DOST-ASTI) signed an agreement with SSTL for the NovaSAR-1 mission last August 2019 to secure a share of the tasking and data acquisition services from the satellite with priority on tasking over the Philippines (DOST-ASTI, 2019). The agreement gave DOST-ASTI access to direct the satellite's activity, download, and process the raw data from the satellite, and license to use and share these data to the research community and its partner agencies. Aside from supporting the Philippines' efforts on monitoring environmental resources, the data products will also be used for a variety of fields and applications with its capabilities in all-day and all-weather capture, such as, but not limited to, ship detection, flood mapping, and structural identification, among others (DOST-ASTI, 2020).

The payload of the NovaSAR-1 mission utilizes the S-band microwave frequency, which serves as a robust alternative for the abovementioned applications among the existing spaceborne Optical systems and SAR systems that commonly use the C- and X- bands. The trade-off it offers intends to complement the other SAR systems, for example, in terrestrial monitoring and maritime surveillance (Vicente, R. et al, 2020).

Given its potential on a variety of applications, the NovaSAR satellite may also serve as a medium for identifying the distribution of various land cover types. The Philippines' National Mapping and Resource Information Authority (NAMRIA) is the mandated central mapping agency of the country's resources. They release maps essential for the planning and management of the country's land resources. In 2019, DOST-ASTI signed a Memorandum of Agreement with NAMRIA for the nationwide landcover mapping using the former's science and technology infrastructure, including the available datasets from the NovaSAR satellite.

For the land cover maps of NAMRIA, they were generated from digital interpretation primarily of the Sentinel-2 image, along with other available high-resolution satellite images, and was adopted from the Forest Cover and Land Use definitions provided by the Department of Environment and Natural Resources (DENR, 2005). These 12 land cover categories are shown in Table 1.

Land Cover Types		
Closed Forest	Grassland	Built-up
Open Forest	Perennial Crop	Marshland/Swamp
Mangrove Forest	Annual Crop	Fishpond

* Corresponding author

Brush/Shrubs	Open/Barren	Inland Water

Table 1. List of Land Cover Types used by NAMRIA

1.2 Objective

In this paper, statistical analyses and understanding of the backscatter values collected from the NovaSAR-1 S-band on a variety of land cover types in the Philippines was explored.

The study aims to evaluate and highlight the viability of the NovaSAR satellite in characterizing land cover types. Specifically, this study aims to: (1) explore the optimal land cover groups that are distinguishable using the SAR satellite based on the classification categories adopted by NAMRIA, and (2) apply basic machine learning clustering techniques to predict the land cover type based on the optimal combination of land cover groups.

2. METHODOLOGY

Land Cover Datasets: The 2020 Land Cover Map (LCM) produced by NAMRIA were used, which is available for download through their Geoportal Project website. The corresponding class IDs of each land cover type are shown in Table 2.

Class ID	Land Cover
1	Closed Forest
4	Open Forest
7	Mangrove Forest
10	Brush/Shrubs
13	Open/Barren
14	Grassland
15	Marshland/Swamp
16	Annual Crop
17	Perennial Crop
19	Fishpond
20	Built-up
21	Inland Water

Table 2. Class IDs of each land cover

However, only a few regions have available land cover data, which, in turn, restricted the number of NovaSAR images that could be incorporated throughout the study. Specifically, the regions of interest are restricted to the following regions as shown in Figures 1 to 5.

Figure 1. Region of interest: National Capital Region (NCR) Bounding coordinates: W – 120.899899, E – 121.136986, N – 14.785019, S – 14.343628

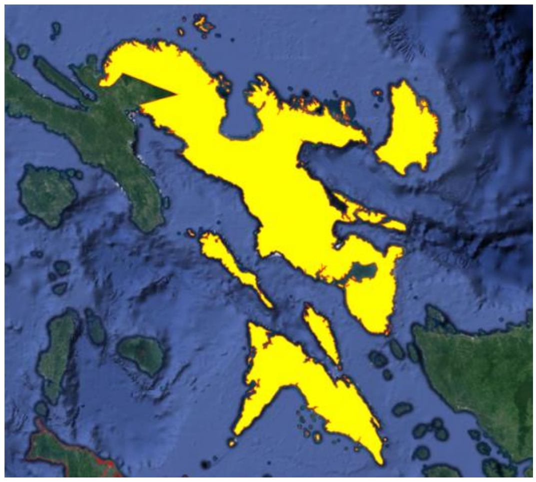

Figure 2. Region of interest: Bicol Region (R5) Bounding coordinates: W – 122.99822, E – 124.425935, N – 14.500926, S – 11.720585

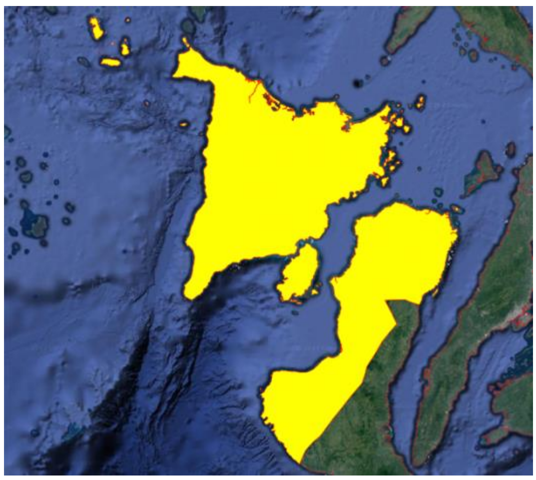

Figure 3. Region of interest: Western Visayas Region (R6) Bounding coordinates: W – 121.283300, E – 123.573032, N – 12.132514, S – 9.420463

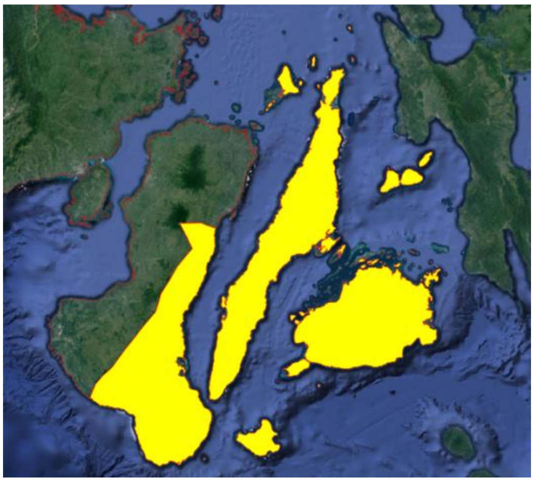

Figure 4. Region of interest: Central Visayas Region (R7)
Bounding coordinates: W – 122.615677, E – 124.645504,
N – 11.577653, S – 9.038688

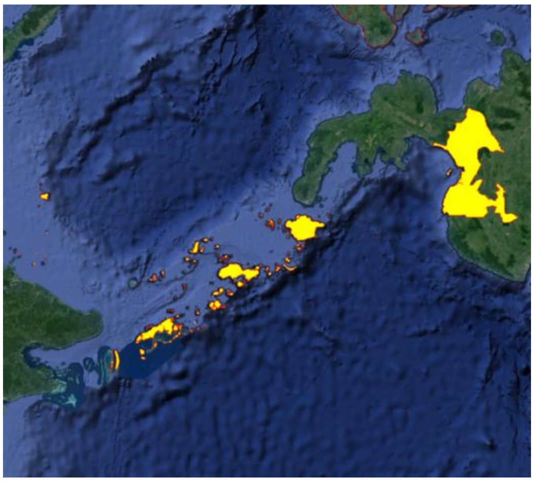

Figure 5. Region of interest: Bangsamoro Autonomous Region in Muslin Mindanao (BARMM)
Bounding coordinates: W – 118.064190, E – 125.000868,
N – 8.199420, S – 4.587147

NovaSAR Datasets: The following NovaSAR images were used in the study as they covered most sections if not the entirety of the abovementioned regions. These are ScanSAR tri-polarization products with a ground resolution of 30m. Shown in Table 3 are the regions covered in the images.

Image	Region/s Covered
NovaSAR_01_11331_scd_22_200428	Region 6
NovaSAR_01_11650_scd_22_200515	NCR, Region 6
NovaSAR_01_13084_scd_22_200719	Regions 5, 7, and BARMM

Table 3. NovaSAR images used

2.1 NovaSAR Pre-Processing Workflow

The SNAP Software was used for data pre-processing of the acquired satellite images using the NovaSAR Product Reader Plugin. The backscatter coefficient (or, sigma-nought σ^0) for the images was computed using Equation (1) in reference to the NovaSAR-1 User Guide of the Commonwealth Scientific and Industrial Research Organization (CSIRO)'s Centre for Earth Observation.

$$\sigma^0 = \frac{(pixel\ amplitude)^2}{calibration\ constant} \quad (1)$$

The calibration constant varies depending on the product and is available in each satellite image's metadata file.

Additional pre-processing steps like Speckle Filtering were done as shown in Figure 6 to potentially reduce the inherent speckle effects and improve the accuracy of classifying land covers (Hasan, 2021). Terrain correction was also done to remove distortions inherent to image acquisition and apply appropriate map coordinates. The final pre-processed products are in GeoTIFF format, and in decibel scale.

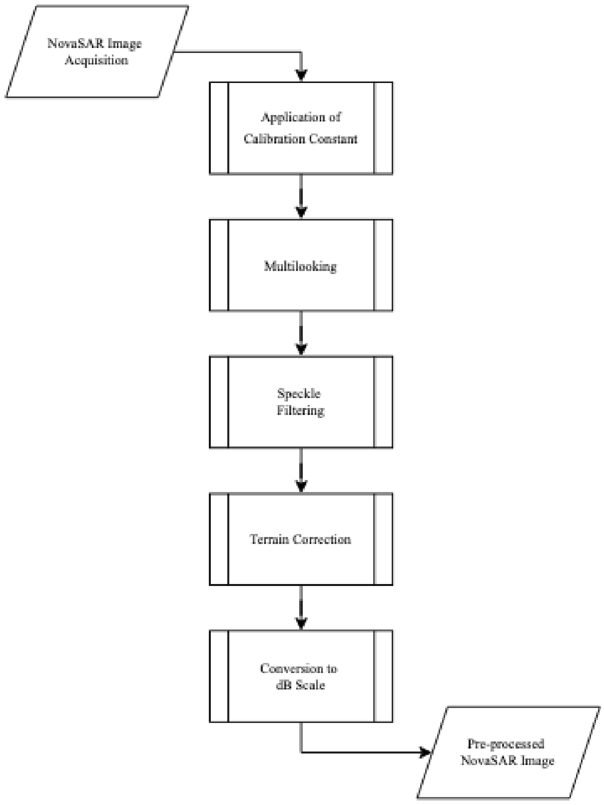

Figure 6. NovaSAR-1 pre-processing workflow

2.2 Statistical Analysis Workflow

The analysis workflow is shown in Figure 7. Once the NovaSAR images are pre-processed, the images were clipped according to the extent of the regional boundaries, and it was then stacked with the rasterized land cover map dataset from NAMRIA.

Random pixels/points were selected using stratified sampling where the stratas are the land cover types. The sampled pixels were used to test for significance using Multivariate Analysis of Variance (MANOVA). This is to test if there is at least one mean backscatter coefficient of any polarization is significantly different between land cover types.

If the test resulted in no significant difference in mean backscatter coefficient between land cover types, it would imply that the pixel values for each land cover type is not distinguishable from other types. However, once statistical significance was found, post-hoc tests were then conducted to identify which group/s are different from the rest. This was achieved by testing for Analysis of Variance (ANOVA) for each polarization then using Tukey's honestly significant difference (Tukey's HSD) test to determine the difference between the mean backscatter coefficient of all possible pairs of land cover types.

A clustering technique was then used to check for the resulting accuracy of the fitted model.

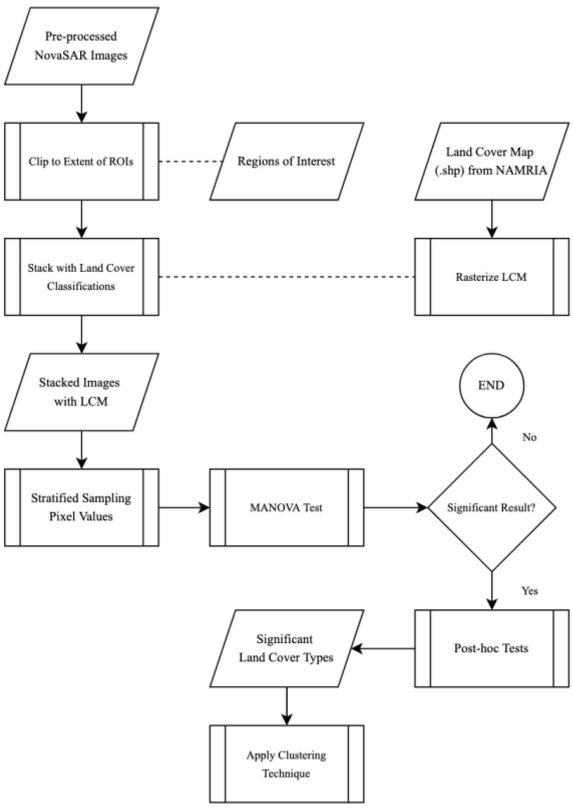

Figure 7. Statistical Analysis Workflow

3. RESULTS AND DISCUSSION

The R Software was used for data transformation and analysis in extracting the pixel values from the regions of interest and for testing statistical significance.

Stratified sampling was used to select pixels based on their associated land cover type, where each strata has a sample of size 65. Due to the limitations of the land cover dataset used in the study, the groups Mangrove Forest, Open / Barren, and Marshland / Swamp were removed from the test as the images only contain 18, 9, and 4 pixels, respectively. A total of 585 pixels (n=585) were used in testing for the significance using MANOVA as shown in Table 4.

	Df	Approx. F	P-value
class	8	10.036	<2.2e-16
Residuals	576		

Table 4. MANOVA Test Results

The results of the MANOVA Test showed that there is a significant difference in backscatter coefficients for each polarization among the land cover types at 0.05 confidence level.

Furthermore, upon testing for significance for each individual polarization using ANOVA showed similar results as shown in Tables 6 to 8.

	Df	F	P-value
class	8	328.1	<2e-16
Residuals	576	15.3	

Table 6. Individual ANOVA Test Results for HH Polarization

	Df	F	P-value
class	8	332.5	<2e-16
Residuals	576	26.3	

Table 7. Individual ANOVA Test Results for HV Polarization

	Df	F	P-value
class	8	204.4	<2e-16
Residuals	576	13.57	

Table 8. Individual ANOVA Test Results for VV Polarization

From the ANOVA tables, there is similarly sufficient evidence to conclude that there are significant differences in the individual backscatter coefficients among the land cover types at 0.05 level of significance. To identify which pairs of land cover types across each polarization are different, the Tukey's Honestly Significant Difference (Tukey's HSD) was used to perform multiple pairwise-comparison between the mean backscatter coefficients among the land cover types as shown in Figures 8 to 10.

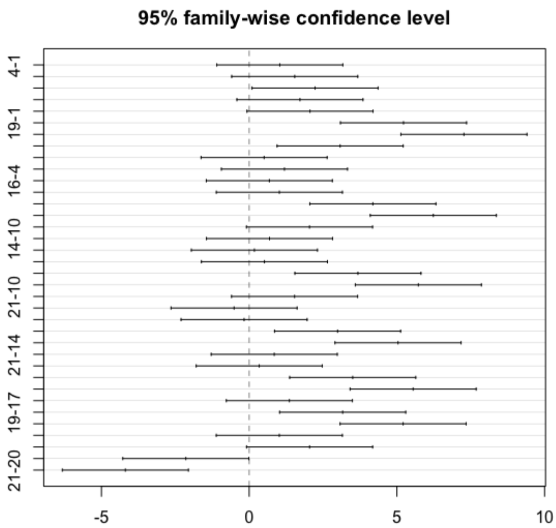

Figure 8. Tukey HSD Pairwise Comparisons for HH Polarization

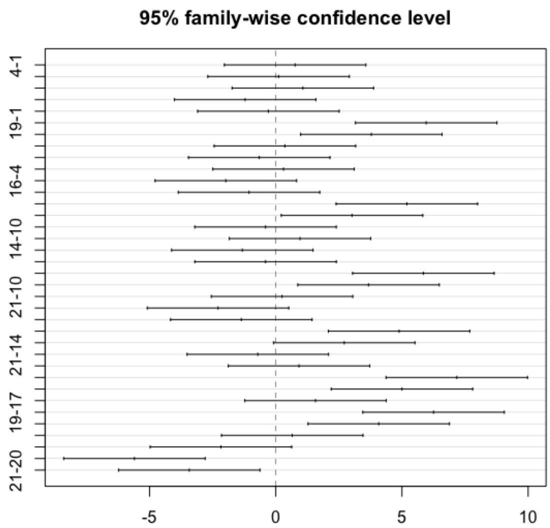

Figure 9. Tukey HSD Pairwise Comparisons for HV Polarization

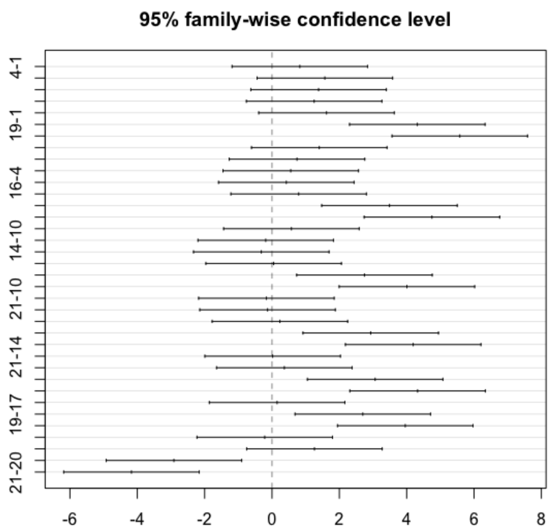

Figure 10. Tukey HSD Pairwise Comparisons for VV Polarization

The post-hoc tests show that there is a significant difference in the mean backscatter coefficients when comparing pairs of land cover types across each polarization at 0.05 level of significance. This suggests the potentiality of the NovaSAR images in distinguishing between land cover types for resource monitoring and sustainable development.

Given this information, both the Fuzzy C-Means and Random Forest algorithms were used to cluster the dataset according to the pixels' respective land cover types and test the clustering results in reference to its actual land cover type (Figure 11).

The validation of the clustering results using Fuzzy C-Means is shown in Table 9. Although the results showed there is an overlap and confusion on the classification of the land cover types, it is expected that using other machine learning clustering techniques showed relatively better results as shown in Table 10.

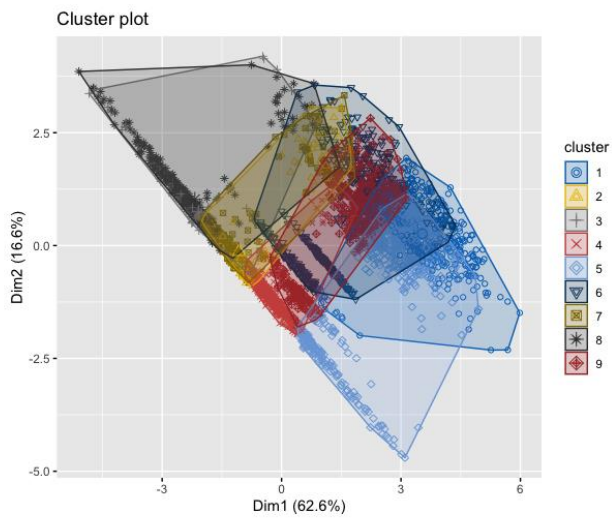

Figure 11. Fuzzy C-Means Clustering Results

Index	Result
Partition Entropy	1.420621
Partition Coefficient	0.3765103
Mod. Partition Coefficient	0.298574
Fuzzy Silhouette Index	0.5128171

Table 9. Clustering Validation Results

Parameter	Value
Test data accuracy	66.93%
95% Confidence Interval	(64.83%, 68.98%)
P-value	0.0003727

Table 10. Random Forest Results

4. CONCLUSIONS

The analysis of the backscatter coefficients of each polarization using the NovaSAR 30-m ScanSAR product showed that it can classify all land cover types. However, there is still a challenge in classifying other land cover types adopted by NAMRIA since there are little to no difference between its backscatter coefficients. Nonetheless, it is still a good candidate for data fusion with optical satellites, (i.e,. Sentinel-2, Planetscope, etc.) for data augmentation.

Moreover, by applying the prior information on the optimal combination of land cover types from the MANOVA test, an accuracy of 66.93% was achieved using Random Forest algorithm without further optimization and/or consolidation of land cover types to reduce classes. It still showed promising results in providing added value for mapping and monitoring land covers, both for research and operational purposes.

5. ACKNOWLEDGEMENT

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