



## Utilizing Open-Source GIS and Multi-Criteria Decision Analysis for Onion Cold Storage Site Selection in Nueva Vizcaya, Philippines

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### Abstract

Onion is an important agricultural commodity in the Philippines, and it provides livelihood to the farmers and contributes to food security in the country. Despite its observed increase in production, challenges remain in terms of postharvest management, particularly due to inadequate storage. This study aimed to locate suitable sites for cold storage infrastructure in the province of Nueva Vizcaya using Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA). Spatial data such as land cover, road network, onion production area, and agricultural markets were used for weighted overlay analysis through Quantum GIS (QGIS). The findings showed that approximately 43.84% (171,997 ha) of the total area of the province is suitable for cold storage of onions, with a large extent of areas in the municipalities of Kayapa, Aritao, Santa Fe, and Bambang. The applicability of the model was demonstrated by the spatial analysis that verified the proposed onion cold storage location in Aritao was in an appropriate location. This exhibited the capability and importance of using an open-source GIS for siting postharvest facilities. It is suggested for future studies to incorporate parameters including socioeconomic indicators, facility capacity, and logistical costs to enhance future investments in agricultural infrastructure.

**Keywords:** Cold storage, Infrastructure, Postharvest management, Spatial planning, Site selection

### 1. Introduction

Onion (*Allium cepa* L.) is an important agricultural crop in the Philippines because it is integrated in a variety of cuisines and provides economic opportunities for farmers and entrepreneurs. From 2011 to 2020, the area planted with onions increased at an average annual rate of 4.91% while the average annual growth of national production is approximately 10.72% [1]. About 252,487 mt of onion produced was valued at 497 million US dollars (1 USD = 57.06 Philippine pesos) by the end of 2023 [2]. The top ranked provinces by area and volume harvested were Nueva Ecija, Occidental Mindoro, Ilocos Sur, Ilocos Norte and Nueva Vizcaya. Most of these provinces which are located in the Luzon island have led consistently in onion production due to their favorable climate, topography, and soil conditions [3]. Despite the general positive growth of the Philippine onion production, the 2023 average yield at 11.84 mt ha<sup>-1</sup> is still below the average onion yields of neighboring Southeast Asian countries [4].

Even if onion yields improve, the industry is still at risk of potential losses that could affect the overall production gains if postharvest management is not given the needed support. According to a study, bulb onion postharvest losses in the Philippines can accumulate up to 31.49%, with handling and storage contributing to the majority of these losses [5]. These losses are often attributed to factors such as mechanical damage, inadequate drying, and exposure to adverse environmental settings. To address the challenges in postharvest losses and other concerns of the onion sector, the Philippine Department of Agriculture (DA) crafted a roadmap to guide the development of the industry [1]. The roadmap envisions achieving a sustainable supply of onions to meet increasing local and international demand. It targets a production level of 279,270 metric tons by the end of 2025 through expansion of cropped areas and enhancement of productivity. This expected increase in onion production will require a proportional expansion in cold storage capacity to manage postharvest losses and stabilize market

availability. Cold storage refers to temperature-controlled facilities used to preserve perishable agricultural products, such as onions, by maintaining consistent low temperatures that reduce spoilage and extend shelf life. Hence, another key strategy highlighted is the establishment of postharvest facilities, specifically cold storages.

Nueva Vizcaya, one of the major onion-producing provinces in the Cagayan Valley Region, has been identified as a strategic location for such interventions. The province's favorable agro-climatic conditions and its role in off-season onion production make it a critical area for infrastructure development. For instance, farmers in Bagabag, Nueva Vizcaya, have been successfully engaging in off-season onion cultivation, planting between July and August and harvesting in December, thereby capitalizing on higher market prices during lean months [6]. This practice exemplifies the need for adequate cold storage facilities to preserve quality and extend shelf life, especially during off-peak seasons.

Despite the recognized importance of cold storage, challenges remain in ensuring that these facilities are properly located to serve major producing areas effectively. Improper site selection can lead to underutilized facilities and higher operational costs. Thus, a systematic and data-driven approach is necessary to optimize the location of future cold storage facilities. While Geographic Information System (GIS) and Multi-Criteria Decision Analysis (MCDA) have been applied for site selection of cold storage facilities for other agricultural commodities such as potatoes in Bardhaman District, West Bengal, India [7], horticultural crops in Kolar District, Karnataka, India [8], and cold chain development in different agricultural zones [9], studies specifically focusing on onion cold storage remain very limited. Previous works have optimized potato cold storage infrastructure using remote sensing and GIS [10] and developed geospatial models for positioning new postharvest facilities [11]. Reviews on cold chain logistics [12] have emphasized the importance of data-driven planning in managing perishable goods, yet targeted applications for onion storage infrastructure are lacking. Studies on the political economy of cold storage facilities [13] and postharvest mapping of mango supply chains [14] have also primarily focused on broader commodity groups. In the Philippine context, there remains a significant research gap in applying GIS-MCDA methodologies for identifying suitable locations for onion cold storage infrastructure.

This study aims to address this gap by utilizing GIS and MCDA to map and identify the most suitable areas for onion cold storage in Nueva Vizcaya. By integrating spatial analysis with multi-criteria evaluation, the research seeks to provide a data-driven approach to infrastructure planning, thereby enhancing postharvest management and supporting the sustainability of the onion industry in the province.

## **2. Materials and methods**

### *2.1 Study Area*

The study area is situated in the landlocked province of Nueva Vizcaya of Region II (Cagayan Valley), Philippines. Nueva Vizcaya is bordered, clockwise from the north, by Ifugao, Isabela, Quirino, Aurora, Nueva Ecija, Pangasinan, and Benguet (Figure 1). For this site suitability mapping, the proposed cold storage was planned to be established in the municipality of Aritao, Nueva Vizcaya. Aritao has an indicative land area of 30,252 ha, which constitutes 7.71% of Nueva Vizcaya's total area [15]. It has 22 barangays. The approximate coordinates of the municipal center of Aritao are 16° 18' North, 121° 2' East. It is around 89 kilometers away from the National Capital Region of the country. Although Aritao is specifically mentioned because of the proposed cold storage project at the time of planning, the application of the GIS-MCDA was conducted across the entire province of Nueva Vizcaya, since the suitability mapping is intended to benefit other municipalities within the province as well.

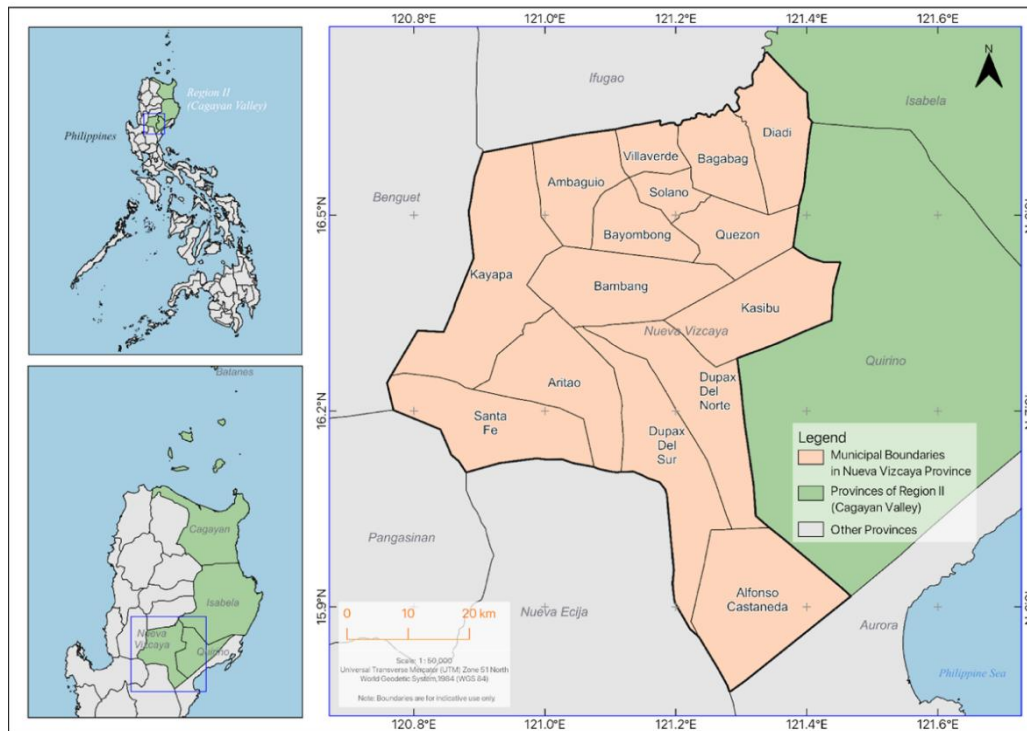


**Figure 1** Study area for onion cold storage suitability mapping in Nueva Vizcaya, Philippines.

## 2.2. Framework

The overall approach of this study follows a two-stage spatial analysis framework (Figure 2). The first stage involved mapping suitable areas for onion production across Nueva Vizcaya to address the limited availability of digitized onion production data. Shapefiles of actual onion areas for Aritao municipality, provided by the Department of Agriculture Regional Field Office Region II, were merged with areas identified as moderately suitable to very highly suitable for onion production through GIS-based suitability mapping. The resulting dataset represented the onion area in the province. In the second stage, this merged onion production layer was used, together with other spatial criteria, to identify suitable sites for cold storage facilities through weighted overlay analysis.

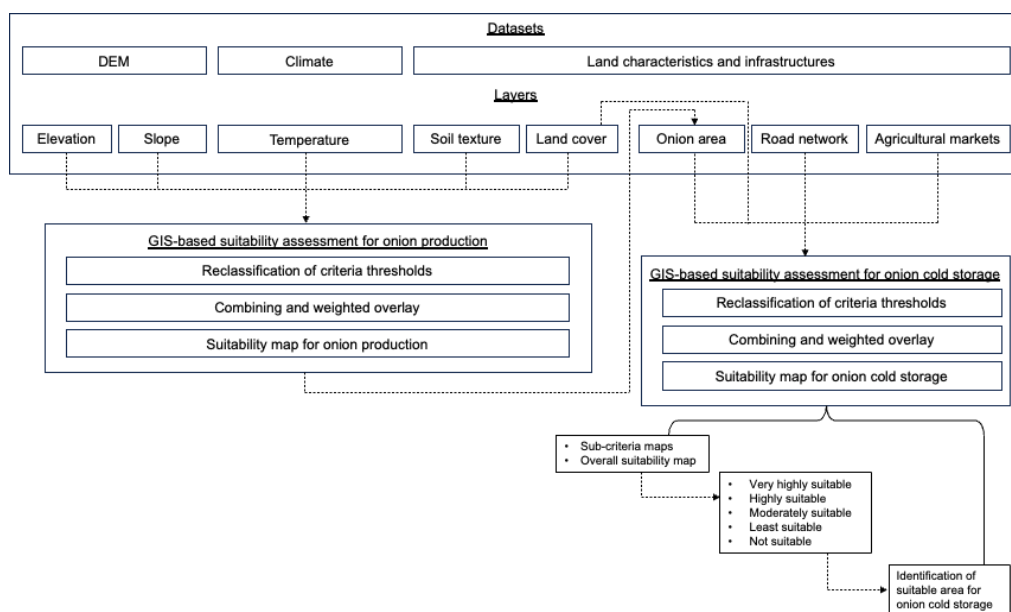


**Figure 2** Framework for land suitability assessment for onion cold storage

### 2.3. Selection of Suitability Criteria and Weight Assignment

Spatial datasets were collected for the suitability mapping. These datasets were sourced from the online platforms and government agencies. Table 1 summarizes the datasets used, along with their descriptions, formats, and sources.

The selection of factors for both onion production suitability and cold storage site identification was guided by agronomic requirements, infrastructure considerations, and available geospatial data. For onion production, physical parameters such as elevation, slope, temperature, soil texture, and land cover were considered due to their established influence on crop growth and yield potential [16]. Rainfall was not included in the analysis because most onion production areas in Nueva Vizcaya are irrigated, as supported by findings in the studies comparing various onion production systems [17-19].

**Table 1** Spatial datasets for onion suitability mapping and cold storage site selection in Nueva Vizcaya.

| Spatial data            | Description                                                 | Geospatial data type | Source |
|-------------------------|-------------------------------------------------------------|----------------------|--------|
| Administrative boundary | Indicative boundaries of study area                         | Vector polygon       | [15]   |
| Elevation               | Digital elevation model used for terrain and slope analysis | Raster               | [20]   |
| Slope                   | Derived from elevation data to assess terrain suitability   | Raster               | -      |
| Temperature             | Long-term average temperature for climate suitability       | Raster               | [21]   |
| Soil texture            | Soil texture characteristics                                | Vector polygon       | [22]   |
| Land cover              | Land cover classification                                   | Vector polygon       | [23]   |
| Road network            | Road systems used to assess site accessibility              | Vector line          | [24]   |
| Agricultural markets    | Local agricultural trading and public markets               | Vector point         | [25]   |
| Onion area              | Combined onion suitability map and digitized onion fields   | Vector polygon       | [26]   |

**Table 2** Criteria and scale used in suitability mapping of onions in Nueva Vizcaya.

| Weight of factors (%) | Factors      | Unit  | Suitability class and suitability scale (score) |                     |                         |                    |                  |                     |
|-----------------------|--------------|-------|-------------------------------------------------|---------------------|-------------------------|--------------------|------------------|---------------------|
|                       |              |       | Very highly suitable (5)                        | Highly suitable (4) | Moderately suitable (3) | Least suitable (2) | Not suitable (1) | Restricted area (0) |
| 15                    | elevation    | meter | 10 - 100                                        | 100 - 200           | 200 - 300               | 300 - 400          | 400 - 500        | < 10;<br>>500       |
| 15                    | slope        | %     | 0 - 2                                           | 2 - 4               | 4 - 8                   | 8 - 16             | 16 - 32          | > 32                |
| 30                    | temperature  | °C    | 26 - 28                                         | 24 - 26             | 22 - 24                 | 20 - 22            | 18 - 20          | <18;<br>>28         |
| 20                    | soil texture | class | loamy                                           | clayey              | very clayey             | sandy              | beach sand       | -                   |
| 20                    | land cover   | class | cultivated area                                 | agricultural land   | grassland               | wooded land        | inland water     | forest, built-up    |

**Table 3** Criteria and scale considered for site selection for onion cold storage in Nueva Vizcaya.

| Weight of factors (%) | Factors                            | Unit  | Suitability class and suitability scale (score) |                     |                         |                    |                                   |
|-----------------------|------------------------------------|-------|-------------------------------------------------|---------------------|-------------------------|--------------------|-----------------------------------|
|                       |                                    |       | Very highly suitable (4)                        | Highly suitable (3) | Moderately suitable (2) | Least suitable (1) | Not suitable (constraints) (0)    |
| 8                     | Land cover                         | class | built-up area                                   | grassland           | arable land             | cultivated area    | forest, lake, river, road network |
| 37                    | Proximity to road                  | km    | < 1                                             | 1 - 2               | 2 - 5                   | > 5                | -                                 |
| 50                    | Proximity to onion production area | km    | < 5                                             | 5 - 10              | 10 - 20                 | > 20               | -                                 |
| 5                     | Proximity to agricultural markets  | km    | < 1                                             | 1 - 2               | 2 - 3                   | > 3                | -                                 |

For cold storage, accessibility and logistical efficiency were prioritized through the inclusion of proximity to road networks, production zones, and agricultural markets, together with land cover suitability. While this study did not incorporate natural hazard layers such as flooding, landslide, and earthquake susceptibility in the GIS-based suitability analysis, these considerations are addressed at the project implementation level. The DA RFO II utilizes the HazardHunterPH, a platform developed by GeoRisk Philippines [27] to assess geohazard risks for proposed infrastructure sites. The weights applied to each parameter are summarized in Tables 2 and 3. Weights for onion suitability mapping were adapted from [16], while weights for cold storage suitability were derived from earlier cited literature on GIS-based cold storage planning, proportionally adjusted to reflect the selected factors. The onion suitability map, which combined modeled suitability with actual onion area shapefiles, was incorporated as a key input in the cold storage assessment. Specifically, proximity to onion production zones was assigned a weight of 50% (Table 3).

## 2.4. Data Processing, Overlay Analysis, and Suitability Mapping

The spatial data was processed using QGIS software version 3.22 [28]. All datasets were clipped to the administrative boundary shapefile of Nueva Vizcaya and projected onto WGS 1984 UTM Zone 51N for uniformity. The proximity zones to the road networks, onion areas, and agricultural markets were delineated using the multi-distance buffer tool in QGIS software [29]. In generating the onion suitability map, the suitability thresholds (0.0 to 5.0) were classified following the method in [16], using evenly distributed score intervals. This approach grouped the results into six classes as shown in Table 2. For the onion cold storage suitability mapping, the spatial datasets with varying units were reclassified through the reclassify raster by table-processing tool [30], utilizing a score system of 0, 1, 2, 3, and 4, which correspond to not suitable, least suitable, moderately suitable, highly suitable, and very highly suitable, respectively, as displayed in Table 3. A scale was created that includes the values of each criterion corresponding to a suitability score. The suitability scales were developed based on a comprehensive literature review.

Based on the reclassified criteria maps in raster format and the percentage weight assigned to each criterion, the overall suitability scores (OSS) were determined using the formula as follows [31].

$$OSS = \sum_i^n W_i S_i$$

where  $W_i$  represents the relative weight of criterion  $i$  as established in existing literature, and  $S_i$  is the suitability score of the area according to that criterion. The OSS was subsequently reclassified according to the scale presented in Table 4. The map layout was prepared using QGIS. To validate the suitability maps, two spatial comparison approaches were employed. First, ground-referenced shapefiles of actual onion production areas in Aritao, obtained from the DA-RFO II, were overlaid on the onion suitability map. This spatial overlay assessed agreement between modeled suitability and existing cultivation zones. Second, to verify the cold storage suitability map, the locations of known government-funded cold storage facilities within Nueva Vizcaya were overlaid on the generated suitability map. The suitability map was considered acceptable when the majority of the reference features (e.g., existing cold storage or onion areas) intersected with moderately to highly suitable zones [32]. Additionally, exploratory data analysis was conducted using a Python script executed in Google Colab.

**Table 4** Classification of overall suitability score for onion cold storage facility site selection.

| Overall Suitability Score | Classification       | Description                                                                                                                                |
|---------------------------|----------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| 0                         | Not suitable         | Areas with land and locational constraints that hinder the development of onion cold storage facilities                                    |
| 1.00–1.49                 | Least suitable       | Areas with limited accessibility and suboptimal land cover, making them less favorable for cold storage facility establishment             |
| 1.50–2.49                 | Moderately suitable  | Areas that meet some but not all critical criteria for suitability, offering moderate potential for cold storage development               |
| 2.50–3.49                 | Highly suitable      | Areas that meet most suitability requirements in terms of land cover and proximity to key infrastructure and agricultural production zones |
| 3.50–4.00                 | Very highly suitable | Areas that optimally satisfy the combined suitability criteria, making them ideal locations for onion cold storage facility development    |

## 3. Results and Discussion

### 3.1. Onion Production and Cold Storage Suitability Maps and Validation

The resulting suitability maps show spatial variations across Nueva Vizcaya for both onion production and potential cold storage development. These outputs help visualize where infrastructure and interventions can be prioritized. The overall suitability map for onion production (Figure 3) reveals that 39.78% (156,043 ha) of Nueva Vizcaya's total land area (392,296 ha) is moderately suitable, while 11.13% (43,662 ha) is highly suitable, and only 0.06% (248 ha) is classified as very highly suitable. These very highly suitable areas are concentrated in the municipality of Bagabag, which is the only locality identified with this highest suitability class. In terms of highly suitable areas, the municipalities of Bambang, Aritao, and Solano stand out, each having over 4,000 ha. Moderate suitability dominates most municipalities, with large areas in Aritao, Kayapa, Dupax del Norte, and Bambang. These findings are consistent with previous assessments emphasizing the role of topographic and climatic conditions in determining viable onion-growing areas [16].

The cold storage suitability map (Figure 4) shows that 171,997 ha (43.84%) are very highly suitable, while 93,066 ha (23.72%) are highly suitable. These areas are mostly located near roads, production zones, and markets. Conversely, 127,164 ha (32.42%) were found to be unsuitable due to remoteness, restricted land cover, or lack of access. The municipalities with the largest combined areas of high and very high suitability include Kayapa (37,875 ha), Aritao (26,526 ha), Santa Fe (25,597 ha), and Bambang (24,385 ha), as shown in Figure 6. Notably,

municipalities such as Alfonso Castañeda and Kasibu showed large areas that were unsuitable or marginally suitable due to steep terrain or dense forest cover. The results herein may be used in the planning of agricultural infrastructure. The GIS-MCDA demonstrated that it can generate suitability maps for siting cold storage at a provincial level. The DA RFO II, concerned national government agencies, and funding institutions can refer to this map to identify areas for priority investments. The GIS-based model can be replicated on a regional and national scale, given sufficient spatial data. To evaluate the accuracy of the generated suitability maps, validation was conducted using spatial overlay and exploratory data analysis. For onion production, a spatial overlay with DA-RFO II's ground-referenced shapefiles of existing production areas revealed that 99.58% of these areas fall within moderately to highly suitable zones. A statistical summary further confirmed this alignment. For cold storage, all three known existing government-funded onion cold storage facilities were located in very highly suitable zones, affirming the model's predictive reliability. These validation results support the practical applicability of the GIS-based MCDA in supporting spatial decision-making for agricultural infrastructure development. This was exhibited in similar studies using a multi-criteria approach for the planning and development of cold storage [9, 11]. The maps generated can be integrated with other techniques such as location-allocation modelling [33, 34] and least-cost path methods [35] to optimize the spatial planning of cold storage infrastructure based on supply-demand dynamics.

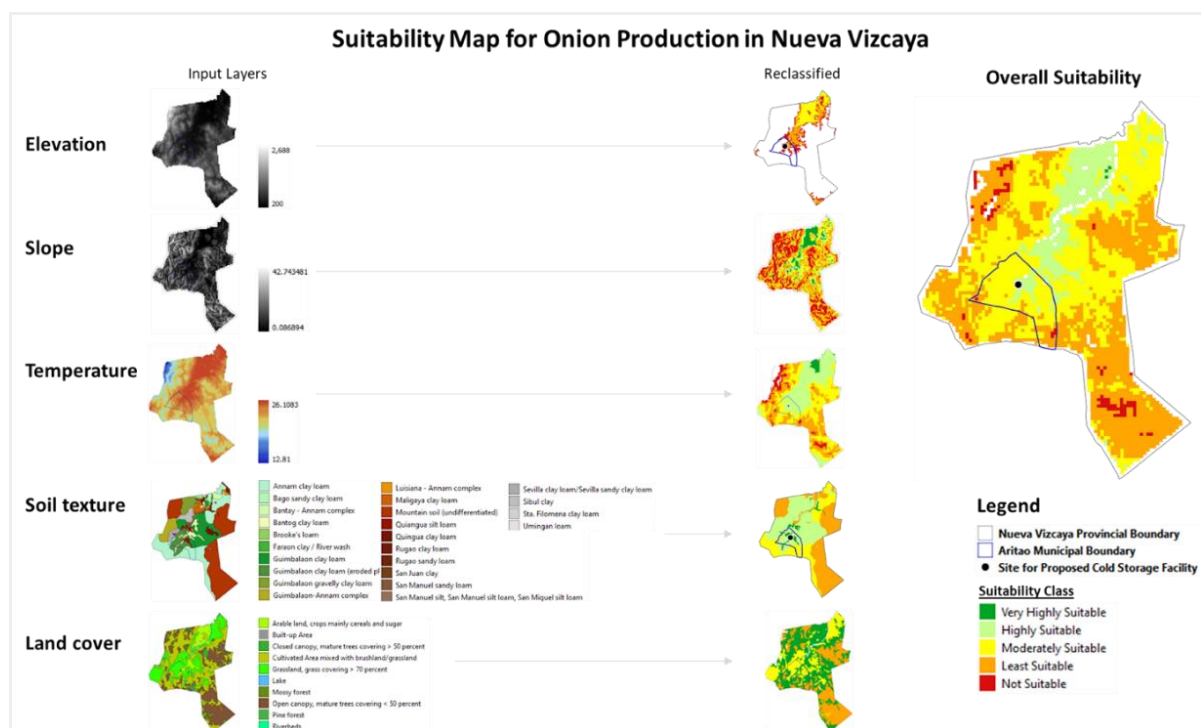


**Figure 3** Suitability map for onion production in Nueva Vizcaya

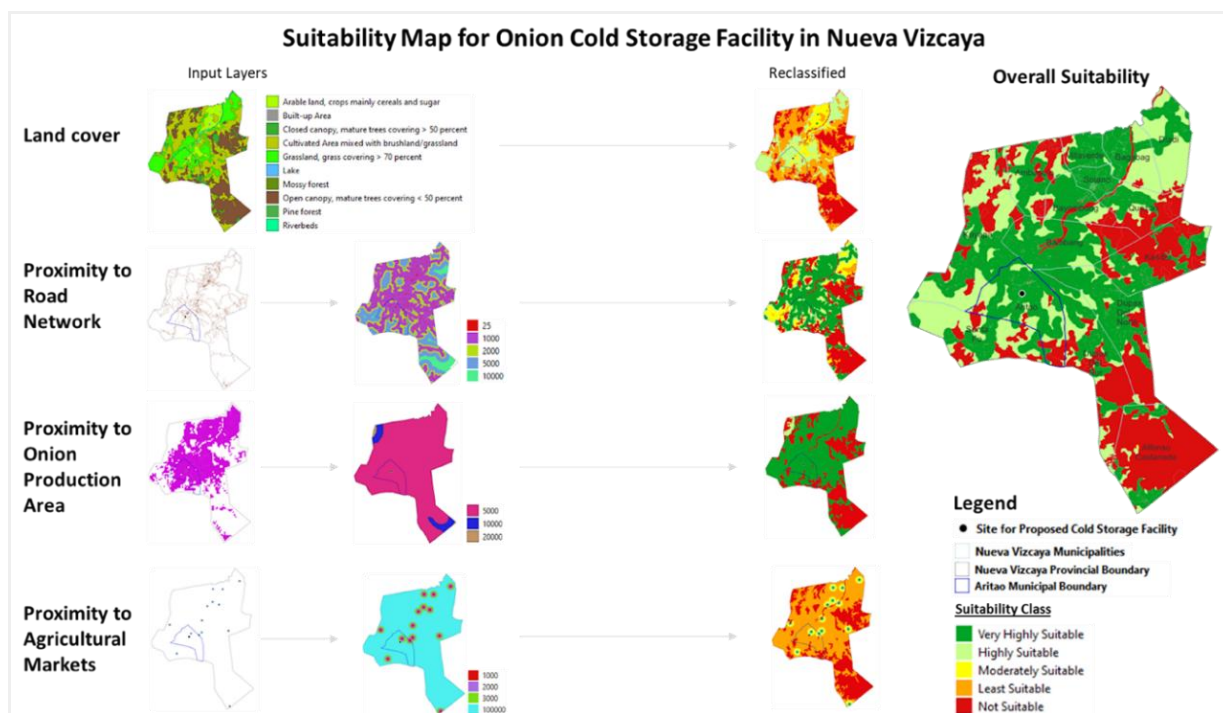


**Figure 4** Suitability map for onion cold storage facility in Nueva Vizcaya

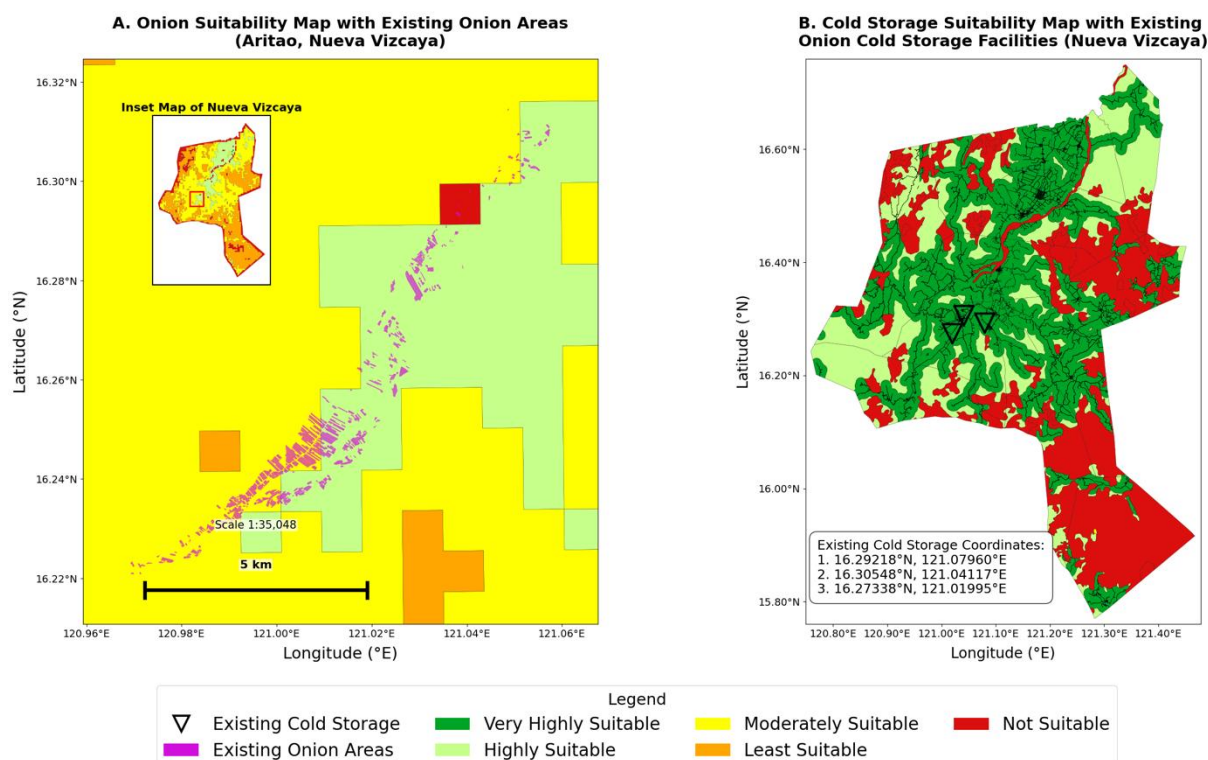
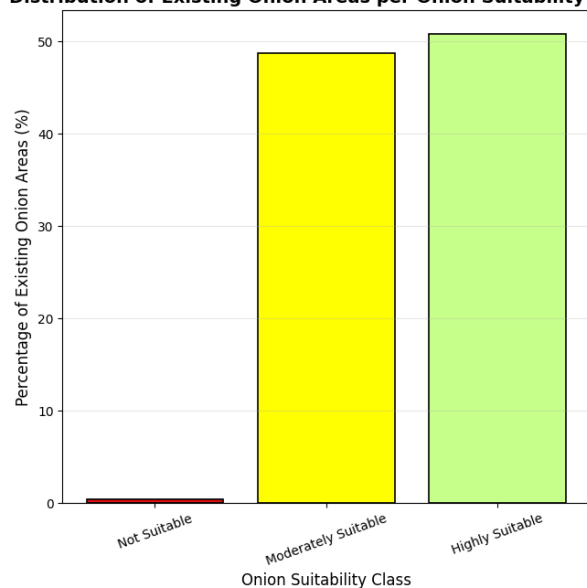


**Figure 5** Validation of suitability maps using spatial overlay and exploratory data analysis

Distribution of Existing Onion Areas per Onion Suitability Class



Exploratory Data Analysis Summary

## Onion Area Suitability Distribution

Not Suitable: 0.85 ha (0.41%)  
 Moderately Suitable: 100.78 ha (48.74%)  
 Highly Suitable: 105.13 ha (50.84%)

## Cold Storage Suitability

Facility 1: Very Highly Suitable (16.292182, 121.079597)  
 Facility 2: Very Highly Suitable (16.305484, 121.041174)  
 Facility 3: Very Highly Suitable (16.273383, 121.019949)

## Validation Metrics

% Onion Area (Moderate-Very High): 99.58%  
 Mean Cold Storage Class: 5.00  
 Median Cold Storage Class: 5.00  
 Std. Dev.: 0.00

Figure 5 Validation of suitability maps using spatial overlay and exploratory data analysis (Cont.)

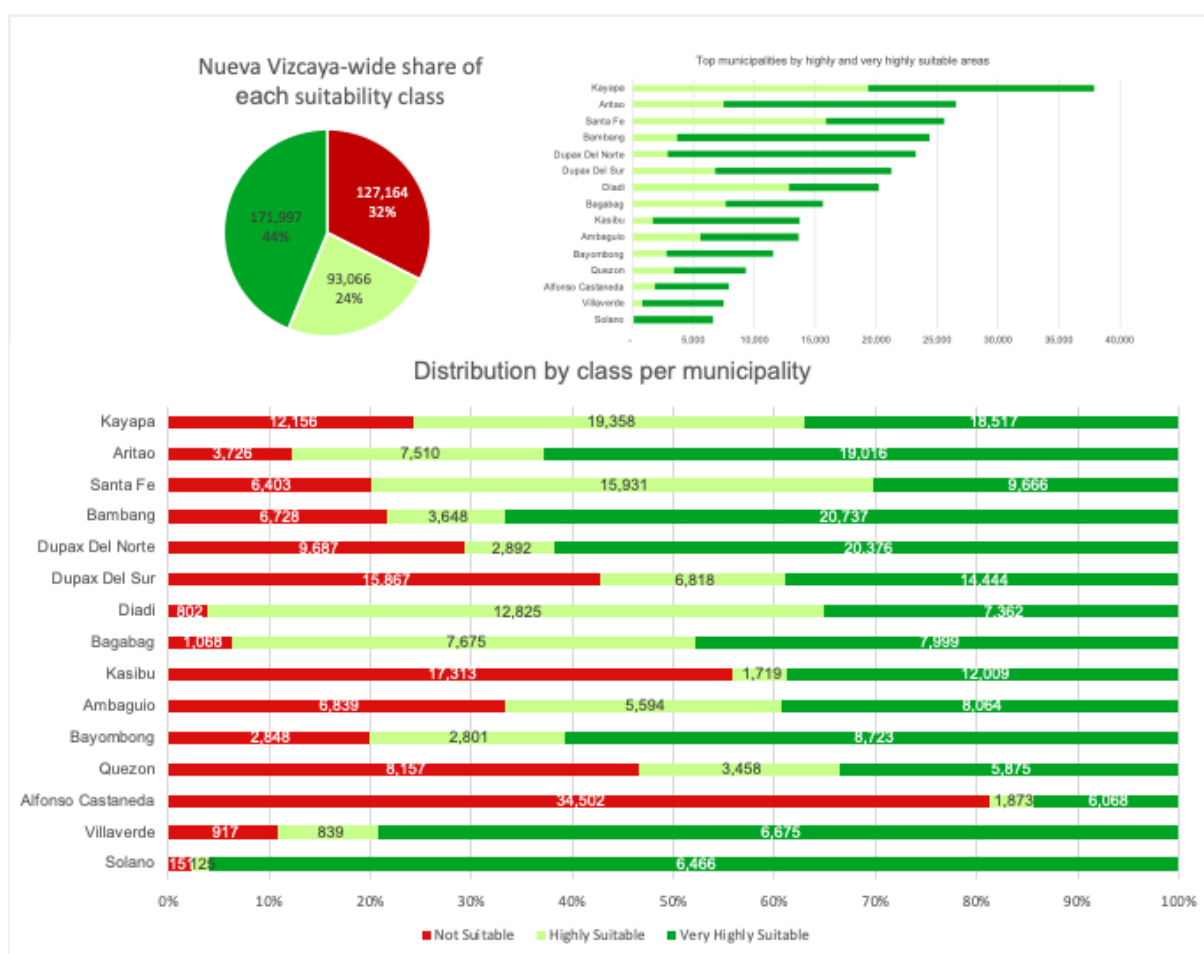


Figure 6 Onion cold storage suitability overview in Nueva Vizcaya province.

### 3.2. Barangay-Level Results in Aritao

Barangay-level analysis in Aritao further identified Bone South, Baan, and Canabuan as having the largest areas suitable for cold storage (Figure 4). These barangays are not only close to major onion production zones but are also accessible and relatively flat. Approximately 87.68% (26,526 ha) of Aritao's land area was classified as highly or very highly suitable for cold storage. This supports the initial plan of the Department of Agriculture to locate a cold storage facility in the municipality.

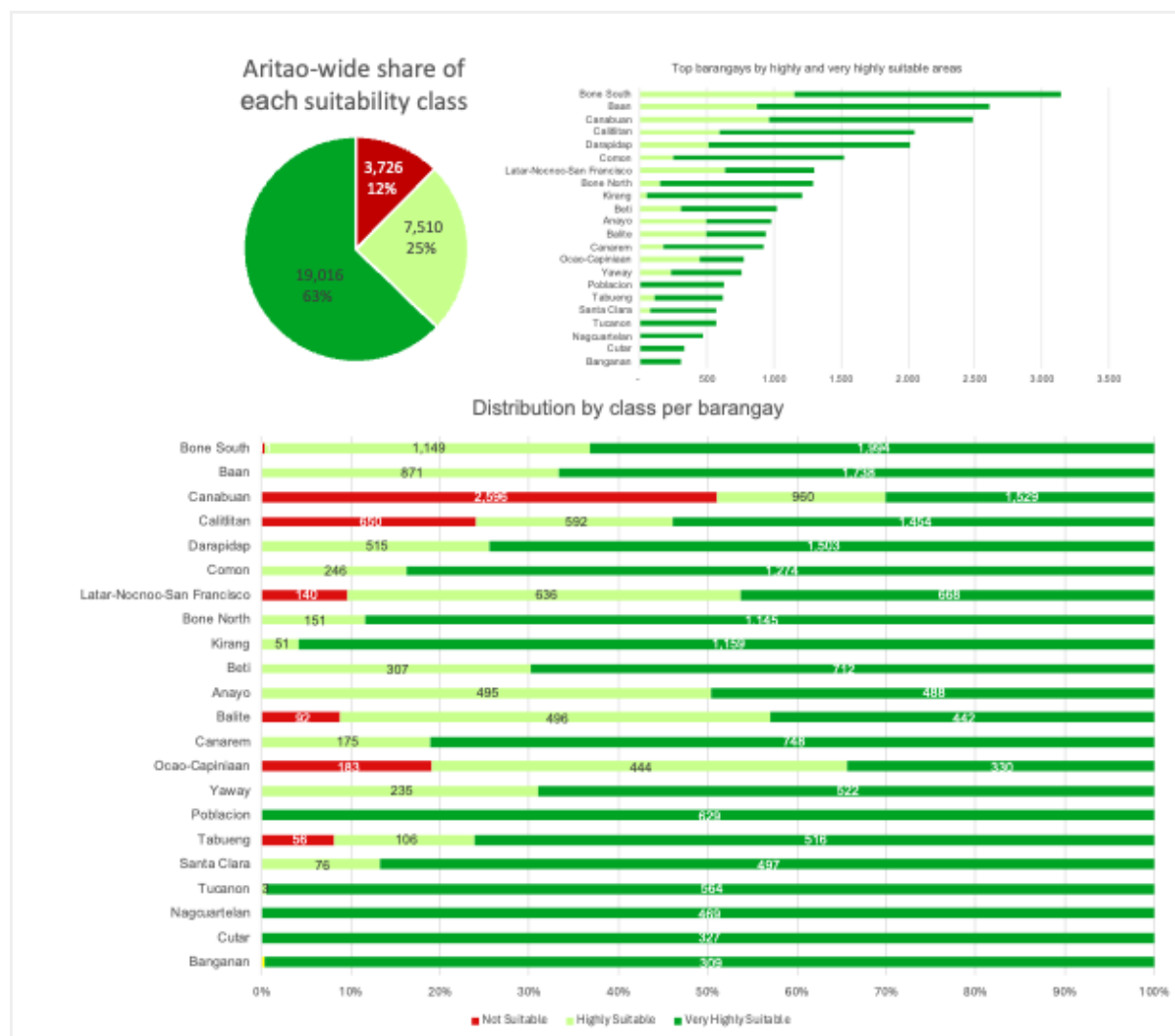


**Figure 7** Onion cold storage suitability overview in the municipality of Aritao

## 4. Conclusion

This study applied GIS and suitability analysis techniques to identify potential sites for cold storage development in Nueva Vizcaya, Philippines. By integrating spatial datasets of road networks, agricultural markets, and onion production areas, suitability maps were generated using a weighted overlay method.

Results revealed that 43.84% of the province is very highly suitable for cold storage, with key municipalities such as Kayapa, Aritao, Santa Fe, and Bambang showing the greatest concentration of suitable areas. Barangay-level analysis in Aritao further validated the strategic relevance of the previously proposed site for cold storage development. The mapping approach provides a replicable tool to assist policymakers and planners in prioritizing locations for infrastructure that align with production clusters and accessibility. Future work should incorporate additional variables such as socio-economic indicators, power supply, and logistics cost. Nevertheless, this research demonstrates the value of GIS-based decision support in enhancing postharvest planning and supporting the long-term sustainability of the onion value chain.

To enhance the spatial planning of postharvest infrastructure, the study advocates the following specific actions:

- Utilize the suitability maps to guide local and provincial investment strategies, especially for revising priorities under the Department of Agriculture's Onion Industry Roadmap.
- Integrate cold storage site selection with geohazard assessment technologies like HazardHunterPH to promote environmental safety and resilience throughout project implementation.
- Formulate a provincial cold storage master plan utilizing the suitability model to direct infrastructure deployment in the most suitable municipalities.
- Develop a provincial cold storage master plan that adopts the suitability model to guide cold storage rollout across the most suitable municipalities.
- Implement the GIS-MCDA methodology in more onion-producing provinces to enhance postharvest resilience and infrastructure planning across the nation

## 5. Acknowledgements

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## 6. Author Contributions

Oca, G.M.: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Visualization, Writing - original draft, and Writing - review & editing.

## 7. Conflict of interests

The author declares that he has no conflict of interest.

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