COMPARATIVE ACCURACY ASSESSMENT OF LIDAR AND IFSAR DEM ON STRATIFIED TERRAIN TYPES

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KEY WORDS: DEM comparison, Land Cover, Zonal Statistics

ABSTRACT: Digital elevation models (DEM) are powerful tools used for various analyses across different applications with one of the foremost being in hydrological modelling and flood mapping. This makes DEM accuracy a critical factor in the final results of these analyses. The study evaluates the vertical accuracy of 1m resolution DEM derived from Lidar data of the Phil-LiDAR project and DEM generated from IfSAR data at the same resolution. The dataset used were the provided pre-generated DEM of the Phil-LiDAR 1 project and NAMRIA processed IfSAR DEM with no additional interpolation conducted. In order to assess model performance in relation to terrain morphology, a stratified approach was utilized, identifying different areas with varying slope and land cover. A comparative error analysis was done using root mean square error (RMSE) and mean absolute error (MAE) of different terrain characteristics and land cover. Validation was conducted using the ground-truthed data acquired during the ground validation phase of the GeoSAFER project with emphasis on using points that were not used for the DEM calibration of the LiDAR DEM. A significant variation of accuracy between LiDAR and IfSAR was observed, primarily on the performance in different morphological classes. The areas determined, where each of the DEM type perform better, will aid in the accuracy assessment of subsequent processing products from these datasets such as flood and risk maps. Finally, the results will help decide which method to prioritize depending on the characteristics of the identified study area as there is a significant discrepancy between financial costs, ease of processing and data size between the two DEM types.

1. INTRODUCTION

Digital elevation models (DEM) are simple numerical data structures with elevation values, usually having equally-sized grid cells, that represents topography (Chaplot, et al., 2006). They are tools used for various analyses. They provide a representation of the landscape which includes elevation values. DEMs provide better visualization of topographic features. Depending upon the resolution of the DEM, the amount of detail it can provide directly correlates to the amount of application it can be used for. This entails that the accuracy and quality of a DEM is a critical factor in producing the final results to be used for numerous management purposes such as storm water assessment, flood control, visualization, etc. (Hodgson & Bresnahan, 2004). Although, a higher resolution DEM is generally better than a lower resolution DEM, having a more detailed DEM comes with a price. A cost-benefit balance between the different sources of DEM is needed to minimize expense while not significantly reducing the overall quality (Fisher & Tate, 2006).

Different sources of DEM provide different levels of resolution and accuracy. LiDAR or Light Detection and Ranging, for instance is a remote sensing technique, able to measure distances by illuminating the target object with pulsed laser light and measuring the distance calculated based on its timed reflection (NOAA, 2018). This produces high-density DEMs which made it as a standard practice for topographic mapping for the aeroservice community (Hodgson & Bresnahan, 2004). Typically, LiDAR provides an accurate result in relation to other sources of DEM. Other relatively inexpensive photogrammetric mapping is often overlooked in comparison with the results of LiDAR. Interferometric Synthetic Aperture Radar, or IfSAR for instance, produces a relatively high-density DEM and is typically more accurate than satellite-acquired data (NAMRIA, 2015). However, the overlapping of DEMs are not meant to minimize the importance of the rest of the models, but in turn, are meant to augment one another. This study explored the extent by which a relatively low resolution DEM could supplement a high resolution DEM, given the different land cover and topographic characteristics.

Each of the DEMs to be compared, has their own resolution and accuracy. Errors in DEMs can occur for both horizontal and vertical orientation. The cause of errors in DEMs are categorized into three groups: gross errors or blunders (derived from variations in the accuracy, density, and distribution), systematic errors due to deterministic bias in the data collection or processing, and random errors, which may include the factors such as the characteristics of the terrain surface being modelled in relation to the representation of the DEM (Aguilar, et al, 2005; Gong, et al., 2000). This study focused on the terrain surface variation, as the factor to assess not only the errors of DEMs but also to how much they differ from each other. Given a normal distribution and assuming no outliers are present in a given DEM, in describing error, using Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) can be applied (Höhle & Höhle, 2009).

1.1 Objectives

The objectives of the study were to compare the accuracy of IfSAR DEM towards the LiDAR DEM on the different stratified terrain types, dictated by the land cover of the study area, together with its topological characteristics, such as the slope and elevation. Specifically, this study aimed to:

1. Determine the RMSE and MAE, of the IfSAR DEM, in terms of the elevation, against the LiDAR DEM, across the different land cover characteristics;
2. Determine the RMSE and MAE, of the IfSAR DEM, in terms of the elevation, against the LiDAR DEM, across the different slopes;
3. Determine the pattern trend of the different land cover characteristics in terms of slope.

2. MATERIALS AND METHODS

2.1 Study Site

The study site is located in Mindanao, one of the major islands of the Philippines. Specifically, region XI, Southeastern Mindanao. Figure 1 shows the location of the study site. The area covers approximately a total of 539 square kilometers.

Figure 2 shows the flow chart of the methodology. The overall data needed were the DEMs for both LiDAR and IfSAR, and land cover characteristics of the given area.

2.2 Data Gathered

2.2.1 DEM: The DEMs are Digital Terrain Models (DTM), where the bare-earth topography is shown. The LiDAR DTM is of a 1-meter resolution with a known vertical error under 20 cm. The IfSAR DTM is of a 5-meter resolution data. Both DEMs covers the whole study area completely.

The IfSAR DTM was resampled to 1-meter resolution to match with the LiDAR resolution for easier processing.

2.2.2 Land Cover: The area covers nine (9) types of land cover in the area: open forest, broadleaved; forest plantation, broadleaved; other wooded land, shrubs; other wooded land, wooded grasslands; other land, cultivated, annual crop; inland water; closed forest, broadleaved; other land, built-up area; and other land, cultivated, perennial. As shown in Figure 3, it is visibly apparent that the area covered is mostly shrubs under other wooded lands. On contrast, the least area observed is broadleaved forest plantation. The area covered by the inland water is seen as streams of rivers, depicted on the map.

2.2.3 Slope: The slope of the area is derived from the LiDAR DTM and was processed using the built-in function of ArcGIS 10.2. Figure 4 shows the generated slope, classified into ten (9) levels.

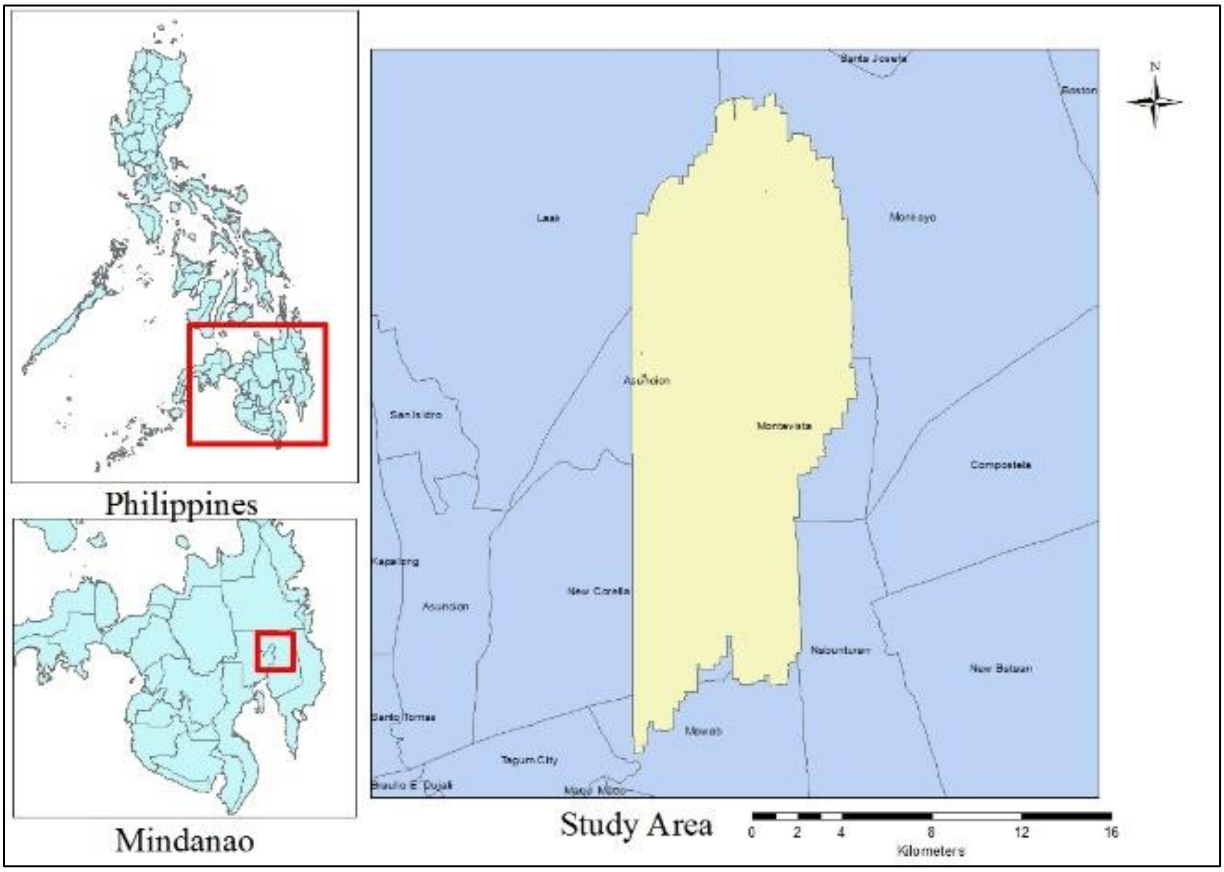

Figure 1. Study site located in Region XI Mindanao Philippines

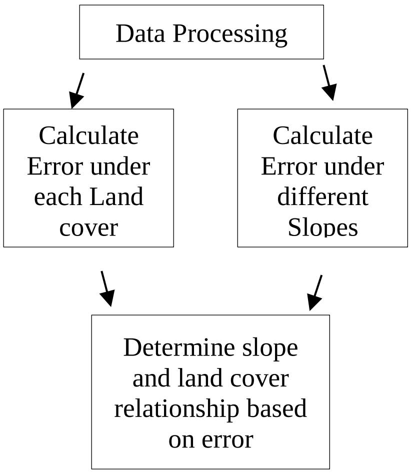

Figure 2. Simplified Methodology Flowchart

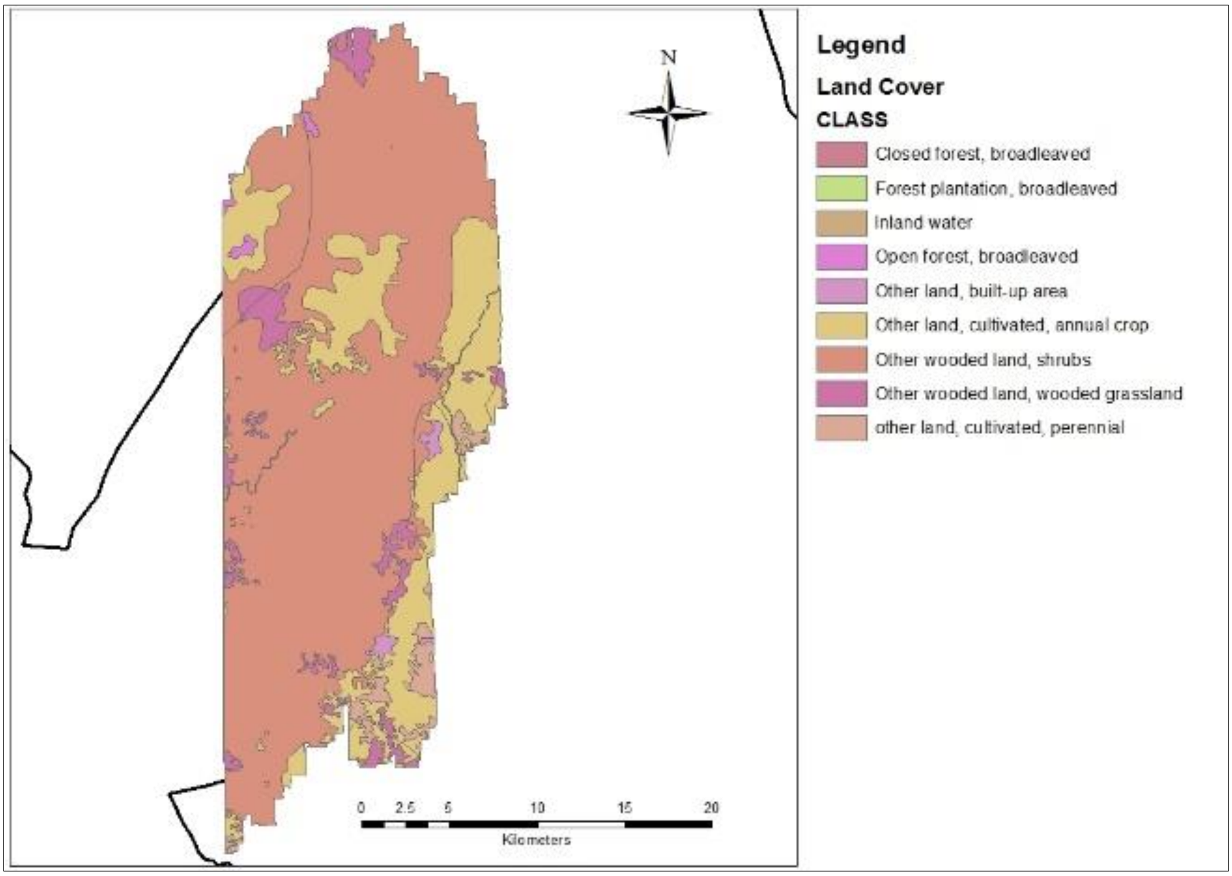

Figure 3. Land Cover Area and distribution.

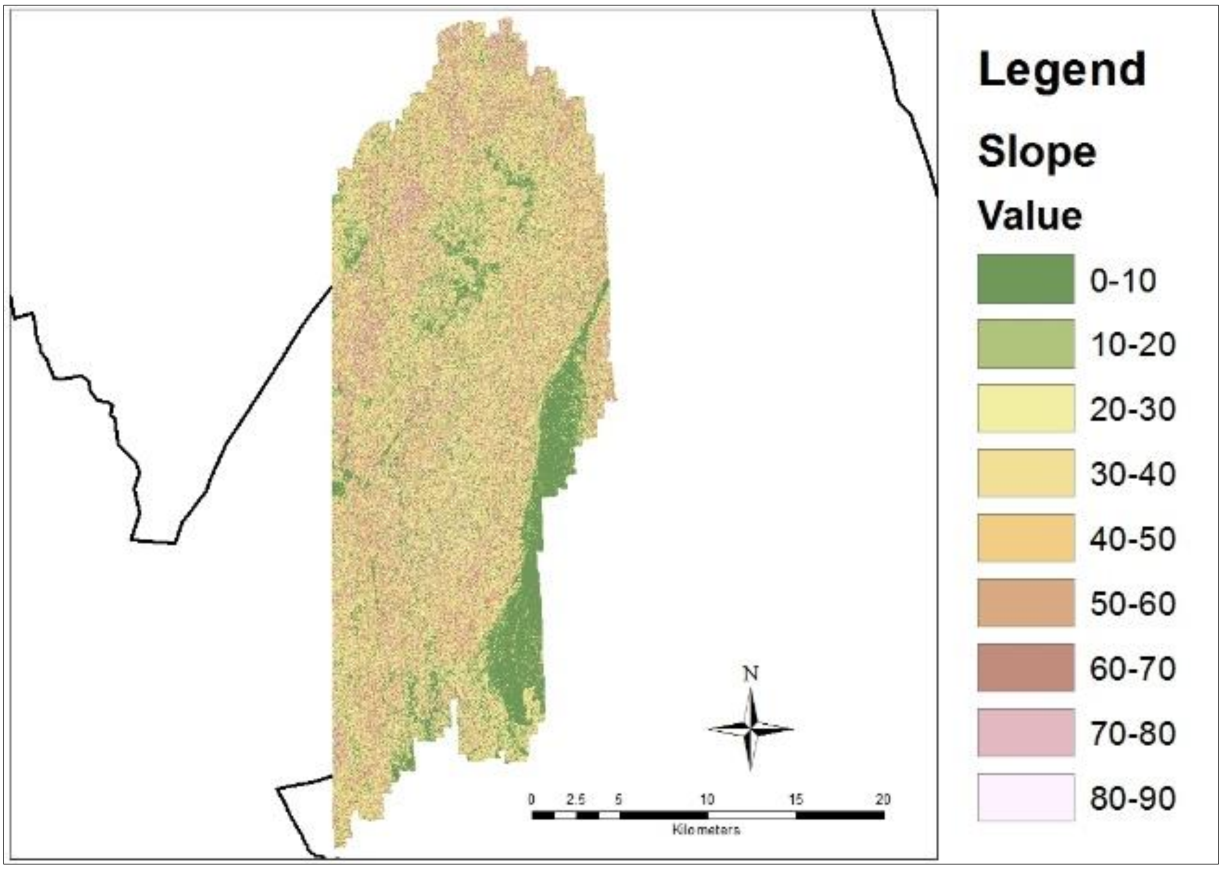

Figure 4. Slope values derived from LiDAR DTM

2.3 Error Computation

The formula for the RMSE and MAE are as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(P_i - O_i)^2}{n}} \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n} |P_i - O_i| \quad (2)$$

Where "P" is the predicted value, in this case the LiDAR DEM, and "O" is the observed value, IfSAR DME, for all overlapping grids "i" over the number of points "n" (Doucette and Beard 2000). It should be noted that the reference model, LiDAR DEM, also contains errors itself up to a certain degree. Both RMSE and MAE was used to measure the error of the IfSAR DTM against the LiDAR DTM summarized for each land cover area and slope.

3. RESULTS AND DISCUSSION

3.1 Errors Under Different Land Covers

Figure 5 shows the absolute error, subtracting the elevation values of the LiDAR DTM and IfSAR DTM. It is apparent with the given mean of 5.952 and standard deviation of 5.258, having a ceiling value of 56.957, there exist possible outliers in the data. This may be a result of highly interpolated data, causing spikes at some of the points.

Table 1 shows the computation of MAE, RMSE, and slope patterns on each of the land cover types. It is noticeable that the results of MAE and RMSE describes the same trend of increase given the ranking. The land cover “other land, built up areas” has the smallest value for both MAE and RMSE, 1.873 m and 3.028 m respectively. The land cover “closed forest, broadleaved” has the greatest value of MAE and RMSE, 11.752 m and 13.823 m respectively. On the same table, the slope mean for each land cover type is shown.

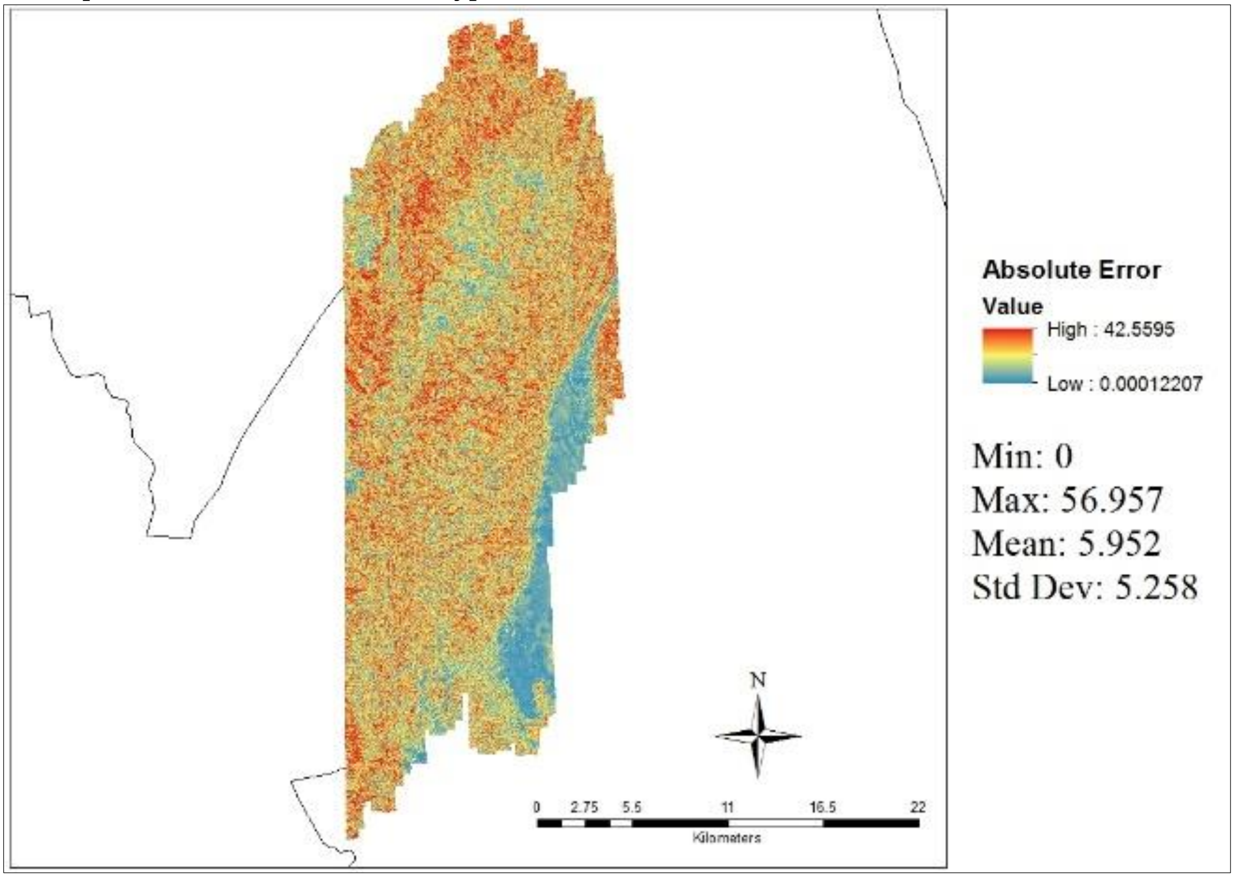

Figure 5. Absolute Error of IfSAR DTM against LiDAR DTM in terms of elevation

Although there is no general trend between land cover and slope, it is shown that the highest and the lowest error values are also consistent with regards to highest and lowest slope values.

It can be inferred that the IfSAR DTM is much more consistent on land covers that have less room for variability such as built-areas or man-made buildings, plantations, and crops. Thick closed forests, consistently shows a higher degree of error and variability. This may be due to the DEM processing limitations based on interpolation techniques used, limited to the ground penetration of the remote sensing device thru thick canopies (Eckert 2007).

3.2 Errors under Different Slopes

Table 2 shows the computation of MAE and RMSE of IfSAR DTM against the LiDAR DTM distributed upon the different slope intervals. It is observed that as the slope increases, the error for both MAE and RMSE also increases. As seen on the distribution of points across the slope intervals, most of the values are found on slopes which are relatively lower. This indicates that the points found on areas with high slopes has a good probability that they are outliers on the data. DEMs are relatively accurate on flat regions and on smooth slopes (Eckert, et al., 2007).

3.3 IfSAR and LiDAR comparison.

Given the data comparisons for factors under the different land covers, it is observed that the minimum error is still significantly large. LiDAR DEMs work on units under a meter whereas the minimum error observed on IfSAR DEMs, in this particular area, exceeds almost up to 1.873-3.028 meters. Although relatively low in comparison with the highest error value, reaching up to 11.752 – 13.823 meters, it is still not a good substitute for the LiDAR DEM under any condition. The errors might be due to a fact that certain horizontal errors might exist on either of the both DEMs. This error creates vertical errors itself, and is very difficult to check, given that there is no

Table 1. MAE, RMSE, and slope tendencies on different land cover.

Land Cover	Area (km)	Min (m)	Max (m)	Range (m)	STD (m)	MAE	RMSE	Slope Mean	Slope STD
Open forest, broadleaved	2.458	0.001	47.428	47.427	4.939	5.285	7.233	18.560	12.455
Forest plantation, broadleaved	0.054	0.043	31.630	31.587	4.752	6.477	8.033	32.240	12.051
Other wooded land, shrubs	384.562	0.000	56.957	56.957	5.307	6.526	8.412	24.703	12.898
Other wooded land, wooded grassland	26.134	0.000	40.792	40.792	5.631	6.814	8.839	24.932	13.051
Other land, cultivated, annual crop	117.226	0.000	42.307	42.307	4.650	4.352	6.368	16.299	13.590
Inland water	1.116	0.000	38.039	38.039	3.920	3.216	5.070	12.547	13.231
Closed forest, broadleaved	0.614	0.001	34.028	34.027	7.278	11.752	13.823	34.972	12.582
Other land, built-up area	3.167	0.000	23.050	23.050	2.379	1.873	3.028	7.807	9.689
other land, cultivated, perennial	12.216	0.000	45.757	45.757	3.443	2.569	4.295	10.484	11.211

Table 2. MAE and RMSE across different slope intervals.

Slope Range	Count	Min	Max	Range	STD	MAE	RMSE
0 - 10	789,187	0	40.224	40.224	3.315	2.583	4.202
10 - 20	780,668	0	47.428	47.428	4.185	4.716	6.305
20 - 30	891,729	0	45.757	45.757	4.460	5.545	7.116
30 - 40	810,076	0	45.382	45.382	4.805	6.193	7.838
40 - 50	761,444	0	55.580	55.580	5.202	6.829	8.585
50 - 60	646,382	0	51.892	51.892	5.695	7.564	9.468
60 - 70	459,787	0	48.067	48.067	6.196	8.281	10.342
70 - 80	265,123	0	56.957	56.957	6.628	8.870	11.073
80 - 90	71,445	0	50.054	50.054	7.048	9.339	11.700

data regarding to how the flight plan was conducted, which might cause horizontal shifts. Given that the range of values are erratic on some instances, outlier detection and trimming of data may be necessary.

CONCLUSION AND RECOMMENDATION

The RMSE and MAE of IfSAR DTM against the LiDAR DTM across the different land cover were determined. The pattern indicates that a more built-up land or the more it is directly affected by anthropogenic activities, the less the error on the areas. This might be attributed to the fact that these areas are less likely to have canopies or any thick covers from the ground which might have affected or obscured any remote sensing tool, thereafter relying upon different interpolation or processing techniques.

The RMSE and MAE of IfSAR DTM against the LiDAR DTM across the varying slopes were calculated. It was observed that the error increases along with the increase of the slope. The distribution of points on the slope histogram implies certain outliers on the data. Large errors tend to arise given a more sloping area since any change of elevation would indicate a larger gap, and since there is a huge difference between the resolutions of both DEMs. Any discrepancy of the sudden slope increase maybe too much interpolated on the DEM with a lower resolution.

Built-up areas, given the study site, tend to have lower slopes against heavily forested areas which tend to have bigger slopes. Lower slopes indicate lesser error. However, there is no statistical trend that correlates slope and land cover, at this point, given the area is inconclusive to summarize the trend as a whole.

Although, other unknown factors might have contributed to these conclusions, it is therefore recommended to apply similar methods on a vaster area to determine whether a comparable result would be concluded. It is recommended to remove clear outliers or spikes on the data to improve the results or at the very least, identify these areas. Doing further statistical analysis may improve the drawn conclusions given a bigger scope with more variability on the data.

ACKNOWLEDGEMENT

The authors acknowledge the help and support of the Department of Science and Technology – Philippine Council for Industry, Engineering and Emerging Technology Research and Development (DOST – PCIEERD), the Geo-SAFER Southeastern Mindanao team, the University of the Philippines Mindanao, PHiL-LiDAR 1 Program, and National Mapping and Resource Information Authority (NAMRIA).

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