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LAND SUITABILITY AND SENSITIVITY ANALYSIS FOR PLANNING APPLE GROWING IN MALA'S VALLEY, PERU

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ABSTRACT

This study determined the suitable zones for planning apple growing in Mala's valley, Peru, using analytical hierarchy process (AHP) in a geographic information system (GIS) environment. The suitability evaluation involved the analysis of nine criteria organized into four groups (soil, topography, hydro-climate and socioeconomic). Based on key informants assessments relative weights were assigned to each nine criteria using the AHP. A digital GIS database was developed with all the thematic maps. The criteria were reclassified before combination, according to a four-class system for suitability. Then, a summarized process was done by applying the weights to each criterion, followed by a summation of the results to yield a suitability map using GIS. Layer and weight sensitivity methods combined with Kappa analysis were carried out in order to prove the robustness of the suitability model. The results revealed that about 12.57 % (9953 ha) of agricultural area are suitable for apple cultivation and out of which 3.98 % and 3.37 % are highly and moderately suitable, respectively. If farmers in the valley considered growing apple crops in the 3149 ha (highly suitable), the gross profit would have substantial increase. Therefore, the final map can become a useful tool of territorial governance and policy in order to assist in the agricultural expansion process of Mala's valley.

Additional key words: Analytical hierarchy process, geographic information system, Kappa analysis, *Malus domestica*, multicriteria decision making

RESUMEN

Aptitud de la tierra y análisis de sensitividad en la planificación del cultivo del manzano en el valle Mala, Perú

Se determinaron las zonas aptas para la planificación del cultivo del manzano en el valle Mala, en Perú, mediante el uso del proceso analítico jerárquico (AHP) en un sistema de información geográfica (SIG). La evaluación de la aptitud implicó el análisis de nueve variables organizadas en cuatro grupos (suelo, topografía, hidro-clima y socioeconómico). El método AHP se aplicó para asignar los pesos relativos a las nueve variables tomando como base las valoraciones de los informantes clave. Antes de combinarlas, las variables, fueron reclasificadas en cuatro clases de aptitud. Seguidamente, se aplicaron los pesos relativos a cada variable y, utilizando un SIG, se sumaron todos los mapas arrojando un mapa integrado de aptitud. La robustez del modelo de aptitud se probó con dos métodos de sensibilidad, uno para las variables y otro para los pesos relativos combinados ambos con el análisis estadístico Kappa. Los resultados expusieron que el 12,57 % (9953 ha) del área de estudio es apta para el cultivo de manzano y dentro de ésta el 3,98 % y el 3,37 % son de clase alta y moderada, respectivamente. Si los agricultores cultivaran las áreas con alta aptitud (3149 ha), el beneficio bruto aumentaría sustancialmente. Así, el mapa final puede convertirse en una herramienta útil para la gobernanza y la política territorial que ayude en la expansión agrícola del cultivo de manzano en el valle de Mala.

Palabras clave adicionales: Análisis Kappa, evaluación multi-variable, *Malus domestica*, proceso analítico jerárquico, sistema de información geográfica

INTRODUCTION

According to the Statistical and Informatics National Institute of Peru, agriculture is the largest economic sector in labour force demand (more than 25 %). *Malus domestica* as the tenth most important fruit tree product represents the 0.3 % (33 US$ millions) of the Gross Value of Agricultural Production (Agriculture and Irrigation Peruvian Ministry, 2016). The exports and national market of apple is growing and consequently the need for new productive, resource efficient and environmentally friendly land areas.

Land suitability evaluation for agriculture consists of the analysis of data relating to soils, topography, vegetation, climate, water conditions, population, during an effort to match the land

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characteristics with crop requirements (Zabihi et al., 2015; Zhang et al., 2015). The selection of optimal land areas for a particular crop production is an issue that many researchers and organizations have broached through the development of different frameworks (Pan and Pan, 2012; Halder, 2013; Yalew et al., 2016).

Multicriteria decision making (MCDM) method can serve to combine the information from many criteria to form a single index of evaluation, and analytical hierarchy process (AHP) (Store and Kangas, 2001; Chen et al., 2013; Zhang et al., 2015) is one of the most often employed MCDM method for land suitability analysis. AHP method can work using a geographic information system (GIS).

GIS-based MCDM methods include uncertainty associated with model predictions (Malczewski, 1999; Malczewski, 2004). Sensitivity analysis (SA) examines uncertainties into MCDM and GIS to prove the robustness of the suitability model (Store and Kangas, 2001; Gómez and Bosque, 2004; Chen et al., 2010). SA deals with the sources of the variation in an output model and measures the dependency on the information fed into it (Saltelli, 2000). The most important element to consider in SA is criterion weight (Malczewski, 1999).

The objectives of this study were: a) to evaluate the apple land suitability in order to determine the optimum zones using AHP in a GIS environment, and b) to illustrate a pertinent methodology including a SA that demonstrates the consistency of the suitability model in Mala´s valley.

MATERIALS AND METHODS

This study was carried out in the Mala’s valley, which is located in the western part of Peru about 95 km south of the capital (Figure 1). The valley is located in the northern part of the Cañete province and includes four districts: Santa Cruz de Flores, San Antonio, Mala and Calango. The main economic activity is the agriculture. The population at the end of 2015 was estimated as 43,725.

This valley is one of the most important producers of apple fruits in Peru, with approximately 2000 hectares, 21 % of the total national land production (Statistical and Informatics National Institute of Peru, 2012). The total study area covers approximately 791.94 km^2. The altitude of Mala’s valley starts at a height of 0 m in the Pacific Ocean at 3500 m above sea level.

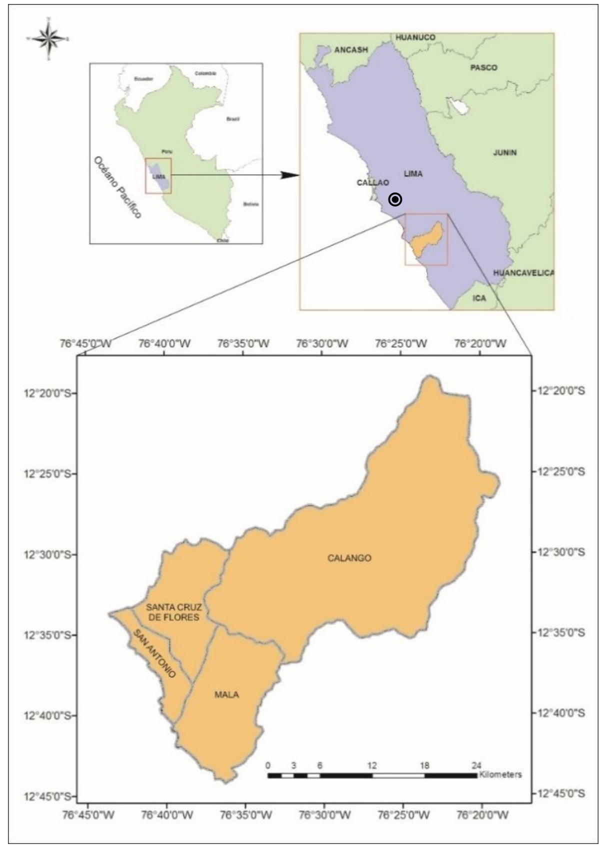

Figure 1. Location map of the study area

Establishing evaluation criteria. Expert information on apple crop was collected with an interview to key informants detailed in Table 1. They were chosen according to their knowledge and professional activities on apple in the study area.

This study established nine crucial criteria organized into four groups according to the literature review (Manandhar et al., 2014; Zabihi et al., 2015; Zhang et al., 2015) and key informants’ opinions (Figure 2).

Assigning weights. The key informants’ assessments were used to derive the relative importance of one criterion to another using the AHP (Saaty, 1980). The procedure consists of three major steps: generation of the pairwise comparison matrix for each hierarchical level (Table 2), the standard weights of the criteria, and the consistency ratio (CR) estimation (Malczewski, 1999). For our study, lambda (λ) = 10.00643191; consistency index (CI) = 0.125803989; n = 9, and random index (RI) = 1.45. Further, the resulting CR value was 0.0867 evidencing that the pairwise comparison matrix had a reasonable level of consistency and that the weight values were valid for the research.

Table 1. Organization and role of the key informants

Organization	Role
Huayuna Institute	Researcher
Agricultural Agency of Mala	Agency chief Agricultural information manager
Agricultural Agency of Cañete	Agricultural information manager
Seasoned veteran farmers	Five informants from Calango Four informants from Mala Three informants from Santa Cruz of Flores
Borough Council of Mala	Land planning manager
Borough Council of Santa Cruz of Flores	Land planning manager
Virgen of Chapi market	Four businessmen

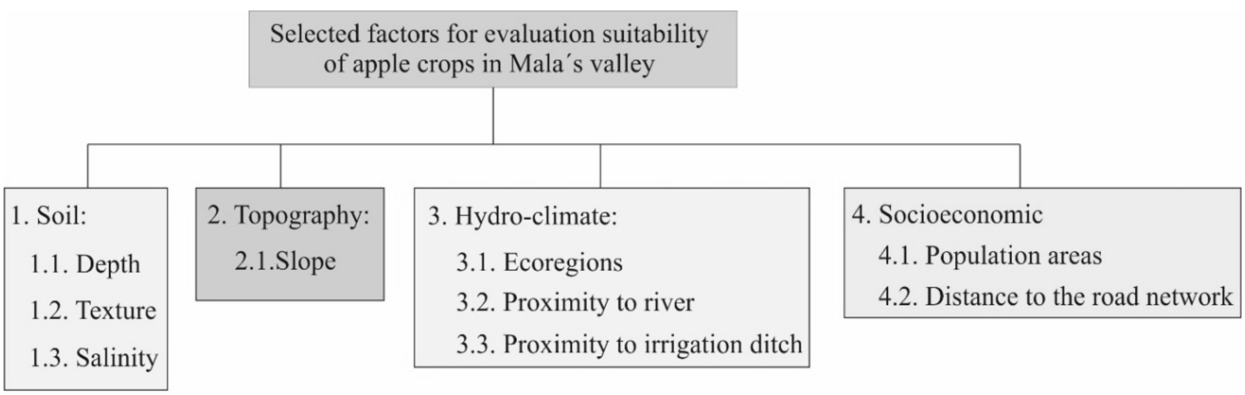

Figure 2. Selected criteria for evaluation suitability

Reclassification of thematic maps. Every criteria data was converted into thematic maps and reclassified into different suitability levels. For practical reasons and according to other authors (Chen et al., 2013; Manandhar et al., 2014; Yalew et al., 2016), the four-class system for suitability used in this study was adapted from FAO (1976), as follows: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N).

Table 3 gives the assigned scaled values to each criterion for reclassification according to their attribute values in each of the four suitability classes. The limits and degree for suitable assessment of apple crops in Mala's valley were determined based on a thorough review of the available literature (references in Table 3) and key informants' opinions.

Table 2. Pairwise comparison matrix for the evaluation criteria and their weights

Criterion	1	2	3	4	5	6	7	8	9	Weight	Ranking
Depth	1	2	1/2	7	8	5	5	9	6	0.233	2
Texture	1/2	1	1/3	6	7	4	4	8	5	0.173	3
Salinity	2	3	1	7	8	5	5	9	6	0.293	1
Slope	1/7	1/6	1/7	1	2	1/3	1/3	5	5	0.052	6
Ecoregions[1]	1/8	1/7	1/8	1/2	1	1/3	1/3	3	3	0.035	7
Proximity to river	1/5	1/4	1/5	3	3	1	1/2	7	6	0.081	5
Proximity to irrigation ditch	1/5	1/4	1/5	3	3	2	1	7	6	0.091	4
Population areas	1/9	1/8	1/9	1/5	1/3	1/7	1/7	1	1/2	0.017	9
Distance to roads network	1/6	1/5	1/6	1/5	1/3	1/6	1/6	2	1	0.025	8

[1] According to Brack and Mendiola (2000) the ecoregions are geographic areas with similar physical, climatic and biological land characteristics. The study area has two ecoregions (and eleven types are identified in Peru)

Summarized procedure. Then, the reclassified scaled values were imported into GIS, in order to create the criterion suitability maps. Finally, a summarized process was done by applying a weight (Table 2) to each reclassified criterion, followed by a summation of the results to yield a suitability map using GIS in a mode comparable to linear combination method:

$$S = \sum(w_i \cdot x_i)$$

where *S* is the land suitability index, w_i the weight of criterion *i*, and x_i is the reclassified scaled value of criterion *i*. Each map polygon got a total score that is categorized according the value range (adapted from Sys et al., 1991) of the index (Table 4).

Consequently, the result is a map that characterizes areas, of high suitability to not suitability, for apple crop production and planting regions.

Sensitivity analysis. Layer and weight sensitivity methods were combined with Kappa statistics (Cohen, 1960) in order to prove the robustness of the suitability model. The consistency of the suitability map was measured with the overall agreement, Kappa coefficient and strength of the agreement (Landis and Koch, 1977). The Kappa coefficient quantifies the degree of agreement between the suitability map and the maps obtained with the sensitivity methods. According to Landis and Koch (1977), the following nomenclature ranges indicates the strength of the agreement: K=<0.00: Poor; K= 0.00-0.20: Slight; K= 0.21-0.40: Fair; K= 0.41-0.60: Moderate; K= 0.61-0.80: Substantial; K= 0.81-1.00: Almost perfect. The overall agreement represents the percentage of coinciding area (and map polygons), under equal class of suitability, among the comparative maps.

Layer sensitivities were organized in three procedures, based in Lodwick et al. (1990). Firstly, “one layer at a time” consisted in removing a criterion once a time; the weights of the criteria in the nine resulting maps were obtained removing one different criterion weight at a time in the pairwise comparison matrix. Each layer removal model was matched to the suitability model. Then, the “combination of layers” involved the removal of the least significance criteria to determine how the suitability model could be shortened. Finally, “criteria group” procedure analyzed the models generated with the weightiest group (soil) and a combination of the others criteria groups.

Weight sensitivity method involved to increase 0.1 of the initial weight assigned to each of the nine criteria (when one is increased by 0.1, the others eights were equally decreased by 0.0125 to keep the sum of weights equal to 1). The nine weight-altering models were compared one by one with the suitability model using Kappa statistics.

Table 3. Criteria, classes and scaled value, limits and degree for suitable assessment of apple crops in Mala’s valley

Criterion	Unit	Classes and scaled values					References
		S1	S2	S3	N		
		1.0	0.75	0.5	0.25	0	
Depth	cm	>90	50-90	-	-	<50	Figueroa (1989); Rodríguez and Ruesta (1996)
Texture	class	Sandy loam, sandy clay loam	Silt loam	Loamy sand, clay loam	-	Gravelly loamy sand, sand, silty clay loam, clay	Rodríguez and Ruesta (1996); Roots of Peace (2008); Manandhar et al. (2014)
Salinity	dS/m	0-2	2-4	4-8	-	>8	Soil Survey Division Staff (1993)
Slope	%	<10	10-20	20-40	-	>40	Westwood (1993); Finnigan et al. (2000); Manandhar et al. (2014); Key informants
Ecoregions	class	Steppe mountain range	Pacific desert	-	-	-	Brack and Mendiola (2000); Key informants
Proximity to river	m	0-1000	1000-2000	>2000-2500	>2500	-	Zabihi et al. (2015); Key informants
Proximity to irrigation ditch	m	0-1000	1000-2000	2000-2500	>2500	-	Zabihi et al. (2015); Key informants
Proximity to populated areas	m	1000-3000	3000-6000	> 6000	-	≤1000	Vega (2005); Ricker et al. (2014); Key informants
Distance to roads network	m	0-500	500-1000	1000-1500	>1500	-	Key informants

Table 4. Index values for the different suitability classes

Value range	Suitability class
> 0.75 – 1.0	Highly suitable
> 0.50 - 0.75	Moderately suitable
> 0.25 - 0.50	Marginally suitable
0 - 0.25	Not suitable

RESULTS AND DISCUSSION

Apple land suitability. Four productivity zones for optimal apple crop production were identified (Figure 3).

Suitability analysis for apple indicates that about 12.57 % of agricultural areas are suitable for apple cultivation and out of which 3.98 % and 3.37 % are highly and moderately suitable, respectively. This land is located nearby the water sources and have excellent soil conditions. Correct irrigation is indispensable to maintaining a healthy and productive apple orchard (Black et al., 2008).

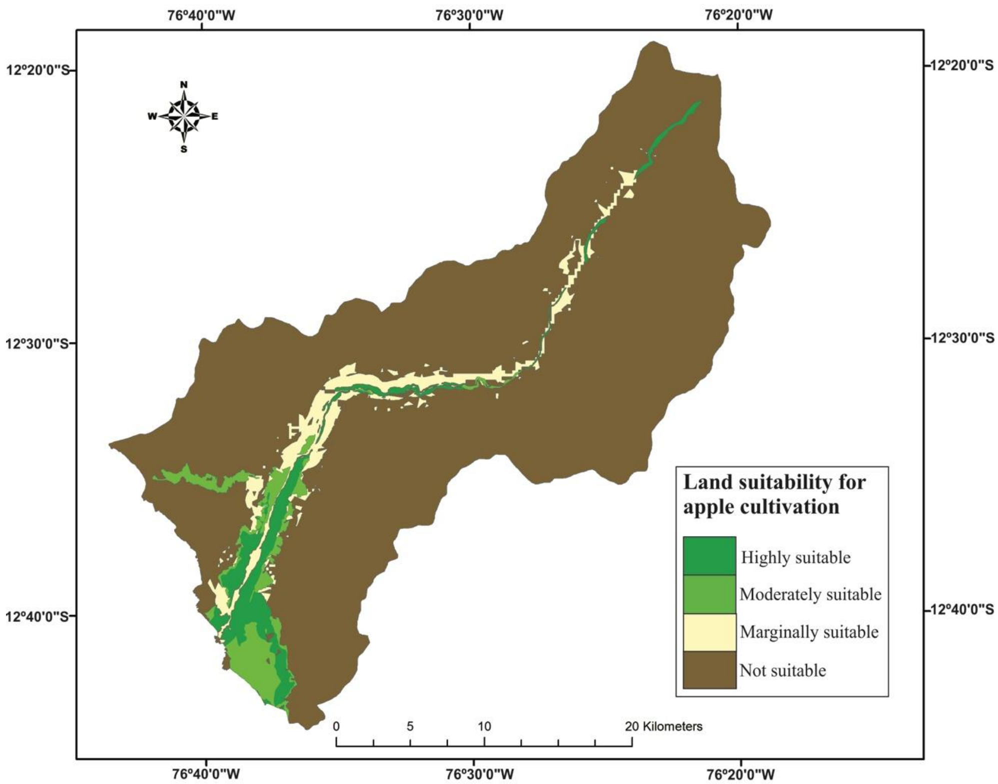

Figure 3. Land suitability zones for apple cultivation in the Mala's valley.

In order to improve soil physics, 90 % of farmers applies guano, manure or farmyard manure (Statistical and Informatics National Institute of Peru, 2012). Marginally suitable areas represent the 5.22 % of the territory and are situated around the river line, in the centre and the north of the study area. This zone has soil limitations. The remaining area (87.43 %) is not suitable for apple crop (Table 5). It is characterized for poor soils, low water resources conditions and steep slopes (>40 % in the northeast side of the valley). According to Finnigan et al. (2000) abrupt slopes cause problems in orchard operations.

Sensitivity analysis

Layer sensitivity. The combination of one-layer removal method and Kappa analysis showed that the model is more sensitive when removing a soil criterion than any one of the others criteria (Table 6a). The elimination of depth, texture and salinity criteria offer "fair", "moderate" and "moderate" consistency, respectively. This demonstrates the importance of the three main criteria, which matches with the opinion of the experts on apple cultivation. The three criteria have the highest weights (together get the sum of 0.774). Saremi et al. (2011), in an apple orchard study in Iran, denoted that the most important limiting factors were the soil conditions.

Table 5. Area under different categories of suitability classes for apple cultivation in Mala's valley

Class	Apple	
	Area (ha)	Area (%)
Highly suitable	3149	3.98
Moderately suitable	2667	3.37
Marginally suitable	4137	5.22
Not suitable	69242	87.43

Table 6. Agreement and Kappa coefficient from the comparison of the suitability map and the resultant map (layer removed)

Procedure	Layer removed (w_i=0)	Overall agreement (%)	Kappa	Strength of agreement
(a) One layer at a time	Depth	75	0.39	Fair
	Texture	81	0.48	Moderate
	Salinity	77	0.45	Moderate
	Slope gradient	94	0.78	Substantial
	Ecoregions	97	0.87	Almost perfect
	Proximity to river	94	0.70	Substantial
	Proximity to irrigation ditch	94	0.65	Substantial
	Population areas	96	0.78	Substantial
	Distance to roads network	95	0.71	Substantial
(b) Combination of layers	Ecoregions + Slope gradient + Population areas	94	0.70	Substantial
	Ecoregions + Population areas	95	0.71	Substantial
	Ecoregions + Slope gradient	94	0.69	Substantial
	Slope gradient + Population areas	95	0.71	Substantial

The ecoregions criterion is the least significant for the suitability model considering that the layer removal map has a strength of agreement of “Almost perfect” and a Kappa coefficient of 0.87. In the study area, climatic criterion is a soft limitation for apple productivity. On the contrary, for Manandhar et al. (2014) it was the largest factor in determining where apples could be grown in Mustang (Nepal). Slope gradient and population areas criteria have “substantial” agreement and minor importance. Opportunely, 70 % of the study area is suitable with respect to topography. In Mala´s valley, many apple orchards grow on terrace cultivation. Table 6b presents the results of layer removal combinations of these three factors. Suitability model is less robust when removing a combination of these criteria that when eliminating only one of them.

Proximity to water courses and distance to the road network are criteria with a significant implication on the suitability model. These criteria have values of overall agreement upper than 90 % representing high consistency. Kappa coefficient proves a substantial accuracy. There are many benefits by having good access to road network with regard to harvest transportation costs, agricultural inputs, trade transactions and regional communication (Zabihi et al., 2015).

The spatial SA illustrates that marginally suitable class have the worst agreement with the suitability model when a layer is removed (Figure 4). Marginal zones become unsuitable when far from water sources, roads or towns. In the case of soil factors, marginally areas represent 5 times more territory than in suitability model. The rest of the criteria have a proportion in decline. In fact, the resultant model of removing ecoregions criterion only has significant differences in marginally suitable areas. In general, highly suitable and moderately suitable classes are the most robust classes expressing low differences in the resultant maps. In the same way, except in soil criteria, variations in unsuitable zones are relatively slight.

Following the earlier procedures, soil-based models combining the others groups of factors were compared with the suitability map (Table 7), in order to find out which criteria group have the least implication and could be removed without varying the main model results.

Table 7. Suitability areas and Kappa coefficient from the comparison of the suitability model and the soil-based model

Procedure	Model	Areas of each suitability class (ha)				Kappa
		S1	S2	S3	N	
(c) Criteria group	Suitability model	3149	2667	4137	69242	1
	Soil	1022	4078	721	73374	0.53
	Soil + Topography	1869	3235	717	73374	0.57
	Soil + Hydro-climate	2962	2397	465	73369	0.67
	Soil + Socioeconomic	1869	3235	720	73370	0.57
	Soil + Topography + Hydro-climate	3216	2498	111	73369	0.71
	Soil + Topography + Socioeconomic	1022	4039	764	73369	0.52
	Soil + Hydro-climate + Socioeconomic	3049	2666	1652	71828	0.72

The highest and substantial agreement is got when hydro-climate criteria is merged in the three combinations. The soil-based model, including hydro-climate and socioeconomic has the highest accuracy (substantial) according to Kappa coefficient. Topography and socioeconomic criteria group appears as the lowest influential. In the case of topography, this may be because there is only one criterion (slope gradient) in the group and the weight rank is sixth.

Whereas, socioeconomic group has two criteria (population areas and distance to roads), but according to expert opinion have the lowest weights (ranking position 9 and 8, respectively) as show in Table 2.

Kappa coefficient indicates that at least the soil-based combinations have moderate accuracy. This means that all the criteria groups have some degree of importance of modeling the apple land suitability and it is inadvisable to remove any of them. In addition, Kappa analysis displays that marginally suitable class has poor precision (coinciding map polygons are lower than 1 %) in all the comparisons. However, not suitable areas have an increased average of about 4000 ha in almost all the soil-based models (Table 7).

Weight sensitivity. Weight sensitivity was undertaken by altering the weights of the nine evaluation criteria (Table 8). Nevertheless, altering the criteria changed slightly the resultant suitability map (Figure 5). Kappa analysis confirmed ecoregions and population areas criteria with the worst agreement. The greatest disparity happens in marginally suitable areas. In the case of population areas, this difference occurred also in highly suitable class.

The cause of this inconsistency is attributed to the construction sector that in the last decade has increased causing land crop reduction. According to this, apple orchards located within or very close to urban areas are in a not suitable category. Ricker et al. (2014) specified that increments of population density are associated with reduced farm size.

This study identifies the limitations for apple crops. Moreover, delineates that the current cultivation surface is much lower than the demarcated suitable areas. About 12.57 % of the total land area was found to be suitable for apple cultivation. If farmers in the valley considered growing apple crops in the 3149 ha (highly suitable), the gross profit would have substantial increase.

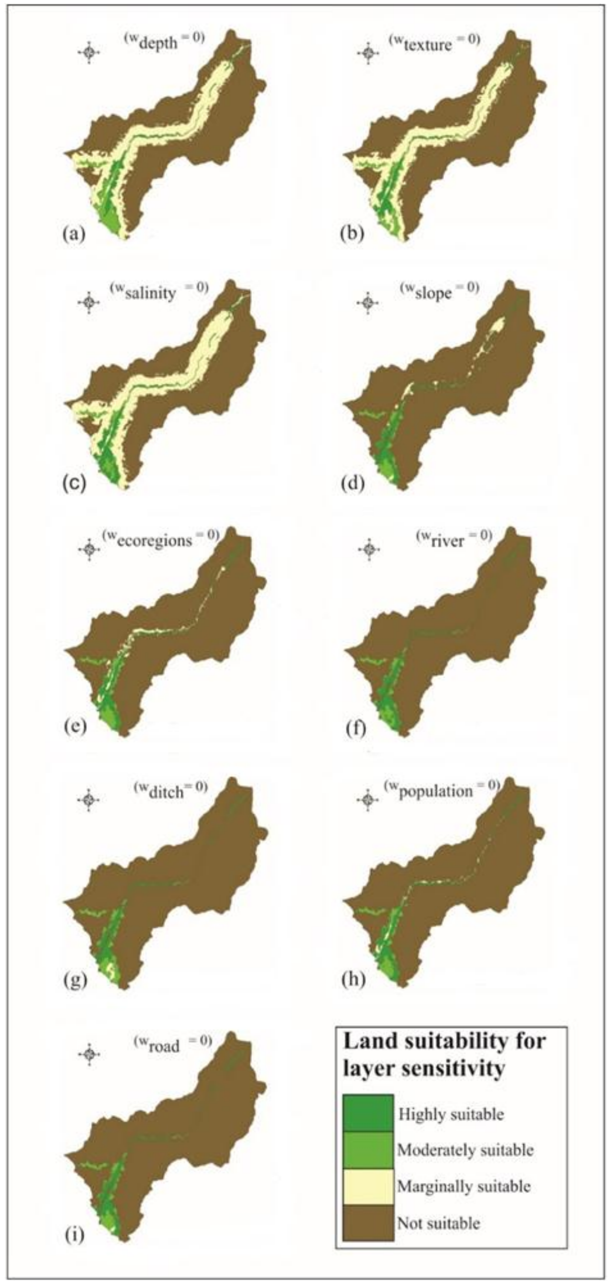

Figure 4. Layer removal map for each removed criterion: (a) depth, (b) texture, (c) salinity, (d) slope gradient, (e) ecoregions, (f) proximity to river, (g) proximity to irrigation ditch, (h) population areas, and (i) distance to roads networks

Table 8. Agreement and Kappa coefficient from the comparison of the suitability model and the weight-altering model

Criterion (w_i + 0.1)	Overall agreement	Kappa	Strength of Agreement
Depth	94 %	0.66	Substantial
Texture	95 %	0.71	Substantial
Salinity	94 %	0.67	Substantial
Slope gradient	93 %	0.75	Substantial
Ecoregions	86 %	0.60	Moderate
Proximity to river	90 %	0.67	Substantial
Proximity to irrigation ditch	87 %	0.62	Substantial
Population areas	81 %	0.36	Fair
Distance to roads network	88 %	0.62	Substantial

CONCLUSIONS

Four productivity zones for optimal apple crop production were identified. The analysis indicates that about 12.57 % of agricultural areas are suitable for apple cultivation, and out of which 3.98 % are highly suitable.

The combination of GIS, AHP method and Kappa analysis defined a flexible and precise procedure for planning apple growing. The final map can become a useful tool of territorial governance and policy in order to assist in the agricultural expansion process of Mala´s Valley. Data from soil criteria are the most limited in the study area and it is recommended to improve it for upcoming researches. This type of research could be replicated in the others Peruvian river basin that flow into the Pacific, considering that there is accessibility to collect data from appropriates sources to create a complete standard database.

A sensitivity analysis showed that the suitability model provided stable results. Soil criteria are the most influential following for hydro-climate group. On the other hand, eco-regions criterion has the lowest implication for the suitability model followed by population areas and slope gradient. Finally, soil criteria have a different performance when a change is submitted.

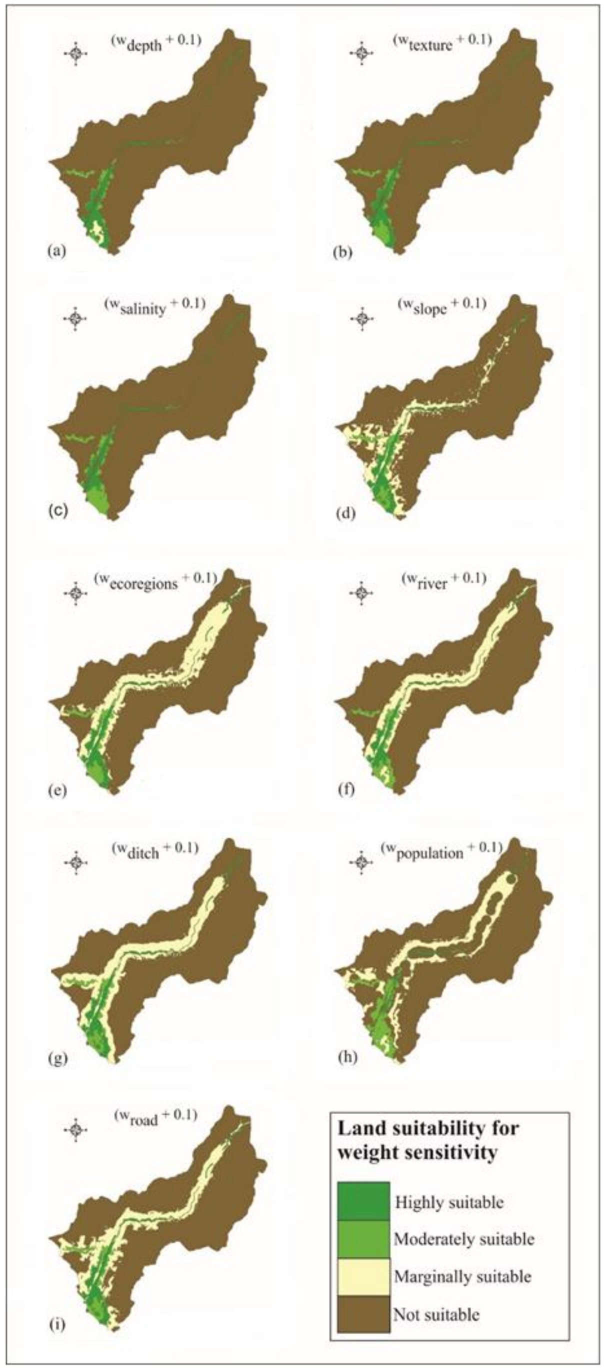

Figure 5. Weight-altering model for each criterion as a result of increasing 0.1 the initial weight: (a) depth, (b) texture, (c) salinity, (d) slope gradient, (e) ecoregions, (f) proximity to river, (g) proximity to irrigation ditch, (h) population areas, and (i) distance to roads networks.

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