Evaluating Agricultural Land Suitability and Vegetable Production in East Bay Area

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ABSTRACT

Urbanization is growing globally. 68% of population will be living in the urban area in 30 years. As the result, residences will struggle with food security and limited job opportunity during the process of urbanization. In order to solve those problems, local government needs to balance up the development of economy, environment, and society at the same time. Urban agriculture can be used as a tool to resolve those problems, since it is able to provide job opportunity, stable food supply, and green space to the city. Geological information system, local demography data, USDA food consumption report are used to compute the agriculture suitable land and potential food production for the East Bay area. There is 10.0% of the land in East Bay is highly suitable for agriculture, 10.1% of land is moderately suitable for agriculture, 32.5% is poorly suitable for agriculture, 4.6% is barely suitable, and 42.8 % is unsuitable. If we use all the land except unsuitable area to perform intense level agriculture practice, it can produce 8475% times of current vegetable consumption. If only highly suitable area is used with sustainable level agriculture practice, it is able to produce 116% times of recommended vegetable consumption. Urban agriculture is able to supply the local vegetable need while mitigating the unemployment problem and greening the city. Stack holders at highly urbanized cities and cities under urbanization should consider incorporating urban agriculture as part of city system.

KEYWORDS

Geological Information System, Analytical Hierarchy System, Suitability Analysis, Urban Agriculture, Food Security

INTRODUCTION

Urbanization is taking a big proportion of land resource globally. According to the UN 2018 Revision of World Urbanization Prospects, there will be another 2.5 billion people live in urban area in the next 30 years, meaning 68 % of the whole population will be living in the city. By that time, food security will be a big problem (Chen 2007 and Djurfeldt 2010). Food security can be broken down to food availability, food accessibility, and food satbility. People lived in the city can only get food that grocery store offers, having less diverse of food option (Pinstrup-Andersen 2009). Residence will not have enough micro-nutrient availability while be controlled by the food price (Tranchant et al. 2018). Food availability and accessibility become problems. Food stability as well, residence cannot get food when outside source is not available (FAO 2017). Food security quite affects urban residence.

Beside the food issues, urbanization makes cities have difficulty to create enough job opportunity for the poor and new migration, resulting high unemployment rate which endanger the public security (Melwor 1991, and Sato and Zenou 2015). San Francisco bay area, one of the most urbanized areas in the world, most of land resource is limited only for industrial and business use. According to the 2016-2017 Economic Outlook Report, the economic structure of East bay focused on science and technology-focused. However, science and technology-related jobs require higher education which limits the chance for residence without high education degree to get jobs. Additionally, local employment market started to meet the plateau. According to the regional economic profile, the year to year non-farm job change starts to decline at 2016, meaning that the chance for poor to get job gets smaller year by year. Since local policies strongly support small business, making it holds a big share on the employment market (2016-2017 Economic Outlook Report). For poor and women stay at home, performing urban agriculture is good option to make profit without special license, complicated skill, and fixed schedule.

In order to solve unemployment and food security problem while having limited space, incorporating agriculture as part of the city is the solution (Pribadi and Pauleit 2015). Agroecology is a new idea of sustainable agriculture which focus on balancing up the environmental health, ecologic profitability, and social equality (Silici 2014). Urban agriculture which follows agroecological principle provides an opportunity to utilize empty patches to perform agriculture practice within the city, mitigating the land use conflict between urbanization and agriculture while providing creating additional employment opportunities and providing food supply (Castells 1983).

For better city planning and land management, land suitability assessment is used to evaluate the level of suitability for certain activity at study area (Bodaghabadi et al. 2015). For urban agriculture, land suitability analysis can be applied to identify the suitability level of the land for specified agriculture practice (Halder 2013). Land could be classified into potential agriculture zone based on the evaluation characteristic we choose (Bandyopadhyay et al. 2009). Food and agriculture organization guidelines on land evaluation is popular rule for land suitability. Land suitability analysis will be based on soil, weather, landscape, erosion hazard, and flood data (FAO 1976). GIS and remote sensing can be used for spatial analysis in order to give a visual view for agriculture suitable land (Herold et al. 2003).

METHOD

Study site

The study was taken place in the San Francisco East Bay area, which is located at the north part of the California, US (Figure 1). For the geographic coordinate system, the East Bay area is located between the northern latitude 38°05’44’’and 37°26’09’’ and western longitudes 122°26’53’’, 121°32’44’’ (Google Earth, 2019). According to the League of California Cities, the East area is considered as the combination of Contra Costa and Alameda County, including 33 cities (East Bay 2019). The approximate surface area of the east bay area is 3760 km^2 and the population is 2,559,296 (State & County Quick Facts 2019).

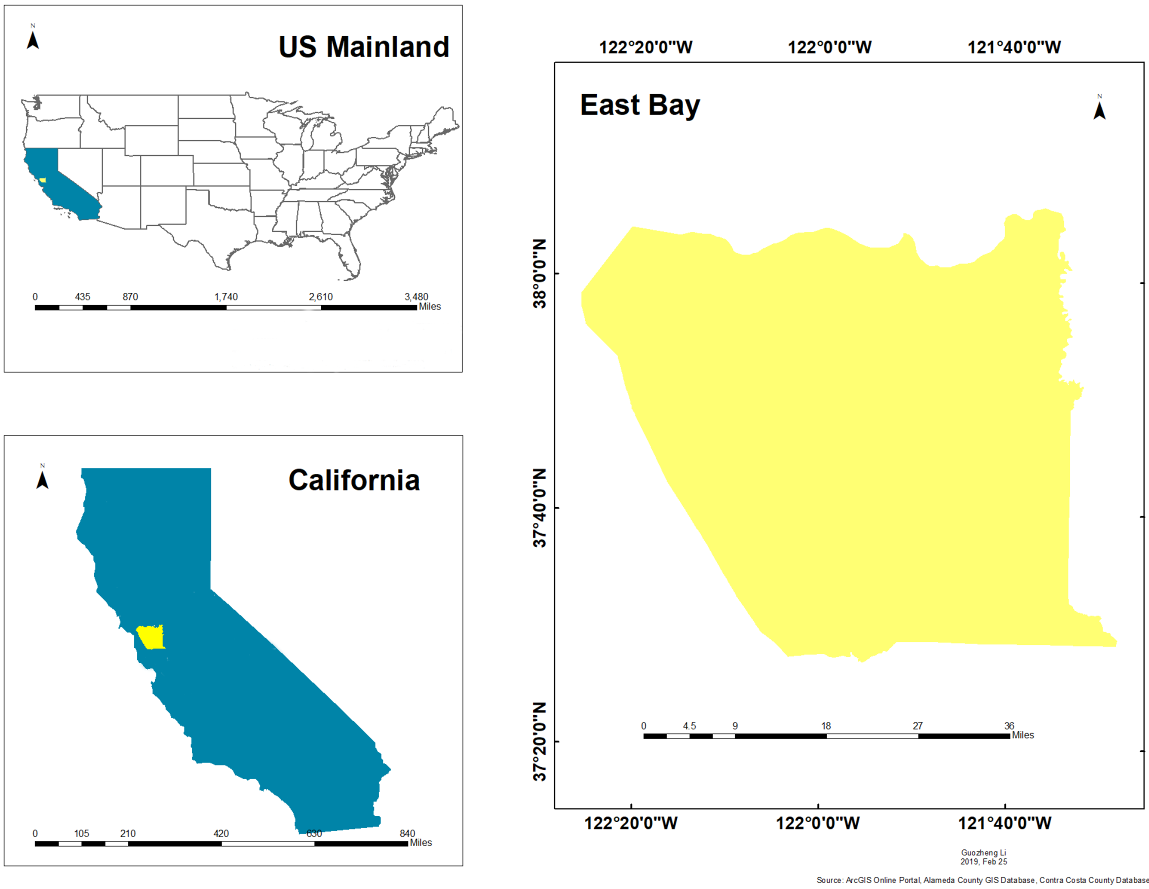

Figure 1. Study site location

Project framework

In this project, I generated the land suitability map for East Bay area and vegetable production, vegetable consumption, and in what percentage can local supply its own vegetable. In order to do that, I collected multiple data layers to generate the overall land suitability map. Then, the agriculture suitable land was used as input to compute food production. And local population and individual consumption were used to compute food consumption (Figure 2). Finally, I computed in what percentage we can supply local vegetable needs in East Bay Area.

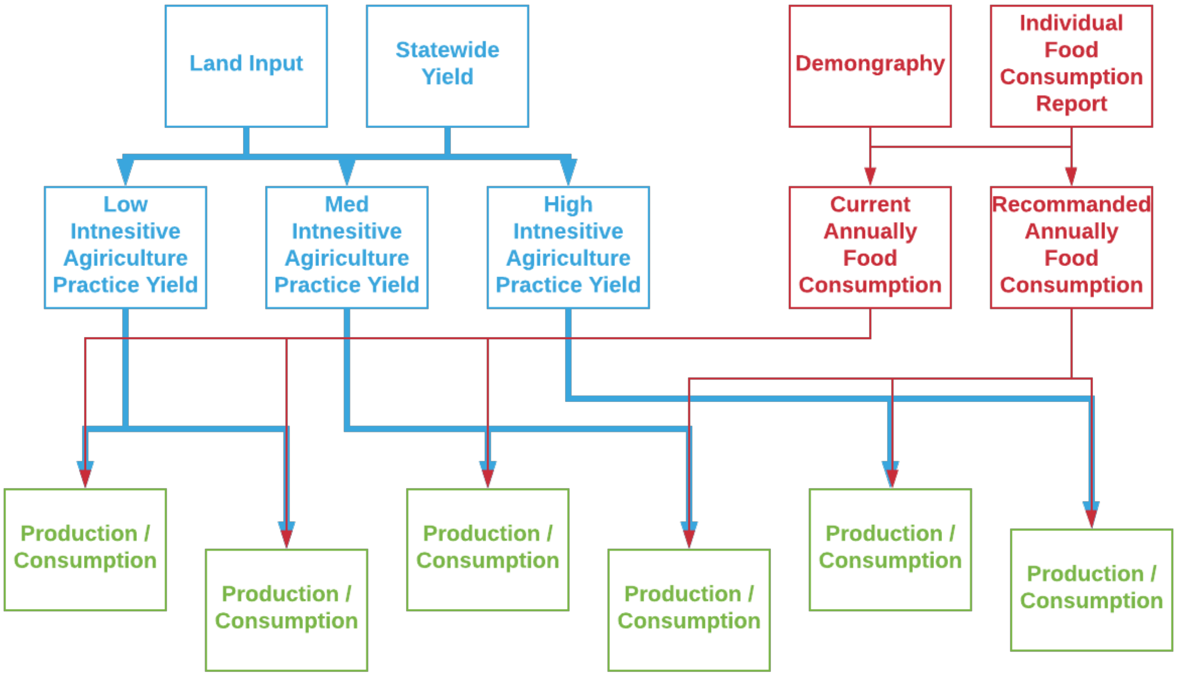

Figure 2. Project framework

GIS analytic framework

Based on the land evaluation framework from Food and Agriculture Organization (1976) and the ideas from *Agricultural land use suitability analysis using GIS and AHP technique* by Akıncı et al (2013), I used Analytical Hierarchy Process as the framework for land evaluation study since it provides top-down analytic system for multi-variables (Saaty 1977, 1994) (Figure 3).

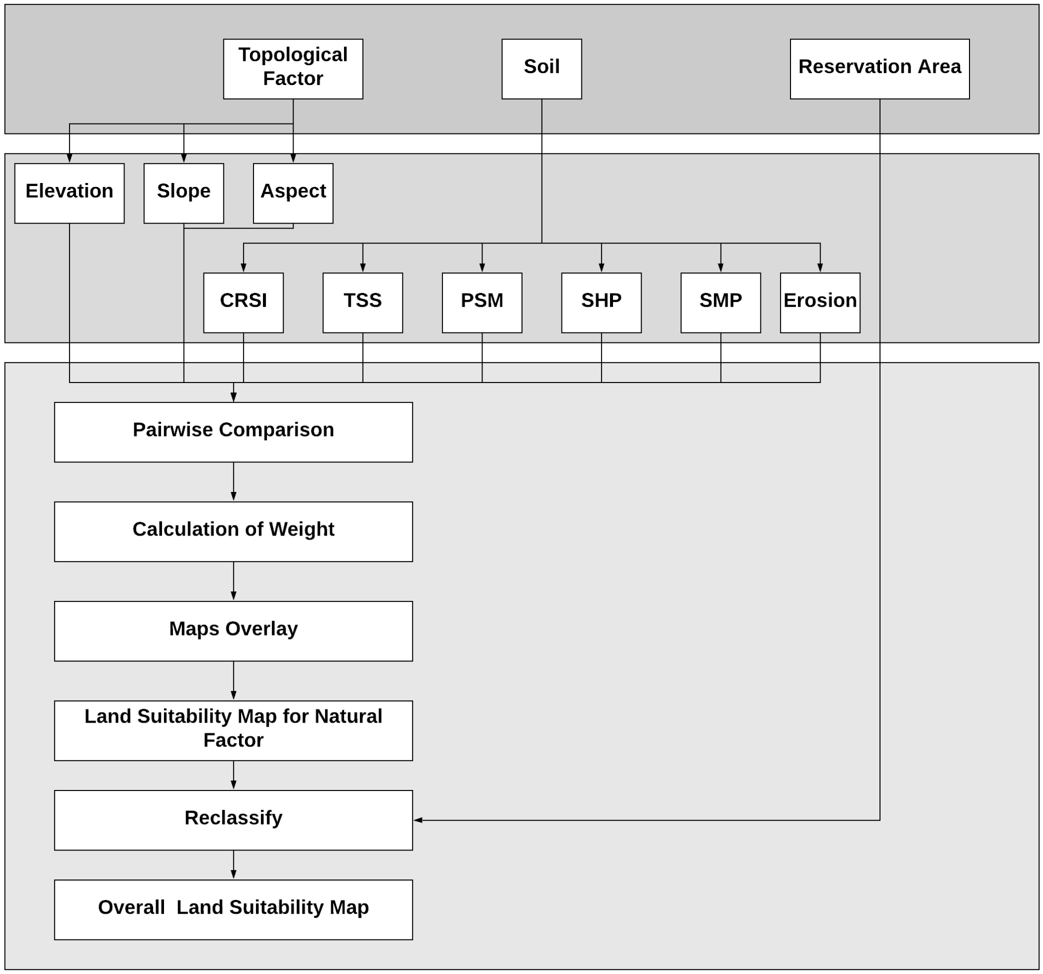

Figure 3. GIS flow chart

Pairwise comparison matrix was used to calculate the weight for each main criteria and sub-criteria in order to build the hierarchy system (Öztürk and Batuk 2010). First, I constructed the rating chart for each criterion by assigning corresponding score of importance to each criteria based on the pairwise scale chart (Table A1 and A2); Then, I normalized the score for each criterion and calculate the weight for each criteria; At last, I performed a consistency ratio check to prove the validity of the weighting process (Saaty and Vargas 1991) (Table A3).

Parameters for Land Suitability Analysis

To determine the level of suitability for agriculture purpose, the California Revised Storie Index, suitability for hand-planting, suitability for mechanical-planting, the potential for seeding mortality, soil erosion, slope, elevation, and aspect were used. Those parameters provide wide breadth information to develop the land evaluation project.

CRSI. (Figure A1(b)) California Revised Storie Index (CRSI) is an evaluating system that focuses on analyzing the suitability of land for irrigated agriculture in California (Ogeen 2008). Based on the soil profile development, texture, slope, and other variables, the CRSI classifies land into 6 categories which are excellent, good, fair, poor, very poor and nonagricultural (Web soil survey).

PSM. (Figure A1(d)) The potential for seeding mortality illustrates the death rate of seeding under natural causation like soil quality, climate change or flooding (Web soil survey). It divides the land into four categories. Low category means the death of seeding is unlikely to happen. Moderate level means that the situation is worse than desirable. Death of seeding happens sometimes. High level means there are multiple natural factors that affect seeding mortality.

SHP. (Figure A1(f)) Suitability for hand-planting indicates how difficult it is to perform hand-planting agriculture. Depends on the rock fragment, surface texture, slope, and other factors. The system classifies land into three categories. Well-suited means that there is no limitation for processing hand-planting. Moderately suited means that hand-planting works only under certain management or agriculture system. Poorly suited means that there are multiple undesirable factors that could affect the hand-planting. Unsuited means that the place is not acceptable for hand-planting (Web soil survey).

SMP. (Figure A1(h)) Suitability for mechanical planting indicated the difficulty of planting by using a mechanical planter. By analyzing rock, soil texture, depth to water, the system classify land into four categories (Web soil survey). Well suited means that good performance will occur expected. Moderately suited means it is suitable for certain management system. Poorly suited means that one or more unfavorable factors exist. Unsuited means that the place is not suitable for mechanical planting.

TSS. (Figure A1(i)) Top soil quality is crucial for plant to grow. The healthy top soil should contain organic matter and microbials which increase the nutrients absorption and moisture restoration for plant growth (Henis 1994). In the shapefile provided by web soil survey, soils are classified into three categories which are good, fair, and poor.

Slope. (Figure A1(g)) As the slope increase, the thickness of the top soil layer decreases (Atalay 2006). Slope can also be used to predict the level of erosion (Koulouri and Giourga 2007). Therefore, poor soil quality exists as the slope increase (Atalay 2006), leading to poor soil depth and fertility. Additionally, the slope plot is hard for machinery tool to be employed.

Soil erosion. (Figure A1(e)) Soil erosion t-factor Indicates average rate of soil erosion in ton per acre per years, indicates the healthy level of seedbed for vegetation (Web Soil Survey and Soil T-Factor).

Aspect. (Figure A1(a)) In order to maintain the physiological activities of plants, the optimal aspect and elevation are crucial. Generally, plants face to the south and west, getting enough solar radiation in a day (Måren et al 2015).

Elevation. (Figure A1(c)) Variation of temperature can cause the delayed flowering, slow growth, and mortality of plant (Atalay 2006). As the increase of elevation every 100 meter, the temperature will drop by 0.5 °C.

Software

ArcGIS was used for integration multiple maps to obtain the final suitability map (Figure 4 and 5). Excel was used to calculate pairwise matrix and make charts (Table A2 and A3).

Data Source

Topography maps (Figure A1 (a), (c), and (g)) will be generated by using satellite image from USGS. TSS, PSM, CRSI, Erosion, SMP, and SHP shapefiles were accessed by visiting Web soil survey (Figure A1 (b), (d), (e), (f), (h), and (i)). Conservation Area and Regional Parks was accessed by visiting ArcGIS online portal.

Food Consumption and Production

Based on the method and yield data in *Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California* used by Mcclintock et al's (2013) in their research, I calculated the potential food production based on land suitability map I generated (Figure 5). The annually total recommend vegetable consumption and the annually total current vegetable consumption will be generated by using demographic data and USDA residential food consumption report (Table A5).

RESULTS

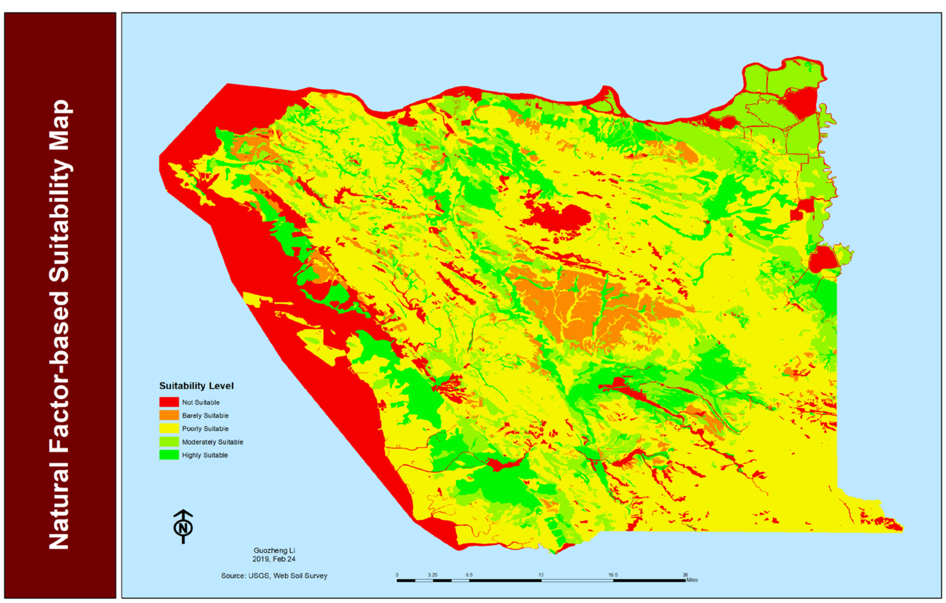

Figure 4. Natural factor-based suitability map

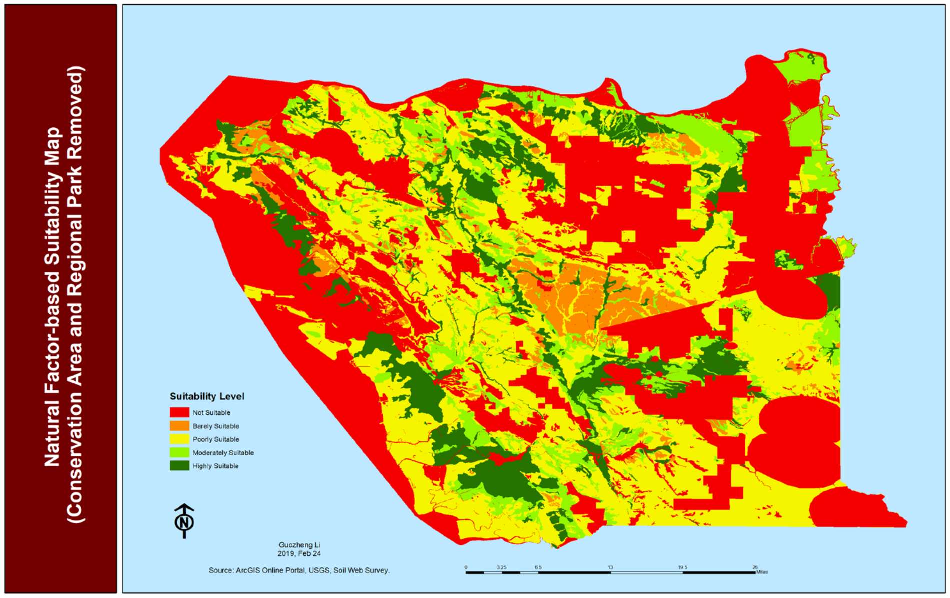

Figure 5. Natural factor-based map (conservation area and regional park removed)

Table 1. Areal and percentile distribution of result maps

Natural Factor-Based Suitability Map	**Level of Suitability**	**Area (ha)**	**Area (%)**	**Natural Factor-Based Suitability Map (Conservation Area and Regional Park Removed)**	**Level of Suitability**	**Area (ha)**	**Area (%)**	**Removed Area (ha)**	**Area Declined Rate (%)**
	Highly Suitable	52104	12.4		Highly Suitable	42933	10.0	9171	17.6
	Moderately Suitable	61371	14.6		Moderately Suitable	43431	10.1	17940	29.2
	Poorly Suitable	213586	50.9		Poorly Suitable	139201	32.5	74385	34.8
	Barely Suitable	22306	5.3		Barely Suitable	19648	4.6	2658	11.9
	Unsuitable	70138	16.7		Unsuitable	183426	42.8	-113288	-161.5

According the land suitability map generated (Figure 4), there is 12.4 % of the land in the East Bay area is highly suitable for agriculture, 14.6% of land is moderately suitable for agriculture, 50.9% is poorly suitable for agriculture, 5.3 is barely suitable, and 16.7% is unsuitable. After removing the conservation area and regional parks (Figure 5), there is 10.0% of the land in east bay is highly suitable for agriculture, 10.1% of land is moderately suitable for agriculture, 32.5% is poorly suitable for agriculture, 4.6% is barely suitable, and 42.8 % is unsuitable (Table 1).

The annual individual vegetable consumption for residence younger than 5 years old is 13,671 Metric tons. For residence age from 5-18 years old is 92,454 Metric tons. For residence age from 18-65 years old, the total annual vegetable consumption is 465,119 Metric tons. And for residence age over 65 years old is 66,895 Metric tons. The total recommend consumption is 638,139 Metric tons a year for all east bay residence. According to the USDA food consumption report, American residence only meet 21% of recommend vegetable consumption. I followed the same assumption as Mcclintock et al's (2013) did, I assumed that East Bay residences share the same pattern which only meet 21% of recommend vegetable consumption. The total current vegetable consumption will be 134,009 Metric Tons (Table 2).

Table 2. Food Production

Intake Level (Metric Ton)	**Intensity of Agriculture Practice**	**Yield (Metric Ton/ha)**	**Area Needed (ha)**	**% production out of vegetable needs (only use 75% of the area as farm area)**			
				Highly, Moderately, Poorly, and Barely Suitable Area (270,493 ha)	Highly, Moderately, and Poorly Suitable Area (250,303 ha)	Highly and Moderately Suitable Area (89,804 ha)	Highly Suitable Area (43,286 ha)
Current 134,009	Conventional	22.4	5982.5	3390%	3135%	1125%	542%
	Low	33.6	3988.4	5086%	4943%	1688%	810%
	Med	56	2393	8475%	7845%	2813%	1358%
Suggested 638,139	Conventional	22.4	28,488	713%	660%	240%	116%
	Low	33.6	18,992	1065%	990%	353%	173%
	Med	56	11,395	1778%	1650%	593%	285%

If we use all the land except unsuitable area to practice a intense level agriculture practice which gives the highest yield while deplete the sol the most, we can produce 8475%times of current consumption. Exclude the barely suitable area, we can produce 7845%times of current consumption. If we only use highly suitable and moderately suitable area, we can still produce 2813% times of current consumption. For highly suitable area, we are able to produce 1358% times of consumption for the current vegetable consumption level. This provides enough food for the East Bay area if we keep the current level of consumption. If we use all the land except unsuitable area to practice a sustainable level of agriculture practice which provides the lowest yield while is the most sustainable for soil, we can produce 713% times of recommended consumption. Exclude the barely suitable area, we can produce 660%times of recommended consumption. If we only use highly suitable and moderately suitable area, we can still produce 240% times of recommended consumption. For highly suitable area, we are able to produce 116% times of consumption for the recommended vegetable consumption level. This provides enough food for the East Bay area if we keep the recommended level of consumption.

DISCUSSION

According to the natural factor-based land use suitability map, 12.4 % of the land in the East Bay area is highly suitable for agriculture. After removing the conservation area and regional parks, highly suitable area drops by 19.4%. There is still 10.0% highly suitable land left. Most of highly and moderately suitable area locate at west side of the East bay, southern Livermore city, and Pleasant Hill. Poorly suitable area which is high slope and hill spread all over the east bay area. Barely suitable area which is occupied by high dense residential area locates at North side of Livermore city. Unsuitable area are conservation area, regional park, and water bodies.

By using the land except unsuitable area to perform intense level agriculture practice, it will yield 8475% times of current consumption. If only high suitable area is used with sustainable level agriculture practice, it will yield 116% times of consumption for the government recommend vegetable consumption level. Since the highly suitable area generally is trail and natural area right next to residential area, it is highly possible to introduce agriculture practice to those area.

However, there are still limitations which could stop or slow down development of urban agriculture in the East Bay area. First, highly suitable area is located at surrounding of conservation and regional park. Agriculture practice remains possibility within those places, but negotiation is required with local government to balance local recreation service and local agriculture farms. Combing regional park with agriculture practice might be a good choice. Second, the land price is too high, making it is hard for private owner to initiate business. Third, agriculture may contradict to local city planning. The space is limited, agriculture is considered a low valuable industry in a metropolitan. Lastly, the local law also requires operator to hold license to start agricultural operation, and trading. According to DailyCal, Berkeley city council allowed low-intensity and low-production to trade their food without special permits while follows the food safety law. However, high-production urban farm still requires license to operate the farm and the business.

The future of agriculture in East bay is bright. Stack holder should have realized the benefit of urban agriculture to the rapid urbanization. It seems like that agriculture doesn't create that much directly economic profit, but it will be beneficial to local government and family by supporting local food system, creating employment, bonding local community and reducing crime rate. It is necessary to incorporate agriculture as part of the urban system.

This experiment is about to find the agriculture suitable land in East bay area and the amount of food production in order to show the agriculture potential of East bay at a macro scale. Therefore, this experiment doesn't analyze geospatial data at a micro scale. There could be more area available for agriculture if we can compute the space for all the backyards and rooftops in East bay area. Precise and accurate experiment require Lidar, drone, GIS program, time, super computer, enough labor, and strong funding. Therefore, it is hard to map out the suitability map in a micro scale. Land suitability analysis is unlike from other statistical analysis project which is based on numerical data only. It can be complicated if we have more categorical data which cannot be quantified. Further research is needed on field data collecting technology, correlation relationship between multiple natural factors, and social impact of agriculture.

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APPENDIX A: Urban agriculture Index

Table A1. The scale for pairwise comparison (Saaty & Vargas, 1991)

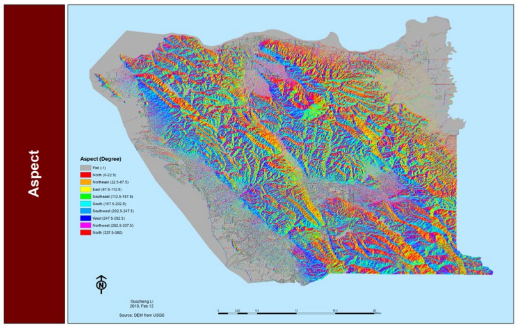
Intensity of Importance	Explanation
1	Two criterion weigh equally to the objective
3	One criteria slightly weigh over another
5	One criteria moderately weigh over another
7	One criteria strongly weigh over another
9	One criteria dominantly weigh over another
2, 4, 6, 8	Weigh in between two level of importance

Table A2. Pairwise comparison matrix

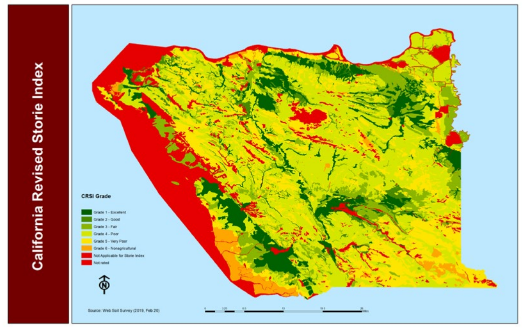
Criteria	CRSI	TSS	PSM	SHP	SMP	Slope	Aspect	Elevation	Erosion	Weight
CRSI	1	2	2	2	2	4	6	8	9	0.243
TSS	1/2	1	2	3	3	4	6	7	9	0.224
PSM	1/2	1/2	1	2	2	3	4	5	7	0.150
SHP	1/2	1/3	1/2	1	2	3	4	5	6	0.124
SMP	1/2	1/3	1/2	1/2	1	3	4	5	6	0.108
Slope	1/4	1/4	1/3	1/3	1/3	1	3	5	6	0.072
Aspect	1/6	1/6	1/4	1/4	1/4	1/3	1	1	2	0.031
Elevation	1/8	1/7	1/5	1/5	1/5	1/5	1	1	1	0.024
Erosion	1/9	1/9	1/7	1/6	1/6	1/6	1/2	1	1	0.020
Consistency Index (CI) = -0.864										
Random Index (RI) = 1.46										
Consistency Ratio (CR) = CI/RI = -0.59										

Table A3. Weight and score of parameters

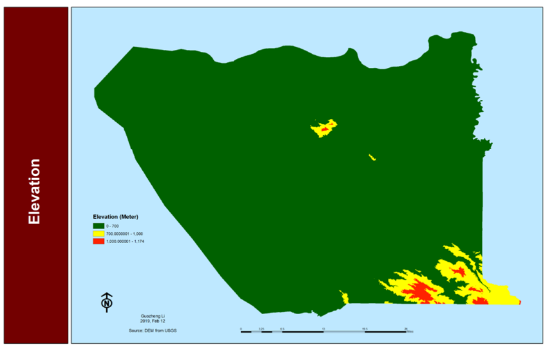
Main Criteria	Weight	Sub-Criteria	Score
CRSI	0.243282	Grade 1 – Excellent	10
		Grade 2 – Good	8
		Grade 3 – Fair	6
		Grade 4 – Poor	4
		Grade 5 – Very Poor	2
		Grade 6 – Non-agriculture	0
		Not Applicable for Storie Index	0
		Not Rated	0
TSS	0.224088	Good	10
		Fair	8
		Poor	6
		Not Rated	0
PSM	0.15060553	High	10
		Moderate	7
		Low	5
		Not Rated	0
SHP	0.12463432	Well Suited	10
		Moderately Suited	8
		Poorly Suited	6
		Unsuited	0
		Not Rated	0
SMP	0.10860829	Well Suited	10
		Moderately Suited	8
		Poorly Suited	6
		Unsuited	0
		Not Rated	0
Slope (degree)	0.07204149	0-10	9
		10-20	7
		20-30	5
		>30	3
Aspect	0.03178393	S, SW, SE	8
		N	7
		NW, NE	5
		W, E	2
Elevation (m)	0.02491595	0-700	10
		700-1000	9
		1000-1300	7
Erosion	0.02003612	0	10
		1	8
		2	6
		3	4
		4	2
		5	0


Aspect
Aspect (Degree)

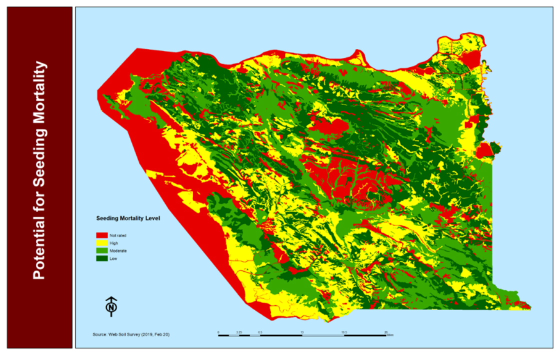
(a)


California Revised Storie Index
CRSI Grade

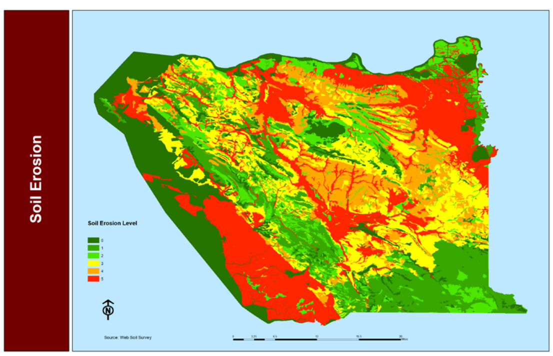
(b)


Elevation
Elevation (Meter)

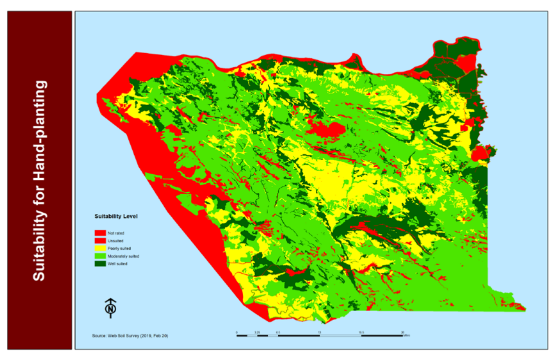
(c)


Potential for Seeding Mortality
Seeding Mortality Level

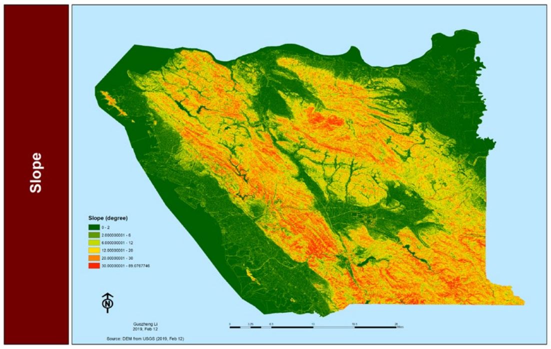
(d)


Soil Erosion
Soil Erosion Level

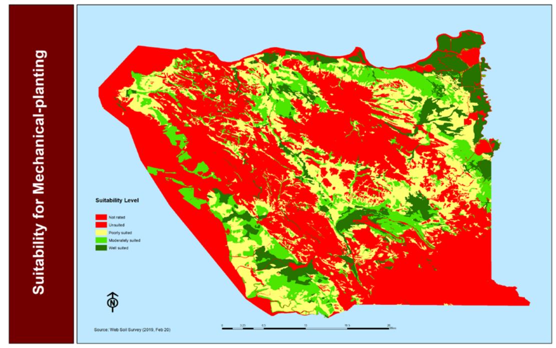
(e)


Suitability for Hand-planting
Suitability Level

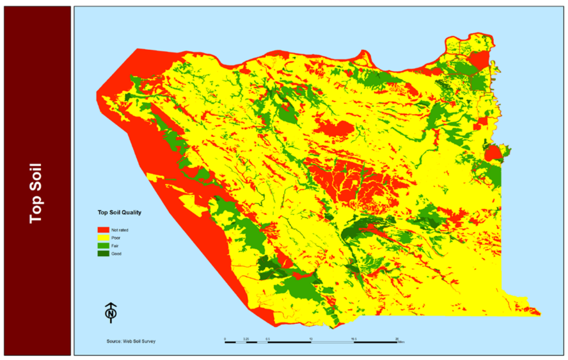
(f)



(g)



(h)



(i)

Figure A1. Maps for Parameters. (a) Aspect, (b) CRSI, (c) Elevation, (d) PSM, (e) Soil erosion, (f) SHP, (g) Slope, (h) SMP, (i) TSS.

Table A4. Areal and percentile distribution of each parameters

Main Criteria	Sub-Criteria	Area (ha)	Area (%)
CRSI	Grade 1 – Excellent	42917	10.2
	Grade 2 – Good	8353	2.0
	Grade 3 – Fair	51004	12.1
	Grade 4 – Poor	154125	36.6
	Grade 5 – Very Poor	74148	17.6
	Grade 6 – Non-agriculture	13087	3.1
	Not Applicable for Storie Index	75921	18.1
	Not Rated	1035	0.2
TSS	Good	8295	2.0
	Fair	52475	12.5
	Poor	262653	62.4
	Not Rated	97171	23.1
PSM	High	94536	28.4
	Moderate	117222	35.2
	Low	111666	33.5
	Not Rated	9717	2.9
SHP	Well Suited	69911	16.6
	Moderately Suited	200041	47.6
	Poorly Suited	80462	19.1
	Unsuited	123	0
	Not Rated	70058	16.7
SMP	Well Suited	40528	9.6
	Moderately Suited	59128	14.1
	Poorly Suited	92607	22.0
	Unsuited	158273	37.6
	Not Rated	70058	16.7
Slope (degree)	0-10	230547	53.1
	11-20	25604	5.9
	21-30	19151	4.4
	30 and above	159016	36.6
Aspect	S, SW, SE	57135	31.7
	N	16290	9.0
	NW, NE	47807	26.5
	W, E	58916	32.7
Elevation (m)	0-700	402932	95.6
	700-1000	15343	3.6
	1000-1300	3307	0.8
Erosion	0	72618	17.3
	1	65594	15.6
	2	44509	10.6
	3	73582	17.5
	4	54474	13.0
	5	109817	26.1

Table A5. East Bay Demography and Individual Food Consumption

East Bay Population						**Individual Consumption**		**East Bay consumption**
	Alameda		Contra Costa		Total Population			
Age	%	Population (2017)	%	Population (2017)		Cups/day	Kg/year	Metric Ton/year
<5	5.9	98,128	5.7	65,404	163,532	1	83.6	13,671
5-18	14.8	246,152	17.1	196,212	442,364	2.5	209.0	92,454
18-65	68.8	1,144,275	61.9	710,265	1,854,540	3	250.8	465,119
>65	13.5	224,531	15.3	175,558	400,089	2	167.2	66,895
Total	100	1,663,190	100	1,147,439	2,810,629			638,139