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Site Suitability Analysis of Small Water Impounding Projects (SWIPs) in CALABARZON Region Using GIS-Based Water Resources Assessment

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ABSTRACT

A study on site suitability analysis of small water impounding projects (SWIPs) in CALABARZON Region, Philippines was conducted using a GIS-based water resources assessment procedure for optimum water resource allocation and utilization. The study involved primary data collection through needs and design assessment survey of farmer-respondents utilizing SWIPs, and geo-tagging of existing SWIPs in the CALABARZON region. Secondary data inputs were also gathered from various institutions to generate the thematic maps and the potential suitability maps for SWIPs. Location maps of existing and potential sites for the development of SWIPs in CALABARZON were generated though GIS-based mapping. The generated SWIP potential suitability map was classified as highly suitable, moderately suitable, or marginally suitable. There were eight (8) factors considered in site suitability mapping of SWIP, namely, (1) average annual total rainfall, (2) soil texture, (3) slope, (4) road accessibility, (5) potential irrigable area (PIA), (6) geology, (7) watershed area, and (8) reservoir area. Of the total 350 potential sites identified for SWIP development in the CALABARZON region, 7% were classified as highly suitable, 61% as moderately suitable, and 32% as marginally suitable. The results can serve as a tool for SWIP planning and development to augment irrigation requirements for sustainable food production in the region.

Keywords: *GIS-based mapping, water resources assessment, small water impounding project (SWIP), small scale irrigation projects (SSIPs)*

INTRODUCTION

Region IV-A (CALABARZON) is comprised of five (5) provinces: Cavite, Laguna, Batangas, Rizal and Quezon. It has a total land area of 1,687,331 hectares and a total agricultural land area of 794,793 ha. CALABARZON is the most populated region in the country with 14.4 million inhabitants accounting for 14.27% of the country's population (Philippine Statistics Authority, 2019). The continued rapid increase in population causes significant pressure on the issue of food security in the country. The Philippines aims to achieve inclusive growth for agriculture, forestry, and fisheries (AFF) sectors through the reduction of economic inequality which can be realized through improved productivity of the AFF sector (National Economic and Development Authority, 2017). One key to boosting the productivity of agriculture is to secure water resources.

As reported by the National Irrigation Administration IV-A (2018), the region has an estimated total irrigable area of 85,929 ha with a 72.88% irrigation development. To improve the productivity of the agriculture sector and to address the limited water resources, the Department of Agriculture (DA) wants to accelerate the development of small-scale irrigation projects (SSIPs). The identification of suitable sites for SSIPs development in Region IV-A is an important step towards maximizing water availability and land productivity.

Small water impounding project or SWIP is a type of SSIP that collects water from rainfall and runoff to irrigate 25 to 150 ha of farmlands. It has an earth dam structure between 5 to 15 m high that are built across narrow depressions or valleys (Philippine National Standard, 2017). The average investment is about Php 250,000 per hectare. Aside from irrigation use, SWIP also conserves water, controls flood, minimizes soil erosion and siltation, and induces groundwater recharge.

The rapid increase of population growth causes more demand for food production thus puts stress on the country's water resources. The agriculture sector alone utilizes about 80% of the total water withdrawal of the country, where irrigation is the largest water user (Luyun, 2015) as cited by Amongo et al. (2019). Another factor that causes stress to water resources is the effect of climate change on temperature and rainfall occurrences. The posed threats, not only by agriculture, but by other sectors such as industrial, domestic, and commercial to the limited water resources require the need to proper management and allocation of available water and proper planning for the development of new irrigation systems. Hence, the need to develop a Geographic Information System (GIS)-based maps as a decision support framework to optimize and identify locations for disaster and climate-resilient SWIPs is important for sustainable food production. In support of the need identified, a study on site suitability analysis of small water impounding projects (SWIPs) in CALABARZON was conducted using a GIS-based water resources assessment procedure for optimum water resource allocation and utilization.

MATERIALS AND METHODS

Inventory and Collection of Available Data and Primary Data

The identification of potential irrigable areas (PIAs) in the CALABARZON Region is essential in the development of SWIP suitability maps for the identification of potential sites for SWIP development. To identify PIAs in the region, relevant information was collected such as climate, topography, soils, groundwater and irrigation systems, among others. Datasets from various agencies were also collected (Table 1).

Needs and design assessment (NADA) survey was conducted for primary data collection. The NADA survey was aimed to gather baseline information from the farmer-respondents on demographic profile and agricultural information, availability, uses, service area and management of SWIPs, and the problems encountered on the use of the SWIPs in the identified project site. A complete enumeration of existing SWIPs was undertaken. The results gathered from the NADA provided information on the SWIP users and status of existing SWIPs in the region.

A total of 124 enumerators from different municipal local government units (MLGU) of the CALABARZON region were trained on the collection of primary data requirements, geo-tagging, parameter measurements of SSIPs, and on how to administer the survey questionnaire and datasets with farmer-respondents. The NADA survey results were used to validate secondary data and to collect information from farmer-respondents on demographic profile and agricultural information (Amongo, et al., 2019). The data collected from NADA were encoded, processed, and analyzed for the development of suitability maps.

Table 1. Sources of input data used to generate thematic maps for SWIP site suitability analysis.

INPUT DATA	DESCRIPTION	SOURCE
DEM	Digital terrain model with a resolution of 5m generated using IfSAR technology	National Mapping and Resource Information Authority (NAMRIA)
Base map	Administrative boundaries	NAMRIA
Land cover	Land cover with twelve categories derived from Landsat 8 satellite imagery	NAMRIA
Climate	Annual total rainfall depth (mm); temporal coverage of 37 years	Climate Hazards group Infrared Precipitation with Stations (CHIRPS)
	Air temperature (ºC), solar radiation (MJ/m^2), relative humidity and wind speed (m/s) daily estimates	National Centers for Environmental Prediction (NCEP)
Soil data	Soil texture data with eight classifications based on USDA soil textural triangle	Bureau of Soil and Water Management (BSWM)
	Soil physical and chemical properties database	Food and Agriculture Organization (FAO)
Hydrogeology	Static water level depth, well discharge, and geology data	Mines and Geosciences Bureau (MGB)
	Groundwater potential	Comprehensive Irrigation Research and Development Umbrella Program (CIRDUP)
River discharge	Daily streamflow data from eight river basins	Department of Public Works and Highways (DPWH)
Road networks	Shapefiles of trunk, primary to tertiary roads	OpenStreetMap (OSM)

Source: (Amongo, et al., 2020)

Generation of Suitable Sites for SWIP

Protocols and Criteria for SWIP Suitability Analysis

The protocols and criteria in site suitability analysis for SWIP development (Table 2) were formulated during the review and planning workshop of the project (Amongo, et al., 2019) which was attended by researchers and experts from different Higher Education Institutions (HEIs) and government agencies. The factors identified in SWIP suitability analysis were the average annual total rainfall, soil texture, slope, and road accessibility. On the other hand, the constraints identified were the PIAs, watershed area, reservoir area, and geology, specifically the presence or absence of limestone or karst formation. Table 3 shows the suitability ratings based on the range of weighted scale average for reclassifying the suitability values.

GIS-based Identification of Suitable Sites for SWIP Development

A GIS-based analysis requires raster and vector formats, hence, input data presented in Table 1 were transformed using the computer program application Quantum Geographic Information System (QGIS). Built-in auxiliary tools and plugins used in transforming these input data were Geospatial Data Abstraction Library (GDAL), Geographic Resources Analysis Support System (GRASS), Soil and Water Assessment Tool (SWAT), and System for Automated Geoscientific Analysis (SAGA). The transformed data were used in the development of different thematic maps using the algorithms shown in Table 4.

The Google Earth Engine was used to download SENTINEL-1A C-band SAR images covering the period of December 2016 to December 2018. C-band radar sensors operate at the wavelength ranging from 3.75 to 7.5 cm (8 to 4 GHz frequency) that can penetrate and see through clouds and vegetative cover. This method was performed to derive the irrigated areas in the region and identify the remaining PIAs.

The flowchart for site suitability analysis for SWIP development is presented in (Figure 1) (Amongo, et al., 2020). The generated thematic maps for the region, namely: rainfall map, slope map, soil texture map, road accessibility map, watershed areas map, geology map, reservoir areas map, and PIAs map were reclassified based on the suitability scales as shown in Table 2. From then on, the suitability scores were computed through the GDAL raster calculator. Final reclassification of maps was performed based on the suitability rating indicated in Table 3 for the generation of the SWIP suitability map. The symbols used in the generated suitability map highlight the stream segments and geographical location markers of potential SWIP sites.

Table 2. Factors and constraints considered in the suitability analysis for SWIP development.

FACTOR	WEIGHT	DESCRIPTION	SUITABILITY SCALE
Average annual total rainfall	40	<1200 mm	1
		1200-2400 mm	2
		>2400 mm	3
Soil texture	25	Sand, loamy sand, and silt	0
		Sandy loam	1
		Silt loam and mountain soils	2
		Clay and clay loam	3
Slope	15	>18%	0
		8-18%	1
		3-8%	2
		0-3%	3
Road accessibility	20	>1000 m	0
		500-1000 m	1
		200-500 m	2
		<200 m	3
Potential irrigable area	Constraint	<15 ha	0
		≥15 ha	1
Geology	Constraint	Limestone areas	0
		Non-limestone areas	1
Watershed area	Constraint	<40 ha	0
		≥40 ha	1
Reservoir area	Constraint	<1 ha	0
		≥1 ha	1

Source: (Amongo, et al., 2020)

RESULTS AND DISCUSSION

Characterization of Input Maps

The DTM of CALABARZON region (Figure 2) reveals the highest locations in the region: Mount Banahaw, with an elevation of 2,170 meters above sea level (masl), Mount Makiling, with an elevation of 1,090 masl, and the southern part of the Sierra Madre with an elevation of 1,915 masl. These topographical features have steep to very steep slopes that cascade to the vast plains where

Table 3. SWIP Suitability ratings based on the range of weighted scale average.

SUITABILITY RATING	RANGE
Highly suitable	3.00
Moderately suitable	2.00 - 2.99
Marginally suitable	1.00 - 1.99
Not suitable	0.00 - 0.99

Source: (Amongo, et al., 2020)

agriculture and other livelihoods flourish. These topographical features play an important role in the climate variability of the region, which influences the hydrologic output of the watersheds and the agricultural productivity of the area, creating local climates that can vary even between short distances (Young *et al*., 1997; Apaydin *et al*., 2010; Napoli et al., 2019).

The scope of the SWIP site suitability analysis covered the entire crop production areas in the region. These areas are classified into annual and perennial crop areas which take almost the entire flatlands. The region had significantly contributed to the national production of commodities such as rice, corn, banana, coconut, and other types of fruits and vegetables. The province of Quezon has considerably large areas for perennial crop production while most of the annual crop production areas are located in the provinces of Batangas, Cavite, Laguna and Rizal. The northern part of Quezon province is home to vast forests, which play an important role in the ecohydrological balance of the watersheds. The spatial distribution of production areas can be linked with the existing potential of the area to support agricultural production., which is influenced mostly by the prevalent spatial distribution of available water resources. Figure 3 shows the land cover distribution of the CALABARZON region based on NAMRIA (2015).

Table 4. SWIP algorithms in QGIS.

PROCESS	THEMATIC MAP	ALGORITHM IN QGIS
Calculation of slope	Slope	GRASS r.slope.aspect, GDAL Slope
Watershed subbasin delineation	Watershed area	QSWAT plugin
	Reservoir area	
Calculation of proximity	Road accessibility	GDAL Proximity (raster distance)
Reclassification of shapefiles	Soil texture	QGIS built-in Field calculator
	Reservoir area	
	Watershed area	
	Service area	
	Non-limestone area	
Delineating reservoir areas	Reservoir area	QGIS built-in Zonal statistics

Source: (Amongo, et al., 2020)

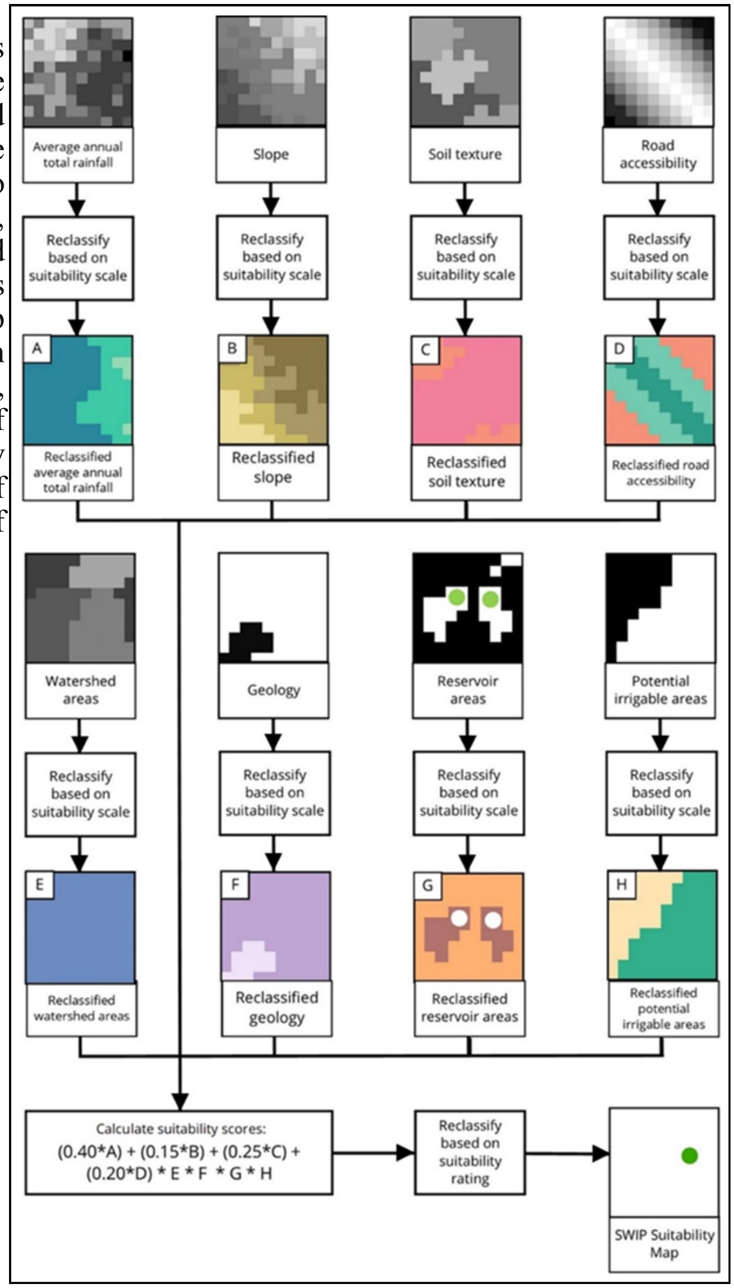

Figure 1. Flowchart of the site suitability analysis for SWIP development in GIS.
Source: (Amongo, et al., 2020)

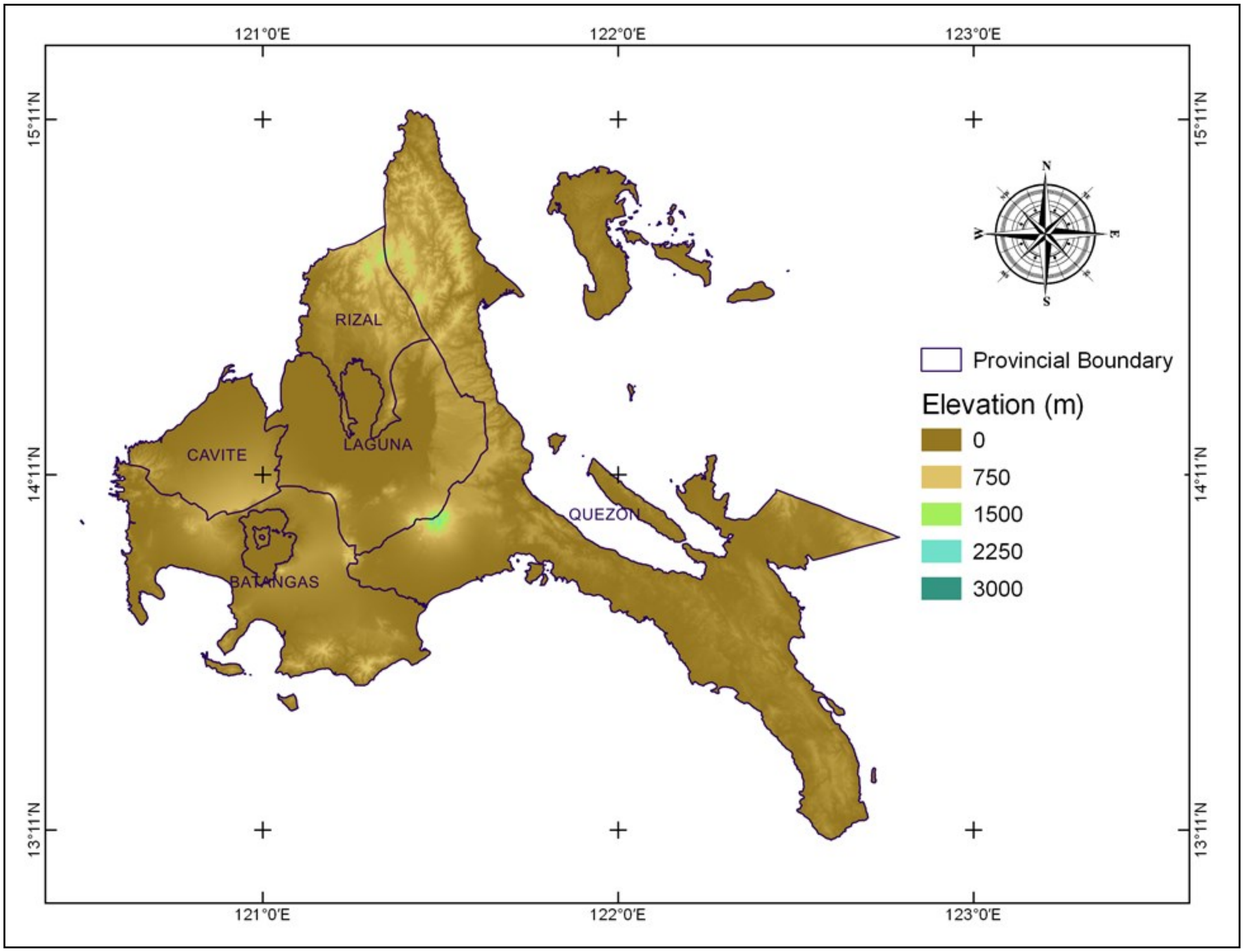

Figure 2. Digital terrain model (DTM) of CALABARZON region.
Source: NAMRIA (2015)

For the average annual rainfall distribution in the region, as seen in **Figure 4**, the eastern side of the region receives a higher magnitude of total rainfall compared to the western side. The northern part of Quezon province receives the highest average annual total rainfall. These available rainwater resources not only support agricultural production but play a paramount role in the recharge of groundwater and surface inland waters like Laguna de Bay and Taal. The average annual total rainfall (mm) in the region exceeds the minimum threshold to support marginally functional SWIP (1,200 mm from Table 2).

However, a high abundance of rainfall alone does not automatically equate to optimal output for on-

Table 5. Typical water-holding capacity values of selected soil textures.

SOIL	WATER HOLDING CAPACITY (mm/cm)
Sand	0.4-0.9
Loamy sand	0.6-1.2
Sandy loam	1.1-1.5
Loam, silty loam	1.7-2.3
Clay loam, silty clay loam	1.4-2.1

Adapted from (Jensen, 1980)

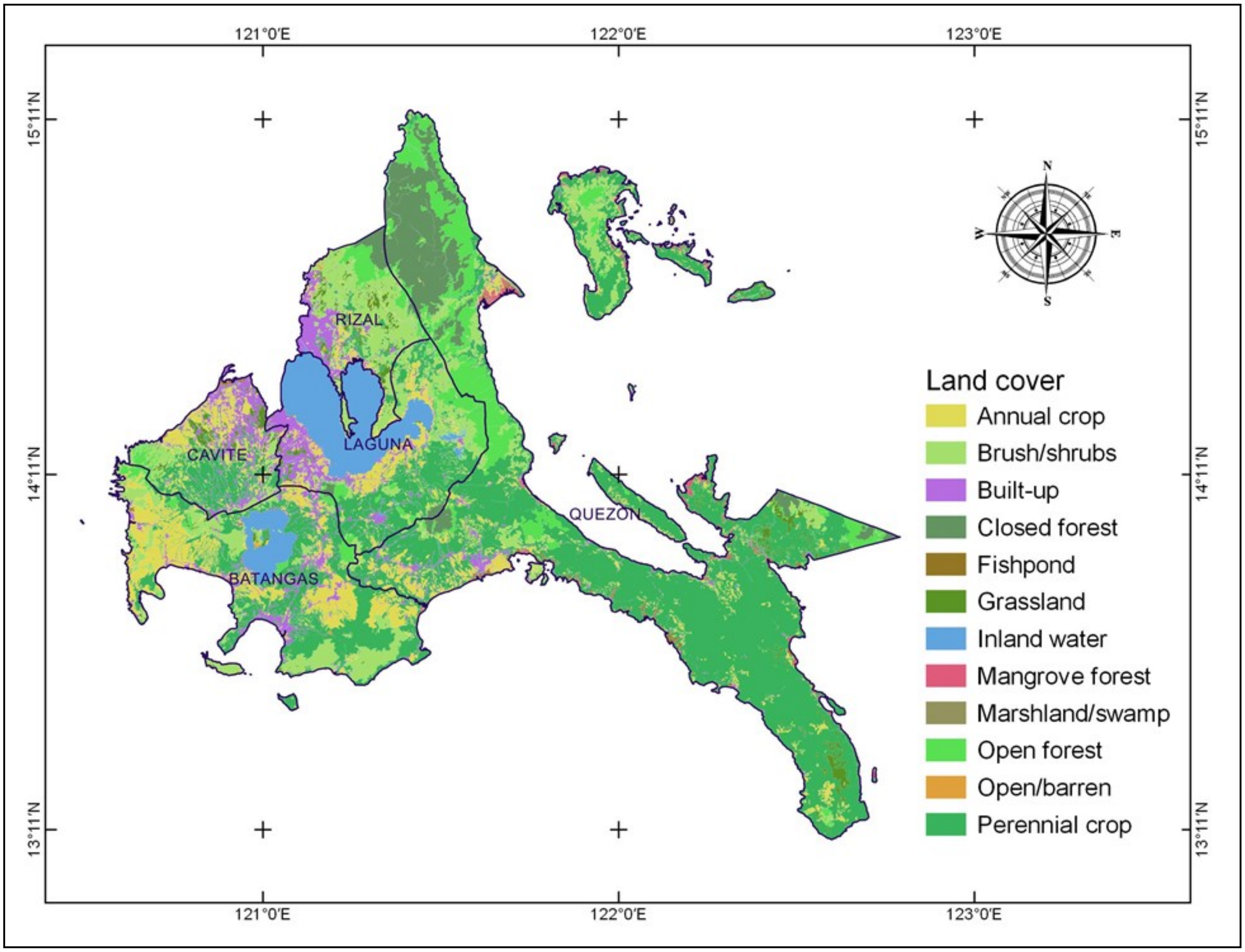

Figure 3. Land cover distribution of CALABARZON region.
Source: NAMRIA (2015)

farm water reservoirs as the former only gauges the potential of the latter. The reservoirs also depend on the effective retention of moisture, which is influenced by slope and soil texture. The map of soil texture in the CALABARZON region is presented in Figure 5.

Figure 5 shows that the region is dominated by clay, clay loam, and mountain soil, which all have relatively high water-holding capacities (Table 5) (Jensen, 1980). Coupled with high rainwater availability, the development of on-farm water storage structures in these areas is highly feasible since they can retain more of the excess rainfall for irrigation. Other soil textures include sand that represents the river washed materials formed along the rivers and streams and subjected to periodic overflow.

The geologic data used for SWIP suitability analysis is limited to the presence or absence of limestone areas in the region. For the provinces of Laguna, Batangas and Rizal the geologic data were obtained from the MGB. For Cavite and Quezon, these were obtained from the Lexicon of Philippine Stratigraphy (Peña, R & Geological Society of the Philippines, 2008). The maps showed that Cavite has no limestone areas while Lingoyen limestone areas can be found in Quezon at the municipality of Burdeos. This information was knitted with the

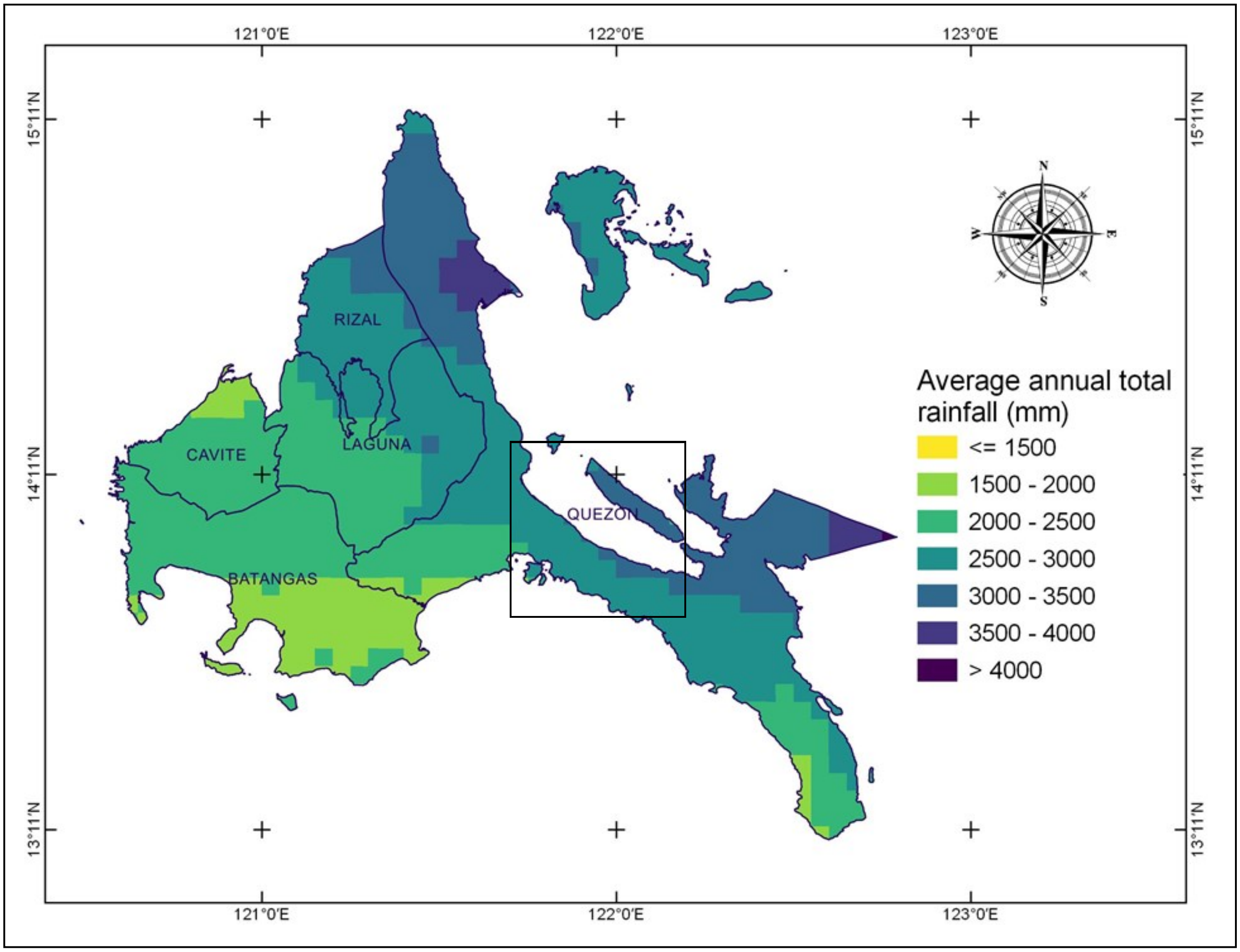

Figure 4. Average annual total rainfall (1981-2018) of the CALABARZON region, 2020.

insights generated from the available data obtained from MGB to complete the characterization of geologic features of the entire region.

Delineation of Service Area for Existing SSIP and Identification of Potential Service Areas for New SSIPs.

The analysis of composite images derived from the Sentinel 1 Synthetic Aperture Radar (SAR) C-band data yielded significant findings on the spatial distribution of irrigated rice areas across the annual crop production areas of CALABARZON

Table 6. Irrigation status per province in CALABARZON region, 2020.

PROVINCE	CROP AREAS (ha)*	IRRIGATED RICE AREAS (ha)	POTENTIAL IRRIGABLE AREAS (ha)
Cavite	63,394.66	2,210.55	61,184.11
Laguna	72,709.00	16,768.56	55,310.44
Batangas	267,461.22	74,529.72	192,931.50
Rizal	15,839.07	401.68	15,437.39
Quezon	530,564.01	26,447.45	504,116.56

**Areas devoted to perennial crops are included*

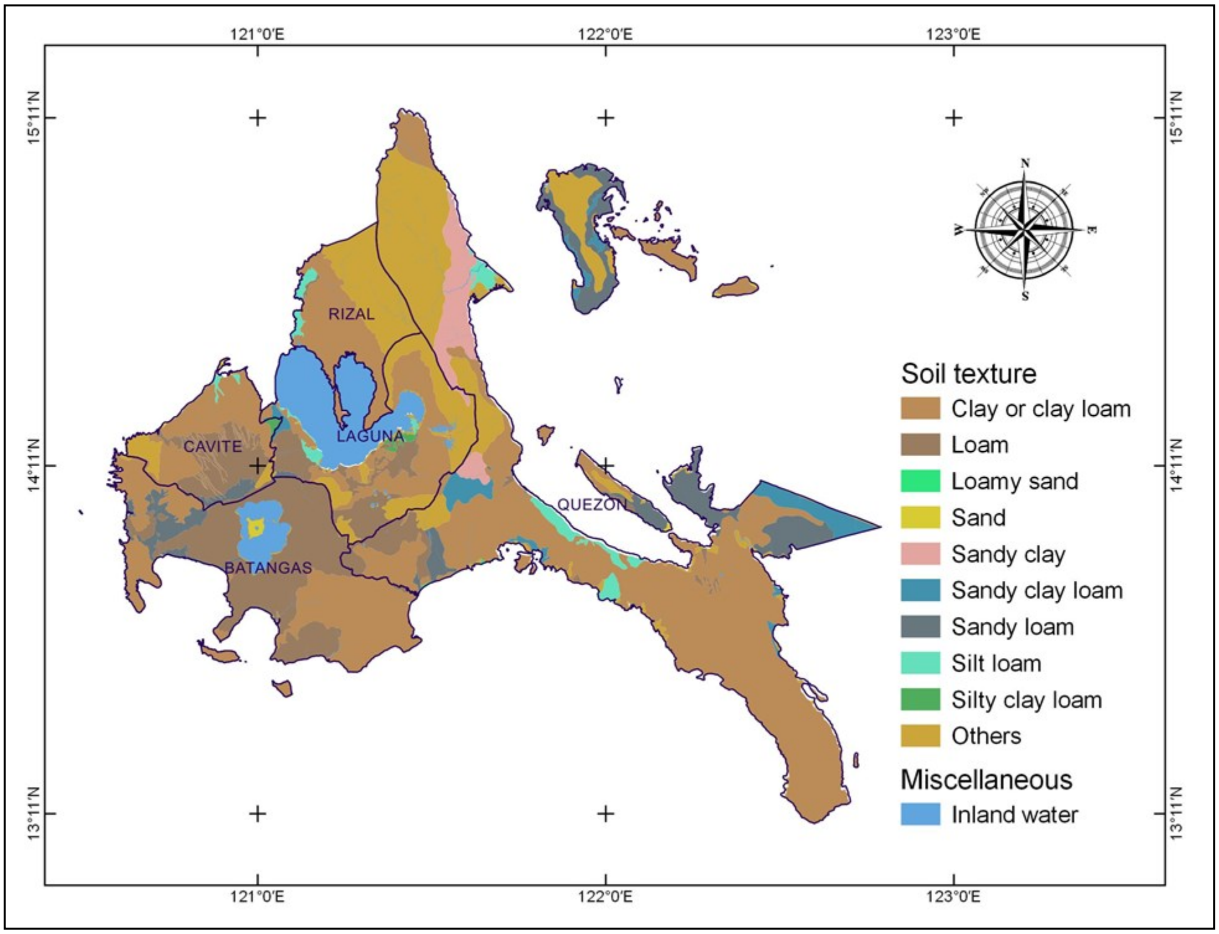

Figure 5. Soil texture distribution in the provinces of CALABARZON region, 2020.

region. This information is fundamental in the delineation of the potential service areas where SSIPs can be developed to supplement irrigation requirements. The results are further elaborated in the following sections. The map of irrigated rice areas and SSIP potential service areas across the region is presented in Figure 6.

Table 6 shows the values of the delineated irrigated rice areas per province of CALABARZON and their percentage of the total land area dedicated to crop production. The vast remaining potential irrigable areas, although it includes perennial crop areas, represent the potential for SSIP development including SWIP installation.

Table 7. Distribution of SWIP suitable sites per municipality in Cavite, 2020.

MUNICI-PALITY	MARGIN-ALLY SUITABLE	MODER-ATELY SUITABLE	HIGHLY SUITABLE
Alfonso	1	0	0
Amadeo	4	0	0
Bacoor City	0	1	0
General Emilio Aguinaldo	1	1	0
General Trias City	2	5	0
Imus City	0	4	0
Indang	7	0	0
Magallanes	1	4	0
Maragondon	2	2	0
Mendez	2	0	0
Naic	3	3	0
Silang	1	0	0
Tanza	1	10	0
TOTAL	25	30	0

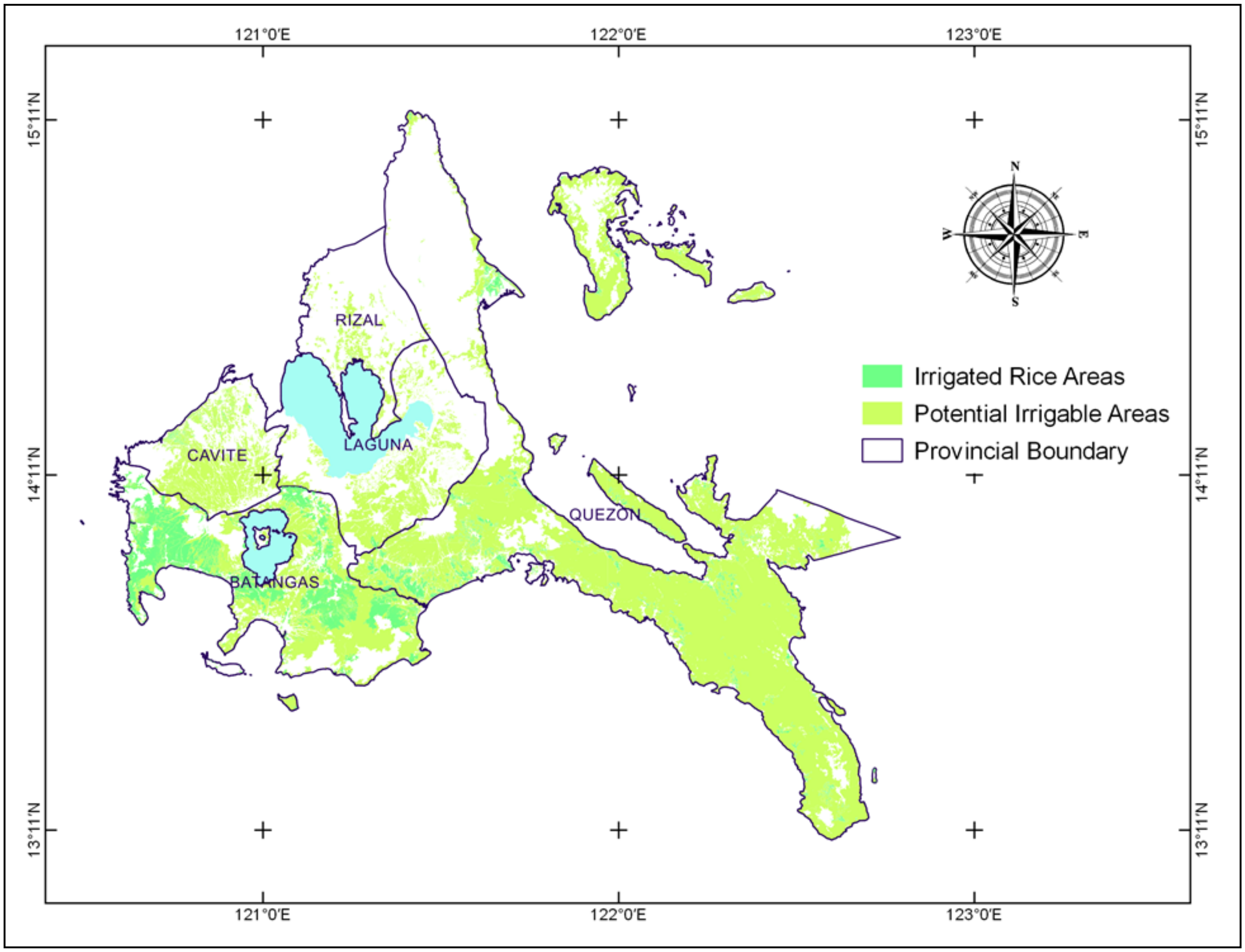

Figure 6. Irrigation status map of CALABARZON, 2020.

Site Suitability Analysis for SWIP development in CALABARZON

There were 350 sites found suitable for SWIP development in the region based on the site suitability analysis (Figure 7).

Suitable Sites for SWIP Development in Cavite

Based on the suitability analysis, there are 55 potential sites for SWIP in the PIAs of the province of Cavite. The distribution of which is presented in Table 7. These include 25 marginally suitable and 30 moderately suitable sites. There were no highly suitable sites identified. The seven marginally suitable sites in the municipality of Indang and 10 moderately suitable sites in the municipality of Tanza are the most per municipality.

Suitable Sites for SWIP Development in Laguna

There were 74 potential sites found in the PIAs of Laguna as presented in Table 8.These include 4 highly suitable, 33 moderately suitable, and 37 marginally suitable sites. Two highly suitable sites are in the municipality of Lumban and one each in Mabitac and Siniloan. Cabuyao has the most number of moderately suitable sites with four while San Pablo City has the most number of marginally suitable with 16 sites identified.

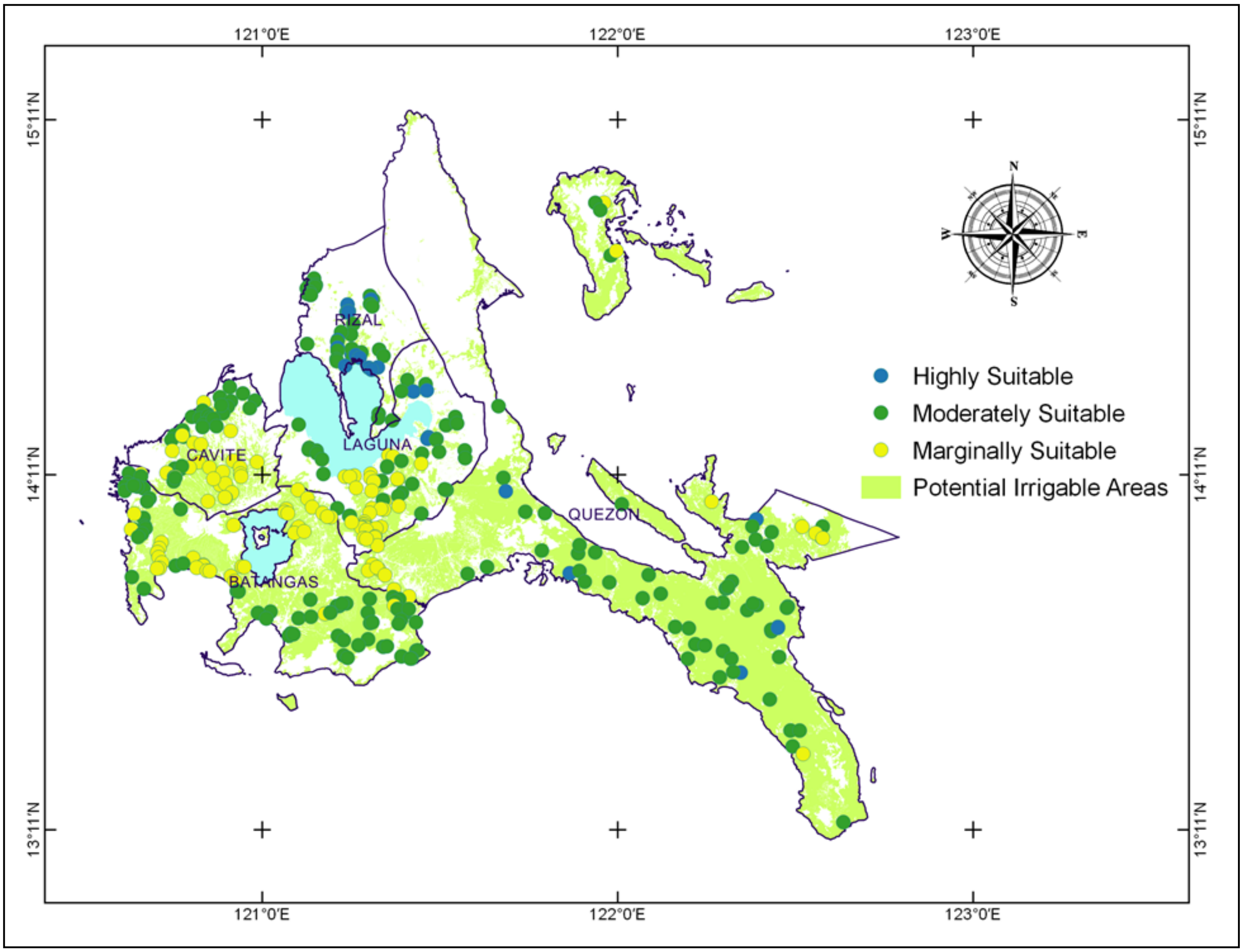

Figure 7. Suitability map for SWIP development in CALABARZON, 2020.

Suitable Sites for SWIP Development in Batangas

There were 103 potential sites identified in the PIAs of Batangas, divided into 37 marginally, 66 moderately suitable sites, and no highly suitable sites, as presented in Table 9. The 17 moderately suitable sites in San Juan and 6 marginally suitable sites in Balayan were the most per municipality.

Suitable Sites for SWIP Development in Rizal

There were 44 potential sites for SWIP development identified in the PIAs of Rizal, the distribution of which is presented in **Table 10**.There were 14 highly suitable sites and 30 moderately suitable sites Antipolo City having the most in both with 5 and 7 sites, respectively. There were no marginally suitable sites identified.

Suitable Sites for SWIP Development in Quezon

There were 74 potential sites for SWIP development in the PIAs of Quezon. These include 6 highly suitable, 54 moderately suitable, and 14 marginally suitable sites as presented Table 11. The highly suitable sites are found in the municipality of Buenavista with two sites, and one site each in Catanauan, Guinayangan, Mauban, and Padre Burgos. The municipality of Lopez has the most

Table 8. Distribution of SWIP suitable sites per municipality in Laguna, 2020.

MUNICIPALITY	MARGINALLY SUITABLE	MODERATELY SUITABLE	HIGHLY SUITABLE
Alaminos	6	2	0
Bay	1	1	0
Cabuyao	0	4	0
Calamba City	0	2	0
Calauan	5	1	0
Cavinti	0	3	0
Famy	0	1	0
Kalayaan	0	2	0
Liliw	0	1	0
Los Baños	3	0	0
Lumban	0	2	2
Mabitac	0	2	1
Magdalena	1	0	0
Majayjay	0	2	0
Nagcarlan	2	2	0
Paete	0	1	0
Pagsanjan	0	1	0
Pila	2	1	0
Rizal	1	1	0
San Pablo City	16	1	0
Santa Rosa City	0	1	0
Siniloan	0	0	1
Victoria	0	2	0
TOTAL	37	33	4

number of moderately suitable sites with nine sites, while the municipality of Tagkawayan has the most number of marginally suitable sites with four sites.

Validation of SWIP Suitability Maps

The generated SSIP suitability maps were validated by superimposing the geo-tagged existing SSIPs with the spatial distribution of suitable areas in the CALABARZON region. It is important to emphasize that the majority of existing SWIPs were documented in the irrigated rice areas of the

Table 9. Distribution of SWIP suitable sites per

MUNICIPALITY	MARGINALLY SUITABLE	MODERATELY SUITABLE	HIGHLY SUITABLE
Agoncillo	1	0	0
Balayan	6	2	0
Balete	2	0	0
Batangas City	0	5	0
Bauan	0	2	0
Calaca	5	0	0
Calatagan	0	2	0
Ibaan	0	1	0
Laurel	1	0	0
Lemery	2	0	0
Lian	1	5	0
Lobo	0	3	0
Malvar	1	0	0
Nasugbu	2	13	0
Rosario	1	11	0
San Juan	2	17	0
San Luis	0	2	0
San Nicolas	1	0	0
San Pascual	0	1	0
Santo Tomas City	5	0	0
Taal	1	0	0
Tanauan City	5	0	0
Taysan	0	2	0
Tuy	1	0	0
TOTAL	37	66	0

Table 10. Distribution of SWIP suitable sites per municipality in Rizal, 2020.

MUNICIPALITY	MARGINALLY SUITABLE	MODERATELY SUITABLE	HIGHLY SUITABLE
Antipolo City	0	7	5
Baras	0	2	2
Cardona	0	0	1
Jala-Jala	0	3	0
Morong	0	4	1
Pililla	0	0	2
Rodriguez	0	4	0
San Mateo	0	5	0
Tanay	0	2	1
Taytay	0	1	0
Teresa	0	2	2
TOTAL	0	30	14

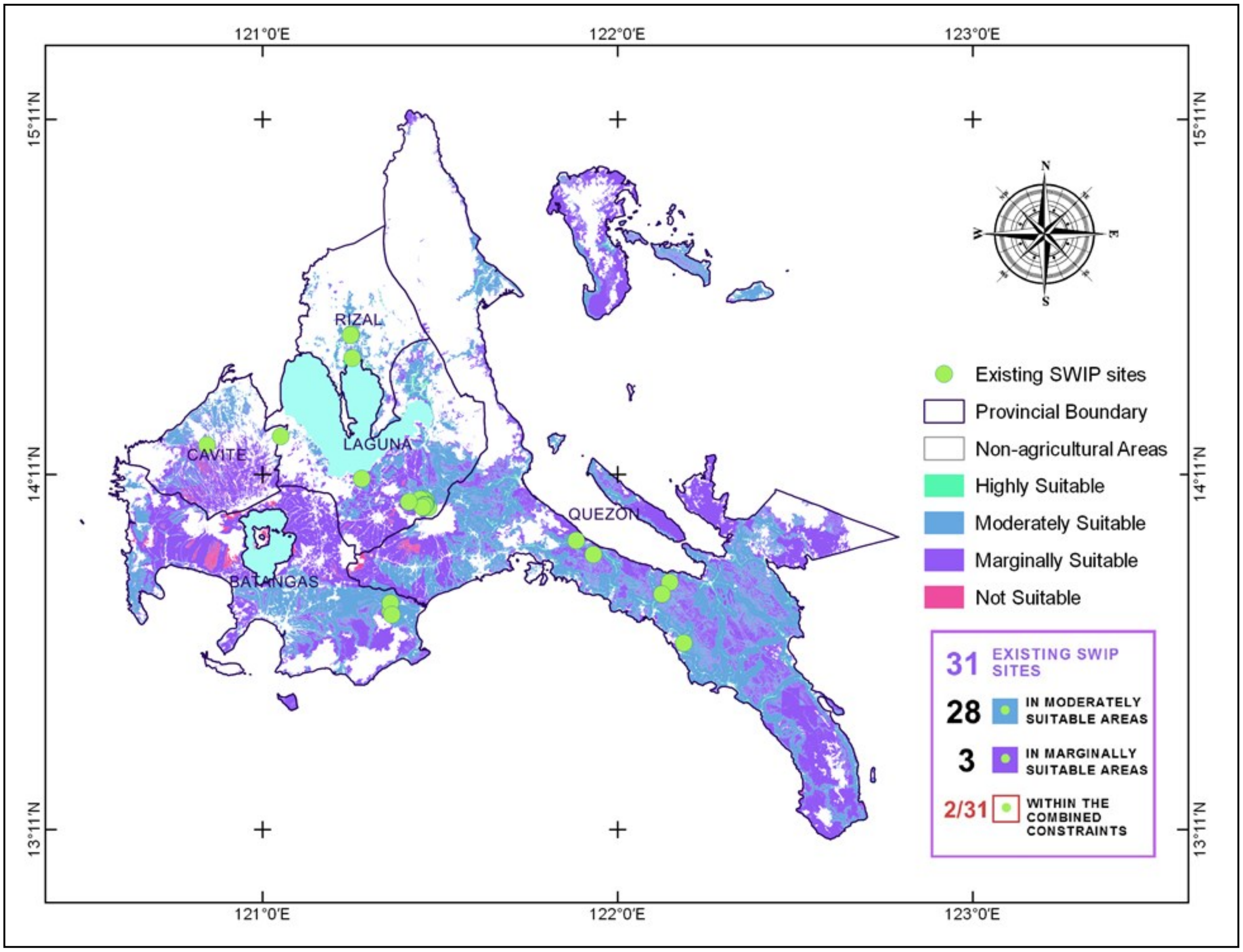

Figure 8. Distribution of documented SWIP sites across suitable areas within the crop production areas of CALABARZON region, 2020.

provinces; hence, the constraint that limits the suitable areas to be within the PIAs was dispensed, and the site suitability analysis was conducted encompassing the entire crop production area.

Figure 8 shows that there were 31 documented SWIP sites in CALABARZON and all were located within the identified suitable sites. Of these, 28 SWIPs were identified in moderately suitable sites, and the remaining three SWIPs were within marginally suitable sites. However, only two SWIPs were found to be within the irrigated rice areas, which technically does not satisfy the integrated constraints. Nevertheless, these findings suggest that the conditions in the crop production areas of the provinces promote reservoirs as an on-farm water storage strategy.

CONCLUSION

Site suitability analysis for SWIP development was performed for the CALABARZON Region using a GIS-based water resource assessment. The criteria used for the generation of the maps were average annual total rainfall, soil texture, slope, road accessibility, PIA, geology, watershed area, and reservoir area. According to the SWIP suitability analysis in the region, there were 350 sites identified as suitable for SWIP development. Around 7% of identified potential sites are highly suitable for SWIP development and roughly 61% are moderately suitable.

Validation of the generated suitability maps was performed by superimposing the geo-tagged existing

SWIPs with the spatial distribution of suitable areas in the CALABARZON region. All the identified existing SWIPs were located within the region's suitable areas for SWIP development.

Table 11. Distribution of SWIP suitable sites per municipality in

MUNICIPALITY	MARGINALLY SUITABLE	MODERATELY SUITABLE	HIGHLY SUITABLE
Alabat	0	1	0
Atimonan	0	3	0
Buenavista	0	2	2
Burdeos	2	2	0
Calauag	1	0	0
Candelaria	1	0	0
Catanauan	0	4	1
General Luna	0	3	0
Guinayangan	0	3	1
Gumaca	0	3	0
Lopez	0	9	0
Lucena City	0	2	0
Macalelon	0	2	0
Mauban	0	3	1
Mulanay	0	4	0
Padre Burgos	0	2	1
Pagbilao	0	1	0
Panukulan	0	1	0
Sampaloc	0	1	0
San Antonio	3	0	0
San Francisco	1	1	0
San Narciso	0	1	0
Tagkawayan	4	5	0
Tiaong	2	0	0
Unisan	0	1	0
TOTAL	14	54	6

RECOMMENDATIONS

For future studies, the effect of rainfall variability, land use, and land cover change can be considered. Irrigated areas vary seasonally, thus generating irrigated areas for wet and dry seasons is recommended. In addition, seasonal rainfall maps can be used instead of the annual rainfall. The generated SWIP suitability maps for the PIAs for crop production can be used as planning and decision tools for future irrigation development in the CALABARZON region. The feasibility and site evaluation must be well-planned in compliance with established standards (i.e., PNS/BAFS/PAES 225:2017: Rainwater and Runoff Management - Small Water Impounding System). The results of site suitability analyses employed in this study for the selection of potential SWIPs should serve only as a reference for further evaluation (e.g., feasibility study). The symbols only suggest a potential site, which should be subjected to further evaluation and verification. One beneficiaries of the output of this project is the Regional Field Unit (RFU) of the Department of Agriculture. They are the direct users of the generated maps since they are tasked to implement agricultural developments in the region. Hence, the RFU should also be capacitated on how to update these SWIP suitability maps to have an up to date reference in irrigation planning and development in the future. This will result to wise use of government resources, increase irrigable areas in the agriculture sector, increase cropping intensities thereby increasing income of farmers for sustainable food production.

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