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GIS-BASED MULTI-CRITERIA LAND SUITABILITY MAPPING FOR SCALING FABA BEAN VARIETIES IN ETHIOPIA

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ABSTRACT

Successful scaling of agricultural technology requires a spatial explicit framework for targeting the right variety at the right place. This entails a multi-criteria evaluation (MCE) approach, using a set of determining factors to delineate the scaling domains for faba bean (*Vicia faba* L.) varieties in and identify potentially suitable land area in a specific region, and zone in Ethiopia. Meeting this challenge will require a solid spatial framework. Land suitability analysis is an evaluation and spatial decision making, involving several determining factors. The factors considered in this analysis include key biophysical parameters such as climate, topography, soil types and properties. The analysis was also focused on improved faba bean varieties *viz*., Dagm, Dosha, Gabelcho, Gora, Hachalu, Moti and Walki. The environmental factors' layers of a specific crop pixel values were classified and given a weight, and then compared among themselves for further ranking to account for their relative importance to delineate variety specific extrapolation domains. The geo-statistical analysis was carried out to estimate the extent of the scalable areas. The classification showed that, it was highly suitable for varieties 0.02 million hectares for Dosha; 0.19 for Gabelcho; 0.11 for Gora; 0.33 for Moti; 0.05 for Dagm; 0.14 for Hachalu; and 0.26 million hectares for Walki. Moderately suitable areas for these varieties covered 5.0, 9.4, 7.2, 15.3, 4.6, 8.8, and 7.5 million hectares, respectively across the country. The largest proportion for all varieties was moderately suitable; while the share of slightly suitable was very low, although there was quite variability within each of the faba bean variety in terms of its agro-ecology adaptation to the target environments. Such biophysical spatial frameworks become essential entry points for introducing variety specific product profiles and this can be further enhanced by incorporating socio-economic attributes accounting for return of the investment in targeting the technology.

Key Words: Environmental factors, spatial decision

RÉSUMÉ

La mise à l'échelle réussie de la technologie agricole nécessite un cadre d' explicite spatial pour se concentrer sur la bonne variété au bon endroit. Cela implique une approche d'évaluation multicritère (ECM), utilisant un ensemble de facteurs déterminants pour délimiter les domaines de mesurage pour les variétés de féverole (*Vicia faba* L.) et identifier les terres potentiellement appropriées dans une région et une zone spécifiques en Éthiopie. Relever ce défi exigera un cadre spatial certain. L'analyse de l'aptitude des terres est une évaluation et une prise de décision spatiale impliquant plusieurs facteurs déterminants. Les facteurs pris en compte dans cette analyse incluent des paramètres biophysiques clés tels que le climat, la topographie, les types de sol et leurs propriétés. L'analyse a également porté sur les variétés améliorées de féverole, à savoir Dagm, Dosha, Gabelcho, Gora, Hachalu, Moti et Walki. Les couches de facteurs environnementaux d'une valeur de pixel de plante spécifique ont été classifiées et pondérées, puis comparées entre elles pour un classement ultérieur tenant compte de leur importance relative dans la délimitation de domaines d'extrapolation spécifiques à une variété. L'analyse géo-statistique a été réalisée pour estimer l'étendue des zones évolutives. La classification a montré qu'elle convenait parfaitement aux variétés 0,02 million d'hectares pour Dosha; 0,19 pour Gabelcho; 0,11 pour Gora; 0,33 pour Moti; 0,05 pour Dagm; 0,14 pour Hachalu; et 0,26 million d'hectares pour Walki. Les zones moyennement adaptées à ces variétés couvraient respectivement 5,0; 9,4; 7,2; 15,3; 4,6; 8,8 et 7,5 millions d'hectares dans l'ensemble du pays. La plus grande proportion de toutes les variétés était modérément appropriée; alors que la proportion de produits légèrement appropriés était très faible, bien qu'il y ait une assez grande variabilité au sein de chaque variété de féverole en ce qui concerne son adaptation agroécologique aux environnements cibles. De tels cadres spatiaux biophysiques deviennent des points d'entrée essentiels pour l'introduction de profils de produits spécifiques à une variété, ce qui peut être encore amélioré en incorporant des attributs socio-économiques permettant de rentabiliser l'investissement dans la focalisation de la technologie.

Mots Clés: Facteurs environnementaux, décision spatiale

INTRODUCTION

Ethiopia is characterised by diverse agro-ecologies that sustain its agricultural production and maintain its rich biodiversity. The existence of diverse farming systems, agro-ecologies, socio-economic, as well as cultural diversity have endowed the country with a biological wealth of species diversity, particularly the agro- biodiversity (IBC, 2007). Faba bean (*Vicia faba* L.) is one of the important legume crops in the highlands of Ethiopia, and secondary centres of diversity are postulated in Afghanistan and Ethiopia (Hawtin and Hebblethwaite, 1983). Ethiopia is also one of the major faba bean producing countries in the world, next to China (Tafere *et al.*, 2012; Ermias and Addisu, 2013).

According to FAO (2019), the area harvested for faba bean increased from 298,490 ha in 1993 to 427,697 ha in 2016, with an increase in production from 312,405 to 878,010 metric tonnes, with corresponding productivity increase from 1.05 to 2.05 tonnes ha^{-1} (Figure 1). This shows an increment of 43.3, 181.1 and 96.15% in area harvested, production and productivity, respectively.

Faba bean yields are low in Ethiopia due to biotic stresses such as foliar diseases (chocolate spot, rust, aschocyhta blight, faba bean leaf gall) (Dereje *et al.*, 2012; Abebe *et al.*, 2017), root diseases (black root rot), insect pests (aphids, pod borer), parasitic weeds (*Orobanche crenata*) and abiotic stresses (soil acidity, waterlogging, drought, and frost).

Geographic Information Systems (GIS) enables a large amount of different geospatial and associated information to be assembled, combined, overlaid, modeled and mapped. With its huge capability, GIS can be a powerful tool in agricultural planning of an area for land use suitability. Therefore, GIS has contributed to the speed and efficiency of the overall planning process in agricultural land use suitability, since it enables quick and efficient access to large amounts of information, exhibiting relationships, patterns, and trends that are useful in monitoring land use potential and suitability evaluation (Singha and Swain, 2016). It is a useful tool for scaling proven technologies and packages of practices, including specific crops and crop varieties to address yield and nutritional gaps (Singha and Swain, 2016; Low *et al*., 2018).

To assist crop technology targeting and scaling-up, the potential of different land for different purposes should be identified so as to be allocated for appropriate use. Crops/ varieties should be selected based on different objectives addressing quality preferences such as adaptability, yield, tolerance to abiotic and biotic stresses, and market and nutritional values. Land suitability analysis work enables identification of where and how much potentially suitable land for a crop and crop variety exists in a specific location or in the country at large (Mokarram *et al*., 2010).

It is, therefore, important to map the agricultural land to show the extent and distribution of areas that are potentially suitable for a crop variety. It was within this context that this study was done, to gather and organise various data sets relevant to environmental requirements of the selected varieties; and analyse and depict the land suitability class of faba in Ethiopia.

Therefore, the objective of the study was to provide information on the choice of faba bean varieties based on crop variety suitability map where to be grown under optimum conditions in the target environments for enhancing faba bean production in Ethiopia.

MATERIALS AND METHODS

Interoperable spatial data layers were prepared to carry out multi-criteria land suitability evaluation. A set of interoperable spatial data layers of various biophysical (e.g. soils, topography and climatic) parameters were prepared to carry out multi-criteria suitability mapping. Key controlling factors were the bio-climatic variables, which vary in time and space. The plant growth parameters such as rainfall and temperature during the growing period and length of growing period (LGP), topography (digital elevation models. i.e. altitude and slope), soil types and soil chemical(PH) and physical properties (depth, texture, and drainage) were used in the AHP analysis to determine the suitable criteria. Park and lake areas were excluded (restricted) in this land suitability analysis. Administrative boundaries and infrastructure (roads, towns, and other facilities) were also used to prepare the final map and generate the tabular data.

The soil data used included soil properties and soil types, which were acquired from two sources. The soil properties were extracted from the Soil and Terrain Database of East Africa and gridded soil database of 250 m (ISRIC, 2015), while the soil type used was from MoA modified by the Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2004). For the altitude information, the Shuttle Radar Topography Mission (SRTM) 90 m digital elevation model (DEM) database (Jarvis *et al*., 2008) was used and the same DEM used for topographic analysis such as generating slope maps. These data were resampled to a common spatial resolution of 200 m for the spatial analysis in the GIS domain.

Crop variety requirement. The faba bean varieties environmental requirement was generated based on product profiles (MoARD, 2006; MoARD, 2008; MoARD, 2009; MoA, 2010), literature review (Jarso and Keneni, 2006), expert consultations and from national variety trials conducted in multi-location and years that submitted for variety release in Ethiopia. The land evaluations study conducted by FAO (1984; 2007) and by Sys *et al.* (1993) were used as a general guide to derive thresholds for defining the suitability categories. Stratification was made in terms of suitability, and were set as S_1 (very suitable), S_2 (moderately suitable), and S_3 (marginally suitable) and N (unsuitable) based on the assumption indicated in the FAO land suitability classification structure (Table 1). According to FAO classification, S_1 corresponds to 85-100%, S_2 to 60-85%, S_3 to 40 - 60%, N_1 to 25 - 40% and N_2 to 25 - 0% (Elsheikh and Abdalla, 2016) of optimum yield under the recommended management practices.

Since the analysis is raster (pixel) based, some of the data, which were in vector format (object based), were converted to uniform raster datasets using polygon-to-raster conversion tool in ArcGIS. The important GIS layers of environmental factors affecting the growth of faba bean varieties were identified and each layer's pixel values classified and assigned weight. Then the environmental factor layers were compared among themselves and ranked using weighted overlay analysis developed under the ModelBuilder. Based on the rate and rank assigned to each pixel, the land suitability map for each variety was computed using weighted overlay analysis. The classification of each layer into suitability categories was done using Re class by Table function in ArcGIS spatial analyst (ESRI GIS package) tool. The reclassification is implemented in the model by preparing separate tables for each factor/criteria layer and faba bean variety.

Assigning criterion weights for overall suitability analysis. The overall suitability map is the combined result of the altitude, slope, soil types and soil properties, and the climate layers. The weighted overlay approach built on ArcGIS Model Builder was used for the overlay analysis to solve such multi-criteria problems of suitability. The suitability criteria

TABLE 1. Categories of FAO land suitability classification

Code	Class name	Description
S_1	Highly suitable	Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity and will not raise inputs above an acceptable level
S_2	Moderately suitable	Land having limitations which, in aggregate, are moderately severe for sustained application of a given use; the limitations will reduce productivity and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably low to that expected on S_1 land
S_3	Marginally suitable	Land having limitations which, in aggregate, are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified
N	Not suitable	Land that cannot support the land use on a sustained basis, or land on which benefits do not justify necessary inputs

Source: FAO, 1976; 1984; 1993

layers were assigned weights to account for their relative importance, and overlaid using the weighted overlay tool to produce the overall land suitability map. The purpose of weighting was to express the relative importance of each factor regarding the effects on crop yield and growth rate (Perveen *et al.*, 2007).

The analytic hierarchy process (AHP) was used to calculate the weights for the different criteria (Saaty, 1987; Chivasa *et al.*, 2019). AHP relies on pairwise comparisons that assign values based on relative importance of criteria layers. The criteria were evaluated, and numerical scales of measurement were derived through comparing against the goal of importance for suitability. The pairwise comparison scales were assigned through discussion among experts. The overall suitability was computed by multiplying the selected criteria weight (Wi) by the assigned sub-criteria score (Xi), and summing these values in the ArcGIS Model Builder (Equation 1):

$$S = \sum_{i=1}^{n} WiXi \quad \text{.......................... Equation 1}$$

Where:

S denotes the final land suitability score, Wi is the weight of the corresponding suitability criteria, Xi is the assigned sub-criteria score of I suitability criteria; and *n* is the total number of criteria maps.

The final suitability result (maps and tabular data), including the explanatory document, were prepared both in softcopy and hardcopy.

Crop varieties. Faba bean varieties were chosen based on information from nationally released varieties registered by Ministry of Agriculture, Ethiopia like, productivity, earliness, grain protein content, export and local market quality parameters; and waterlogging and black root rot tolerance for Vertisols. While the list of faba bean varieties included in the suitability analysis obtained from crop variety register book (MoARD, 2006; MoARD, 2008; MoARD, 2009; MoA, 2010) and were presented (Table 2).

RESULTS AND DISCUSSION

The multi-criteria evaluation (MCE) approach in spatial analytic hierarchy process resulted in production suitable area for growing specific faba bean varieties (Table 2). The zonal statistics of each suitability map were calculated to generate percentages and area coverage of each class, by zonal and regional administrative boundaries. The results of the land suitability analysis are presented in the subsequent sections showing the extent and patterns of land area available for specific faba bean varieties for comparison with area of crop-level (faba bean) land suitability classes (Table 3).

Variety level land suitability

The following section presents varieties and their respective suitability classes in Ethiopia.

Variety Dosha (Coll 155/00-3). The suitability analysis and mapping results for this variety are shown in Figure 2 and Table 4. When compared with the overall (crop level) suitability map of faba bean by Nigussie (2014) and Table 3, the high and moderate suitable areas of Dosha variety was 5,045,228 ha that mostly covering western parts of Amhara and Oromia regional states (Table 11).

Dosha is a variety developed and released by Holleta Agricultural Research Center (HARC) in 2009. This variety yields, on average, 2.8 to6.2 and 2.3 to3.9 t ha^{-1} in research and farmers' fields, respectively (MoARD , 2009). It has a thousand seed weight (TSW) of 797, which is classified as V. faba var. equina with medium seeds (Cubero ,1974; Crépon *et al.,* 2010; Pietrzak *et al.*, 2016), and other important agronomic traits are presented in Table 2. The variety is moderately resistant to chocolate spot and rust.

TABLE 2. Selected characteristics of faba bean varieties used for land suitability mapping

Variety	Year of release	Days to flowering after emergence	Days to maturity after planting (t ha^{-1})	Grain yield with recommended management	Crude protein content (%)	Thousand grain weight (g)	Plant height at heading (cm)	Recommended altitude (m)
Dagm	2002	67	152	3.4-3.6	NA	300	86	2,600-3,000
Dosha	2009	60	144	2.8-6.2	26.5	797	122	1,800-3,000
Gabelcho	2006	46	160	2.5-6.1	26.5	797	131	1,900-3,000
Gora	2014	47	147	2.2-5.7	24	938	131	1,900-2,800
Hachalu	2010	50	141	3.2-4.5	27	890	128	1,900-2,800
Moti	2006	40	137	2.8-5.1	27	781	124	1,800-3,000
Walki	2008	56	140	2.4-5.2	27.5	676	129	1,900-2,800

TABLE 3. Area of land under different suitability classes for faba bean in regional states, Ethiopia

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	635,268	4.14	8,085,316	52.8	450,684	2.94	6,157,636	40.17
Oromia	1,080,008	3.62	10,241,276	34.3	844,448	2.83	17,675,972	59.23
SNNP	165,244	1.56	3,609,584	34.1	78,536	0.74	6,738,564	63.62
Tigray	1,908	0.04	1,552,112	31.5	522,676	10.6	2,855,468	57.89
Afar	0	0	17,780	0.21	82,980	0.99	8,238,976	98.79
BSG	0	0	98,088	1.96	59,432	1.19	4,855,040	96.86
Gambella	0	0	52,260	1.76	4,420	0.15	2,918,540	98.09
Somali	0	0	89,832	0.26	202,460	0.58	34,410,444	99.16
Total	1,882,428	1.67	23,746,248	21.01	2,245,636	1.99	83,850,640	74.19

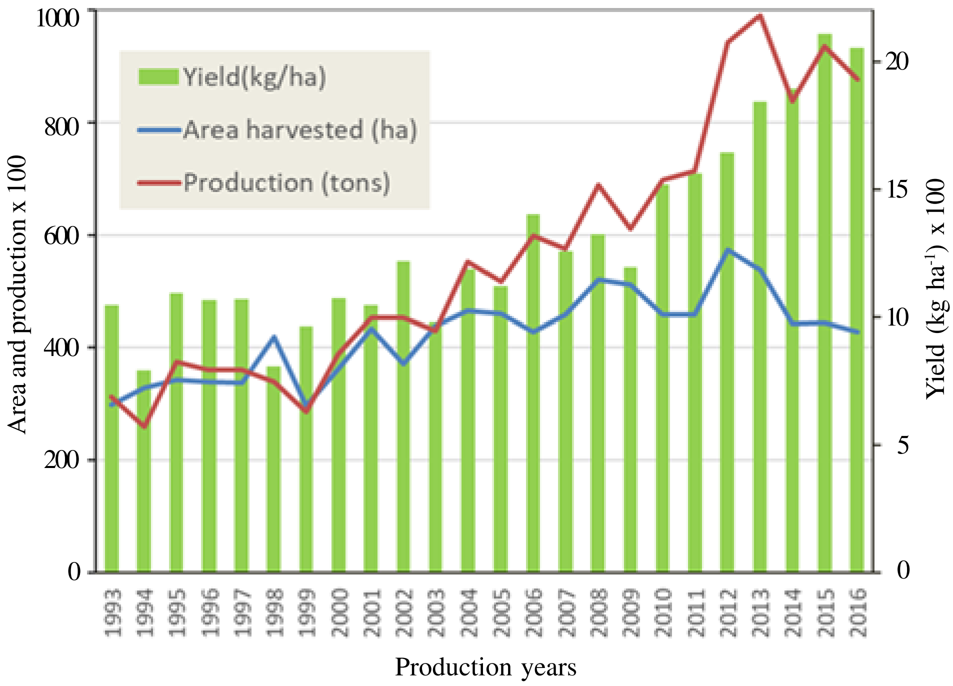

Figure 1. Faba bean harvested area, production and productivity in Ethiopia.
Data source: FAO (2019).

Variety Gabelcho (EH96009-1). The suitability analysis and mapping results for this variety are shown in Figure 3.and Table 5. When compared with the overall crop level suitability map of faba bean by Nigussie (2014), and Table 3 the high and moderate suitable areas of Gabelcho variety was 9,602,444 ha that cover Amhara and central Oromia, which are large parts of the central highlands, and extending to the Harerghie highlands in eastern parts of the country (Table 11).

Gabelcho is a variety developed and released by HARC in 2006.This variety yields, on average 2.5-6.1 and 2.0-3.0 t ha^{-1} in research and farmers' fields, respectively (MoARD, 2006), with a TSW of 797 g, being medium seed size. When surplus production is available, it can be used for export as it has specific market niches. Like most other varieties considered in the analysis, Gabelcho is also moderately resistant to chocolate spot and rust, it is released for soils with good drainage.

Variety Gora (EK 01024-1-2). The suitability analysis and mapping results for this variety are shown in Figure 4 and Table 6. When compared with the overall crop level suitability map of faba bean Nigussie (2014), and Table 3 the high and moderate suitable areas of Gora variety was 7,275,888 ha that cover western parts of Amhara and Oromia, and northern parts of Southern Nations Nationalities and People (SNNP) regional states (Table 11).

Gora is a variety developed and released by Kulumsa Agricultural Research Center (KARC) in 2013. This variety yields, on average, 2.2 to 5.7 and 2.0 to 4.0 t ha^{-1}in research and farmers' fields, respectively, with a high TSW of 938 g (Table 2; MoA 2014). The variety is moderately resistant to chocolate spot and rust.

Variety Moti (EH95078-6). The variety level suitability analysis and mapping results for this variety are shown in Figure 5 and Table 7.

TABLE 4. Area of land under different suitability classes for *var*. Dosha in regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	8,220	0.05	1,918,680	12.33	49,884	0.32	13,586,585	87.3
Oromia	15,348	0.05	2,691,584	8.29	50,908	0.16	29,691,573	91.5
SNNP	0	0	343,836	3.05	34,720	0.31	10,911,430	96.65
Tigray	100	0	40,460	0.81	0	0	4,980,098	99.19
Afar	0	0	0	0	0	0	9,562,336	100
BSG	4	0	26,996	0.54	0	0	4,973,357	99.46
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	23,672	0.02	5,021,556	4.44	135,512	0.12	107,837,480	95.42

TABLE 5. Area of land under different suitability classes for *var*. Gabelcho by regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	57,700	0.37	4,903,888	31.51	245,648	1.58	10,356,133	66.54
Oromia	131,300	0.4	3,895,960	12.01	52,472	0.16	28,369,681	87.43
SNNP	388	0	393,576	3.49	5,480	0.05	10,890,542	96.46
Tigray	3,448	0.07	213,644	4.26	1,452	0.03	4,802,114	95.65
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	2,372	0.05	220	0	4,997,765	99.95
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	0	0	168	0	96	0	31,561,701	100
Total	192,836	0.17	9,409,608	8.33	305,368	0.27	103,110,408	91.23

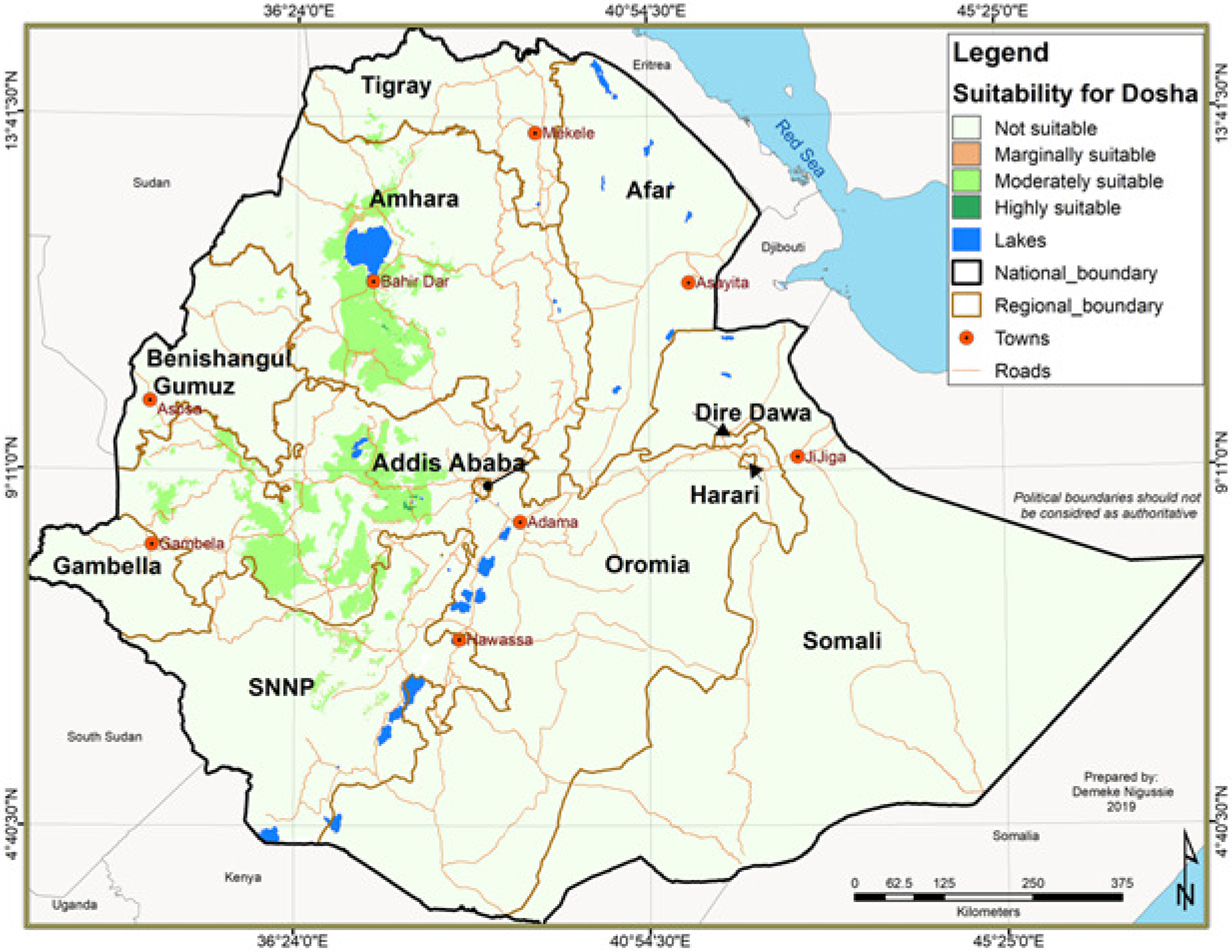

Figure 2. Land suitability map for faba bean *var*. Doshaas established in the present study.

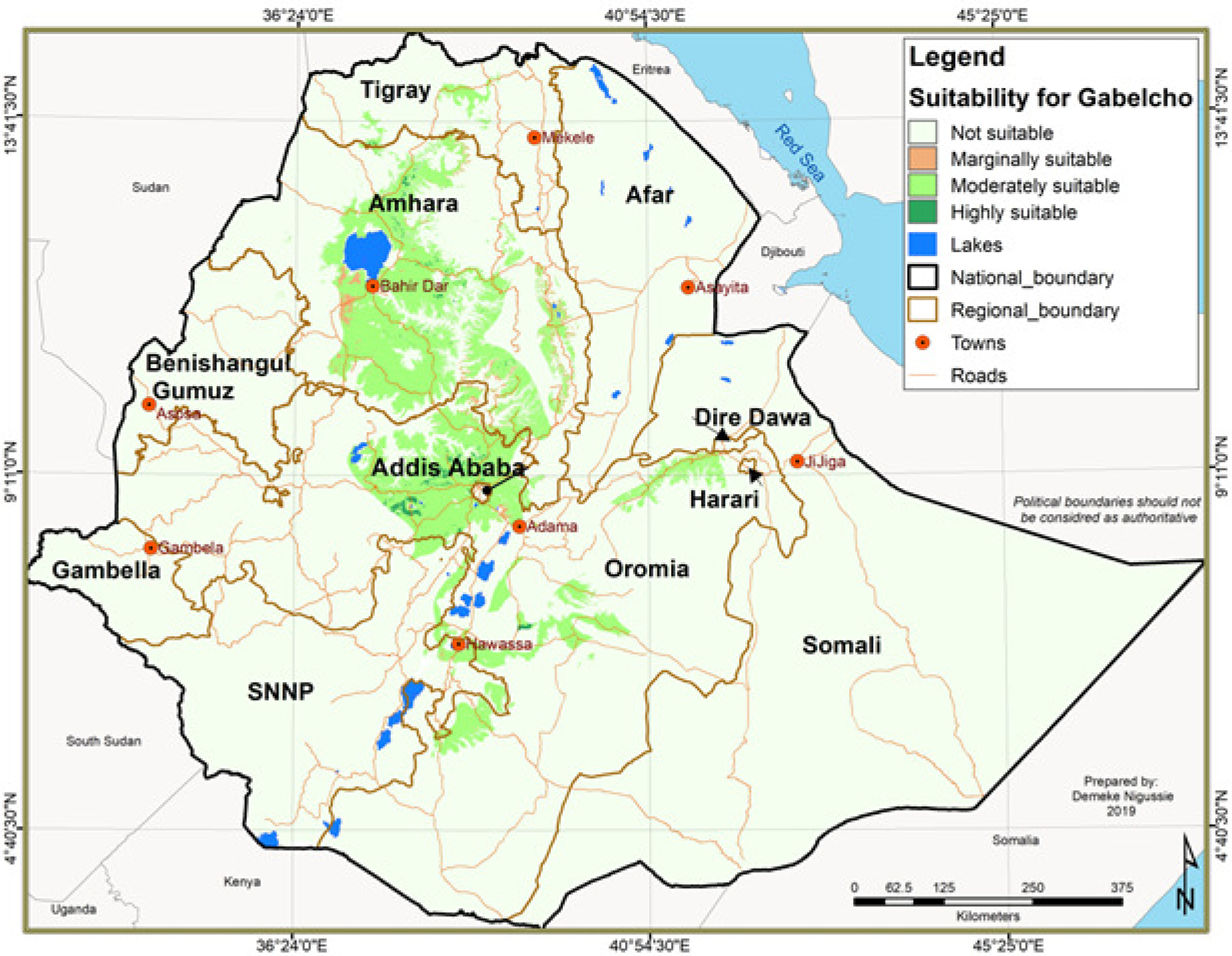

Figure 3. Land suitability map for faba bean *var*. Gabelchoas established in the present study.

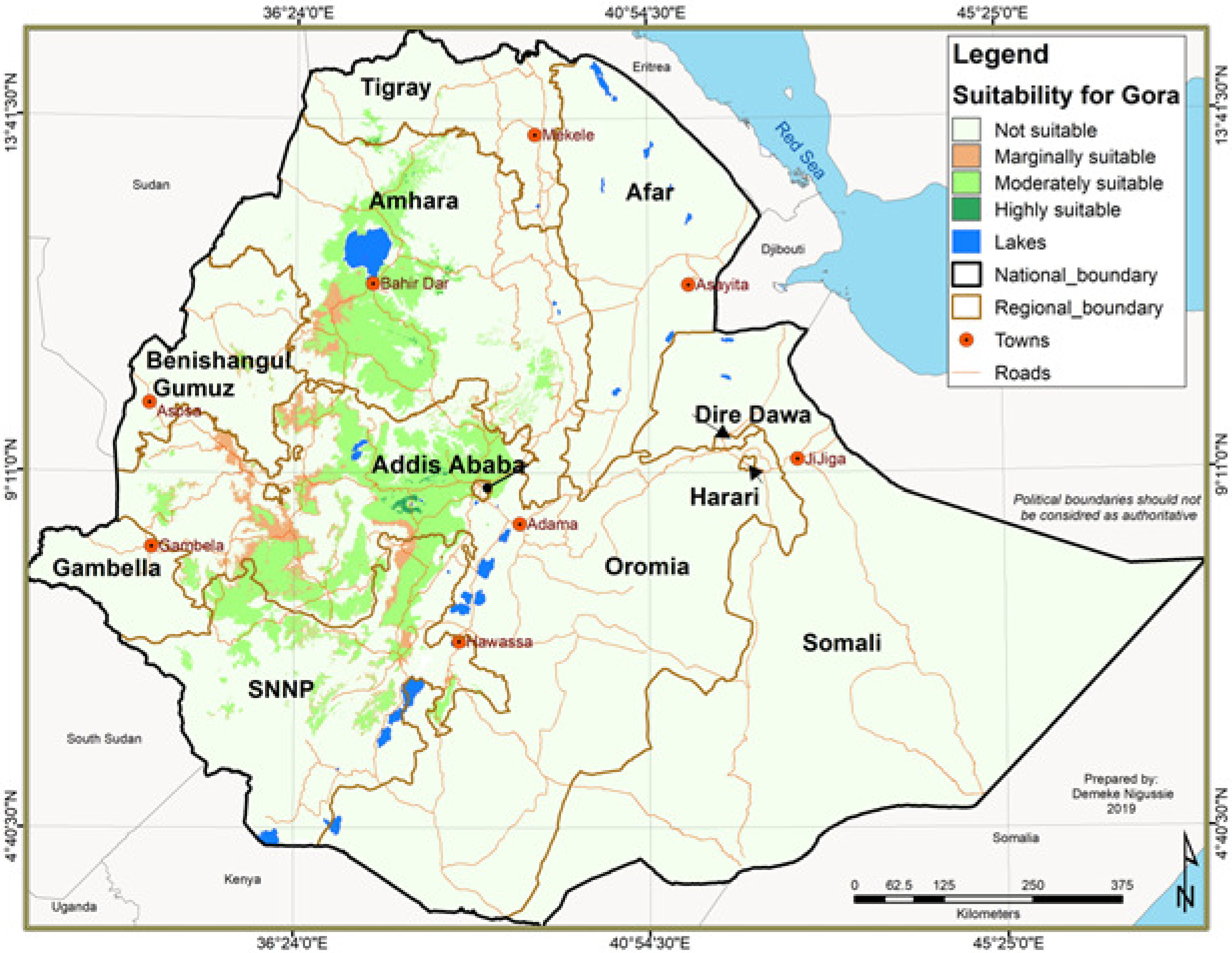

Figure 4. Land suitability map for faba bean *var*. Gora as established in the present study.

TABLE 6. Area of land under different suitability classes for *var*. Gora in regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	28,916	0.19	3,293,744	21.16	250,416	1.61	11,990,293	77.04
Oromia	74,056	0.23	2,778,712	8.56	340,668	1.05	29,255,977	90.16
SNNP	0	0	1,024,368	9.07	271,180	2.4	9,994,438	88.52
Tigray	4,768	0.09	58,508	1.17	0	0	4,957,382	98.74
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	12,812	0.26	9,560	0.19	4,977,985	99.55
Gambella	0	0	4	0	4	0	2,570,128	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	107,740	0.10	7,168,148	6.34	871,828	0.77	104,870,504	92.79

When compared with the overall crop level suitability map of faba bean, the high and moderate suitable areas of Moti variety was 15,615,960 ha. It has better area coverage in large parts of the central highlands and extends to the Harerghie highlands in the east and south-west of the country (Table 11).

Moti is a variety developed and released by HARC in 2006. This variety yields, on average, 2.8 to 5.1 and 2.3 to 3.5 t ha^{-1} in research and farmers' fields, respectively, with a TSW of 781 g (MoARD, 2006). The variety is moderately resistant to chocolate spot and rust and matures early (Table 2), which means it is suitable to areas with a relatively short cropping season that have moderate rainfall.

Variety Dagm (Grarjarso 89-8). The variety level suitability analysis and mapping results for this variety are shown in Figure 6 and Table 8 .When compared with the overall crop level suitability map of faba bean shown by Nigussie (2014) and Table 3. The high and moderate suitable areas of Dagm variety was 4,663,812ha. Where mostly covering western parts of Amhara and Oromia regions and small patches in SNNP region, where waterlogging of heavy black soils was limits faba bean production (Table 11).

Dagm is a variety developed and released by Sheno Agricultural Research Center (now Debre Berhan Agricultural Research Center (DBARC) in 2002. This variety was released for Vertisols and is believed to perform better than other varieties on Vertisols, is limited to heavy black soil of Vertisols and its promotion is low at national level. This variety yields, on average, 2.8 to 6.2 t ha^{-1} in research fields (NAIA, 2003). It is small seeded with TSW of 300 g TSW (Table 2). The variety is highly tolerant to black root rot and chocolate spot. Due to its small seed size, it is sold in local markets to prepare popular dishes, such as *shiro wot*.

Variety Hachalu (EH00102-4-1). The variety level suitability analysis and mapping results for this variety are shown in Figure 7 and

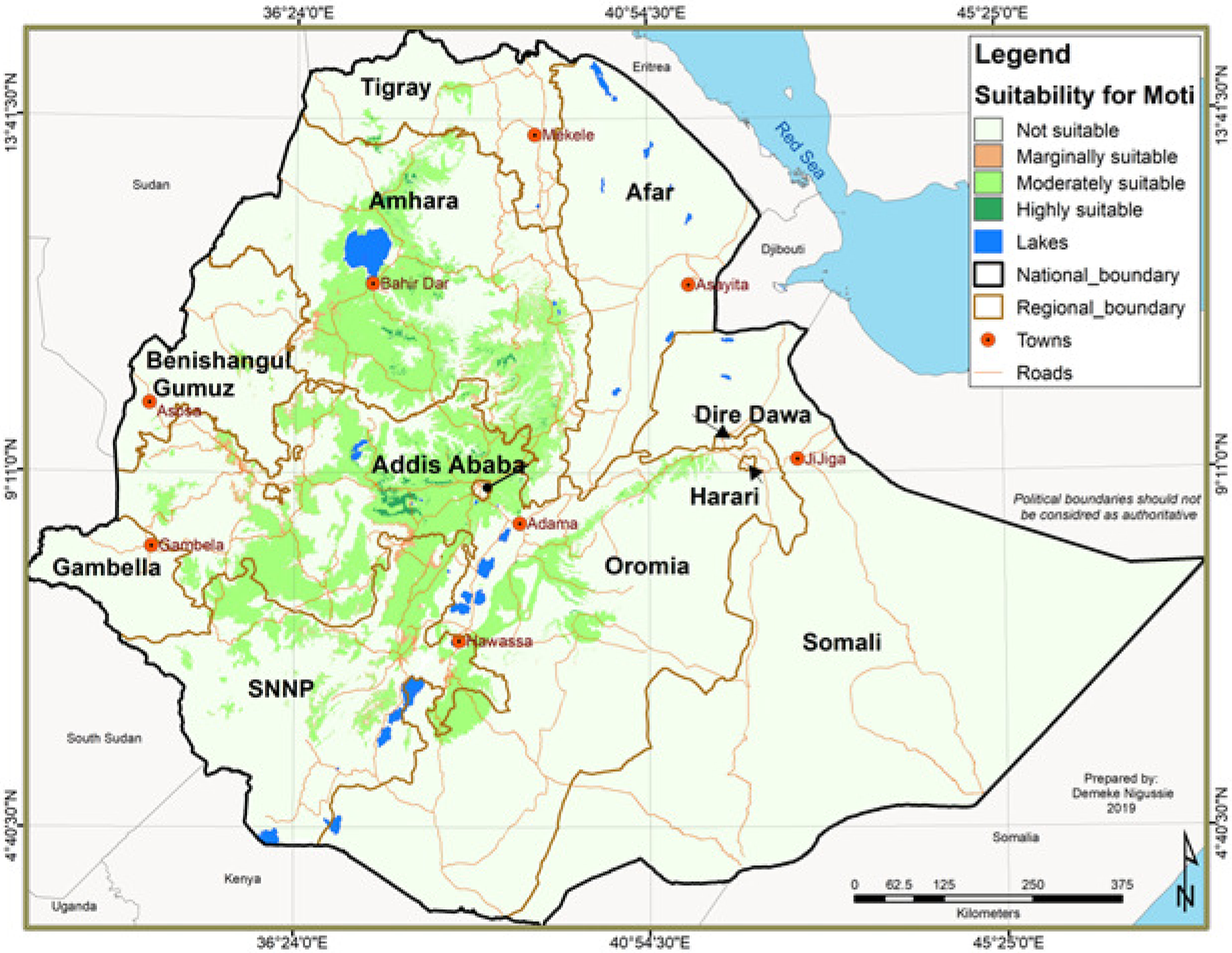

Figure 5. Land suitability map for faba bean *var*.Motias established in the present study.

TABLE 7. Area of land under different suitability for *var*. Moti in regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	132,888	0.85	5,495,292	35.31	163,120	1.05	9,772,069	62.79
Oromia	184,884	0.57	6,933,696	21.37	292,568	0.9	25,038,265	77.16
SNNP	0	0	2,613,396	23.15	208,688	1.85	8,467,902	75
Tigray	7,888	0.16	150,424	3	412	0.01	4,861,934	96.84
Afar	0	0	36	0	0	0	9,562,300	100
BSG	0	0	91,212	1.82	9,796	0.2	4,899,349	97.98
Gambella	0	0	6,244	0.24	4	0	2,563,888	99.76
Somali	0	0	0	0	0	0	31,561,965	100
Total	325,660	0.29	15,290,300	13.53	674,588	0.60	96,727,672	85.59

TABLE 8. Area of land under different suitability for *var*. Dagm in regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	30,876	0.2	2,380,028	15.29	43,688	0.28	13,108,777	84.23
Oromia	22,776	0.07	1,827,616	5.63	47,568	0.15	30,551,453	94.15
SNNP	48	0	307,896	2.73	41,412	0.37	10,940,630	96.91
Tigray	268	0.01	68,704	1.37	5,220	0.1	4,946,466	98.52
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	25,592	0.51	2,848	0.06	4,971,917	99.43
Gambella	0	0	8	0	0	0	2,570,128	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	53,968	0.05	4,609,844	4.08	140,736	0.12	108,213,672	95.75

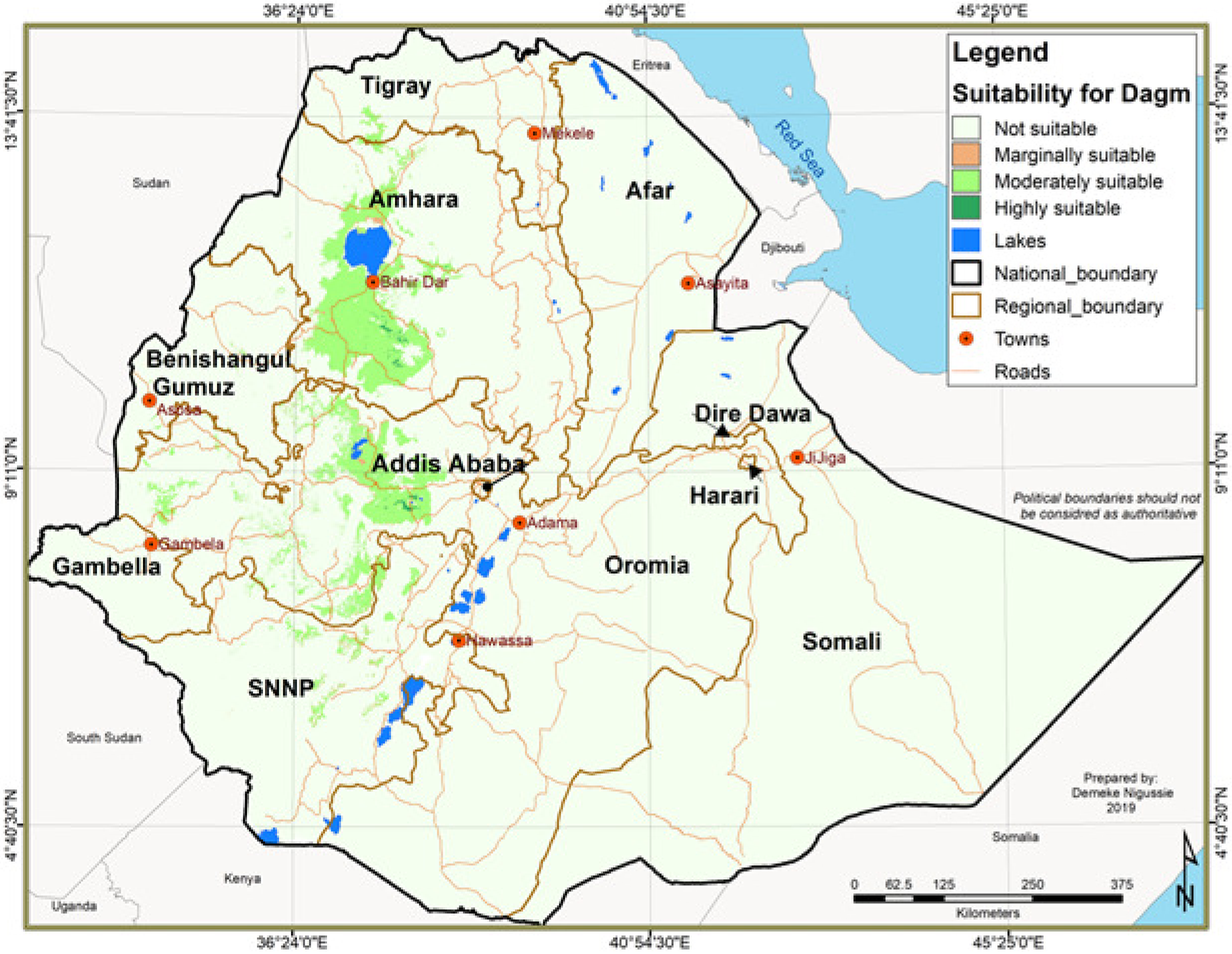

Figure 6. Land suitability map for faba bean *var*. Dagmas established in the present study.

TABLE 9. Area of land under different suitability for *var*. Hachalu in regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	37,860	0.24	3,754,940	24.13	28,756	0.18	11,741,813	75.45
Oromia	96,812	0.3	3,619,408	11.15	92,144	0.28	28,641,049	88.26
SNNP	52	0	1,352,132	11.98	75,620	0.67	9,862,182	87.35
Tigray	1,476	0.03	65,208	1.3	84	0	4,953,890	98.67
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	41,608	0.83	1,132	0.02	4,957,617	99.15
Gambella	0	0	96	0	0	0	2,570,040	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	136,200	0.12	8,833,392	7.82	197,736	0.17	103,850,892	91.89

Table 10. Area of land under different suitability for *var*. Walki in regional states

Regional states	Highly suitable		Moderately suitable		Marginally suitable		Not suitable	
	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	78,228	0.5	3,358,480	21.58	136,368	0.88	11,990,293	77.04
Oromia	178,140	0.55	2,842,356	8.76	172,940	0.53	29,255,977	90.16
SNNP	0	0	1200676	10.63	94,872	0.84	9,994,438	88.52
Tigray	8,516	0.17	54,760	1.09	0	0	4,957,382	98.74
Afar	0	0	0	0	0	0	9,562,336	100
BSG	0	0	17,296	0.35	5,076	0.1	4,977,985	99.55
Gambella	0	0	8	0	0	0	2,570,128	100
Somali	0	0	0	0	0	0	31,561,965	100
Total	264,884	0.23	7,473,576	6.61	409,256	0.36	104,870,504	92.79

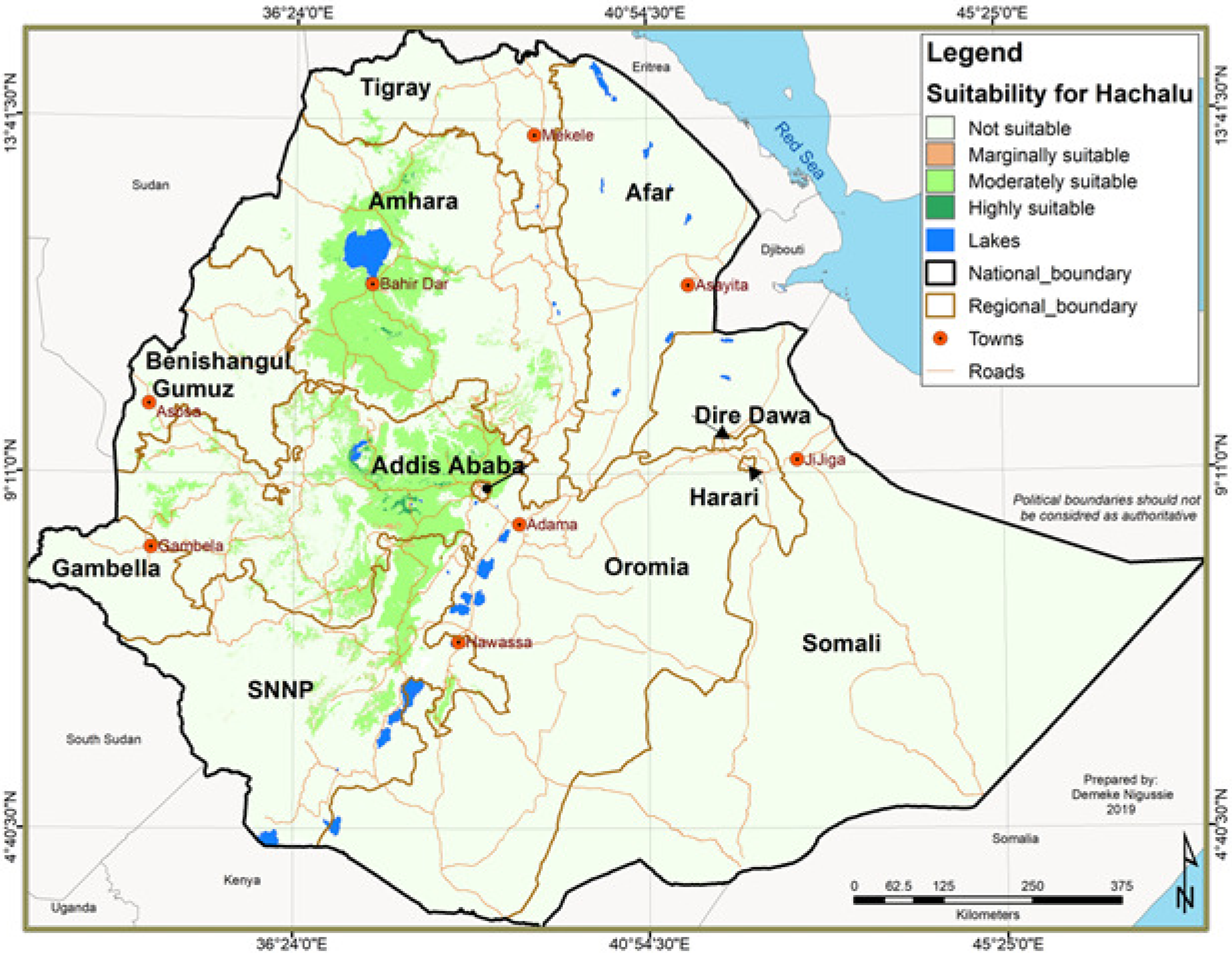

Figure 7. Land suitability map for faba bean *var*. Hachaluas established in the present study.

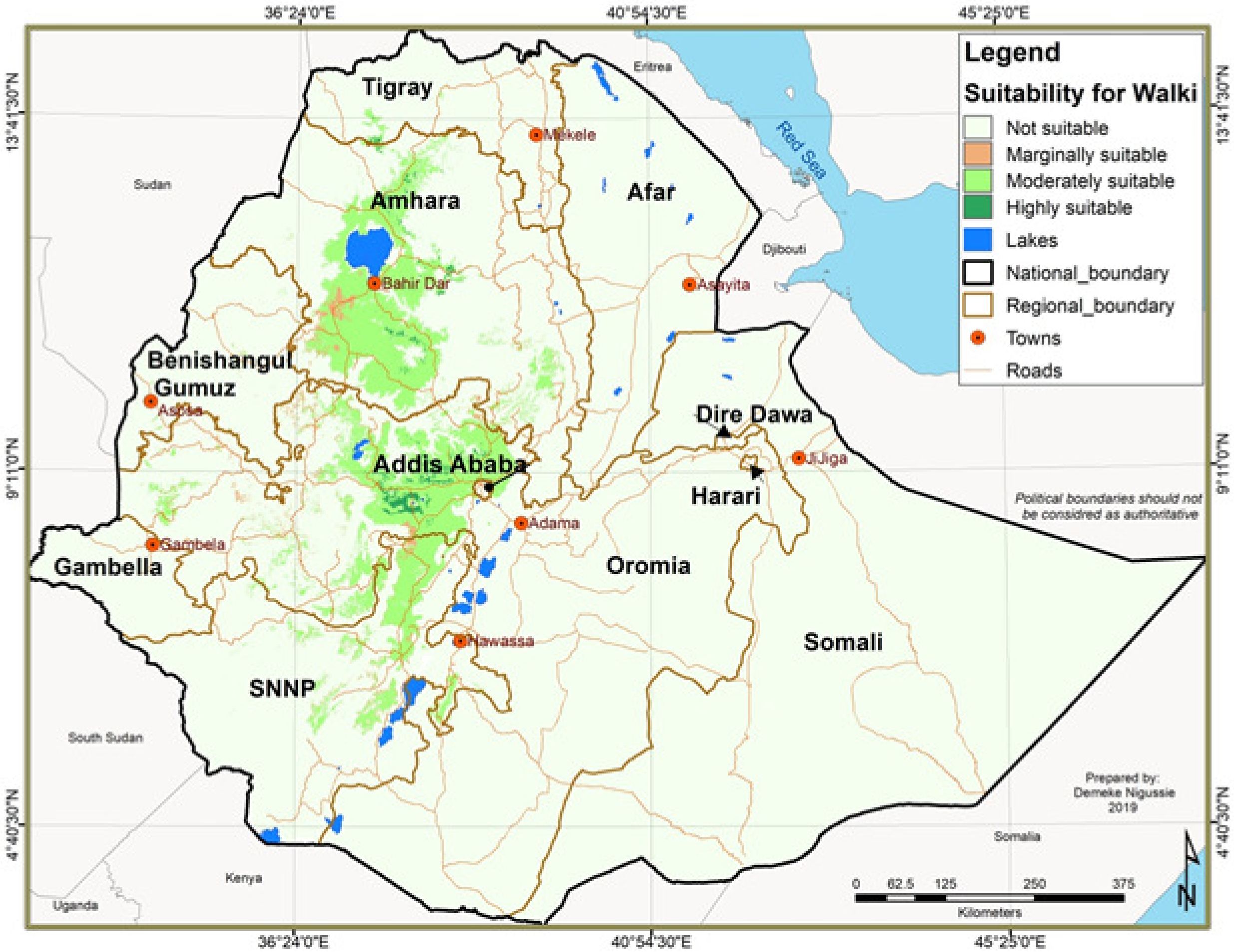

Figure 8. Land suitability map for faba bean *var*. Walkias established in the present study.

TABLE 11. Land suitability for faba bean varieties in Ethiopia

Variety	Suitability classes	Area(ha)	Major zones
Dosha	S_1	23,672	South West Shewa, West Shewa, West Gojam, East Gojam, South Gonder, Horo Guduru, North Gonder, Western, East Wellega, Metekel, Jimma, Ilubabor, West Wellega, Kelem Wellega, Dawro
	S_2	5,021,556	West Gojam, Jimma, West Shewa, East Gojam, Ilubabor, North Gonder, Horo Guduru, East Wellega, South Gonder, West Wellega, Kelem Wellega, South West Shewa, Dawro, Gamo Gofa, Awi/Agew
Gabelcho	S1	192,836	West Shewa, North Gonder, North Shewa (Oromia), South West Shewa, South Gonder, Arsi, South Wollo, West Arsi, Western, East Gojam, North Shewa (Amhara) , Addis Ababa , West Gojam, Bale, Gurage
	S_2	9,409,608	East Gojam, North Gonder, West Shewa, West Gojam, South Gonder, North Shewa (Oromia), South Wollo, North Shewa (Amhara) , South West Shewa, Guji, Bale, West Arsi, Arsi, East Shewa, North Wollo
Gora	S_1	107,740	South West Shewa, North Gonder, South Gonder, East Gojam, Western, North Shewa (Oromia), West Gojam, Horo Guduru, South Wollo, North Shewa (Amhara) Region, Jimma, Gurage, Awi, Gamo Gofa
	S_2	7,168,148	West Shewa, West Gojam, North Gonder, East Gojam, North Shewa(Oromia), South Gonder, South West Shewa, Jimma, Horo Guduru, Gurage, Awi, North Shewa (Amhara), Gamo Gofa, Hadiya, East Wellega
Moti	S_1	325,660	West Shewa, North Gonder, South West Shewa, South Wollo, East Gojam, South Gonder, North Shewa (Oromia), North Shewa (Amhara), West Gojam, Horo Guduru, Western, Arsi, East Shewa, Bale, West Harerge
	S_2	15,290,300	Jimma, West Gojam, West Shewa, East Gojam, North Gonder, South Wollo, North Shewa (Oromia), North Shewa (Amhara), Arsi, South Gonder, Ilubabor, Keffa, South West Shewa, East Wellega, Horo Guduru
Dagm	S_1	53,968	West Gojam, West Shewa, East Gojam, South West Shewa, South Gonder, North Gonder, Horo Guduru, Western, Jimma, Dawro, East Wellega, Awi, Kelem Wellega, Ilubabor, Gamo Gofa
	S_2	4,609,844	West Gojam, West Shewa, North Gonder, East Gojam, Jimma, Awi, Horo Guduru, South Gonder, East Wellega, South West Shewa, Kelem Wellega, Western, Ilubabor, Gamo Gofa, Keffa
Hachalu	S_1	136,200	West Shewa, Horo Guduru, North Gonder, South West Shewa, West Gojam, South Gonder, North Shewa (Oromia) (East Gojam, Western, East Wellega, Jimma, Dawro, North Shewa (Amhara) , Awi, Gurage
	S_2	8,833,392	West Gojam, North Gonder, East Gojam, North Shewa (Oromia), South Gonder, Jimma, South West Shewa, Awi, Gurage, Horo Guduru, East Wellega, Gamo Gofa, Hadiya, North Shewa (Amhara)
Walki	S_1	264,884	West Shewa, North Gonder, South West Shewa, South Gonder, East Gojam, North Shewa of Oromia Region, Western, West Gojam, Horo Guduru, North Shewa (Amhara), Addis Abeba , South Wollo, Jimma, Gurage, Awi
	S_2	7,473,576	West Gojam, West Shewa, North Gonder, East Gojam, North Shewa (Oromia) South Gonder, South West Shewa, Jimma, Horo Guduru, Gurage, Awi, Hadiya, Gamo Gofa, North Shewa (Amhara), East Wellega

Table 9. When compared with the overall crop level suitability map of faba bean Nigussie , (2014), Table 3. The high and moderate suitable areas of Hachalu variety was 8,969,592 ha. While mostly covering the western part of Amhara and Oromia regions and the northern part of South Nation and nationality people SNNP region (Table 11).

Hachalu is a variety developed and released by HARC in 2010. This variety is also released for Vertisols and performs better in grain yield and TSW than other varieties released by NARS in previous years (Table 2). However, it is less tolerant to waterlogging than Dagm. This variety yields on average, 3.2 to 4.5 and 2.4 to 3.5 t ha^{-1}in research and farmers' fields, respectively, having a medium seed size with TSW of 890 g (Table 2 ; MoA, 2010). It has the largest seed size compared to other faba bean varieties released for Vertisols and those released, except Gora, for light soils. The variety is tolerant to black root rot, chocolate spot and rust MoA (2010).

Variety Walki (EH96049-2). The variety level suitability analysis and mapping results for this variety are shown in Figure 8 and Table10. When compared with the overall (crop level) suitability map of faba bean, The high and moderate suitable areas of Walki variety was 7,738,460 ha. Where covering the west-central highlands of Ethiopia including parts of Amhara, Oromia and SNNP regions (Table 11).

Walki is a variety developed and released by HARC in 2008. It was also released for Vertisols and yields on average, 2.4 to 5.2 and 2.0 to 4.2 t ha^{-1} at research and farmers' fields, respectively (MoARD, 2008). Walki performs better on light Vertisols which need well-drained, but should be supported by Broad bed furrow (BBF) on heavy Vertisols for which it is released. Besides, it has a larger seed size with TSW of 676 g compared with Dagm which also released for vertisol and small seed size. The variety is moderately resistant to chocolate spot and rust.

CONCLUSION

This study is a national level and broad scale suitability analysis without considering irrigation potentials and socioeconomic aspects. With all its data limitations, the following are the main summaries of the variety level suitability analysis for faba bean:

(i) Amhara, Oromia, SNNP and Tigray remain the major regions with suitable areas for production of existing varieties of faba bean compared to Afar, Benishangul Gumuz, Gambella, and Somali regions. However, the highly suitable areas are limited compared to moderately suitable areas, which are higher across the regions.

(ii) In general, areas of the highly and moderately suitable lands for faba bean varieties considered in this analysis are smaller than the areas of faba bean crop level suitability Table 3.

(iii) For faba bean varieties considered in this analysis, the highly and moderately suitable areas of each variety was relatively small entail to push faba bean production to marginal areas solving the constraints like draught.. However, Moti followed by Gabelcho, Hacahlu and Walki have broader adaptation than the rest of varieties based on their suitability area coverage.

(IV) For most faba bean varieties analysed, Oromia had more highly suitable areas; whereas Amhara has more moderately suitable areas than other regions. Amhara region has the highest moderately suitable areas for Gabelcho, Moti and Gora accounting for 31.5, 35.3 and 21.16%, respectively.

(V) The suitability analysis results show that the currently available improved varieties of faba bean can be targeted for scaling out in the identified land suitability classes in Ethiopia with agricultural researcher consultation and local expert advice.

(VI) This study is a broad scale nationwide suitability analysis based on biophysical factors and intended to serve as a guide for agricultural research and development related policy and decision-making at national level. One of the constraints that limit the quality of these suitability analyses and mapping is the lack of fine-resolution geospatial data to combine both biophysical and socioeconomic factors. The quality and scale of this work is dependent on the quality of geospatial data and information of environmental requirements of the different varieties included in this analysis. Hence, it should be noted that the outputs may not directly be used for applications that demand finer resolutions (e.g. at farm scale).

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