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Suitability Analysis for *Moringa oleifera* Tree Production in Ethiopia - A Spatial Modeling Approach

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Abstract

Land suitability analysis is a basic premise for allocating specific land for specific purpose. The objective of this study was to predict the suitable sites for cultivating *Moringa oleifera* tree in Ethiopia; using Spatial Analytic Hierarchy Process. Findings of this study will have paramount significance in supporting decision making in the agro-forestry development sector. This study employs Spatial Analytic Hierarchy Process and Geographic Information System to generate valuable information in land allocation for *Moringa oleifera* tree production. Climate, topography, soil type and land use parameters were evaluated for suitability analysis. The results of the study revealed that most of the central parts of the country are categorized as moderately suitable for the production of *Moringa oleifera* tree. Areas classified as highly suitable are distributed along the borders of southern and western part of the country. However, some of the central part was classified as not suitable for *Moringa oleifera* tree production. This paper tried to investigate analysis of spatial data to predict suitable site for moringa tree production at national level. At national level, highly suitable, moderately suitable, and not suitable class covers an area of 308,508.2, 1,628,930.8 and 59891.3 Square Kilometer respectively.

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GIS (Geographic Information System), *Moringa oleifera*, Multi-criteria Evaluation, SAHP (Spatial Analytical Hierarchy Process)

Introduction

Nine of the 13 species in the genus Moringa are native to lowlands of eastern Africa (i.e., south-eastern Ethiopia, Kenya and Somalia). Among 13 species of Moringaceae family, five Moringa tree species is located in Southern-Ethiopia, South east-Ethiopia, Northern-Ethiopia and North east-Ethiopia [9, 10]. Ethno-botanical and bio-chemical studies carried out in various countries where Moringa grow show that these species are multipurpose. They are used for food, medicine, fodder, fencing, firewood, gum and as a coagulant to treat dirty water [12].

Moringa oleifera tree is drought tolerant and fast-growing plant in tropical countries [26]. *Moringa oleifera* tree grows in any tropical and subtropical country with particular environmental features, namely, dry to moist tropical or subtropical climate, with annual precipitation of 760 to 2500 mm and temperature between 18 and 28 °C. It grows in any soil type, but heavy clay and waterlogged, with pH between 4.5 and 8, at an altitude up to 2000 m [13].

All parts of moringa are consumed as food. The plant produces leaves during the dry season and during times of drought, and is an excellent source of green vegetable when little other food is available [5]. Moringa is mainly grown for its leaves in Africa, and much appreciated for its pods in Asia [2]. In Ethiopian context, *Moringa oleifera* trees were found in sorghum/maize fields, both on flat silty soils in Derashe and the sandy upland soils of the Konso terraces but some were found in household compounds. Ethiopian farmers use the edible parts of *Moringa oleifera* tree for food purpose and they use the plant for their livestock as source of livestock food. More than 78% of the farmers in Ethiopia utilized *Moringa oleifera* tree of edible parts in their diet and greeter than 71% were engaged in cultivating these species for over 17 years [9, 10].

A number of studies indicated that *Moringa oleifera* tree is cultivated in different parts of Ethiopia [10, 26]. Authors' observation revealed that *Moringa oleifera* tree presence around home gardens and farmlands in different regions of the country. Plantation of *Moringa oleifera* tree has performed with different actors in the country. Plantation was done with traditional land allocation system which lacks scientific evidences. Currently, farmers in Ethiopia grow *Moringa oleifera* tree without know where to plant this tree for maximum product output.

The basic premise of GIS suitability analysis is that each aspect of the landscape has intrinsic characteristics that are to some degree either suitable or unsuitable for the activities being planned. Land can be evaluated on different levels from the fine one to guide land management in the context of precision agriculture to the more course classifications to inform regional land use planning and allocation [6]. Therefore, the main problem of this research investigation was traditional land allocation system in the country is ineffective for moringa tree production. So, this study aims at spatial modeling of environmental and climatic factors to assist traditional land allocation system with the help of spatial analytic hierarchical process (SAHP).

This study employs Spatial Analytic Hierarchy Process (SAHP) and Geographic Information System (GIS) to generate valuable information in land allocation for *Moringa oleifera* tree production. SAHP is a derivative of Analytic Hierarchy Process (AHP), which is used to resolve highly complex decision-making problems involving multiple factors [21, 24].

Its spatial equivalent, SAHP, is now becoming an emerging tool for multi-criteria analysis in which positional relationship between features is relevant [7, 4, and 29]. SAHP was used by several researchers for land use site selection due to its paramount advantages. Some of the special features of SAHP were explained by [7] and [29] as the ability to review both quantitative and qualitative criteria simultaneously, the possibility of simplifying complex issues into a form of hierarchy, pair-wise comparisons and weighing criteria, simple calculations and possibility of ranking the final options. It also works well with various factor weighting and quantifies experts' opinions [29]. This implies this method can be customized to specific features of a particular field.

Findings of this study will have paramount significance in supporting decision making in the agro-forestry development sector. Having knowledge of where to plant *Moringa oleifera* tree at national level will support Ethiopian green economy annual plan. Local communities, universities, investors, researchers, community-based organization (CBO's) and non-governmental organizations (NGO's) will be benefited from the research results.

To the best of our knowledge, there is no study that has looked at the possibility of mapping the suitable cultivation areas of *Moringa oleifera* in Ethiopia. Therefore, the objective of this study was to predict the suitable sites for cultivating *Moringa oleifera* in Ethiopia using SAHP method. Specifically, this investigation was intended to identify factors, select criteria of growth, classify and weigh variables into different levels of suitability.

Materials and Methods

Study area

Ethiopia is geographically located within the tropics between 3 degrees and 15 degrees of north latitude and between 33 degrees and 48 degrees of east longitude. It has common borders with Kenya, Sudan, South Sudan Republic, Somalia, Eritrea and Djibouti (Figure 1). The mean annual temperature of the country is 22.2°C. The lowest temperature ranges from 4°C to 15°C in the in the lowlands at the Danakil Depression [1]. The country receives mean annual rainfall of 812.4 mm, with a minimum of 91 mm and a maximum of 2,122 mm.

Data source

All of the dataset for this study was obtained from secondary data sources. Climate data types such as temperature, rainfall and precipitation were downloaded from world climate website (www.worldclim.org). Climate data used in this study were obtained from the World Climate Data with a spatial resolution of 30 s (~1 km2) and they represent average monthly climate data of the year 2019-2020. The soil data (soil Ph, soil texture) were obtained from the Harmonized World Soil Database (FAO, 2018) with a spatial resolution of 0.0083° which is equivalent to approximately 90m. Land use data of the country was obtained from Ethiopian Mapping Agency; since an authority of producing Land use data at national level was given to EMA. After the data layers of the criteria variables were obtained, they were standardized by resampling all variables to a 30 m resolution and projected to Universal Transverse Mercator (UTM) projection.

Data analysis

Selecting criteria for suitability assessment

The criteria of suitability assessment were selected through an intensive literature review on site requirements of *Moringa oleifera* tree production. Besides review of international experience from literature about the subject matter, expert consultation was a helpful tool used in the rating of factors using pair-wise comparisons. (Table2)

Standardization of criteria

Standardizing criteria means transforming different input data into the same unit of measurement scale. Different input data such as rainfall, temperature, precipitation, soil ph, soil texture, land use data needs to be converted into the same measurement scale. Each dataset was converted into raster format. Raster pixels of each parameter were classified into suitability classes for *Moringa oleifera* tree production. After classification, all raster data of each factor had values of 3, 2 and 1 representing “Highly suitable”, “moderately suitable” and “not suitable areas”, respectively.

Weighing of the criteria

Pair-wise comparison matrix developed by [21] which uses nine-point weighing scale was used to determine the relative importance of each criterion in overlay analysis (Table3). In pair-wise comparison, the first important issue was assigning importance value relative to each factor. According to different literatures, relative importance value of each factor was assigned in pair-wise comparison.

Consistency ratio

For preventing bias during criteria weighing, consistency ratio was used as a tool to ensure coherent comparisons. Consistency ratio is a general measure of the comparative judgments goodness in building up decision matrices within the AHP. It was calculated as the ratio of consistency index (CI) and random consistency index (RI). The RI is the random index representing consistency of a randomly generated pair-wise comparison matrix. Consistency ratio is a decision tool to evaluate whether an AHP is acceptable for decision making or not [22].

$$CI = \frac{(\lambda max - n)}{(n-1)}$$

$$CR = \frac{CI}{RI}$$

Where; n=number of items being compared, λmax = the largest eigen value, CI = consistency index, CR = consistency ratio

Spatial modelling

Spatial model that is used for suitability analysis was built in ArcGIS (version 10.6). In spatial model; format conversion, reclassification and the final weighted overlay analysis were performed. Various factors (i.e. precipitation, rainfall, temperature, soils, land use/cover and slope) were combined to a suitability map of three levels of suitability. In the overall weighted overlay analysis, each criterion was weighed by its importance value, which reflects influence of the criteria in the overall suitability (S).

$$S = \sum_{i=1}^{n} (Wi \ x \ CI)$$

Where; S = over all suitability, Wi= weight of each criteria, CI = consistency index.

Results and Discussions

Single factor suitability evaluation

Rainfall

According to [14,15], *Moringa oleifera* tree can grow in areas that receive an annual rainfall of 250 to 1500 mm, with optimal growth of *Moringa oleifera* requiring between 700 and 2200 mm of annual rainfall. Studies carried out by [29] indicate that *Moringa oleifera* tree is a hardy plant that does well semi-arid and arid regions if the minimum annual rainfall requirement is below 250mm.

Temperature

Moringa oleifera tree is adapted to different agro-climatic conditions. It is most commonly cultivated in tropical or sub-tropical semi-arid regions. Optimal temperature required for M. oleifera growth is between 25 and 35 °C [18, 11]. The plant can tolerate high temperatures up to 48 °C [25], but does not do well in cold areas that have temperatures below 10 °C [18].

Soil PH

Soil pH is one of the factors that significantly affect *Moringa oleifera* cultivation. *Moringa oleifera* tree can grows very well (highly suitable) in soils having a PH of between 6.3 and 7. Soil PH value between 4.5-6 is moderately suitable and Ph value below 4.5 and above 8.5 is not suitable for *Moringa oleifera* tree production [14,29].

Soil texture

The property of soil texture is related with infiltration rate and water logging tendency. A soil with good infiltration rates and without water logging tendencies is suitable for *Moringa oleifera* tree cultivation. *Moringa oleifera* tree can be grown in variety of soil types and conditions from well drained sandy loam soils to heavier clay loam soils. Excessively drained, moderately well drained and well drained soils are all classified as well suited to Moringa tree growing [16, 18]. So, soil texture types such as loam, loamy sand, sandy and sandy loam are highly suitable; whereas, clay loam, sandy clay, silty clay and sand clay loam are considered to be moderately suitable for *Moringa oleifera* tree production. Soil textures with clay and heavy clay property are not suitable for *Moringa oleifera* tree production.

Table.1 Data types used for suitability analysis of *Moringa oleifera* tree in Ethiopia

Data type	Spatial resolution	Source
Rainfall	1 km	www.worldclim.org
Temperature	1 km	www.worldclim.org
Precipitation	1 km	www.worldclim.org
Solar radiation	1 km	www.worldclim.org
Soil texture	90m	FAO, 2018
Soil PH	90m	FAO, 2018
Slope	SRTM 30m	www.usgs.org
Land use	-	EMA (Ethiopian mapping agency)

Table.2 Suitability criteria for production of *Moringa oleifera* tree production

Dataset	Suitability class			Reference
	Highly suitable (S3)	Moderately suitable (S2)	Not suitable (S1)	
Temperature (^{0}C)	25-35	18-25 and 35-45	<10	[15]
Rainfall (mm)	700-2200	250-700	<250	[29]
Precipitation (mm)	50-100	100-150	>150	[14]
Elevation (m)	50-500	500-1000	>1500	[14]
Slope (%)	0-4	4-12	>12	[14]
Land use (class)	Grassland, shrubland, bushland, cultivation,	Forest, alpine vegetation, woodland	Barren land, swamps, waterbodies	[15]
Soil PH	6.3-7	4.5-6.3	<4.5 and >8.5	[3]
Soil Texture	Loam, loamy sand, sandy, sandy loam	Clay loam, sandy clay, silty clay, sand clay loam	Clay, heavy clay	[16,18]

Table.3 Analytical hierarchical process (AHP) criteria importance

Importance score	Definition
1	Equal importance of *i* and *j*
3	Weak importance of *i* over *j*
5	Strong importance of *i* over *j*
7	Very strong importance of *i over j*
9	Extreme importance of *i* over *j*
2,4,6,8	Intermediate values between *i* and *j*
Reciprocal of the above	If criterion i has one of the above non-zero numbers assigned to it when compared with criterion j, then j has the reciprocal value when compared with i

Source: [21, 22]

Table.4 Random index table

Random Index										
N	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.46	1.49

Source: [21]

Table.5 Relative importance values of factors that affect *Moringa oleifera* production in Ethiopia

	Elevation	**Temperature**	**Rainfall**	**Soil pH**	**Soil texture**	**Land use**	**Slope**
Elevation	1.00	9	7	3	3	3	7
Temperature	0.11	1.00	5	3	3	5	5
Rainfall	0.14	0.20	1.00	3.00	0.50	7	3
Soil pH	0.33	0.33	0.33	1.00	3.00	7	7.00
Soil texture	0.33	0.33	2.00	0.33	1.00	5	7
Land use	0.33	0.20	0.14	0.14	0.20	1.00	7.00
Slope	0.14	0.20	0.33	0.14	0.14	0.14	1.00
Total	**2.40**	**11.27**	**15.81**	**10.62**	**10.84**	**28.14**	**37.00**

Source: - Author's observation and experts view

Table.6 Weight and consistency ratio (CR) of pair-wise comparison matrix of factors that affect *Moringa oleifera* production

	Elevation	**Temperature**	**Rainfall**	**Soil pH**	**Soil texture**	**Land use**	**Slope**	**Criteria weight**	**Consistency Measure**	**weight percent**
Elevation	0.42	0.80	0.44	0.28	0.28	0.11	0.19	0.36	1.21	**36**
Temperature	0.05	0.09	0.32	0.28	0.28	0.18	0.14	0.19	0.82	**19**
Rainfall	0.06	0.02	0.06	0.28	0.05	0.25	0.08	0.11	0.83	**11**
Soil pH	0.14	0.03	0.02	0.09	0.28	0.25	0.19	0.14	0.85	**14**
Soil texture	0.14	0.03	0.13	0.03	0.09	0.18	0.19	0.11	0.89	**11**
Land use	0.14	0.02	0.01	0.01	0.02	0.04	0.19	0.06	1.07	**6**
Slope	0.06	0.02	0.02	0.01	0.01	0.01	0.03	0.02	1.40	**2**
Total	1	1	1	1	1	1	1	1	7.07	100

Table.7 Consistency ratio

CI	0.07
RI	1.32
C. Ratio	0.05

Source: - Author's calculation

Table.8 Area coverage proportion

Suitability class	Area coverage (km^2)
Highly Suitable	308,508.2
Moderately Suitable	1,628,930.8
Not Suitable	59891.3
Total	**1,997,330.30 km^2**

Fig.1 Location map of study area

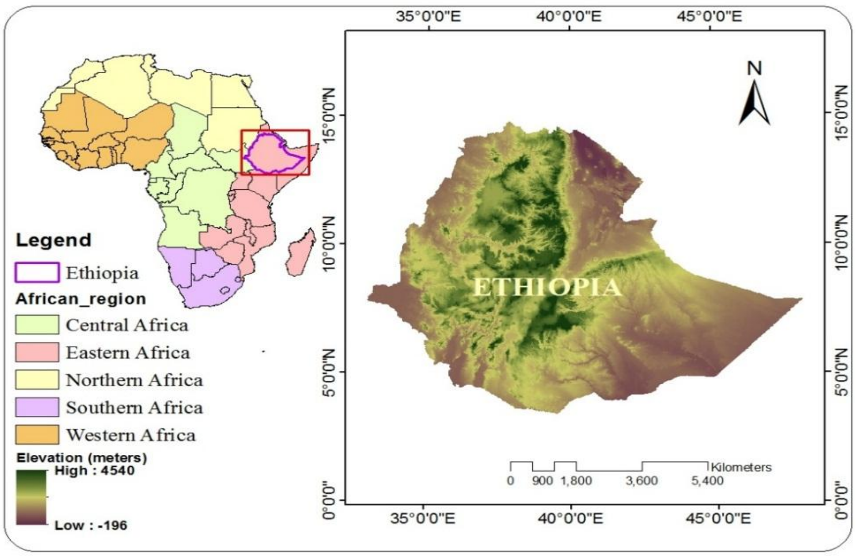


Fig.2 Schematic Description of Spatial modeling

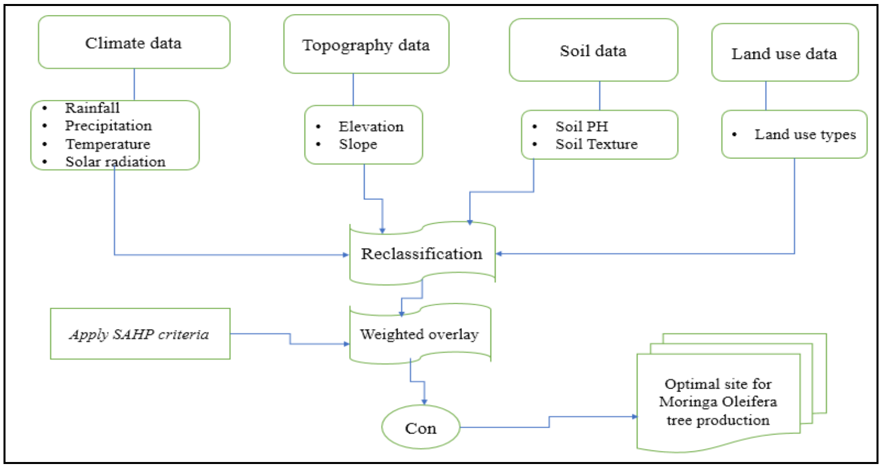


Fig.3 Individual parameter suitability class

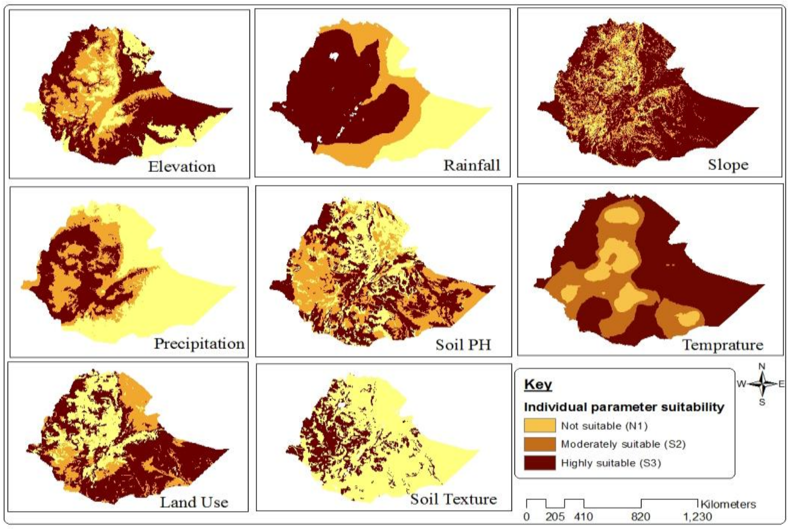


Fig.4 spatial modeling

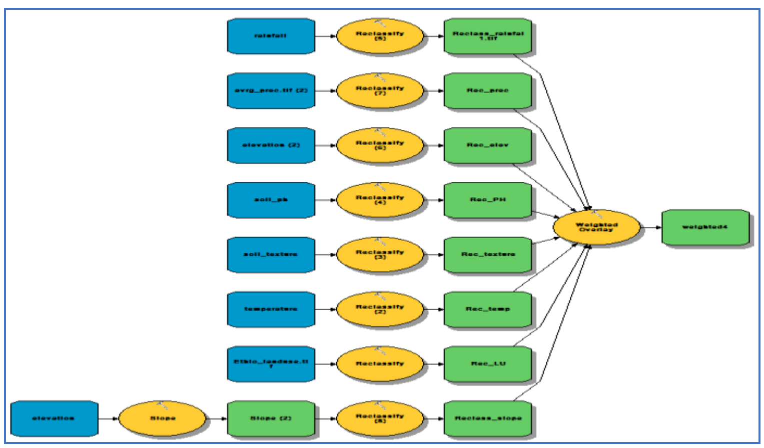
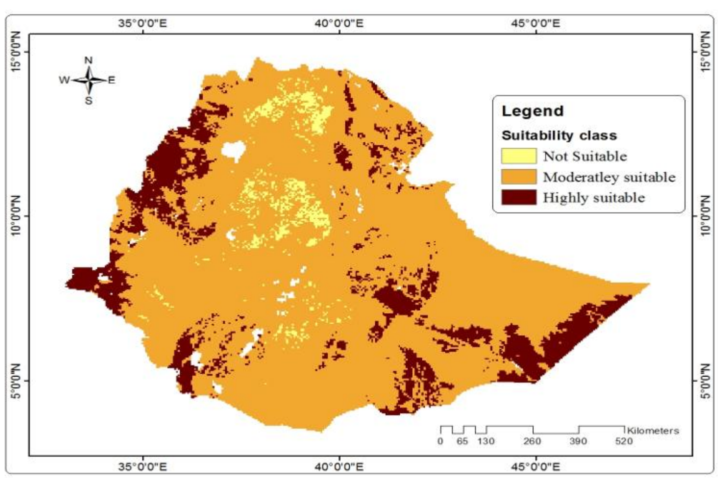


Fig.5 Overall suitability



Precipitation

Water and precipitation are the main limiting factors affecting plant growth and survival in arid and semiarid regions. The adaptation characteristics of desert plants are all related to the use of water resources. Limited precipitation directly restricts the expression of plant morphology, and plants are confronted with the balance of resource allocation in growth, reproduction, and maintenance [28]. *Moringa oleifera* tree can grow in areas having relatively low precipitation and seasonal rainfall [14]. Therefore, precipitation of the study area was classified into highly suitable (S1), moderately suitable (S2) and not suitable (N1) depending on [14] classification.

Slope

Slope is an important indicator of land suitability since it affects drainage, irrigation and soil erosion [27]. Steep slope is subjected to runoff which increases infiltration efficiency of rainfall. Slopes up to 8 percent are ideal for optimum growth of Moringa tree production; whereas slope above 12 percent are not optimal for Moringa tree production. Slopes of the study area were reclassified as 0-4 highly suitable, 4-8 moderately suitable and above 12 percent not suitable. Therefore, suitability classes of slope were classified as S1, S2 and N1; highly suitable, moderately suitable and not suitable respectively in accordance with similar classification done by [14].

Land use

Land use types are an important factor which affects the growth of *Moringa oleifera* tree. *Moringa oleifera* can grow in open lands, shrub lands, cultivation lands and forest areas. The level of suitability of each land use is significantly different from each other. According to [15], open and shrub lands are the optimal land use types for *Moringa oleifera* tree grow. Land use of the study area was reclassified as open and shrub-lands are highly suitable, forest area as moderately suitable and cultivation land as not suitable.

The results of individual parameter suitability evaluation such as rainfall, elevation, slope and temperature show highly suitable for *Moringa oleifera* tree grow in most part of the study area. Meanwhile, precipitation and land use parameters reveled moderately suitable range of the study area. However, parameters such as soil texture and soil ph indicate not suitable range for *Moringa oleifera* tree production in Ethiopia. The following figure depicts suitability range of individual parameter for *Moringa oleifera* tree production (Figure3).

Criteria weights

In this study weights for selected parameters was derived using SAHP method. Relative importance of factors/parameters that affect the growth of *Moringa oleifera* tree was assigned in pair-wise comparison matrix. In the matrix, above diagonal values were assigned in comparison with column parameter. The values of each parameter were given in accordance with parameter effect on the growth of *Moringa oleifera* tree production. Below diagonal values of each parameter are the reciprocal of the above diagonal. After assigning relative importance values of above diagonal and reciprocal of above diagonal matrix, normalization of each cell value was done. Normalization can be computed by dividing each cell value to column total of each parameter. Normalization of parameters value was performed in order to generate criteria weights for each parameter. Criteria of each parameter were obtained by summing up row values of each cell. According to criteria weights value, elevation parameter is paramount importance for Moringa tree growth. Consistency ratio of all parameter was computed to check whether the calculated value of is correct or not correct. Values of consistency ratio exceeding 0.10 are indicative of inconsistent judgments; whereas values of 0.10 or less indicate reasonable level of consistency in the pair-wise comparison. In this case computed consistency ratio is 0.05 and this indicates reasonable level of consistency in the matrix.

Weighted overlay

A Weighted Suitability Model was developed in ArcMap for proposing suitable locations for *Moringa oleifera* tree production depending on a number of parameters and based on the principle of Multi-Criteria Evaluation. Such models are used for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. In the suitability model parameters such as rainfall, temperature, elevation, slope, soil types and land use were reclassified and weighed together to produce overall optimal sites for *Moringa oleifera* tree production.

Proportions of area coverage

The proportion of area coverage shows that most of the central part of the country is categorized as moderately suitable range. However, the central part of Amhara and Tigray regional states classified as not suitable for *Moringa oleifera* tree production.

Areas which is classified as highly suitable for *Moringa oleifera* tree production is distributed along the borders of southern and western part of the country.

In conclusions the Spatial Analytical Hierarchical Process (SAHP) is a precise technique for allocating specific land for specific purpose. In this paper climate, topography, soil type and land use parameters were evaluated for suitability analysis of moringa tree production in Ethiopia. Individual parameter evaluation was performed to estimate how each parameter have paramount influence in the model. Multicriteria evaluation technique was employed to assign weights for each parameter in suitability analysis. The results of individual parameter suitability evaluation such as rainfall, elevation, slope and temperature show highly suitable for *Moringa oleifera* tree grow in most part of the study area. Meanwhile, precipitation and land use parameters revealed moderately suitable range of the study area. However, parameters such as soil texture and soil ph indicate not suitable range for *Moringa oleifera* tree production in Ethiopia. Model builder was used for applying a common measurement scale of values to diverse and dissimilar inputs in order to create an integrated analysis. In the suitability model parameters such as rainfall, temperature, elevation, slope, soil types and land use were reclassified and weighed together to produce overall optimal sites for *Moringa oleifera* tree production. The overall suitability range shows that most of the central part of the country is categorized as moderately suitable range. However, some central part of Amhara and Tigray regional states was classified as not suitable for *Moringa oleifera* tree production. Areas classified as highly suitable for *Moringa oleifera* tree production was distributed along the borders of southern and western part of the country. In proportion, highly suitable range covers an area of 308,508.2 square kilometer. Whereas, moderately suitable and not suitable class covers an area of 1,628,930.8 and 59891.3 square kilometers respectively.

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