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GIS-BASED SUITABILITY MAPPING OF BANANA IN THE PHILIPPINES

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ABSTRACT

A banana suitability map shows various areas with different levels of suitability for banana growth: high, moderate, marginal, and not suitable. Suitability levels may be regarded as potentials for successful banana cultivation. This research sought to generate a banana suitability map covering the whole Philippines using Geographic Information Systems (GIS) and the most recent sensor-based data. The following spatial data were used to generate the suitability map: digital elevation model, topography, slope, soil series and texture, monthly minimum temperature, monthly maximum temperature, monthly rainfall, and 2010 land cover/land use. These various spatial data were processed within the GIS using series of recoding, map algebra, and cross-classification procedures. The resulting banana suitability map for the Philippines was published in static PDF or JPEG format and interactively in the World Wide Web.

Key words: SARAI, land use, ASTER GDEM, soil, slope, Landsat, interactive map

INTRODUCTION

For a country to be progressive, agricultural production should improve and contribute to food security and the national economy. Land resources should be utilized optimally for different land uses, especially crop production. Different crops have different growth requirement for soil, temperature, and rainfall. The challenge is to match these crop growth requirements to areas where they can be met. Crop suitability assessment addresses this challenge. There have been crops suitability maps generated in the past, but these maps were of a national-scale and are only suitable for national-level planning purposes. There is a need to create newer suitability maps that are usable at municipal and provincial-levels and of much higher spatial detail and accuracy. Such higher accuracy is now achievable through the use of the latest remote sensing products and the use of Geographic Information Systems (GIS). These newer crop suitability maps will contribute to the country's goal of increasing agricultural production and sustaining food security.

Creating a suitability map for banana involves integrating various types of information like: soil, temperature, rainfall, topography, and slope. The complexities and details of the input varies, with data on soil sometimes including very detailed information on pedology, physical, and chemical properties. But such information are very difficult to obtain or even unavailable, especially for the entire country of the Philippines. Nevertheless, a suitability map for banana could still be generated in the absence of very detailed level of soil-survey information. Other data such as finer resolution digital elevation models, slope, rainfall, temperature, and land cover/land use maps, together with soil series and texture data adds to the overall accuracy and usability of the suitability map. In the end, a banana suitability map could be generated and used as guide in banana cultivation. The success or failure of the crop would still depend on fertilizer, pest, and water management and the prevailing weather.

Bananas (Musa spp.) are of great importance to small-scale farmers in the developing countries of the tropics and sub-tropics (Frison et al. 2004). In 2016, the Philippines produced 8,903,684 metric-tons of banana (PSA, 2017). The Philippines is the largest exporter in the region, which accounts for some 90% of the total export volume from Asia (FAO 2017). Bananas prefer freely drained, deep and fertile loamy soils, but [can be] cultivated on a wide range of soil types following proper agro-management. Swelling clay and high bulk density appear to pose drainage problems, thereby lowering crop yield. Banana grows well in pH range of 4.5 to 8.2 (Kadao et al. 2003). The potential for bananas to produce year round is best expressed when water is abundant and the daily temperatures are in the range of 20-30 degrees Celsius (Van den Bergh et al. 2012).

A GIS-based land suitability assessment for banana was performed for Bang Kratum District, Phitsanulok Province, Lower Northern Thailand (Boonyanuphat et al. 2004). Five environmental factors were used in the generation of the suitability map: soil property, topography, climate, availability of supplementary water, and market factor. Each factor, was given a weight, depending on its importance on the growth of banana. The end product banana suitability map features four suitability classes: highly suitable, moderately suitable, marginally suitable, and currently not suitable.

Soil characteristics for the growth of banana in Hainan Island, China were studied by Zhao (2018, 2005). The SOTER (Soil and Terrain Digital Database) database was utilized as source of soil and terrain information. An expert model for physical land evaluation was created in ALES (Automated Land Evaluation System), which was used to separate the potentially suitable AEU (Agricultural Ecological Units) from the unsuitable ones. The following parameters were considered during the modeling process: soil depth; surface horizon depth; texture, structure; bulk density; CEC (Cation Exchange Capacity); pH; total nitrogen; total phosphorus; exchangeable calcium, magnesium, and potassium; growing period; and rainfall and typhoon occurrences. A GIS-based land suitability analysis for rice cultivation was also performed in Morobe Province, Papua New Guinea (Samanta et al. 2011). A spatial multi-criteria decision-making approach, where geographical data is combined and transformed into a decision, was utilized in the overall process. ArcGIS 10 and ERDAS Imagine's model builder was used to construct the index model for rice land suitability analysis. Shuttle Radar Topography Mission (SRTM) data was selected to generate the digital elevation model (DEM) where topographic information was extracted. It also utilized climate data, soils data (texture, depth, N, P, K, and pH), and market access data (or travel time and distance from village to market). The final rice suitability map has three classes: suitable, moderately suitable, and unsuitable.

Remote sensing and GIS were utilized to map and evaluate the land suitability of the Northern part of the Nile Delta, Egypt (El Baroudy 2016. Remote sensing data can be used to delineate various physiographic units together with site-specific soil and climate data. When coupled with soil survey information it can be integrated in a GIS to assess crop suitability (Abdel Rahman et al. 2016). Physiographic map units were identified based on Landsat ETM+ satellite data and the DEM. Land suitability was based on the interaction of soil fertility, chemical, and physical factors. Each factor is computed based on the interactions of several sub-factors. The result of the modeling are various classes with weighted-index according to its significance to land suitability for crop production.

The land capability classification by Mary-Silpa and Sowshaja (2015) made use of GIS as the platform for assessment. Aside from utilizing slope, soil depth, soil texture, and permeability in the land assessment, the research also considered soil erosion. Input soil erosion map was obtained using the RUSLE (Revised Universal Soil Loss Equation) model.

A Multi-Criteria Evaluation (MCE) approach was utilized by Ceballos-Silva and López-Blanco (2003) to identify suitable areas for corn and potato production in Central Mexico. The researchers utilized the MCE algorithm of IDRISI Software and performed supervised classification of 1996 Landsat TM data to generate the land use/cover map. The final suitability maps for corn and potato are of five suitability levels: very high, high, medium, low, and very low.

A combination of an expert system and GIS for land suitability evaluation was developed by Kalogirou (2002), resulting in the LEIGIS (Land Evaluation using an Intelligent Geographical Information System) software. This utilizes the FAO 1976 framework for land evaluation of crops. The evaluation process has two main parts: the physical evaluation, which features a new interpolation function that maps values to scores of land characteristics, and the economic evaluation that includes income-maximization while taking into account market restrictions. The GIS functions help in managing the spatial data and visualizing the result. The software was developed using Microsoft Visual Basic (VB) programming language. The GIS functionality was implemented using MapObjects ActiveX Controls developed by ESRI (Environment Systems Research Institute) (Kalogirou 2002).

Land suitability evaluation for different crops is heavily anchored on numerous soil-related information that are mostly available at a regional scale. Utilizing such a generalized data at a local-scale or planning-scale land evaluation will be one of the “weakness” of the resulting suitability map. However, soil attributes could be predicted through models that utilize terrain attributes from digital elevation models (DEM) (Ziadat 2007). Furthermore, the accuracy of the suitability classification derived from predicted soil attributes compares favorably with the accuracy of classifications derived from traditional soil maps.

This study sought to utilize GIS to generate the suitability map for banana in the Philippines. Specifically it sought to develop a framework for banana suitability mapping that uses GIS and various spatial data, create various thematic maps needed as input to the suitability map, and publish the suitability map as static and interactive web-based maps.

MATERIALS AND METHODS

Study area. The study area covered the entire Philippines. Map outputs vary in scale from country-level to provincial-level.

Identification of criteria. Criteria for suitability are based on the growth requirements for banana (PCARRD 1988) which are the following:

1. Rainfall: 20 – 22 centimeters per month, evenly distributed
2. Temperature: 15 – 36 ^{o}C
3. Soil: deep and friable loam soil
4. Topography: flat terrains are highly desirable, but ravines and hilly lands may also be used
5. Drainage: banana is sensitive to standing water

Data collection. Table 1 shows the sources of data utilized for generating the banana suitability map.

Hardware and software. The suitability mapping of banana was performed on a 64bit IBM (International Business Machines) compatible PC (Personal Computer), with an Intel® Core(TM) i5-4210U CPU (4 cores) running at 1.70GHz, a RAM (Random Access Memory) of 12GB, and an operating system of Microsoft Windows 10.

Various software were used in this study. GDAL (Geospatial Data Abstraction Library) utilities were used in repetitive tasks that required script programming, such as the re-projection and mosaicking of ASTER GDEM (Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Map) tiles. PCRaster Software (April 16, 2015 version) was utilized in the quick visualization of maps and in non-complex map algebra. IDRISI Selva Software was utilized in the cross-tabulation of constraint maps. ArcGIS 10 was utilized in map layout creation and printing.

Table 1. Source of data for various layers used in the banana suitability map.

Data source	Data	Format	Data characteristics
https://asterweb.jpl.nasa.gov/gdem.asp	DEM (Digital elevation model)	Raster	Resolution: 30 x 30 meters Description: Elevation is in meters
http://www.worldclim.org/	Precipitation and temperature	Raster	Resolution: 1,000 x 1,000 meters Description: - Monthly precipitation - Monthly maximum temperature - Monthly minimum temperature
https://philgis.org/	Soil	Vector	Description: Each polygon represents soil series and texture
NAMRIA (National Mapping and Resource Information Authority)	2010 Philippines Land Use Map	Vector	Description: Each polygon represents a land use type

Data characteristics of the output. The technical characteristics of the data output are described below (Table 2).

Table 2. Technical characteristics of the data output.

Parameters	Description
Pixel size (minimum mapping unit)	100 by 100 meters (10,000 squared-meters or one hectare)
Projection	UTM, WGS84 datum (Universal Transverse Mercator Projection, World Geodetic System of 1984)
Image dimension	10,749 x 18,350
Formats	Raster: GEOTIFF Vector: Shapefile

Database generation

a. **Rainfall.** Banana requires 20 to 22 cm. of rainfall per month. From the gridded monthly precipitation data of the Philippines, a Boolean map was created per month with areas having 20 to 22 centimeters of rainfall getting a value of one, while the rest was zero. The process of creating the Boolean map requires recoding or re-classing the pixel values. The monthly rainfall Boolean maps were combined together using map algebra through the multiplication operation and the output is the rainfall constraint map.

b. **Temperature.** The optimum growing temperature for banana ranges from 15 to 36 ^{o}C. The gridded monthly minimum temperature maps of the Philippines were used to create a minimum temperature Boolean map. Areas with temperatures equal-to and above 15 ^{o}C were given a value of one while zero was set for the rest. A maximum temperature Boolean map was created by utilizing the gridded monthly maximum temperature maps. Areas with temperatures equal-to and below 36 ^{o}C were given a value of one, and the rest, zero. The individual minimum and maximum monthly temperature Boolean maps were combined together using map algebra through the multiplication operation. This process resulted to the creation of the temperature constraint map.

c. **Elevation.** The source of the digital elevation model (DEM) is the ASTER GDEM. To cover the entire Philippines, 95 ASTER GDEM tiles were required. The ASTER GDEM data is natively in angular reference units (longitude and latitude), with a WGS84 datum. This data had to be re-projected to UTM, a linear reference system (units are in meters), also in the WGS84 datum and under Zone 51, North. After re-projecting, the individual ASTER GDEM tiles were mosaicked together to a single DEM covering the whole Philippines and resampled from 30-m-resolution to 100-m-resolution. The DEM was resampled to 100 meters to achieve a minimum mapping unit of one-hectare and to reduce computing load.

The task of re-projecting, mosaicking, and resampling the ASTER GDEM tiles was performed using the GDAL utility (gdalwarp.exe). Using GDAL requires creating batch scripts, which runs in the MS DOS (Microsoft Disk Operating System) console, to automate repetitive tasks. The batch script minimizes error and increases the speed of various GIS operations.

Prior to using the mosaicked ASTER GDEM as an input to an operation, low-pass filtering was performed to smoothen-out the roughness and remove artifacts inherent in the data. From the mosaicked ASTER GDEM, an elevation map was created by recoding ranges of elevation based on the BSWM (Bureau of Soils and Water Management) elevation categorization (0-100m→1, 100-500m→2, 500-1,000m→3, and >1,000m→4). Figure 1 shows the digital elevation model from the ASTER GDEM, while Figure 2 shows the categorical elevation map.

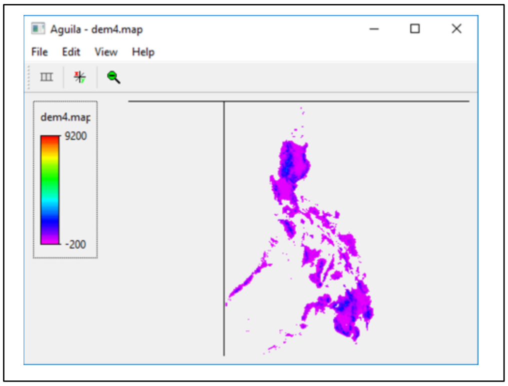

Fig. 1. Digital elevation map of the Philippines.

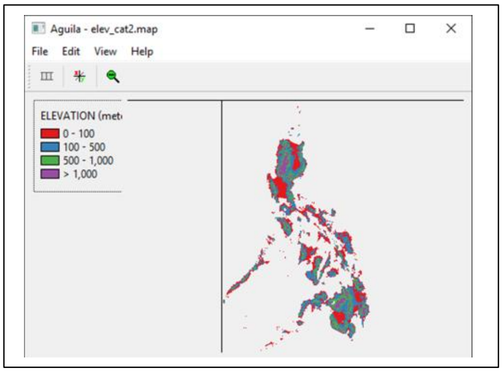

Fig. 2. Categorical elevation map of the Philippines.

d. **Slope.** Slope was computed in PCRaster using the mosaicked DEM as an input. The output of this operation is a slope map image with a continuous data type. Slope ranges were recoded into categories in accordance to BSWM's slope categories (0-3% →1, 3-8% →2, 8-18% →3, 18-30% →4, 30-50% →5, and >50% →6). Figure 3 shows the categorical slope map.

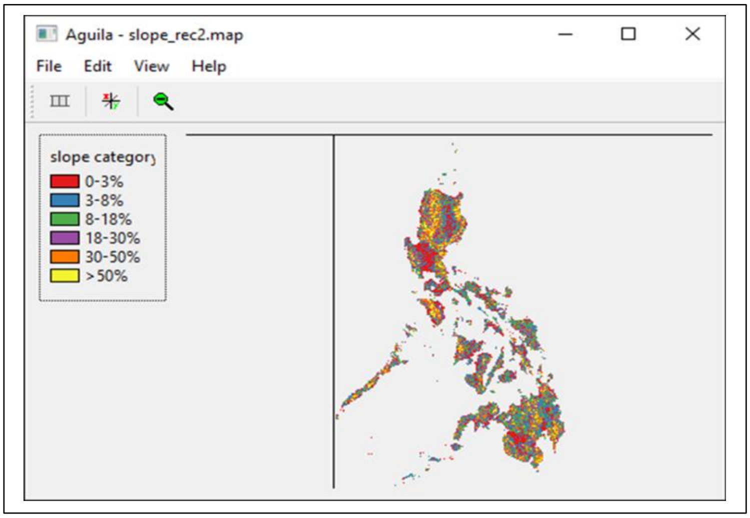

Fig. 3. Categorical slope map of the Philippines.

e. **Soils.** The soils data that came from the BSWM was in vector format (Shapefile format) and had to be converted to raster. The raster version of the soil map has a resolution (100 meters x 100 meters) and image dimension similar to the categorical elevation and slope maps to enable overlay within the GIS. The soils map of the Philippines is shown in Figure 4.

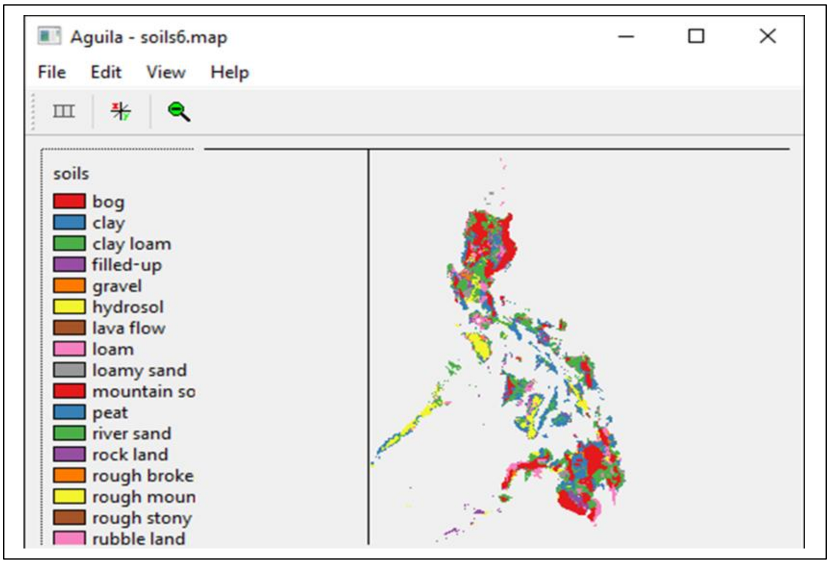

Fig. 4. Soil map of the Philippines.

Banana requires deep, friable and well-drained loam soils. The soil map was recoded according to the preference of the crop. Soils that are highly suitable for banana were assigned a value of one, those that are moderately suitable a value of two, and those that are not suitable, a value of zero. Thus, soils with textures of clay loam, loam and loamy sand were assigned a value of one; clay, sandy clay, sandy clay loam, sandy loam, silt, silt loam, silty clay, and silty clay loam were assigned a value of two; and the rest, those that are not suitable for banana cultivation (bogs, filled-up, gravel, hydrosol, lava flow, mountain soil, peat, river sand, rock land, rough broken terrain, rough mountain, rough stony, rubble land, sand, sand dune, and undifferentiated soils), were assigned a value of zero. Potential soil fertility-level as a function of the soil's cation exchange capacity, inferred from the clay content of the soil, was also considered in the categorization of the different soil series and textures. The output of this process is a soil constraint map.

f. **Land cover/land use.** The 2010 land cover/land use map (Fig. 5) from NAMRIA is based on image classification of medium-resolution Landsat data. The land cover data was in vector format and had to be converted to raster format to enable overlay and map algebra within a GIS. The image dimension and resolution of the raster land cover map is similar to that of the rasterized soils map.

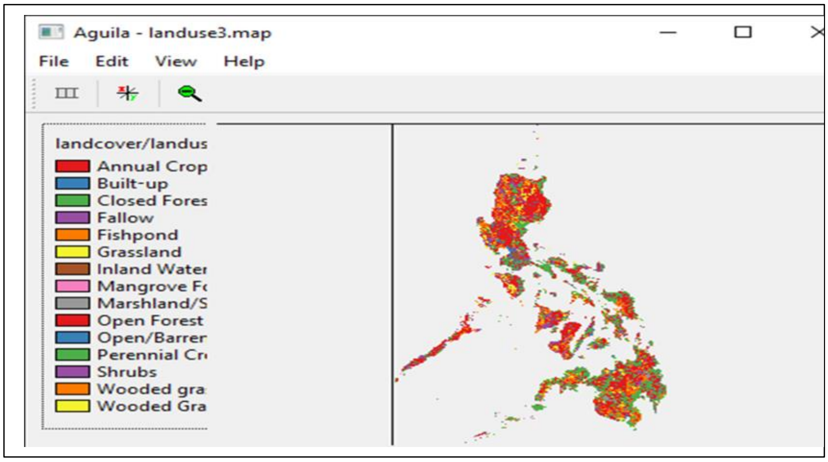

Fig. 5. Land cover/land use map of the Philippines (2010).

In this study, the land cover map was used to further refine the banana suitability map by constraining areas suitable for banana cultivation to areas with the following land uses: annual crops, fallow, grassland, open/barren, perennial crops, and shrubs. Areas with the following land uses were not included in the suitable areas for bananas: Built-up, closed forest, fishponds, inland waters, mangrove forests, marshlands/swamps, open forests, wooded grasslands, and forest reserve areas. Thus, from the land cover map, a Boolean image was created through recoding of values. Areas that could be planted to banana were assigned a value of one, while areas that are not suitable or should not be planted to banana were assigned a value of zero. A land use constraint map is the output of this process.

GIS suitability modelling. Geographic Information System (GIS) is a very powerful tool in agricultural research and natural resource management (Samanta et al. 2011). In suitability modelling IDRISI Selva Software was used. Cross-classification of the categorical elevation and slope maps yielded a preliminary physical constraint map. The result of this process are combinations of values shown on Table 3. Cross-classification of the preliminary physical constraint map with the soils constraint map yielded the preliminary biophysical constraint map, with the possible combination of values and their explanations shown on Table 4. Intersecting the preliminary biophysical constraint map with the land use, rainfall, and temperature constraint maps yields the final banana suitability map. Figure 6 shows the flowchart of process used in the suitability modelling.

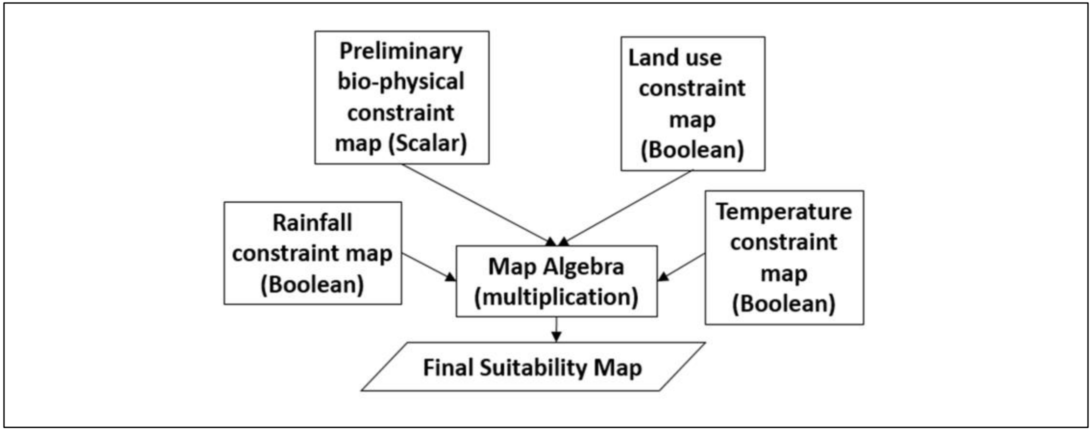

Fig. 6. Flowchart process of banana suitability mapping.

Table 3. Cross-classification values of categorical elevation and slope maps.

Slope categories (t)	**Elevation categories (e)**		
	1 (0-100 m.)	**2 (100-500 m.)**	**3 (500-1,000 m.)**
1 (0-3%)	S1	S2 e	S3 e
2 (3-8%)	S2 t	S2 et	S3 e
3 (8-18%)	S3 t	S3 et	S3 et

Table 4. Cross-classification values of preliminary physical constraint map and soil constraint map.

Preliminary physical constraint map values	**Soil constraint map values**	
	1 (highly suitable soils)	**2 (moderately suitable soils)**
S1	**S1** Highly suitable	**S2 s** Moderately suitable, with limitation on soil
S2 e	**S2 e** Moderately suitable, with limitation on elevation	**S2 es** Moderately suitable, with limitations on elevation and soil
S2 t	**S2 t** Moderately suitable, with limitation on slope	**S2 ts** Moderately suitable, with limitations on slope and soil
S2 et	**S2 et** Moderately suitable, with limitations on elevation and slope	**S2 ets** Moderately suitable, with limitations on elevation, slope, and soil
S3 e	**S3 e** Marginally suitable, with limitation on elevation	**S3 es** Marginally suitable, with limitations on elevation and soil
S3 t	**S3 t** Marginally suitable, with limitations on slope	**S3 ts** Marginally suitable, with limitations on slope and soil
S3 et	**S3 et** Marginally suitable, with limitations on elevation and slope	**S3 ets** Marginally suitable, with limitations on elevation, slope, and soil

RESULTS AND DISCUSSIONS

The banana suitability map that was generated by this study have two versions: the static map and the interactive map. Figures 7 and 8 shows the output suitability maps (static maps) for banana for Laguna province (sample provincial-scale map output) and for the entire Philippines (Philippine-scale map output). The static maps were generated in JPEG (Joint Photographic Experts Group) and PDF (Portable Document Format) formats. Such formats could be easily downloaded, printed on paper, or viewed using a computer or smartphone. The static maps are designed for easy viewing and distribution and are suited for users who have limited access to technology. The banana suitability maps for all 81-provinces of the Philippines and an overview banana suitability map showing the entire country are available for download from the SARAI Website (http://www.sarai.ph).

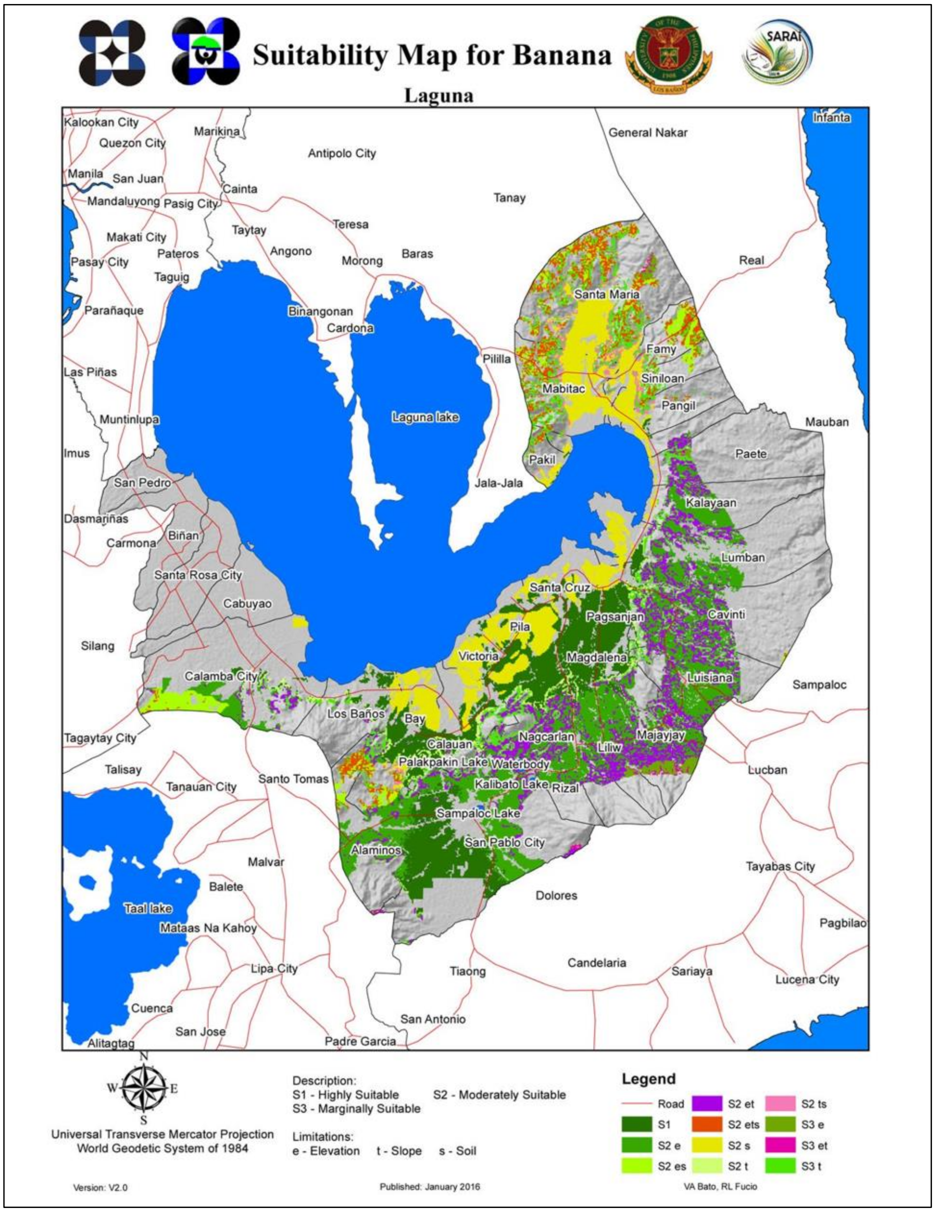

Fig. 7. Banana suitability map for Laguna province.

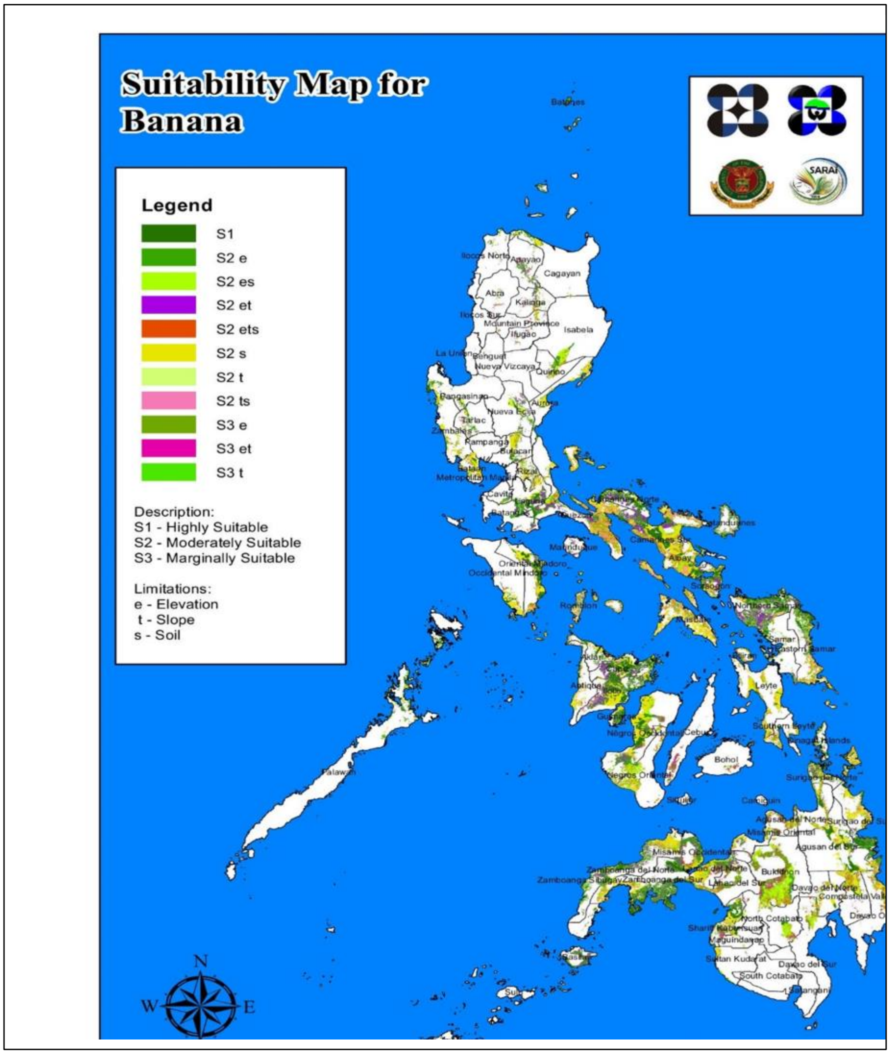

Fig. 8. Banana suitability map of the Philippines.

The interactive, web-based version of the banana suitability map (Fig. 9) can be accessed through the SARAI Maps Website: http://maps.sarai.ph/suitability-maps or through the Philippine Geoportal Website: http://www.geoportal.gov.ph/viewer/. The interactive version of the suitability map is designed for more advanced users who have computers with moderate to fast Internet connections. The user interface of the interactive map enables the user to zoom-in-and-out of an area of interest, perform drill-down attributes query with a mouse click, perform name-place search, make use of various base maps, and overlay thematic maps from various sources. Tools, such as distance and area measurements, are also available in the interactive map user interface.

A clear advantage of the interactive suitability map for banana over the static version is that the user interface enables the use of the most recent, high-resolution satellite data from Google Maps as a base map. The Google Map enables users to easily locate areas of a certain suitability class due to the easily recognizable landscape features on the base map.

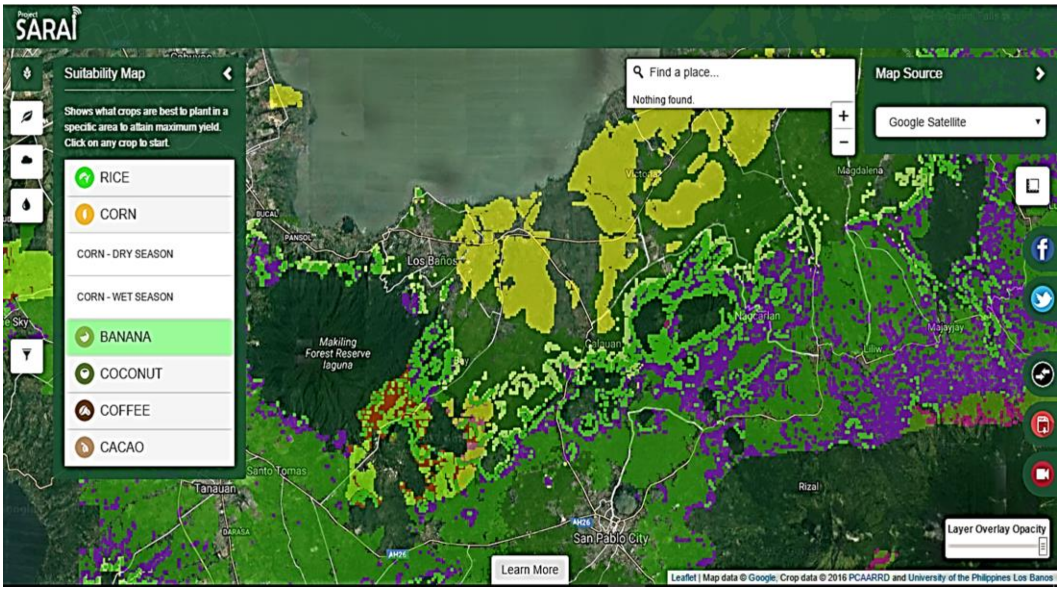

Fig. 9. Interactive banana suitability map at the SARAI Maps Website.

This study also computed the area for various suitability classes for the different banana suitability classes for the Province of Laguna (Table 5). It is just a sample area computation for one province, area computations for suitability classes have been done for the various provinces in the Philippines. This tabular information complements the map and is needed by decision makers in the local and national government and bureaus.

Table 5. Area computation for different suitability classes of banana for Laguna province.

Suitability Class	Area (hectares)
S1	15,582
S2 s	12,764
S2 e	21,510
S2 es	3,105
S2 t	1,502
S2 ts	1,127
S2 et	9,957
S2 ets	3,652
S3 e	760
S3 es	-
S3 t	7,688
S3 ts	-
S3 et	240
S3 ets	-

Limitations of the suitability map. The banana suitability map that was generated in this study is partly a product of the reconnaissance soils map of the Philippines made by the Bureau of Soils and Water Management (BSWM). The digital soils map is a compilation of digitized, provincial-level, paper-based soils maps which vary in scale from 1:250,000 to 1:500,000. The level-of-detail in the soils map limits the precision of the suitability map to only the provincial-level.

CONCLUSION

This study dealt with the GIS-based suitability mapping of banana in the Philippines. Using GIS, together with the most recent sensor-based data on elevation, temperature, rainfall, and land use, a banana suitability map covering the entire Philippines was generated in a very short period of time. Sensor-based data enabled the creation of a spatially accurate suitability map, something very difficult to generate in the past. Also, advances in hardware enabled faster computing of large datasets. The availability of advanced software enabled the automation of repetitive tasks, generation of professional-level output, and distribution of data through various media (Internet and print). The method developed in this study that utilized GIS and satellite-based data serves as a generic framework for suitability mapping of banana. Such method can also be applied to the suitability mapping of other crops. This study also generated various thematic maps that were utilized in the generation of the banana suitability map. Finally, the banana suitability map is published online in the SARAI website in both interactive and static versions.

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