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Agricultural Land Use Allocation under Current and Projected Scenarios

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Abstract. A model-based systems approach in optimizing agricultural land use spatial allocation integrating climate change adaptation was developed in this study. A land use planning and analysis system framework was modified and adopted under current conditions and anticipated scenarios for 2035. Climatic scenarios were reflected in land suitability ratings by conducting a land evaluation. All agricultural inputs and outputs were estimated and analyzed by multiple goal linear programming using Gurobi software. The results demonstrated that under current conditions, the city can meet its crop production, increase total farmers' net income, maximize agricultural labor, and provide a suitable residential area by optimally allocating grids to suitable uses. Under the 2035 scenario, the city can still achieve its development goals despite the change in land suitability and increase in population.

Keywords: Climate change adaptation; Land suitability; Land use allocation; Systems approach

1. Introduction

The growing global human population, coupled with intensifying climate change is putting intense pressure on land. Nations are challenged to strike a balance among different land uses to meet the needs of the people while safeguarding ecosystems (Brown et al., 2008). Land use as an imperative process must evolve to meet the demands and changing climate. The use of land dictates human development since it is the platform of social and economic activities (Corpuz, 2013). However, some development goals are conflicting regarding land, such as residential and commercial land uses encroaching into agricultural land or agricultural and timber production competing with protected areas (Kaim et al., 2018).

Agriculture is among the economic activities greatly affected by competing land use and aggravated by climate change, hence threatening food security. Climate change would put 5–170 million people at risk of hunger by 2080 (Abd-Elmabod et al., 2020). Agricultural productivity is predicted to decrease because of changes in land suitability and water availability brought about by the changing climate.

Climate influences plant growth rate, and any change in climatic parameters brings new opportunities or poses risks to agricultural land use. Exploration of climate change impacts on land suitability can identify areas where a range of options may be expected to change in the future (Brown et al., 2008).

The formulation of a land use plan mainstreaming climate change is being mandated to

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local government units (LGUs) of the Philippines. However, the process does not entail specifying what crops to grow on specific land based on suitability or where to allocate residential areas such that economic gains from the agricultural sector would not be compromised. The country's growing population necessitates more food supply, but farmland expansion options have shrunk significantly. A systems approach is required to determine the allocation of land for residential and agriculture. This would help the decision-makers in selecting the best course of action regarding land use allocation by providing a better understanding of the interrelatedness of different components of the system, broadening the scientific information base, and facilitating the prediction of the consequences of the options (Armenakis, 2008). Agricultural land use allocation involves several actors, such as farmers, farmer's associations, environmental agencies, land planners, and economists (Kaim et al., 2018), representing their respective concerns. Linear programming is an important tool that can be used to explore land use allocations that optimize agricultural, economic, or environmental objectives translated as objective functions (Makowski et al., 2000). Decision variables are areas assigned to production activities of land utilization type, and constraints may include resource availability and supply of and demand for crops.

In this study, a methodological framework was developed in formulating a land use plan integrating land evaluation under current and 2035 climate scenarios in San Jose City, Philippines. A systems approach was utilized to optimally allocate agricultural land use, considering the land suitability of major crops under current and projected climate scenarios, farmers' yield and income, agricultural employment, and the disaster risk of San Jose City residents. Various development scenarios and land use options are presented to provide a decision-support system for LGUs.

2. Methods

2.1. Study Area

San Jose City, Nueva Ecija, Philippines, is geographically located at 15.7833°N, 121.0000°E, 160 km north of Manila. The city has 38 villages, covering a total land area of approximately 187,250,000 m^2 (City Planning Development Office, 2011).

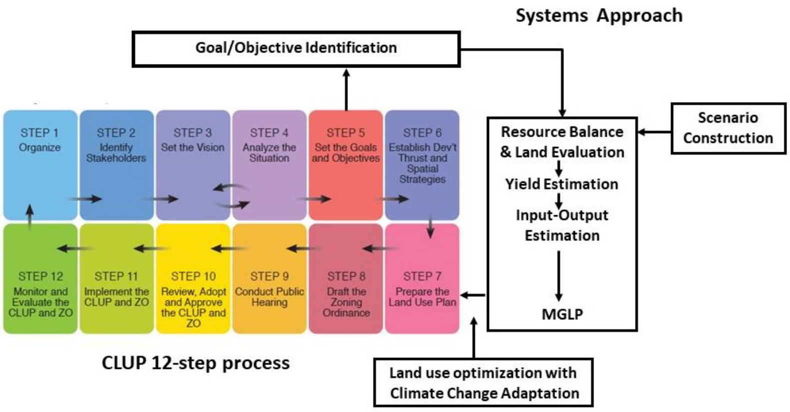
A level to nearly level terrain covers more than 60% of the city's entire land area. The city is mostly covered in silt loam and is classified as agro-climatic type C3, with five to six dry months and five to six wet months. The city receives 1,830 to 2,295 mm of rain annually, with an average monthly temperature of 25.78°C (World Climate Data, 2005, as cited by PhilGIS, 2014). San Jose is made up of nearly 69% agricultural land, 23% woodland, 6% built-up land, and 2% inland water.

2.2. Data Collected

This study explored four agricultural production systems: rice, onion, tomato, and bitter gourd. Irrigated rice farmers have two cropping seasons: the dry season (November–March) and the wet season (June–October). Rainfed rice farmers only plant during the rainy season, which runs from May to September. During the dry season, rainfed rice is followed by various vegetables, such as onion, bitter gourd, and tomato.

2.3. Model Description

The methodology developed in this study aimed to integrate climate change projections into a land classification for agricultural land use planning that is useful in optimizing the land of any LGU. The methodology does not divert from the 12-step process of formulating a comprehensive land use plan for a city or municipality prescribed by the Department of Human Settlements and Urban Development as shown in Figure 1; rather, it allocates land in a more scientific and objective way.



CLUP – Comprehensive Land Use Plan

Figure 1 Methodological framework of agricultural land use allocation

2.3.1. Identification of goals and objectives

A meeting with the members of the Municipal Council or the legislative body and the Association of Village Captains of San Jose City was held to determine their prioritized development goals. The identified goals and objectives were aligned with national and provincial levels such that development at the city level would not conflict with the goal achievement of the country.

2.3.2. Resource balance and land evaluation

Land management units (LMUs) were delineated by overlaying soil, agro-ecological, slope, land use, and administrative boundary maps using geographic information system software. Generated LMUs were further divided into one-hectare grids to ensure that a piece of land is allocated more specifically with appropriate use. The total land area to be managed (i.e., agricultural land) was computed using geographic information system software, excluding inland water, existing residential areas, and protected areas.

2.3.3. Crop yield estimation

A socioeconomic resources database consisting of the agricultural production system and the demand for products by the local population was gathered from 283 randomly selected farming households. The average crop yield per hectare of each LMU was obtained and multiplied by the area of the grid. The number of man-days for all the major planting stages of each crop of each LMU was also drawn from the survey.

2.3.4. Input-output estimation

The number of agricultural inputs of the surveyed farmers was multiplied with the corresponding unit cost to determine the total cost of the agricultural inputs for each grid. The total production cost was deducted from the gross income to obtain the farmer's net income.

2.3.5. Construction of scenarios

Current conditions and 2035 scenarios were constructed. Changes in the average total monthly rainfall and the average monthly mean temperature of the three months of the growing cycle based on the projected data were added or subtracted from the baseline data using the Raster Calculator. The projected value was the average of 50 years centered in 2035 under the Representative Concentration Pathway 4.5 scenario using 17 general circulation models generated through MarkSimGCM. The land suitability index scores of each crop were adjusted according to the projected climatic characteristics of the grids. The available water supply in 2035 in the constraint equation was also adjusted according to changes in the amount of annual rainfall.

2.3.6. Multiple goal linear programming

The modeling equations were formulated following the set goals and objectives. The identified development goals were translated into objective functions. Goals 1–4 are to maximize crop production by maximizing land suitability in the following order: tomato, bitter gourd, rice, and onion, as expressed in Equation 1.

$$Max = \sum_{i=1}^{n} y\_c_i * x\_c_i * s\_c_i \tag{1}$$

where

y_c_i: yield of crop per hectare; x_c_i: binary variable; s_c_i: suitability for the crop.

Goal 5 is to maximize farmers' income, expressed in Equation 2.

$$Max = \sum_{i=1}^{n} (i\_C1_i * x\_C1_i) + (i\_C2_i * x\_C2_i) \dots (i\_Cn_i * x\_Cn_i) \tag{2}$$

where

i_C1_i: farmer's income from Crop 1 per hectare of each grid; x_C1_i: binary variable assigned to each grid; i_Cn_i: farmer's income from Crop n per hectare of each grid; x_Cn_i: binary variable assigned to each grid.

Goal 6 is to maximize agricultural employment in San Jose City, expressed in Equation 3.

$$Max = \sum_{i=1}^{n} (j\_C1_i * x\_C1_i) + (j\_C2_i * x\_C2_i) \dots (j\_Cn_i * x\_Cn_i) \tag{3}$$

where

j_C1_i: man-days of Crop 1 farming per hectare of each grid; i_Cn_i: man-days of Crop n farming per hectare of each grid.

Constraints were set to limit the value of the decision variables so that they could not go above or below a certain value of the variable. The first constraint was that the land use allocated should not exceed the total agricultural land area. This was expressed in Equation 4.

$$\sum [(a_i * x\_C1_i) + (a_i * x\_C2_i) + \cdots (a_i * x\_Cn_i)] \leq TotalArea \tag{4}$$

where

a_i : area of each grid.

Another constraint set was that the available water should not exceed the water consumption of each land use. Equation 5 was used.

$$\sum [(w\_C1_i * a_i * x\_C1_i) + (w\_C2_i * a_i * x\_C2_i) + \cdots (w\_Cn_i * a_i * x\_Cn_i)] \leq WaterRes \tag{5}$$

where

w_C1_i : annual water consumption of Crop 1 per hectare; w_C2_i : annual water consumption of Crop 2 per hectare; w_Cn_i: annual water consumption of Crop n per hectare; $WaterRes$: total water resource supply of the city.

The third constraint was that the target supply of production of each crop should not be less than the yield of each crop. Equation 6 was employed.

$$\sum y\_C_i * x\_C_i \geq TargetSupply_i \tag{6}$$

Lastly, there should only be one land use assignment in each grid. This was expressed in Equation 7.

$$x\_C1_i + x\_C2_i + \cdots x\_Cn_i = 1 \tag{7}$$

Data were encoded using columns in Microsoft Excel. Gurobi was used for multiple goal linear programming (MGLP). All variables and equations were written on the SolverStudio interface, a Microsoft Excel add-in application.

3. Results and Discussion

3.1. Goal/Objective Identification

Seven objective functions emerged from the alignment of development goals from national to household levels (Table 1).

Table 1 Objective functions corresponding to development goals

Development Goals	Objective Functions
To develop agriculture as a reliable economic linkage to the industry by increasing crop production and ensure optimization of land use in the city	1. Maximize tomato production 2. Maximize bitter gourd production 3. Maximize rice production 4. Maximize onion production 5. Maximize residential suitability
To pursue equitable employment and ensure economic sustainability at the household level	6. Maximize farmers' income in the city 7. Maximize agricultural employment in the city

San Jose City is part of the rice granary of the Philippines. As such, the city is not only a dependable supplier of rice but also onions and other vegetables. However, farmers are used to planting rice such that other crops, which may be more suitable and profitable, are not explored. This problem can be addressed by the first four objective functions.

The continuous increase in population in urbanized villages has led to urban sprawl in nearby villages converting agricultural areas to commercial and residential uses. Flooding incidence also endangers the lives and properties of people living in flood-prone areas. As such, objective function 5 is also important.

Respondents of farming household surveys relayed that the high price of farm inputs and low price of produce constituted an economic problem, forcing them to take loans with an average interest rate of 6%. Objective function 6 addresses the decreasing economic returns of farmers.

Based on the survey, the labor requirement per cropping of rice was 53 man-days/ha, onion was 218 man-days/ha, tomato was 330 man-days/ha, and bitter gourd was 165 man-days/ha. Considering the agricultural area of 12,991 ha, the city can accommodate the available agricultural labor force of 32,226. Objective function 7 deals with this concern.

3.2. Resource Balance and Land Evaluation

In the constructed 2035 scenarios, the annual rainfall would decrease from 1,969.22 mm of the baseline data to 1,931.90 mm. The mean temperature would have an average increase of 1.78°C throughout the year. These changes (1950–2000 for monthly precipitation and 1965–1978 for monthly mean temperature) were reflected in crop suitability scores.

From 2008 to 2015, the computed average population growth rate of the city was 1.47%. The population was projected to increase, which will require the conversion of 78.53 ha of agricultural land to support residential needs. From the 2015 population, it will increase to 191,640 in the next 20 years (2035) and will demand a land space of 351.78 ha for the additional populace. The increase in population will also trigger an increase in the demand for crops. The areas for residential expansion should be according to their suitability—which is based on the population growth rate of each village and the hazard susceptibility, specifically flooding and earthquake hazards, of the area.

With the changes in precipitation and temperature, the yields of the four crops were assumed to change as affected by suitability. All three agronomic stages of development, vegetative, reproductive, and maturation, are sensitive to temperature—that is, development accelerates as temperature increases, with a linear correlation up to critical temperatures. For every 1°C rise in temperature, there is a depression in grain yield by 8%–10%, mediated through 5%–6% fewer grains and 3%–4% smaller grain weight (Niyogi, 2013).

Most of the grids maintained their suitability index scores of 4.5 or were moderately suitable for rice because of the broad optimum temperature range for rice during the growing cycle, which is 31°C–36°C (Sys et al., 1993; Figure 2).

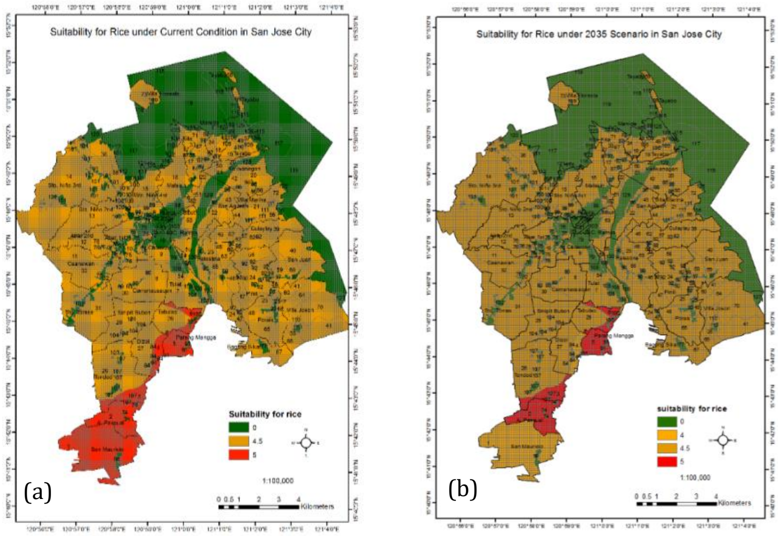


Figure 2 Suitability for rice in San Jose City: (a) current condition; (b) 2035 scenario

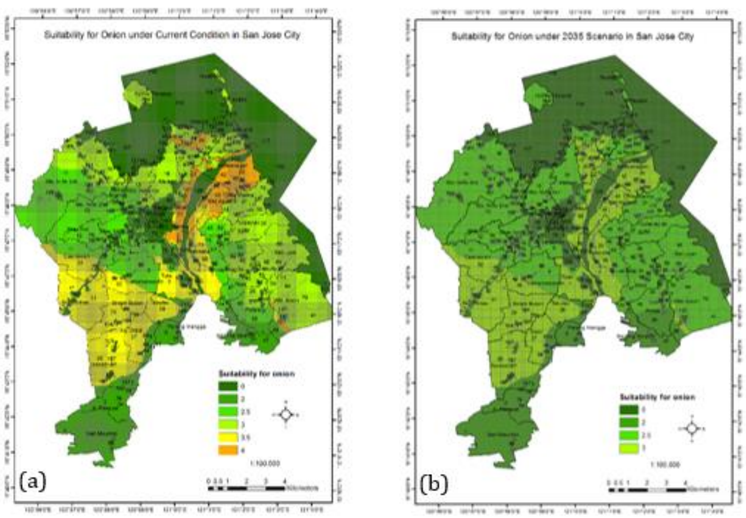


Figure 3 Suitability for onion in San Jose City: (a) current condition; (b) 2035 scenario

Grids graded with moderately suitable land for onions (Figure 3a) were predominantly covered by Umingan silt loam, which lies nearly level with and is bisected by Talavera River. River deltas are excellent for growing areas (Abon et al., 2004). The soil exhibits good drainage, medium fertility, shallowness, draughtiness, slight alkalinity, and salinity (City Planning Development Office, 2011). In terms of climatic requirements, the optimum precipitation requirement during the growing stage of onion is 450–600 mm, and the mean temperature is 19°C–22°C (Sys et al., 1991). Onion is grown from October to February. Half of the area of the city met the climatic requirements of onion; however, the characteristics of the soil of some parts did not meet the optimum requirements of onion, thus the rating of 3.5 and below. Under the 2035 scenario, all the grids received lower land suitability index scores than the current conditions (Figure 3b). According to Harrison et al. (1995), warming will reduce the duration of crop growth and hence yield (McCarthy, 2001).

Tomato grows at any time of the year and grows best in sandy loam or clay loam soil with a pH range of 5.7–6.0 (Tiburcio et al., 2004). The highly suitable land for tomato is covered with Annam clay loam (Figure 4a). Half of the surveyed tomato farming respondents had a cropping calendar of October to January. The optimum growth can only be accomplished at air temperature between 18°C to 26°C and accumulated rainfall of 400–700 mm/growing cycle (Sys et al., 1993). Under the 2035 scenario, grids received one point lower than the scores under the current condition (Figure 4b). The observation can be further attested to by a study conducted by Tsutsumi et al. (2015)—wherein an increase in CO_2 concentration and a 1°C rise in temperature increased heat stress in the summer, resulting in a lower growth rate of tomato.

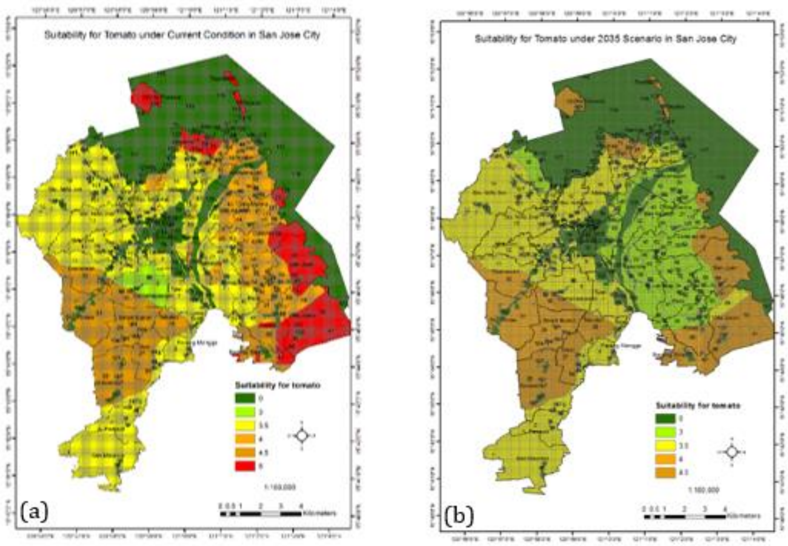


Figure 4 Suitability for tomato in San Jose City: (a) current condition; (b) 2035 scenario

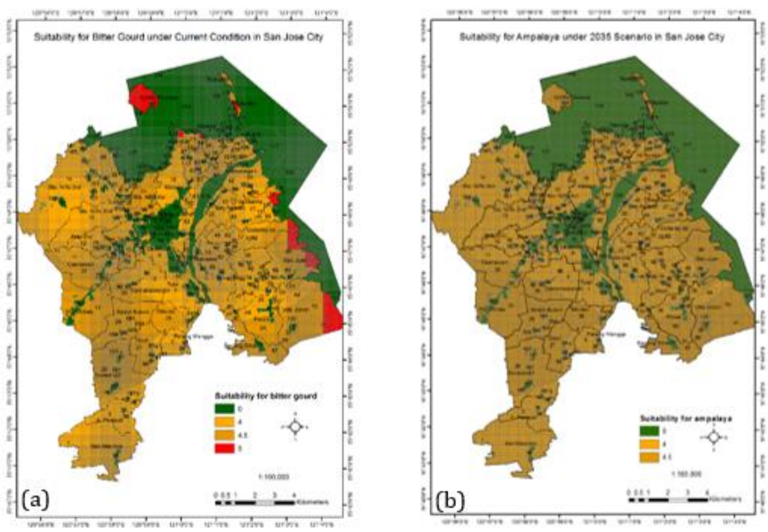


Figure 5 Suitability for bitter gourd in San Jose City: (a) current condition; (b) 2035 scenario

Bitter gourd grows in all types of soil that are well drained; however, the best soil texture for the crop is sandy or clay loam with a pH range of 5.5–6.5 (Gajete et al., 2004). Grids that received a suitability index score of 5 are found in hilly slope covered with Annam clay loam, which is best for upland and lowland rice, corn, root crops, vegetables, and perennial trees (Carating, 2012). Based on the survey, bitter gourd farmers prefer June to August and December to February for planting the crop, which made it possible for most of the grids to receive a suitability index score of 4–4.5 under normal conditions (Figure 5a). Under the 2035 scenario, most of the grids maintained the same scores because of the wide optimum range of temperature for bitter gourd (Figure 5b).

3.3. Crop Yield Estimation

The total rice production is more than the city requirement (Figure 6). There was also an overproduction of onion, considering the demand of only 529 mt/year. Conversely, tomato was underproduced compared to the city's need of 1,095 mt/year. Bitter gourd or ampalaya was also underproduced.

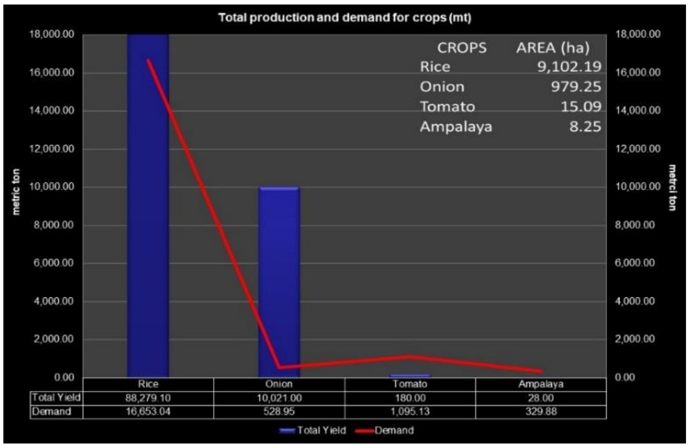


Figure 6 Total production and demand for major crops in San Jose City

Tomato had the largest yield deficiency of 763 tons per annum based on the demand of the city, followed by bitter gourd with a yield deficit of 176 tons per annum. Conversely, there was an overproduction of rice and onion: 71.63 tons and 9.49 tons per year, respectively.

The deficit in the average actual rice production of the city was 1.61 tons/ha when compared to the attainable yield. Rice farming respondents placed typhoons and pests as the top reasons for low yield. Almost 66% and 44% of the respondents relayed that the major pests attacking the crops were insects and weeds, respectively. As stated by the FAO (1993), the highest contributors to crop yield loss are pests and diseases, except for calamities such as typhoons and drought.

Onion production had a deficit of around 6.52 tons/ha. Most of the respondents (80%) mentioned that onions were affected by armyworms. As stated by Arahan et al. (2019), armyworms are the most common pests infesting onions in Nueva Ecija during the production season. Meanwhile, almost half (46%) of the respondents identified pests as the reason for the decline in yield. Aside from typhoons and pests, onion-producing respondents attributed the low yield of onions to flooding. The yield penalties resulting from water logging were at 15% and 80%, depending on the soil type and duration of the stress (Rao, 2011).

Tomato production fell short of 13.33 tons/ha. It was also affected by typhoons and pests. Most (73%) tomato-producing respondents were affected by insects and worms.

Losses due to pests were estimated to be about 34.4% of attainable tomato yield under current production practices worldwide (Zalom, 2003).

Compared to the maximum attainable yield, bitter gourd production was lower than 2.30 tons/ha. Respondents ranked typhoon as the first contributory factor to the low yield of bitter gourd and pests as the second. Insects affected bitter gourd production.

3.4. Input-Output Estimation

Onion and tomato had high production costs of Php 103,137.22/ha/year and Php 99,000.88/ha/year, respectively (Figure 7). These crops also earned high net income of Php 260,298.61/ha/year and Php 600,048.54/ha/year, respectively. Rice and bitter gourd had a low cost of production but with low net income.

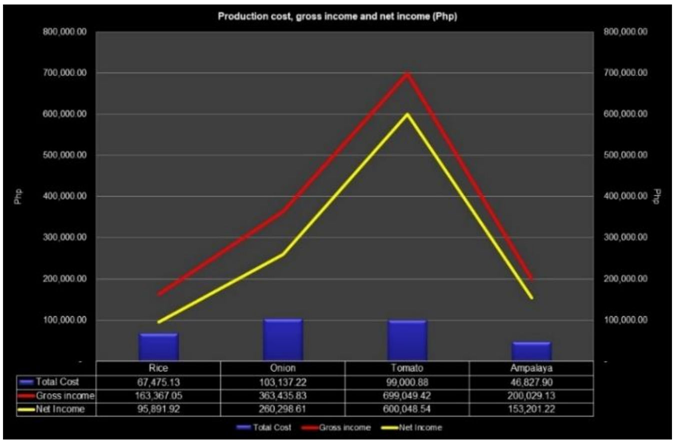


Figure 7 Total production cost, gross income, and net income of farmers

Based on the survey, rice farming respondents had the lowest average annual net income of Php 95,891.92 when, in fact, rice had the largest planting area in the city, covering 9,102.19 ha. According to Bordey et al. (2016), this can be attributed to the low productivity and high production cost of paddy and not the low price received by the farmer. This finding is an indication that farmers need to improve their farm management practices to increase yield and reduce production costs, including labor, fertilizer, seeds, fuel, and transport, to increase their income from rice farming (Salam et al., 2019). Tomato, with a high average yield of production provided a sizable net income of Php 600,048.54, with only 8.25 ha. of planting area.

3.5. Multiple Goal Linear Programming

The 2015 total production of tomato, bitter gourd, rice, and onion in the city was set as the target production under the current conditions. Due to the increase in population, the demand for each crop will naturally increase by 2035.

Under the 2035 scenario, soil characteristics remained the same, and only the suitability scoring on climatic characteristics was altered based on the projected 50-year monthly total rainfall and monthly mean temperature centered in 2035. To simplify the model, the costs of agricultural inputs and the selling prices of the different crops were assumed to be the same in 2035, resulting in no changes in the farmers' income data.

The demographic scenario entailed that more people need to be provided with residential areas. Combined with the scenario of the extreme events, more residents need to be relocated. The total land area to be managed was the remaining agricultural area of 12,991.43 ha both under current and 2035 scenarios.

For the current condition, the water requirement for each crop was based on FAO (1993) computation, whereas for the 2035 scenario, the water requirement for all the crops was projected to increase by 2.3% (Rao, 2011). Annual rainfall was projected to decrease; thus, the total amount of water in the city would be 13,015.17B m^3.

3.6. Decision – Support System

Under the current condition, the city will have an annual tomato production of 268,292.60 tons using a total land area of 4,895 ha—which is more than the current production of tomatoes and more than the demand of the city populace, with the land use resulting from running all the goals (Figure 8a and Table 2). The city would have a bitter gourd production of 155.81 tons per year. Using a total land area of 5.19 ha, the city can exceed the current bitter gourd production but not the demand of the city populace. The city can still meet its current rice production of 88,279 tons and overproduce for the city populace despite the smaller land area for rice production. The current onion production can be met using the recommended land area of 472 ha, smaller by 508 ha. The target production can still be achieved using smaller but more suitable areas for onions. Based on the model, the city can attain a net income of Php 7.2B from the four major crops alone.

The model provided a solution allocating the residential areas mostly needed, specifically in grids under Brgy. Sto. Niño 1st and Malasin, and concomitantly provided for the additional populace of 10,725 based on the 2020 projection. Both villages need large land areas for housing to accommodate the additional populace and relocate people living in slums and unsafe areas. The total land area assigned by the MGLP for the residential area is 567.87 ha.

The total water requirement of the four crops would be 37.82M m^3 per year, which would not exceed the current available water capacity of San Jose City. All the grids in the land area to be managed were assigned with a specific land use type; hence, a total land area of 12,991.43 ha would be used (Table 2).

Under the 2035 scenario, with the land use options processed by MGLP (Figure 8b), tomato production would decrease by 242,177 tons but still surpass the target of 337 tons in 2035 (Table 2). Bitter gourd production would increase from 156 tons/year under the current condition to 192 tons/year. Even with the increase in targets, rice and onion production can still meet the targets in 2035.

Income from the four agricultural systems of the city would still be as high as Php 6,609.21B annually. Residential areas would cover 970.05 ha, which is more than enough for the additional populace of 48,044 (Table 2).

LGUs are provided with optimal land use allocation options that can achieve all the development goals identified. Model outputs, under current and 2035 scenarios, are optimal, as illustrated in one of the villages wherein the land was assigned tomato and rice production, the yield of which exceed the current and target average production per hectare. The income of the respective farmers surpasses the current income and can provide employment for 1,961 and 1,662 people. The area allocated for residential use is 29.48 ha in the village.

The results of the goal programming imply that even with planting in a smaller area, the city may still perform its role as the rice and onion producer of the country. Moreover, it can pursue an increase in tomato production to meet, and even exceed, the current demand of the populace.

Conversely, bitter gourd production can attain its current production with a smaller area. MGLP assigned residential use to grids most needed due to a higher population density, even with a high disaster risk. Residential areas may be assigned to some of the agricultural land recommended for tomato production where there is less disaster risk.

Climate change adaptation was manifested in locating where to plant the major crops that would give the optimum yield and income and provide employment by the MGLP. Thus, appropriate adjustments and changes are required in adapting to climate change to mitigate its negative effects (Akinnagbe and Irohibe, 2014; Ahmed et al., 2019). The land use allocation options provided to the LGUs were optimal under both scenarios. Thus, sound decisions can be made as science-based information and quantified parameters are provided.

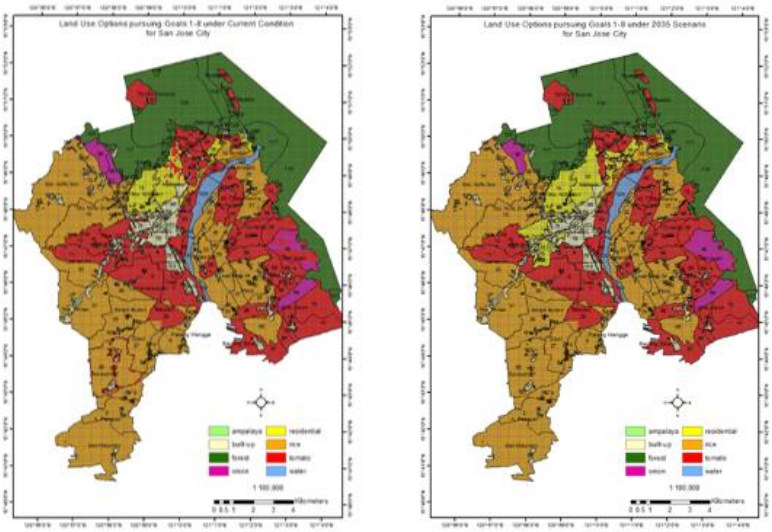


Figure 8 Land use options pursuing Goals 1–8: (a) current condition; (b) 2035 scenario

Table 2 Optimization run results pursuing Goals 1–8 under current and 2035 scenarios in San Jose City, Nueva Ecija, Philippines

			CURRENT CONDITION		2035 SCENARIO	
	Goals	Unit	Target Level	Optimal Achievement Level	Target Level	Optimal Achievement Level
1	Total tomato production	tons	331.98	268,292.60	336.84	242,176.82
2	Total bitter gourd production	tons	154.03	155.81	156.28	191.55
3	Total rice production	tons	88,279.10	88,279.10	89,571.77	89,571.77
4	Total onion production	tons	10,017.73	10,017.73	10,164.42	10,164.42
5	Total suitable residential area	ha	78.53	567.87	351.78	970.05
6	Total farmers' income	Php ('000,000)	1,472.91	7,203.35	1,472.91	6,609.21
7	Total agricultural employment	persons	110,742	354,862	150,348	341,547
	Constraints		Available Level		Available Level	
1	Water used	m^3 ('000,000)	13,022.20	37.82	13,015.17	37.18
2	Land area used	ha	12,991.43	12,991.43	12,991.43	12,991.43

4. Conclusions

The science-based methodology is doable and can be transferred to any LGU so that they can comply with the Hyogo Framework of Action and Climate Change Act of 2009.

The integration of climate change adaptation into the comprehensive land use plan should be done using a systems approach to provide decision-makers quantified parameters as the basis. Decisions on the use of the finite land are vital in the pursuit of economic, social, and environmental development goals.

Since the framework functioned in San Jose City, it can be adopted by other LGUs. One way of adapting to climate change in the agricultural sector is through a modification of the cropping system. For one, farmers may be planting crops based on what used to be planted and not on crop suitability. Farmlands may meet the land and climatic requirements of crops or varieties other than what farmers used to plant. Crops or varieties may be more resilient to the changing climate and thus can contribute more to economic development.

The result of the optimization runs is a sound basis for decision-making because a better understanding of the system (San Jose City) was provided and the prediction of consequences was facilitated. Optimal land use allocation is a tool for climate change adaptation toward the resiliency of the community.

This study offers the following recommendations: (1) crops planted in different distinct seasons may be included in the MGLP to identify more specifically the use of the land by making it as another type of crop; (2) minimizing disaster risk specific to agriculture may be customized by considering only drought and/or flood as hazards; (3) constraint regarding the assignment of grids for residential use with specific risk scores may be added; (4) in the disaster risk assessment, the coping capacity may be considered another element in the vulnerability equation, including but not limited to a good governance index, material insurance, and hospital services; and (5) in vulnerability assessment, the weights of the factors considered in exposure, susceptibility, and a lack of adaptive capacity must be validated in the Philippine setting.

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