# SITE SUITABILITY ANALYSIS OF MATERIAL RECOVERY FACILITY IN CARAGA STATE UNIVERSITY USING GIS AND RS TECHNIQUES

Wilson F. Sanawi[1] and Arturo G. Cauba Jr.*[2]
[1]Engineer 1, Department of Public Works and Highways, Region X
Cagayan de Oro 9000, Misamis Oriental, Philippines
Email: wilson.sanawi@carsu.edu.ph

[2]Faculty member, Caraga State University
Ampayon, Butuan City 8600, Philippines
Email: agcauba@carsu.edu.ph

**KEY WORDS:** Analytical Hierarchy Process, Geographic Information System, Remote Sensing, Butuan City

**ABSTRACT:** Site suitability analysis is an effective method for identifying appropriate locations, such as the selection of a suitable site for a Material Recovery Facility (MRF) to address waste management challenges. This study utilized Geographic Information System (GIS) and Remote Sensing (RS) techniques to identify suitable areas for constructing MRF within Caraga State University (CSU). Five crucial criteria were considered to determine the suitability of the potential areas, and the Analytical Hierarchy Process (AHP) pairwise comparison technique was utilized to assign weights to these criteria. The findings of the suitability analysis revealed that within the 320,000 m² area of CSU, 58.427% or 186,813.40 m² is moderately suitable, 41.458% or 132,556.98 m² is constrained suitable, and 0.1155% or 369.23 m² is low suitable for establishing the MRF. Meanwhile, within the 2,000,000 m² agricultural area of CSU, 40.94% or 818,393.05 m² is highly suitable, 56.086% or 1,121,175.41 m² is moderately suitable, 2.973% or 59,431.04 m² is constrained suitable, and 0.001% or 21.70 m² is low suitable. The results indicate that the 320,000 m² area in CSU lacks a highly suitable site for the MRF, making it more favourable to construct the facility within the 2,000,000 m² agricultural area, specifically in the most suitable region identified in the analysis. By adopting this data-driven approach and considering the site suitability factors, the implementation of the MRF in the optimal location within CSU's 2,000,000 m² agricultural area can lead to improved waste management outcomes and more effective solutions to the region's waste-related challenges.

## 1. INTRODUCTION

### 1.1 Background of the Study

MRF is a facility that involves processing, sorting, receiving, and storing recyclable material. MRF accepts material that sources are separated or mixed to process, separate, and storing raw materials for reprocessing and manufacturing (Ip et al., 2018). MRF's essential purpose is to produce a material that generates revenue in the market while maximizing the quantity of processed recyclable materials (Budihardjo et al., 2022). Also, MRF has the function of collecting waste turning into feedstock for biological conversion, which can produce a fuel source for energy production. MRF is vital to our community because as the population keeps increasing, the demands of material for the community used are also growing. Virgin materials need to be harvested, mined, and processed, reducing environmental pollution, and significantly increasing energy use (Taebi & Kloosterman, 2008). Having MRF can do material salvaging that reduces the consumption of virgin materials, costs less energy and fills the scarcity of materials.

In Caraga State University (CSU), a waste generation survey has been conducted in different university offices (Seronay, 2011). The survey data have shown that CSU generated a total waste of 3.67 tons per month. Classified bio-degradable waste in CSU has generated up to 2.7 tons per month that are 74% of the total volume of junk. In contrast, non-degradable has generated up to 0.97 tons per month and up to 26% total volume of waste. This complete accumulated waste in CSU can be processed to the MRF, and it can produce many valuable materials for the community. It can bring revenue if sold to the manufacturer and make a fuel source for energy production. Having an MRF in CSU can get many benefits to the university. Thus, with the use of GIS and RS techniques, this study aims to look for the possible location of MRF's in CSU.

GIS can be used for research or studies like conducting a suitability analysis to identify MRFs' suitable location (Ihia et al., 2023). GIS is a platform for data processing, management, and analysis. It is also a system that can store, check, manage, manipulate, and display related data to the earth's position. GIS can combine many data (such as streets, buildings, and vegetation) into one and display them on a map. GIS can organize information layers and analyze spatial location, which can be shown into a map or 3D scene. RS data can be acquired by satellites or aircraft using the process of detecting and monitoring the characteristics of objects by measuring the emitted and reflected radiation of the area. Remote sensing can provide information such as land use/land cover (Rwanga & Ndambuki, 2017). In classifying land use/land cover in locating MRFs, supervise classification algorithms useful in generating outputs such as land cover maps and image analysis.

### 1.2 Study Area

CSU Main Campus in Butuan City, Philippines is located along the highway which traverses from Butuan City to Davao City, Surigao City, Cabadbaran City and the provinces of Agusan Del Norte, Agusan Del Sur, Surigao Del Norte, and Surigao Del Sur. CSU has a total land area of 2,320,000 m², from which 320,000 m² is allocated for academic buildings and support facilities. The remaining 2,000,000 m² is alloted for agricultural, production, research, and extension activities of the university.

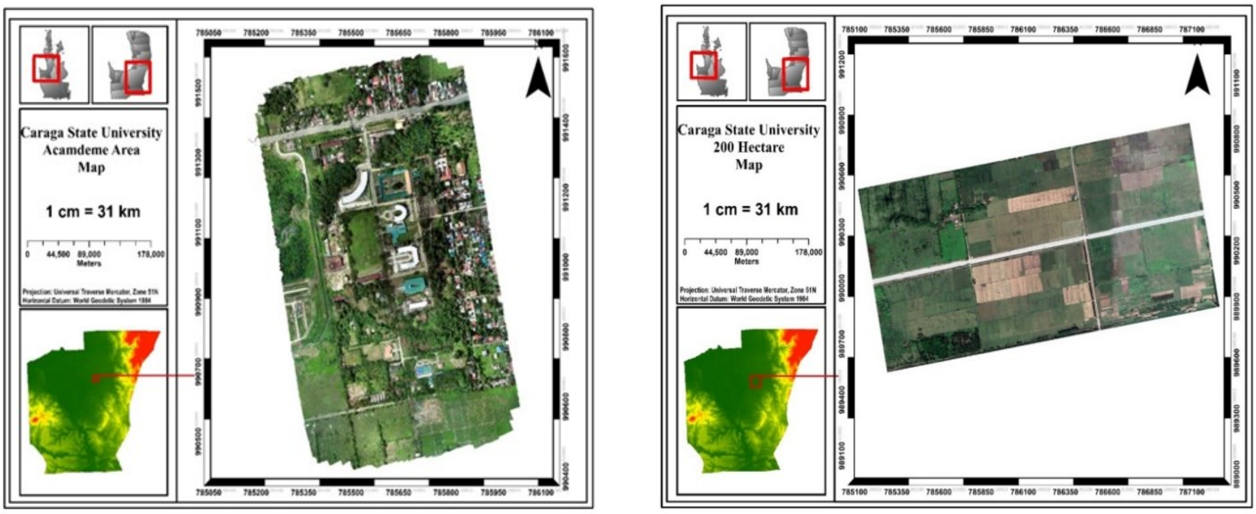

*Figure 1.1 CSU's 320,000 sq. m area (left) and 2,000,000 sq. m area (right)*

## 2. METHODOLOGY

The methodology of the study consists of six major activities namely, data acquisition, land use land cover map generation, digitizing, establishing criteria, AHP weight generation, and weighted overlay analysis. The weighted overlay tool was used in this research because it applies the most used approach for overlay analysis that can solve a multi-criteria problem such as site selection and suitability models. The suitability map was produced to locate suitable areas for MRF in CSU. Figure 2.1 shows the methodology flowchart of this study.

### 2.1 Data Acquisition

Data acquisition involves gathering data from various sources such as organizations and downloadable internet datasets. Images in CSU's agricultural area were acquired through Google Earth image. Flood hazard map was acquired from CSU's Caraga Center for Geoinformatics (CCGEO). In addition, images captured from Unmanned Aerial Vehicle (UAV) for pixel-based classification of very high-resolution imagery were also acquired from CCGEO. Table 2.1 presents the specification of the different data used in this study.

*Table 2.1 Data specification*

| Data | Data type | Sources |
|---|---|---|
| Ortho- Image | Raster Data | CCGEO |
| Flood Hazard | Vector Data | CCGEO |
| Google earth image | Raster Data | Google Earth |

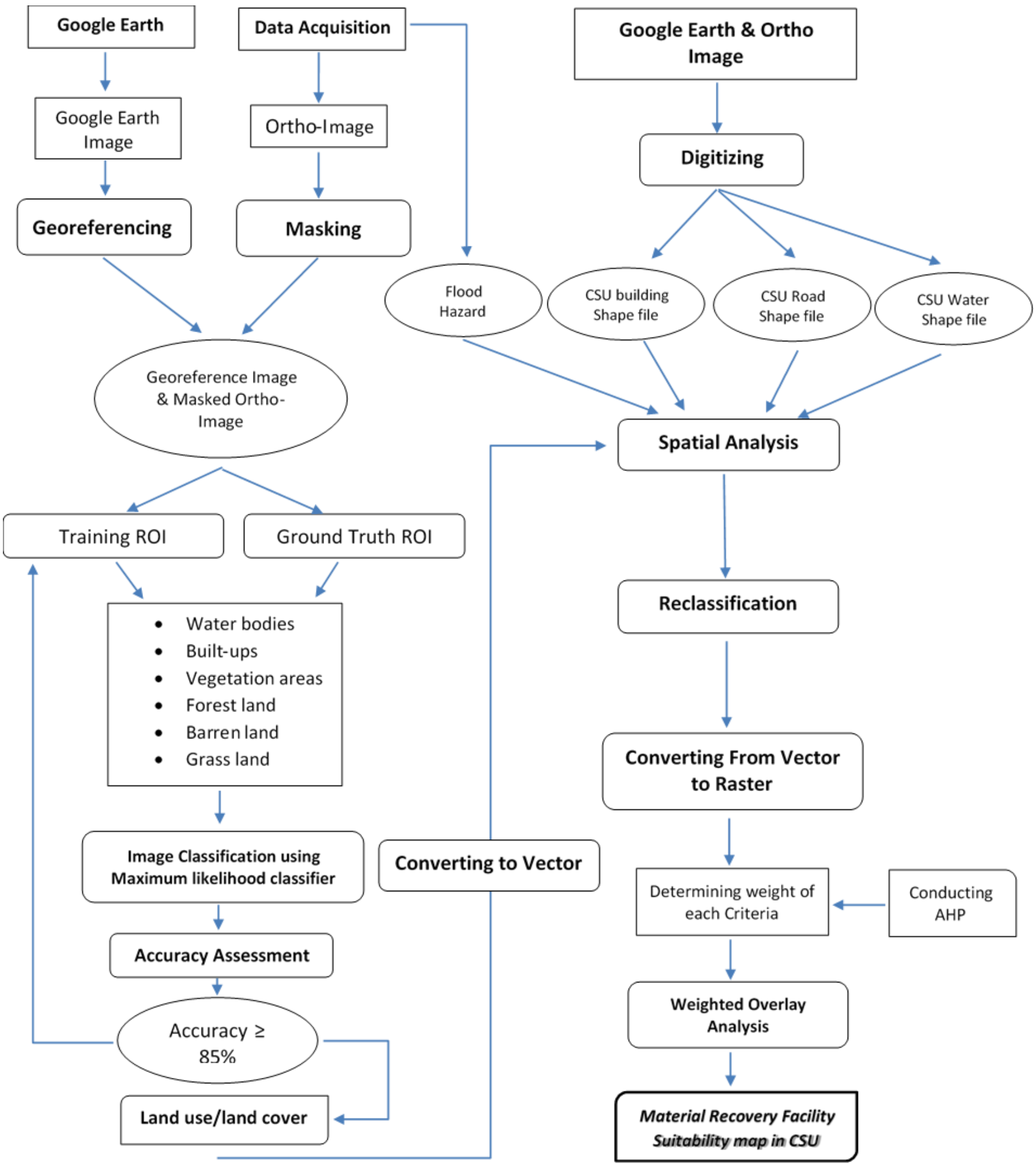

*Figure 2.1 Methodology flowchart*

## 2.2 Land Use Land Cover (LULC) Mapping

To produce LULC map, training samples and ground truth region of interest (ROI) must be generated. To ensure that the training sample is well distributed, the ROI tool was used to choose samples per pixel of images for the classification of each class (Jia et al., 2014). Training ROI’s were collected to generate LULC map, while ground truth ROI’s were used to assess the accuracy of the generated LULC map. The image was classified using maximum likelihood classifier (MLC). This approach is widely employed for the classification of LULC(Bruzzone & Prieto, 2001; Shivakumar & Rajashekararadhya, 2018). The images were categorized using MLC technique, defined as the pixel classifications that assign the highest probabilities to various classes to all possible images. The same recoding process was done under the incorrect categorization of pixels with inappropriate varieties. To classify ground truth ROI’s in each class, the careful examination of UAV Images, Google Earth Images, and field validation was adopted for verification (Debnath et al., 2017).

## 2.3 Digitization

Digitizing is the conversion of geographical features on- the act of turning them into digital form (Jyothi et al., 2010). The digitizing tool can create new features or edit features previously contained on the source map, but it needs to reprocess the map first. Digitization in ArcGIS created a shape file for boundary, waters, buildings, and road network shape file of CSU. After the digitization, each generated layer of shape file was added to the spatial analysis tool.

### 2.4 Establishment of Criteria

When doing a suitability analysis, various parameters related to MRF to locate suitable areas must be considered. The Department of Environment and Natural Resources-Environmental Management Bureau (DENR-EMB) and the Building Code of the Philippines have provided certain criteria and necessary standards to properly identify suitable areas. Shown in Table 2.2 is the Department of Environment and Natural Resources Environmental Management Bureau (DENR-EMB) MRF site requirements.

*Table 2.2 DENR-EMB Site Requirements*

| SITING CRITERIA/ MINIMUM REQUIREMENTS | DETAILS |
|---|---|
| Land ownership | The facility shall be established in a barangay-owned or leased land or any suitable open space to be determined by the barangay through its Sanggunian. |
| Geology | The site should be flat or gently sloping, stable area to reduce excavation cost and avoid problems of slope stability |
| Geology | The site should not be in a flood-prone area |
| Proximity to receptors | A minimum buffer zone of 100 meters should be observed for sensitive receptors such as schools, hospitals, parks, and residential areas. If the site is zoned, MRFs are preferably located in |
| Land use | If the area is zoned, MRFs are preferably located in an industrial zone or close to a sanitary landfill to facilitate the efficient movement of waste from various generators and dispose of residual materials. |
| Accessibility | MRFs need to be located close to existing roads, but traffic resulting from the movement of waste collection trucks should be considered.<br>There should be adequate space for the entry and exit of waste trucks. |
| Basic connections for water and electricity | The MRF should be provided with the basic connections for water and electricity and provisions for washing and a septic tank. |

### 2.5 AHP Weight Generation

We employed AHP to assign weights to the criteria. AHP is a method for organizing and analyzing complex decisions, and it works by extending a problem layer by layer until it is solved at a higher stage (Saaty, 1988). It uses intensity scores of various preferences based on the criteria. It places them on an emphasis on criteria, with the following scores being given a value of nine on the low end. After evaluating the criteria, the values are then calculated to generate weight. To determine the importance of each criterion , we calculated the nth root using Equation 1.

$$\boldsymbol{Nth\ root = \llbracket(X_1 * X_2 * X_3 \ldots X_n)]^{1/2}} \qquad \text{(Equation 1)}$$

Where:

n = number of indicators
X = Rating of experts

The priority vector is calculated using Equation 2, and the result is the weight of each criterion.

$$\boldsymbol{Priority\ vector} = \frac{\boldsymbol{Nth\ root}}{\Sigma(\boldsymbol{Nth\ root})} \qquad \text{(Equation 2)}$$

To apply the calculated weight for each criterion, consistency ratio (CR) must be calculated. CR is an assessment of how accurate the judgment of the evaluators. According to Saaty (1988), CR acceptable values are less than 0.10. However, few sources suggest that a CR value of less than 0.20 may be accepted (Apostolou & Hassell, 1993; Raharjo & Endah, 2007).So, if the CR value is greater than 0.20, then the judgment is questionable since they are much closer to randomness than dependability. In addition, the evaluation must be repeated if the measurements are not accurate. To come up with CR, the consistency index (CI) must be calculated using Equation 3.

$$CI = \frac{(\lambda - n)}{(n-1)} \quad \text{(Equation 3)}$$

Where:

λ = Derive from the summation of the product of each criterion multiplied by priority vector.
n = number of indicators

Then, the consistency ratio is calculated using Equation 4.

$$CR = \frac{CI}{RI} \quad \text{(Equation 4)}$$

Where:

CR = Consistency Ratio
CI = Consistency Index
RI = Random Index

Random Index (RI) is an index of consistency for random judgment. In addition to providing the standard indices of random number pairwise comparison matrices, the RI function provides a particular mean accuracy index to each random number pairwise comparison matrix. The values of RI with its corresponding number of indicators are shown in Table 2.3.

*Table 2.3 Values of Random Index*

| N | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.46 | 1.49 |

## 3. RESULTS AND DISCUSSION

### 3.1 LULC Map and Accuracy Assessment

LULC map was generated using MLC supervised classification technique. The image was classified into six different classes namely, built-up areas, barren areas, shrubs and trees, agricultural area, grassland, and water (Figure 3.1). The land cover which contains classified types like grassland and barren lands, is the most suitable area for establishing a Material Recovery Facility.

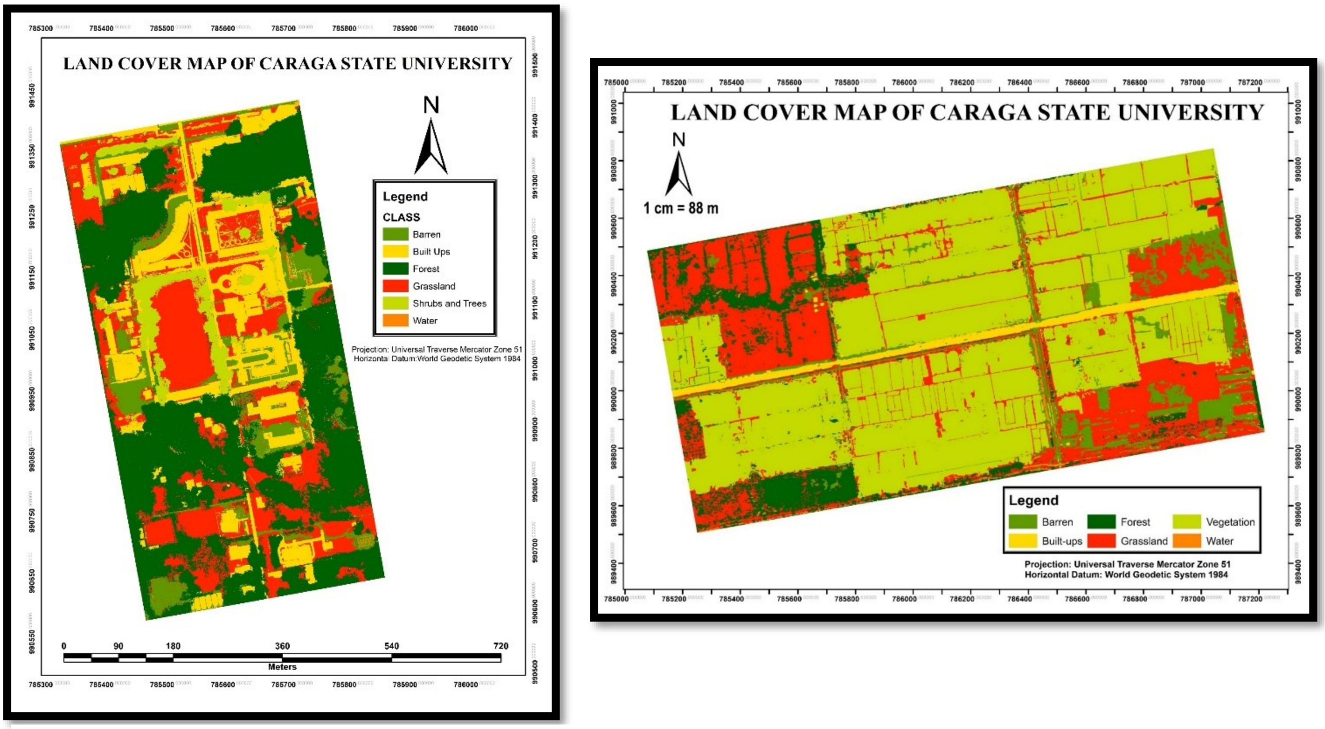

*Figure 3.1 LULC Map of CSU's 320,000 sq. m area (left) and 2,000,000 sq. m area (right)*

Table 3.1 shows the LULC classification accuracy assessment result of CSU's 320,000 sq. m area. The land cover yielded an overall accuracy of 97% and Kappa coefficient of 0.964, while the User's Accuracy values for barren, built-up areas, forest, shrubs and trees, water, and grassland are 98.98%, 97.03%, 94.12%, 96.04%, 99.00%, and 96.94%

respectively. Moreover, the generated Producer's Accuracy values for barren, built-up areas, forest, shrubs and trees, water, and grassland are 97%, 98%, 96%, 97%, 99%, and 95%, respectively.

*Table 3.1 Accuracy assessment result of LULC classification of CSU's 320,000 sq. m area*

| **Product** | **Barren** | **Built up** | **Forest** | **Shrubs and Trees** | **Water** | **Grassland** | **Total** | **U.A.** |
|---|---|---|---|---|---|---|---|---|
| **Barren** | 97 | 1 | 0 | 0 | 0 | 0 | 98 | 98.98 |
| **Built ups** | 3 | 98 | 0 | 0 | 0 | 0 | 101 | 97.03 |
| **Forest** | 0 | 0 | 96 | 2 | 1 | 3 | 102 | 94.12 |
| **Shrubs and Trees** | 0 | 0 | 2 | 97 | 0 | 2 | 101 | 96.04 |
| **Water** | 0 | 1 | 0 | 0 | 99 | 0 | 100 | 99.00 |
| **Grassland** | 0 | 0 | 2 | 1 | 0 | 95 | 98 | 96.94 |
| **Total** | 100 | 100 | 100 | 100 | 100 | 100 | 600 | |
| **P.A** | 97 | 98 | 96 | 97 | 99 | 95 | | |
| **O.A.** | 97 | | | | | | | |
| **R(p)** | 0.167 | | | | | | | |
| **Kappa** | 0.964 | | | | | | | |

Table 3.2 shows the LULC classification accuracy assessment result of CSU's 2,000,000 sq. m area. The land cover generated an overall accuracy of 96.167% and a Kappa coefficient of 0.954, while the User's Accuracy values for vegetation, barren, forest, grassland, built up areas, and water bodies are 93.20%, 97.00%, 95.96%, 92.16%, 99.01%, and 100% respectively. On the other hand, the generated Producer's Accuracy values for vegetation, barren, forest, grassland, built up areas, and water bodies are 96%, 97%, 95%, 94%, 100%, and 95%, respectively.

*Table 3.2 Accuracy assessment result of LULC classification of CSU's 2,000,000 sq. m area*

| **Product** | **Vegetation** | **Barren** | **Forest** | **Grassland** | **Built ups** | **Waters** | **Total** | **U.A.** |
|---|---|---|---|---|---|---|---|---|
| **Vegetation** | 96 | 2 | 0 | 4 | 0 | 1 | 103 | 93.20 |
| **Barren** | 1 | 97 | 0 | 0 | 0 | 2 | 100 | 97.00 |
| **Forest** | 0 | 0 | 95 | 2 | 0 | 2 | 99 | 95.96 |
| **Grassland** | 3 | 0 | 5 | 94 | 0 | 0 | 102 | 92.16 |
| **Built ups** | 0 | 1 | 0 | 0 | 100 | 0 | 101 | 99.01 |
| **Waters** | 0 | 0 | 0 | 0 | 0 | 95 | 95 | 100.00 |
| **Total** | 100 | 100 | 100 | 100 | 100 | 100 | 600 | |
| **P.A.** | 96 | 97 | 95 | 94 | 100 | 95 | | |
| **O.A.** | **96.167** | | | | | | | |
| **R(p)** | 0.167 | | | | | | | |
| **Kappa** | 0.954 | | | | | | | |

### 3.2 Generated Weights

Five different parameters were used in this study to identify suitable sites for MRF. These parameters were evaluated by five experts whose knowledge and expertise relate to this study to determine the weight of each criterion.

*Table 3.3 Generated weight for each criterion*

| CRITERIA | Priority Vector | Average Final Weight |
|---|---|---|
| Land use | 0.360899463 | 36.09% |
| Road Network | 0.193531516 | 19.35% |
| Buffer zone to water bodies | 0.167580368 | 16.76% |
| Buffer zone to sensitive receptors | 0.205500054 | 20.55% |
| Flood Hazard | 0.072488598 | 7.25% |

Evaluators need to be considered and it is necessary to determine if they are consistent. To assess the consistency of their judgment, A CR value of 0.20 is sufficient, but values that are more than that may require additional evaluation. This is important because if the CR is not good enough, then the weights would be inaccurate. With these CR values (Table 3.4), the average calculated weight shown in Table 3.3 is valid because each expert is consistent with their decisions.

*Table 3.4 Name of the experts and the corresponding CR values*

| Criteria | Consistency Ratio |
|---|---|
| Engr. Jeruel D. Plazo | 0.19 |
| Engr. Sherwin P. Pulido | 0.14 |
| Engr. Rudney C. Zambas | 0.10 |
| Levita B. Grana | 0.15 |
| Regin Rex A. Guerra | 0.16 |

### 3.3 Suitability Map for MRF

The suitability analysis outlines the search for sites or places that are characterized by a combination of qualities. Using the Weighted Overlay Analysis tool of GIS, the reclassified maps of each criterion were integrated with its corresponding weight. Hence, the suitable sites for the establishment of MRF's were identified. The suitability maps show suitable areas for MRF (Figure 3.2).

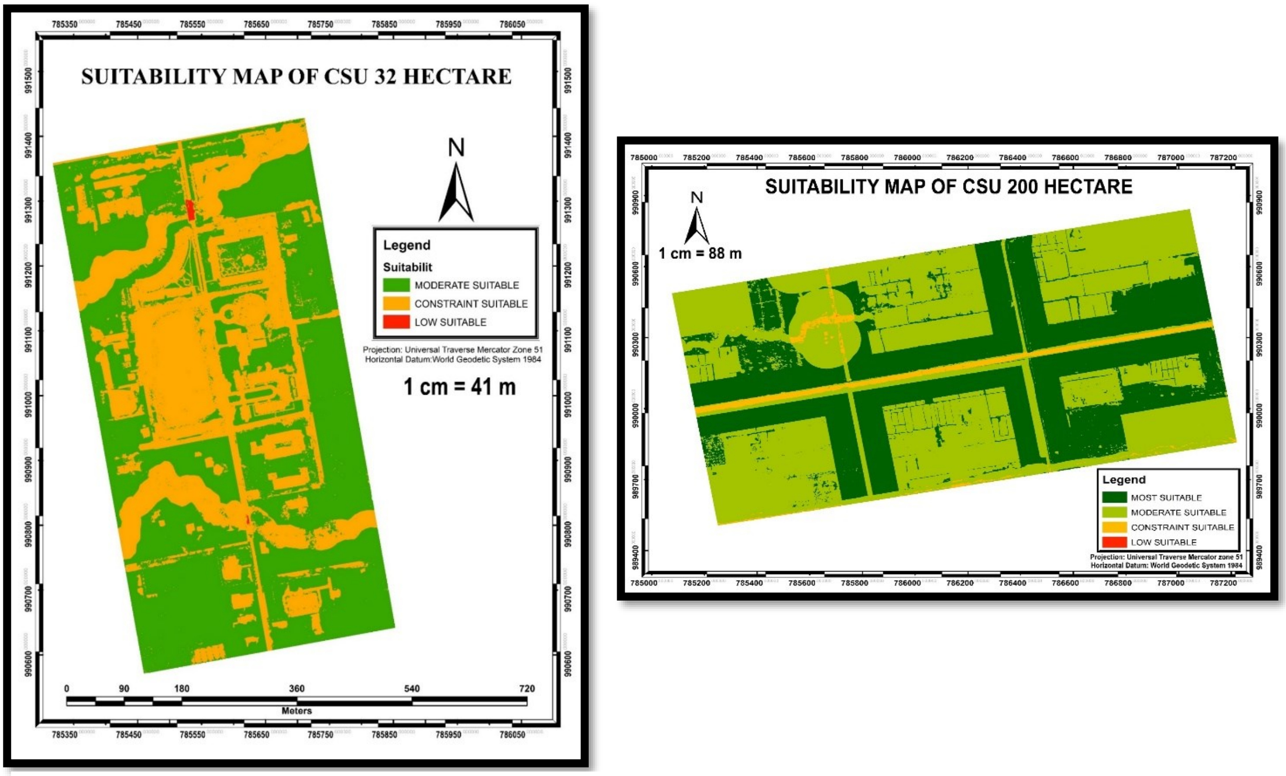

*Figure 3.2 Suitability map for MRF within CSU's 320,000 sq. m area (left) and 2,000,000 sq. m area (right)*

As shown in Figure 3.3, there are only three categories: moderate suitability, constraint suitability, and low suitability. Moderately suitable has the highest percentage among the three categories at 58.427%, covering an area of 186,813.40 m². The constraint suitable category accounts for 41.458%, which translates to approximately 132,556.98 m². Lastly, the lowest percentage of area among all classes belongs to the low suitable category, comprising 0.1155% of the total percentage and covering an area of 369.23 m².

The percentages for different suitability classes of the 2,000,000 square meter area are presented in Figure 3.4. The most suitable area covers 40.940%, approximately 818,393.05 m² of the entire area. Second, in terms of suitability, is the moderately suitable category, which accounts for 56.086% and has an area of 1,121,175.41 m². The constraint suitable category represents 2.973% of the overall area, equivalent to approximately 59,431.04 m². The lowest percentage of area among all classes is found in the Low Suitable category, accounting for 0.001% of the total percentage and covering an area of approximately 21.70 m².

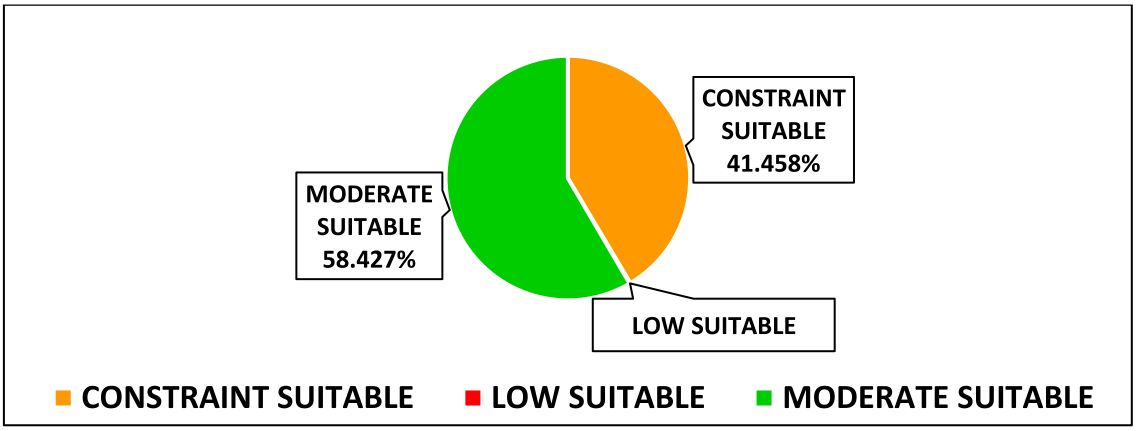

*Figure 3.3 Percentage distribution of suitability classes for MRF within CSU's 320,000 sq. m area*

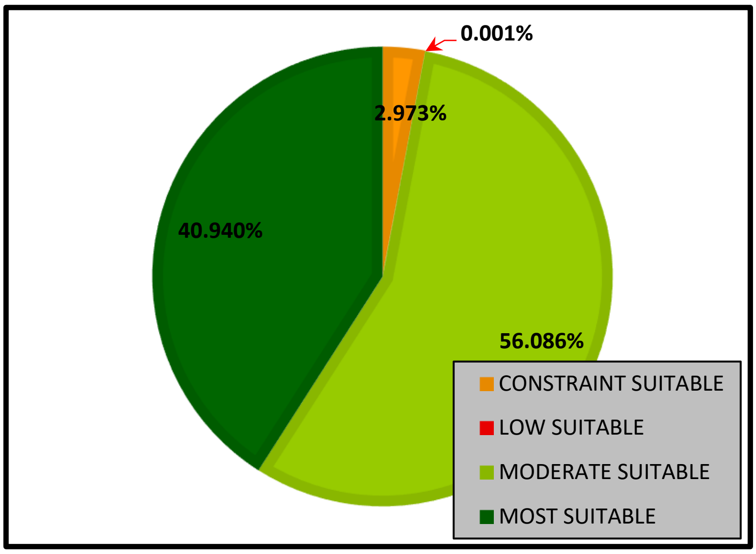

*Figure 3.4 Percentage distribution of suitability classes for MRF within CSU's 2,000,000 sq. m area*

## 4. CONCLUSION AND RECOMMENDATION

This study establishes various criteria for a suitability analysis for MRF. LULC map was generated to identify suitable land cover classes such as grassland and barren land. We used a Maximum Likelihood Classifier, a supervised classification method, to generate the LULC map of CSU. This process resulted in an overall accuracy of 97% and a kappa coefficient of 0.964 for the LULC of CSU's 320,000 sq. m area. Similarly, the CSU's 2,000,000 sq. m area produced an overall accuracy of 96.167% and a kappa coefficient of 0.954. Notably, the LULC map of the CSU's 320,000 sq. m area indicated that barren and grassland covered 29,262.01 m² and 63,742.00 m², respectively, making them the most suitable land cover classes for establishing an MRF.

Various agencies in Butuan City, including the City Engineer's Office, the Office of the City Architect, the Office of City Planning and Coordination, City-Environment Natural Resources (City-ENRO), and the Department of Environment and Natural Resources – Environmental Management Bureau (DENR-EMB) played a crucial role in helping in the determination of the most important criteria for the research.

The results of GIS application demonstrated the effectiveness of spatial suitability analysis in identifying ideal sites for MRF. In the case of CSU's 320,000 sq. m area, it was found unsuitable due to the presence of existing facilities. However, for the CSU's 2,000,000 sq. m area, an area of 818,393.05 m², accounting for 40.940% of the total area, was identified as suitable for the construction of an MRF. This suitable area is primarily located in grassland and barren land, near road networks, and away from existing facilities. These criteria were given the highest weights among others, explaining their significance.

We developed a suitability map for MRF, which can serve as a guide for establishing an MRF. The study's findings can be beneficial for CSU's planning department and the community at large, as the establishment of an MRF can contribute to improved waste management in the area. Moreover, this study provides a valuable resource for identifying suitable MRF sites.

To enhance the scope and utility of this study, we recommend expanding the analysis beyond Caraga State University (CSU) to encompass larger areas such as Butuan City or the entire Caraga Region.

## 5. REFERENCES

Apostolou, B., & Hassell, J. M. (1993). An empirical examination of the sensitivity of the analytic hierarchy process to departures from recommended consistency ratios. *Mathematical and Computer Modelling*, *17*(4–5), 163–170. https://doi.org/10.1016/0895-7177(93)90184-Z

Bruzzone, L., & Prieto, D. F. (2001). Unsupervised retraining of a maximum likelihood classifier for the analysis of multitemporal remote sensing images. *IEEE Transactions on Geoscience and Remote Sensing*, *39*(2), 456–460. https://doi.org/10.1109/36.905255

Budihardjo, M. A., Ardiansyah, S. Y., & Ramadan, B. S. (2022). Community-driven material recovery facility (CdMRF) for sustainable economic incentives of waste management: Evidence from Semarang City, Indonesia. *Habitat International*, *119*, 102488. https://doi.org/10.1016/J.HABITATINT.2021.102488

Debnath, J., Das (Pan), N., Ahmed, I., & Bhowmik, M. (2017). Channel migration and its impact on land use/land cover using RS and GIS: A study on Khowai River of Tripura, North-East India. *Egyptian Journal of Remote Sensing and Space Science*, *20*(2), 197–210. https://doi.org/10.1016/J.EJRS.2017.01.009

Ihia, O. A., Khomsi, D., & Hassani, N. S. A. (2023). *Combination of GIS and Fuzzy AHP with the VIKOR Method for the Optimal Strategies for Municipal Solid Waste Management: Case Study of the Province of Tiznit*. 1–7. https://doi.org/10.1109/IRASET57153.2023.10152985

Ip, K., Testa, M., Raymond, A., Graves, S. C., & Gutowski, T. (2018). Performance evaluation of material separation in a material recovery facility using a network flow model. *Resources, Conservation and Recycling*, *131*, 192–205. https://doi.org/10.1016/J.RESCONREC.2017.11.021

Jia, K., Wei, X., Gu, X., Yao, Y., Xie, X., & Li, B. (2014). Land cover classification using Landsat 8 Operational Land Imager data in Beijing, China. *Geocarto International*, *29*(8), 941–951. https://doi.org/10.1080/10106049.2014.894586

Jyothi, S., Anand, S., & Varma, K. (2010). *Digitizing the Forest Resource Map Using ArcGIS*.

Raharjo, H., & Endah, D. (2007). Evaluating Relationship of Consistency Ratio and Number of Alternatives on Rank Reversal in the AHP. *Http://Dx.Doi.Org/10.1080/08982110500403516*, *18*(1), 39–46. https://doi.org/10.1080/08982110500403516

Rwanga, S. S., & Ndambuki, J. M. (2017). Accuracy Assessment of Land Use/Land Cover Classification Using Remote Sensing and GIS. *International Journal of Geosciences*, *08*(04), 611–622. https://doi.org/10.4236/IJG.2017.84033

Saaty, T. L. (1988). What is the Analytic Hierarchy Process? *Mathematical Models for Decision Support*, 109–121. https://doi.org/10.1007/978-3-642-83555-1_5

Seronay, R. (2011). *CSU goes Solid Waste-Conscious | Caraga State University*. http://masao.carsu.edu.ph/carsu/?q=csu-goes-solid-waste-conscious

Shivakumar, B. R., & Rajashekararadhya, S. V. (2018). Investigation on Land Cover Mapping Capability of Maximum Likelihood Classifier: A Case Study on North Canara, India. *Procedia Computer Science*, *143*, 579–586. https://doi.org/10.1016/J.PROCS.2018.10.434

Taebi, B., & Kloosterman, J. L. (2008). To recycle or not to recycle? An intergenerational approach to nuclear fuel cycles. *Science and Engineering Ethics*, *14*(2), 177–200. https://doi.org/10.1007/S11948-007-9049-Y/FIGURES/3