Suitability Analysis for Scaling Chickpea Improved Varieties in Ethiopia

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Research

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SUITABILITY ANALYSIS FOR SCALING CHICKPEA IMPROVED VARIETIES IN ETHIOPIA

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Abstract

Background: Appropriate decision-making on crop production will reduce various risk factors associated with unsustainable land management. The limited available arable land be taken for granted which may turn from 'best' to 'worst' irrespective of the kind of land use and management practice without understanding its special requirements and potential use.

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. As crop's environmental requirements vary from variety to variety, it is recommended to undertake variety specific analysis and mapping for better understand the extent of scaling-up the specific crop technology

Results: GIS-based land suitability map for chickpea was generated for each variety under consideration mapped showing their percentage area coverage of suitability for each regional states in Ethiopia. Based on, the suitability analysis desi chickpea varieties Mastewal, Naatolii,

Teketay and Arerti, Habru, Kasech, and Yelbey kabuli chickpea varieties classified as highly suitable that cover 0.67, 0.71, 1.4, 2.3, 1.3, 2.4 and 1.2 million ha of the country respectively. While moderately suitable areas for the same varieties cover 25.2, 11.3, 25.9, 26.4, 26.6, 9.6, 17.1 million ha.

Conclusion: The suitability analysis results show that the currently available improved varieties of chickpea can be targeted for scaling out in the identified land suitability classes in Ethiopia with some caution. Amhara, Oromia, SNNP and Tigray remain the major regions with suitable areas for production of available varieties of chickpea 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.

Keywords: Land use suitability; Multi-criteria decision analysis; GIS, Chickpea;

Background

Agriculture is a source of food and income, but, where, when, how and what to cultivate are the main issues that farmers and land managers are confronted daily (Mokarram et al. 2010). Appropriate decision-making on crop production will reduce various risk factors associated with unsustainable land management. The limited available arable land be taken for granted which may turn from 'best' to 'worst' irrespective of the kind of land use and management practice without understanding its special requirements and potential use (FAO 1993; Biradar et al., 2019).

Land suitability classification for agriculture is very important for future planning to help decision-makers and agricultural development planners; and determine how appropriate use of the land in a location is more suitable for certain agricultural use (Singha and Swain 2016).

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. It is useful tool for scaling proven technologies and packages of practices including the specific crops and crop varieties to address the yield and nutritional gaps (Singha and Swain 2016; Low et al., 2018). As crop's environmental requirements vary from variety to variety, it is recommended to undertake variety specific analysis and mapping for better understand the extent of scaling-up the specific crop technology (Nigussie, 2014).

The objective of the study assesses the extent and distribution of areas that are potentially suitable for chickpea *(Cicer arietinum* L.) varieties using Geographic Information System (GIS), and Multi-Criteria Decision–Making Analysis (MCDA) technique.

The Chickpea crop

On average, chickpea production globally consists of about 75% of desi and 25% of kabuli types (AAFC, 2004). Ethiopia is the largest chickpea producer in Africa and ranking sixth globally (http://ethioagp.org/chickpea/). According to FAO (2019), chickpea area, production, and productivity have increased between 2009-2108 respectively (Fig.1).

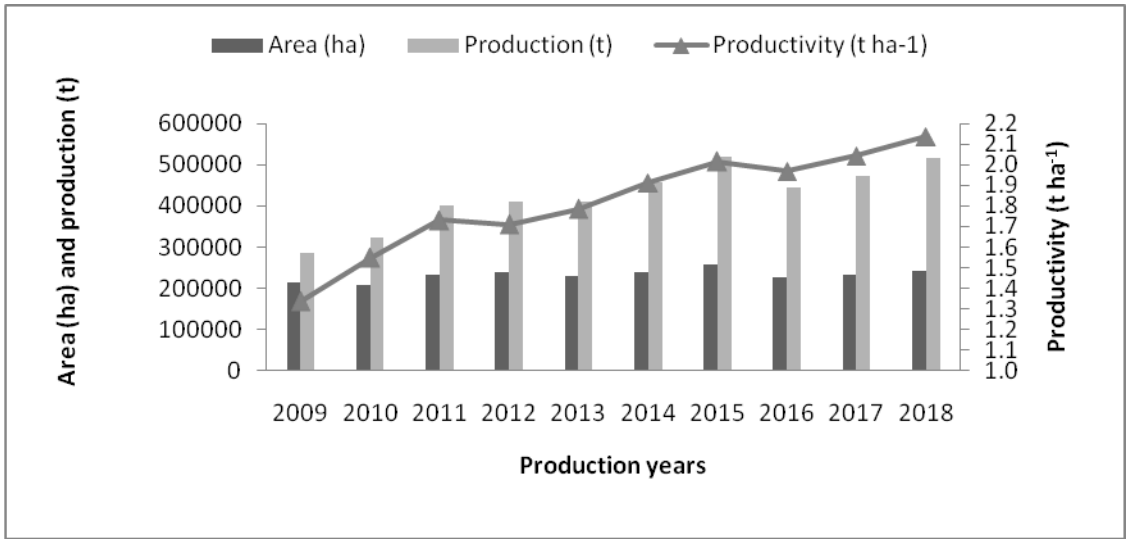

Figure 1.Area harvested, production and productivity of chickpea in Ethiopia
Source: FAO (2019)

In Ethiopia, chickpea with thousand seed weight (TSW) below 200 g is considered as small; between 200-380 g is medium; and greater than 380 g is considered as large seeded. Chickpea varieties released between 1990 and 2000 showed an increase in seed weight of 31.9% and 12% for kabuli and desi, respectively. Remarkable progress has been achieved in genetic gain for seed size in the chickpea breeding program because of the primary focus on the development of large-seeded Kabulis due to world market demand (Bekele et al. 2015). Seed size is the most important quality trait for Kabuli types as larger seeds fetch higher premium price in international trade (Gaur et al. 2007).

Materials and methods

Geospatial data used

The main factors were used in the generation of the suitability map: rainfall and temperature surface maps (during the growing period) interpolated at a resolution of about 300 m which again re sampled to 200 m to match the 200 m analysis resolution; and length of growing period (LGP) from the Ministry of Agriculture (WBISPP 2004) with a slight modification (i.e. joining the values of dependable length of period and converting to raster (pixel based). The soil types data were acquired from MoA modified by the Woody Biomass Inventory and Strategic Planning Project (WBISPP, 2004) while, the soil properties ([chemical (pH) and physical (depth, texture, and drainage)], were extracted from the Soil and Terrain Database of East Africa and gridded soil database of 250m (ISRIC, 2015). 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 for generating slope maps. These data were re-sampled to a common spatial resolution of 200 m for the spatial analysis in the GIS domain.While administrative boundaries, and infrastructure (roads, towns, and other facilities) were used to compute statistical information and prepare the final maps respectively. However, park and lake areas were excluded (restricted) in this land suitability analysis.

Defining environmental requirements

The land suitability class boundary thresholds were mainly based on (FAO 1984; FAO 2007) employing multi-criteria evaluation technique that integrates major determinant factors that affect chickpea production in Ethiopia. The national variety trials conducted at multi-locations and multi-seasons were used to define various suitability ranges/limits. Then, environmental requirements of each variety were defined by means of a set of critical values, which determine

the limits between the land suitability levels (classes) that reflect the degree of suitability (Table 1). According to FAO classification, S_1 corresponds to 85-100% of optimum yield under the recommended management practices, 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).

Table 1.Structure of the 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 & 1993

Since the analysis is raster (pixel) based, some of the data, which were in vector format (object based), were converted to uniform raster datasets. The important GIS layers of environmental factors affecting the growth of chickpea varieties were identified and each layer's pixel values were classified and assigned weight. Following this, the environmental factor layers were compared among themselves and ranked. Based on the rate and rank assigned to each pixel, the land suitability map for each variety was computed. The classification of each layer into suitability categories was done using Reclassify 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 chickpea variety.

Criteria layers and 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 ModelBuilder was used for the overlay analysis to solve such multi-criteria problems of suitability. The suitability criteria 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 is to express the relative importance of each factor regarding the effects on crop production (Perveen et al. 2007). The analytic hierarchy process (AHP) was used to evaluate and calculate the weights for the different criteria (Saaty, 2008) and numerical scales of measurement were derived through comparing against the goal for importance. The pair wise comparisons scales were assigned through discussion among experts. The overall suitability is computed by multiplying the selected criteria weight (Wi) by the assigned sub-criteria score (Xi) and summing these values in the ArcGIS Model Builder (Eq.1):

$$S = \sum_{i=1}^{n} WiXi \quad \text{---------- (Eq.1)}$$

Where **S** denotes the final land suitability score, **Wi** denotes the weight of the corresponding suitability criteria, **Xi** denotes 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 are prepared both in softcopy and hardcopy.

Crop varieties

Seven chickpea varieties (Mastewal, Naatolii, Teketay, Arerti, Habru, Kasech and Yelbe) were used in suitability analysis. The varieties were selected based on current production and area

coverage in the technology transfer productivity earliness export and local market quality parameters (

Table 2).

Table 2.Agronomic characteristics of chickpea varieties used for land suitability mapping

Variety	Type	Year of release	Releasing Center	DF flowering after emergence	Days to maturity after planting	Grain yield with recommended management (t/ha)	Thousand grain weight (g)	Plant height at poding (cm)	Altitude (m)	Germplasm source
Mastewal	Desi	2006	DBARC	52	122	2.5-3.1	240	40	2,000-2,600	ICRISAT
Naatolii	Desi	2007	DZARC	60	115	2.5-3.6	240	41	1,800-2,700	ICRISAT
Teketay	Desi	2013	DZARC	50	118	1.8-4.4	310	38	1,800-2,700	ICRISAT
Arerti	Kabuli	2000	DZARC	59	130	0.73-3.2	257	45	1,800-2,600	ICRISAT
Habru	Kabuli	2004	DZARC	60	121	2.4-3.2.	319	46	1,800-2,600	ICARDA
Kasech	Desi	2011	SIARC	46	118	2.0-2.5	375	50	1,400-2,000	ICARDA
Yelbey	Kabuli	2006	SIARC	44	92	0.8-2.3	355	42	1,450-2,300	ICRISAT

Source: Crop Variety Registers (NSIA, 2000; MoARD, 2004, 2006 & 2007; MoA, 2011 &2013); and regional variety trial (RTV) data submitted to MoA/MoARD for varietal releases

DBARC; Debre Berhan Agricultural Research Center, DZARC; Debre Zeit Agricultural Research Center, SIARC; Sirinka Agricultural Research Center, ICRISAT; International Crops Research Institute for the Semi-Arid Tropics, ICARDA; International Center for Agricultural Research in Dry Areas,

Results and discussion

Area and suitability mapping

GIS-based land suitability map for chickpea was adopted from (Demeke, 2018) followed by variety level land suitability map showed the percentage area coverage of suitability for each regional state computed based on their respective total area Table 3.

Table 3. Area (ha) of regional administrative states in Ethiopia*

Regional administrative states	Area (ha)	Percentage area (%)
Afar	9,562,336	8.45
Amhara	15,563,369	13.75
Benishangul Gumuz (BSG)	5,000,357	4.42
Gambella	2,570,136	2.27
Oromia	32,449,413	28.66
Somali	31,561,965	27.88
SNNP	11,289,986	9.97
Tigray	5,020,658	4.43
Addis Ababa	55,069	0.05
Dire Dawa	105,556	0.09
Harari	37,165	0.03
Total	113,216,009	100

Note: *The total area includes all agriculture, forest, water, town, and other lands bounded within the boundary of each regional state; Addis Abeba, Dire Dawa and Harari are city administrations with limited agricultural land for crop production.

Crop-level land suitability mapping

From the outset, it should be noted that the suitability analysis in this study does not exclude the areas occupied by non-agricultural areas such as forests, woodlands, towns (except Addis Abeba, Dire Dawa and Harari) and another non-cropland uses. It also does not account the updated cropland currently under active cultivation. The chickpea crop level suitability area showed 1.61% (highly suitable) and 19.36 % (moderately suitable) for chickpea production across the

regions (Figure 2 and **Error! Reference source not found.**). Generally, the crop level highly suitable land areas of chickpea are still larger than the highly suitable land area for most individual varieties. This is expected because the environmental range boundaries for the different suitability class thresholds are defined considering broader ranges of adaptation to encompass the adaptation ranges of most of the varieties currently available.

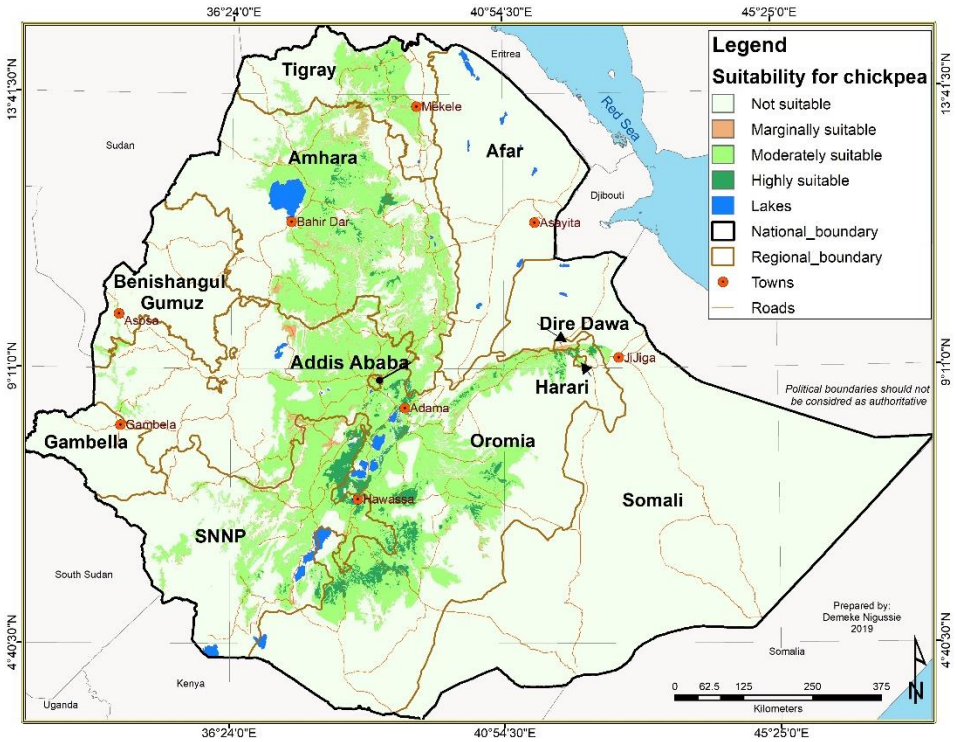

Figure 2. Land suitability map for chickpea Source: Demeke (2018)

Table 4.Land area under different suitability classes for chickpea in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%
Amhara	206,884	1.34	6,759,484	43.66	394,688	2.55	8,122,488	52.46
Oromia	1,167,484	3.9	9,685,144	32.37	248,568	0.83	18,818,876	62.9
SNNP	406,908	3.83	3,605,024	33.94	187,052	1.76	6,422,968	60.47
Tigray	27,268	0.55	1,459,352	29.46	63,376	1.28	3,404,436	68.71
Afar	0	0	29,384	0.35	460	0.01	8,407,408	99.65
BSG	0	0	82,468	1.64	12,040	0.24	4,941,076	98.12
Gambella	0	0	1,888	0.06	44	0	2,990,684	99.94
Somali	0	0	111,588	0.32	2,312	0.01	34,697,740	99.67
Total	1,808,544	1.61	21,734,332	19.36	908,540	0.81	87,805,676	78.22

Source: Nigiussie (2018)

Variety level land suitability

Mastewal (ICCV-92006)

Chickpea variety Mastewal yields, on average, 3.0 and 1.9 tons ha^{-1} in research and farmers' fields, respectively (MoARD 2006). It has a medium seed size (TSW of 240 g) in comparison with the prior releases of chickpea varieties (

Table 2). It is an early maturing variety and can be potentially used in double cropping in areas having a short rainy season (*belg*) following the harvest of the main rainy season crops. In the local market, it is preferred for its relatively larger seed size than the local varieties and for its light red color. The variety is relatively tolerant to wilt and root rot fungal diseases.

The variety level suitability analysis and mapping results for this variety are shown in Figure 3 and Table 5. When compared with the overall crop level suitability result of chickpea (Figure 2 and **Error! Reference source not found.**, the highly suitable lands for Mastewal are still smaller. The highly suitable lands are in the west-central highlands of Ethiopia largely in parts of Amhara and Oromia and SNNP regional states. The moderately suitable and marginally suitable areas of Mastewal variety is mainly covering most of Amhara and Oromia, and central and northern SNNPR.

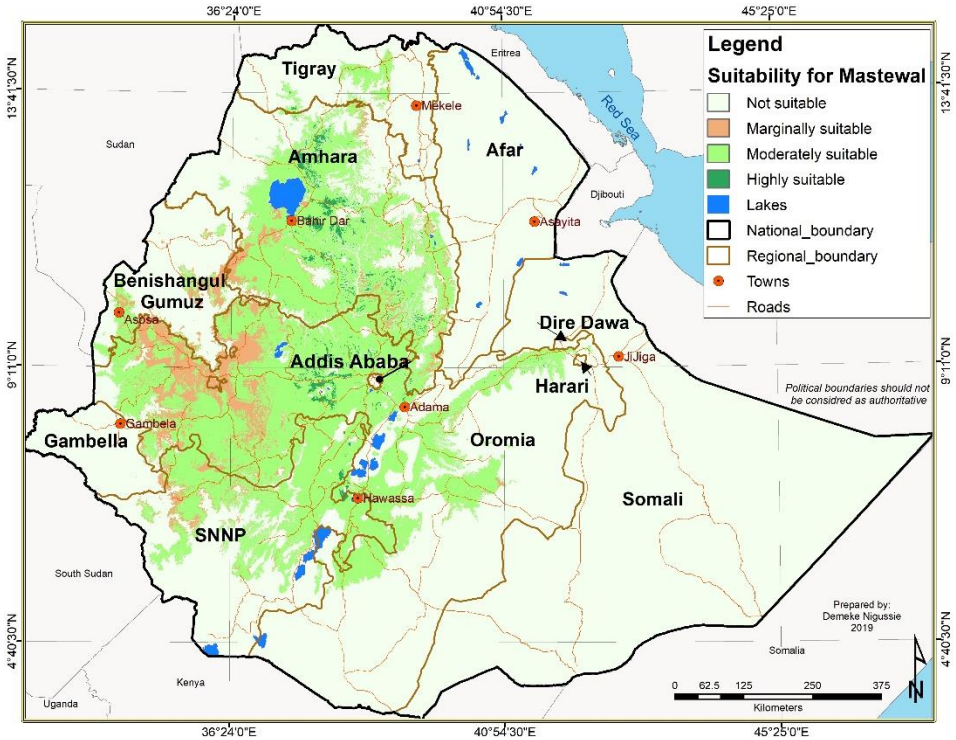

Figure 3. Land suitability map for chickpea *var*. Mastewal

Table 5. Land area under different suitability classes for Mastewal variety in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%
Amhara	419,300	2.69	7,603,708	48.86	677,736	4.35	6,862,625	44.09
Oromia	225,988	0.7	11,994,180	36.96	2,315,952	7.14	17,913,293	55.2
SNNP	20,584	0.18	4,862,344	43.07	410,092	3.63	5,996,966	53.12
Tigray	5,232	0.1	472,764	9.42	20,088	0.4	4,522,574	90.08
Afar	0	0	6,488	0.07	13,592	0.14	9,542,256	99.79
BSG	0	0	554,984	11.1	519,736	10.39	3,925,637	78.51
Gambella	0	0	15,520	0.6	33,044	1.29	2,521,572	98.11
Somali	0	0	5,264	0.02	1,088	0	31,555,613	99.98
Total	671,104	0.59	25,515,252	22.58	3,991,328	3.53	82,840,536	73.30

Naatolii (ICCX-910112-6)

Naatolii grain yields ranged from 2.5-3.5 tons ha^{-1}in the research field (MoARD 2007). It is a high yielding and short duration chickpea variety resistant to fusarium wilt disease in waterlogging Vertisol areas. However, it is recommended to advance the planting date and drain excess water from the field. There are local and foreign market demands to meet producing chickpea varieties like Naatolii, although the supply is very limited, as its production has not yet expanded. It has a local market preference due to its light golden seed color and medium seed size of 240g of TSW (

Table 2).The variety level suitability analysis and mapping results for this variety are shown in Figure 4 and Table 6.

The moderately suitable and highly suitable areas for this variety cover large parts of Amhara followed by mainly central Oromia. It covers also part of central Tigray and northern SNNP to a smaller extent. Compared with the overall (crop level) suitability result of chickpea, this variety has relatively smaller coverage.

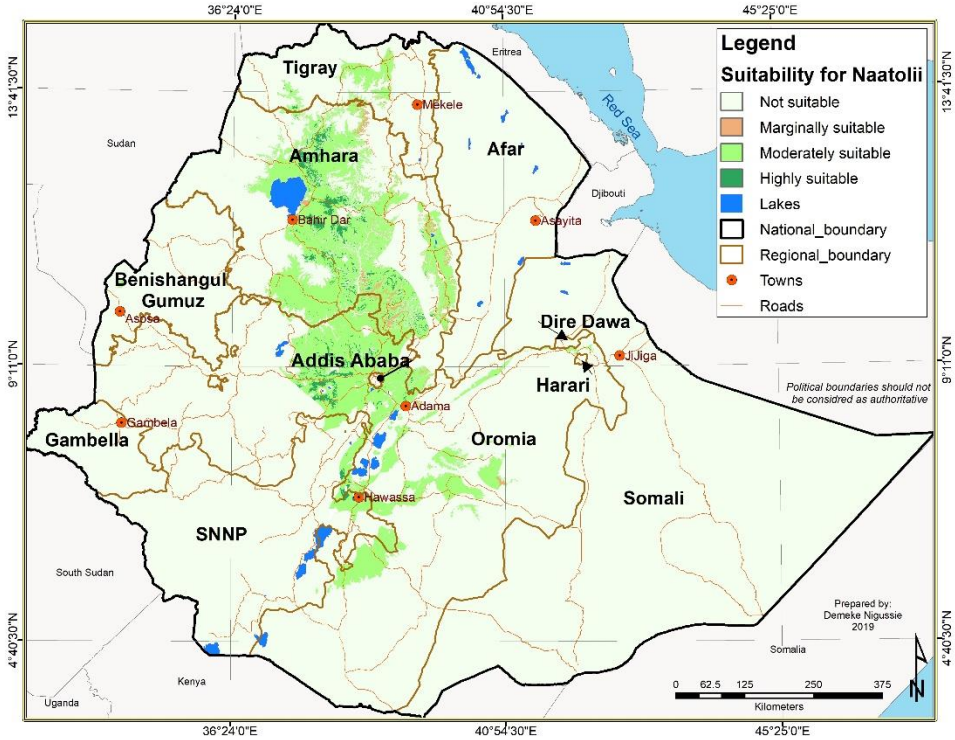

Figure 4. Land suitability map for chickpea *var*. Naatolii

Table 6. Land area under different suitability classes for Naatolii variety in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%
Amhara	453,120	2.91	5,733,520	36.84	276,976	1.78	9,099,753	58.47
Oromia	235,504	0.73	4,544,288	14	50,560	0.16	27,619,061	85.11
SNNP	20,580	0.18	544,856	4.83	1,156	0.01	10,723,394	94.98

Tigray	5,388	0.11	472,384	9.41	20,052	0.4	4,522,834	90.08
Afar	0	0	856	0.01	596	0.01	9,560,884	99.98
BSG	0	0	13,220	0.26	612	0.01	4,986,525	99.72
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	0	0	4,480	0.01	748	0	31,556,737	99.98
Total	714,592	0.63	11,313,604	10.01	350,700	0.31	100,639,324	89.05

Teketay (ICCX-940002-F5-242P-1-1-1)

Teketay variety yields, on average, 2.0 to 2.7 and 1.6 to 2.2 tons ha^{-1} at research stations and on farmers' fields, respectively, with a medium seed size for having TSW of 310 g (

Table 2). The observed yield potential on farmers' fields during the 2015-2018 scaling project of ICARDA in potential chickpea growing areas of the country was by far higher than the yield reported for release, which was attributed to sub-optimal crop management and weather conditions in the selected test locations during nationwide testing.

The variety level suitability analysis and mapping results for this variety are shown in Figure 5 and Table 7. The result shows that the moderately and highly suitable areas for this variety cover large parts of east-central Amhara followed by central Oromia. It also covers a smaller part of central Tigray and northern SNNPR. Compared with the overall crop level suitability map of chickpea, it covers a relatively small area of suitable lands.

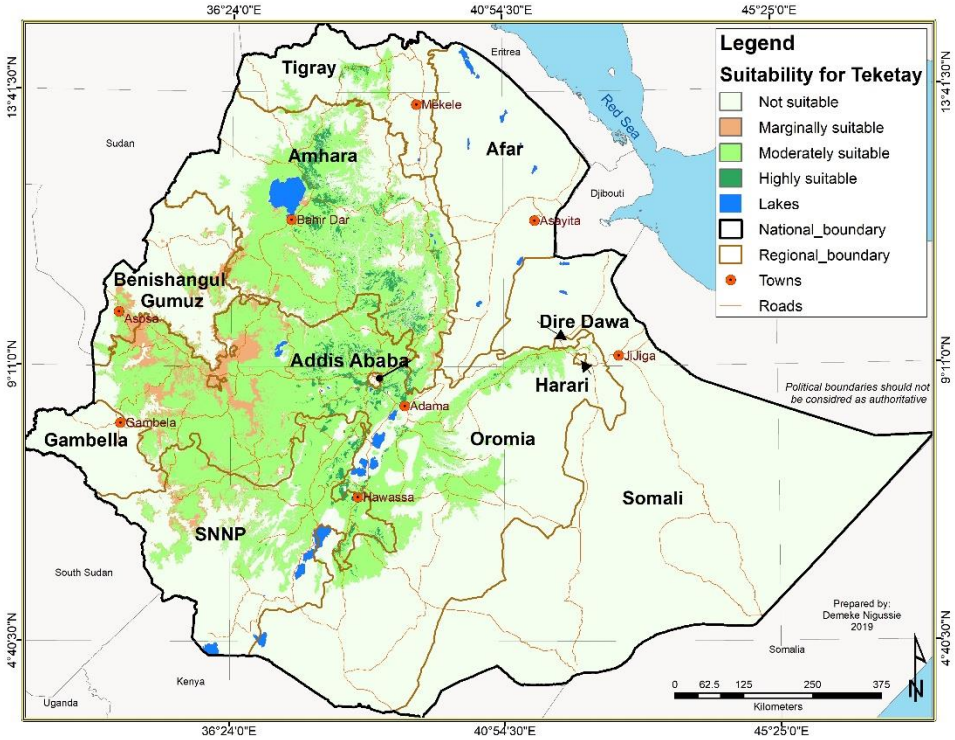

Figure 5. Land suitability map for chickpea *var*. Teketay

Table 7. Land area under different suitability classes for Teketay variety in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%

Amhara	714,396	4.59	7,640,040	49.09	346,308	2.23	6,862,625	44.09
Oromia	471,908	1.45	12,511,392	38.56	1,552,820	4.79	17,913,293	55.20
SNNP	160,792	1.42	4,748,356	42.06	383,872	3.40	5,996,966	53.12
Tigray	31,104	0.62	466,124	9.28	856	0.02	4,522,574	90.08
Afar	0	0.00	7,056	0.07	13,024	0.14	9,542,256	99.79
BSG	0	0.00	494,752	9.89	579,968	11.60	3,925,637	78.51
Gambella	0	0.00	20,292	0.79	28,272	1.10	2,521,572	98.11
Somali	0	0.00	5,840	0.02	512	0.00	31,555,613	99.98
Total	1,378,200	1.22	25.893,852	22.91	2,905,632	2.57	82,840,536	73.30

Arerti (FLIP 89-84C)

Arerti variety yields, on average, 1.6-5.2 and 1.8-4.7 tons ha^{-1} in research and farmers' fields, respectively, with 257 g of TSW (

Table 2; NSIA 2000), being medium in seed size. It is widely grown in the country and is a dominant chickpea variety under production as the result of national level pre-scaling up activities by EIAR in addition to its merits prior to 2015.

The variety level suitability analysis and mapping results for this variety are shown in Figure 6 and Table 8. Compared with the overall crop level suitability result of chickpea, the highly and moderately suitable areas of Arerti variety is large, covering most of Amhara, Oromia, SNNPR and part of central Tigray. The result shows that the highly suitable areas are larger in Amhara region when compared with the crop level suitability maps and they are mainly found in central Amhara and Oromia. Highly suitable lands are larger than the crop level suitability, which is about 1.81 million ha, while that of Arerti variety is 2.29 million ha, which is the second largest next to Kasech with 2.4 million ha compared with other chickpea varieties included in this study.

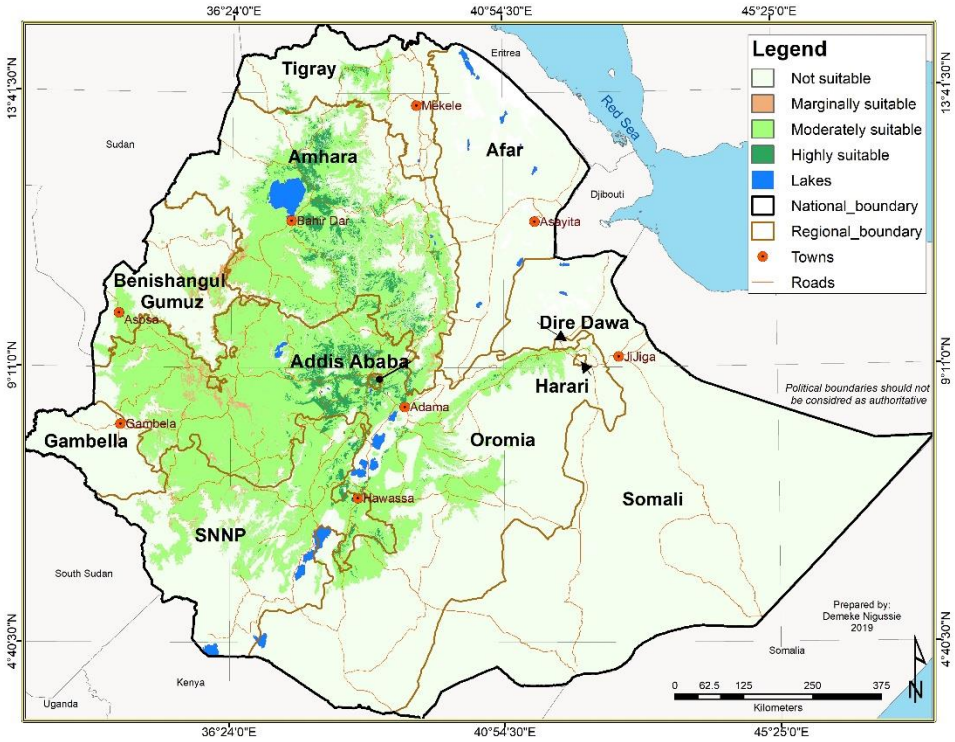

Figure 6.Land suitability map for chickpea *var*. Arerti

Table 8. Land area under different suitability classes for Arerti in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%
Amhara	1,121,812	7.21	7,069,028	45.42	188,360	1.21	7,184,169	46.16
Oromia	940,676	2.9	12,995,936	40.05	377,828	1.16	18,134,973	55.89
SNNP	180,972	1.6	4,962,804	43.96	117,688	1.04	6,028,522	53.4
Tigray	44,156	0.88	449,700	8.96	784	0.02	4,526,018	90.15
Afar	0	0	8,612	0.09	11,468	0.12	9,542,256	99.79
BSG	0	0	852,780	17.05	221,940	4.44	3,925,637	78.51
Gambella	0	0	42,756	1.66	5,808	0.23	2,521,572	98.11
Somali	0	0	5,800	0.02	552	0	31,555,613	99.98
Total	2,287,616	2.02	26,387,416	23.35	924,428	0.82	83,418,760	73.81

Habru (FLIP-88-42C)

Habru yields, on average, 2.4 to3.2 tonsha^{-1}inresearch field with TSW of 319 g (

Table 2; MoARD 2004), being medium in seed size, even though it has a relatively larger seed size than chickpea varieties considered, except Yelbey, in this land suitability analysis. It has got wide adaptation and is a dominant variety as a result of national level pre-scale up activities by EIAR prior 2015 in addition to its biological merits, such as better performance in both moisture stress and mid to high altitude areas. This variety is moderately resistant to wilt.compared with the overall crop level suitability result of chickpea, shown in Figure 2 and **Error! Reference source not found.**, the suitable areas of Habru variety (see Figure 7 and Table 9) is large, covering most of Amhara, Oromia, SNNP and part of central Tigray. The result shows that the highly suitable areas are larger in Amhara region when compared with the crop level suitability maps and they are mainly found in central Amhara and Oromia. Highly suitable areas are still large in the crop-level suitability, which is about 1.8 million ha; while that of Habru variety is 1.29 million ha, which is the third largest compared with other chickpea varieties.

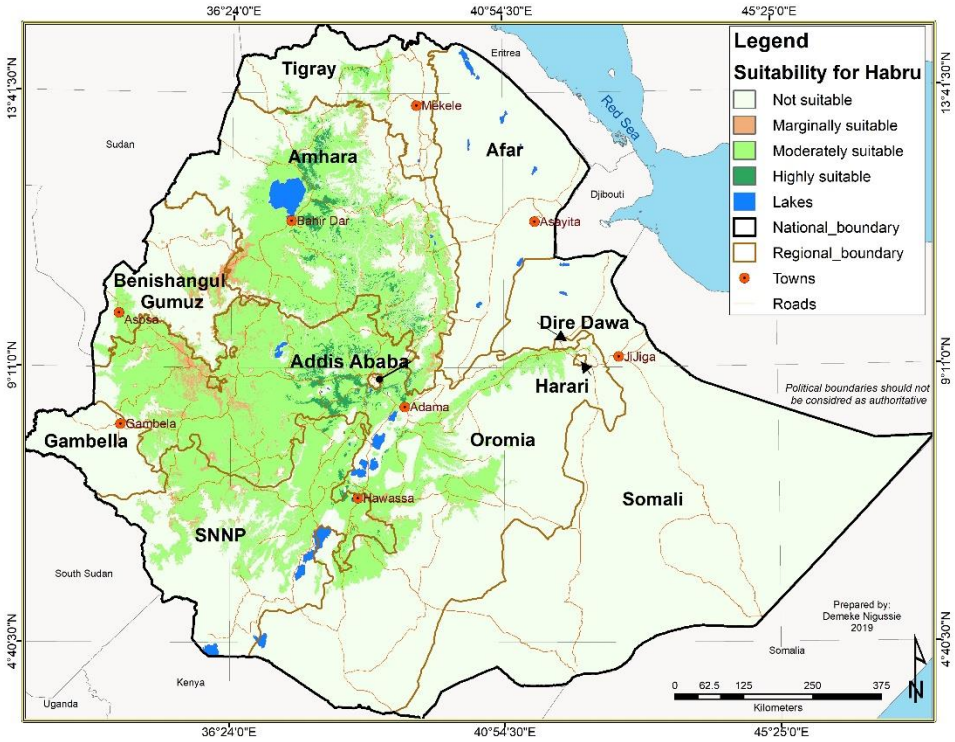

Figure 7. Land suitability map for chickpea *var*. Habru

Table 9. Land area under different suitability classes for Habru variety in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%
Amhara	640,304	4.11	7,358,364	47.28	380,532	2.45	7,184,169	46.16
Oromia	570,968	1.76	12,947,872	39.9	778,932	2.4	18,151,641	55.94
SNNP	58,832	0.52	4,985,464	44.16	217,168	1.92	6,028,522	53.4
Tigray	23,372	0.47	465,844	9.28	5,424	0.11	4,526,018	90.15
Afar	0	0	5,984	0.06	14,096	0.15	9,542,256	99.79
BSG	0	0	755,380	15.11	319,340	6.39	3,925,637	78.51
Gambella	0	0	40,912	1.59	7,652	0.3	2,521,572	98.11
Somali	0	0	5,532	0.02	820	0	31,555,613	99.98
Total	1,293,476	1.14	26,565,352	23.51	1,723,964	1.53	83,435,428	73.82

Kasech (FLIP-95-31C)

Kasech variety yields, on average, 2.0 to2.5 and 1.6 to2.0 tons ha^{-1} in research and farmers' field, respectively, with a TSW of 375g (

Table 2; MoA 2011), which falls in medium seed size although it has the biggest seed size than the varieties included in this study. Even though it is low yielding, Kasech is an early maturing variety, which is well adapted to moisture stress areas.

The variety level suitability analysis and mapping results for this variety are shown in Figure 8 and Table 10. The variety has the largest highly suitable land (2.395 million ha) compared with both the crop and variety level suitability analysis results. These areas are found in Amhara largely followed by Oromia, Tigray and SNNP. The combined highly suitable and moderately suitable areas of the Kasech variety is, however, still smaller than the crop level suitability and other varieties considered in this analysis.

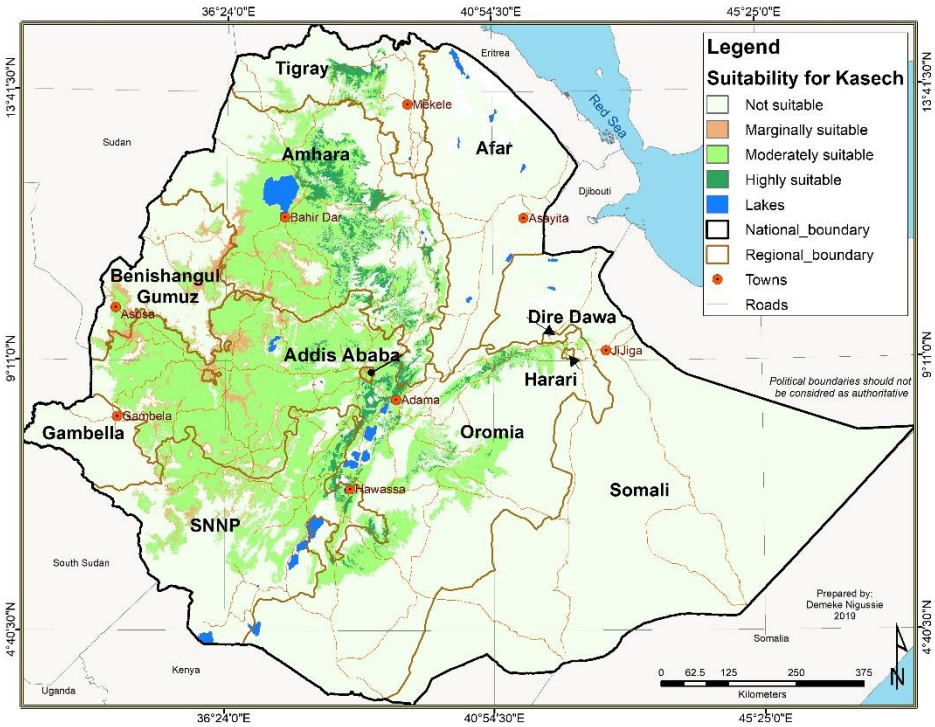

Figure 8. Land suitability map for chickpea *var*. Kasech

Table 10. Land area under different suitability classes for Kasech variety in regional states

Regional states	Highly suitable	Moderately suitable	Marginally suitable	Not suitable

	area (ha)	%	area (ha)	%	area (ha)	%	area (ha)	%
Amhara	1,366,880	8.78	4,255,224	27.34	59,320	0.38	9,881,945	63.49
Oromia	587,344	1.81	4,441,420	13.69	23,752	0.07	27,396,897	84.43
SNNP	200,124	1.77	323,188	2.86	128	0	10,766,546	95.36
Tigray	240,732	4.79	568,680	11.33	3,620	0.07	4,207,626	83.81
Afar	0	0	2,740	0.03	184	0	9,559,412	99.97
BSG	0	0	0	0	0	0	5,000,357	100
Gambella	0	0	0	0	0	0	2,570,136	100
Somali	60	0	24,360	0.08	3,244	0.01	31,534,301	99.91
Total	2,395,140	2.12	9,615,612	8.508	90,248	0.08	100,917,220	89.29

Yelbey (ICCV-14808)

Yelbey variety yields, on average, 1.8 and 1.4 tonsha^{-1}inresearch and farmers' fields, respectively, with a TSW of 355 g (

Table 2; MoARD 2006). It is medium seed size chickpea, though with the second largest seed size among the varieties used for land suitability analysis in this study. It is relatively resistant to wilt and root rot. Although its productivity is low, it is early maturing and well adapted to moisture stress areas.

Compared with the overall crop-level suitability result of chickpea, shown in Figure 2 and **Error! Reference source not found.**, the suitable areas of Yelbey variety are smaller than that of the crop level results, mostly covering the central highlands of the country; stretching from most of central Tigray, central and western Amhara, central Oromia, to large parts of northern SNNP (Figure 9 and Table 11). The results show that the highly suitable areas are the fourth largest (1.22 million ha), when compared with the variety level suitability results and they are found in Amhara largely followed by Oromia and SNNP.

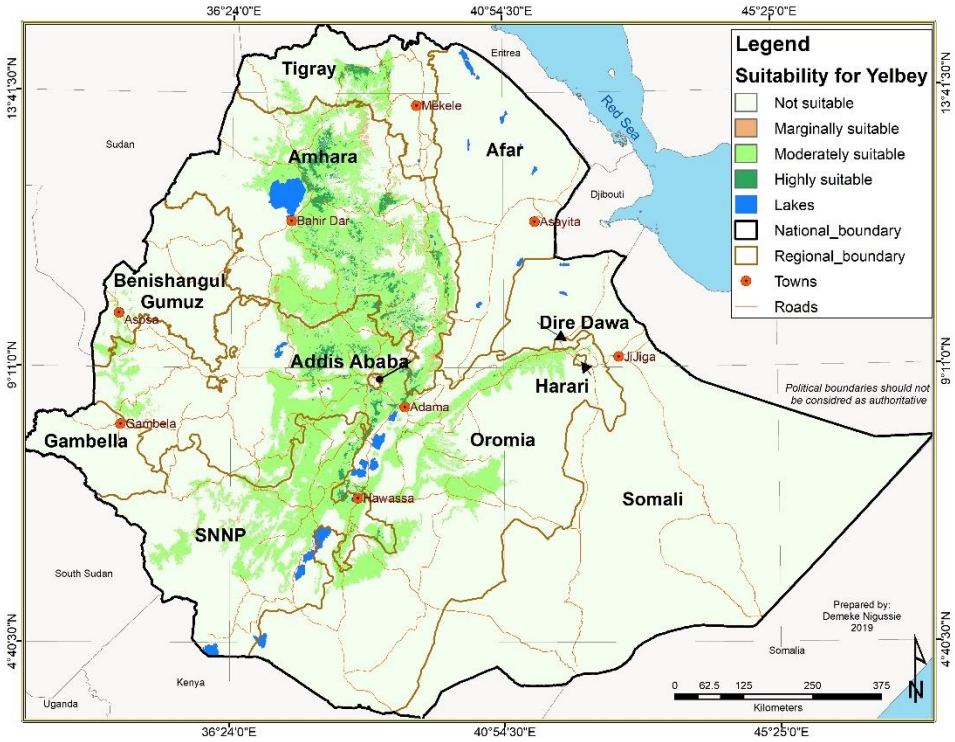

Figure 9. Land suitability map for chickpea *var*. Yelbey

Table 11. Land area under different suitability classes for Yelbey variety in regional states

Regional states	Highly suitable area (ha)	%	Moderately suitable area (ha)	%	Marginally suitable area (ha)	%	Not suitable area (ha)	%
Amhara	764,752	4.91	6,053,652	38.9	221,004	1.42	8,523,961	54.77
Oromia	303,224	0.93	6,683,624	20.6	52,672	0.16	25,409,893	78.31
SNNP	66,468	0.59	3,520,984	31.19	46,832	0.41	7,655,702	67.81
Tigray	88,532	1.76	630,236	12.55	4,832	0.1	4,297,058	85.59
Afar	16	0	8,888	0.09	11,888	0.12	9,541,544	99.78
BSG	0	0	147,912	2.96	20,068	0.4	4,832,377	96.64
Gambella	0	0	3,056	0.12	1,448	0.06	2,565,632	99.82
Somali	0	0	6,172	0.02	180	0	31,555,613	99.98
Total	1,222,992	1.08	17,054,524	15.09	358,924	0.32	94,381,780	83.51

Conclusion

- Amhara, Oromia, SNNP and Tigray remain the major regions with suitable areas for production of available varieties of chickpea 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.
- In general, areas of the highly and moderately suitable lands for most varieties considered in this analysis are smaller than the areas of crop level suitability. This difference is expected since the crop level environmental range boundaries for the suitability class thresholds are defined to encompass the adaptation ranges of available varieties.
- Chickpea varieties considered in this analysis, the highly suitable areas are much larger than the current estimated area under chickpea production in the country. For example, some kabuli chickpea varieties such as Kasech and Arerti have close to 2.3 million ha each of highly suitable areas, which is over the estimated crop suitability areas. Overall, Arerti variety, followed by Teketay and Mastewal, have broader adaptation compared to other varieties

- Amhara has more highly suitable areas whereas Oromia has more moderately suitable areas than other regions. Oromia region has more land of moderately suitable area for Arerti and Teketay chickpea varieties with the respective regional share of up to 40.05% and 38.59%.
- The suitability analysis results show that the currently available improved varieties of chickpea can be targeted for scaling out in the identified land suitability classes in Ethiopia with some caution.

Abbreviations

AAFC: Agricultural and Agri-Food Canada; CABI :Centre for Agriculture and Bioscience International;CSA: Central Statistical Agency; EIAR: Ethiopian Agricultural Research Institute ;FAO: Food and Agriculture Organization; IBC: I nstitute of Biodiversity Conservation);ICARDA: International Center for Agricultural Research in the Dry Areas; ISPRS: International archives of the photogrammetry, remote sensing and spatial information sciences; ISRIC: International Soil Reference Information Center; MCDA: Multi-Criteria Decision–Making Analysis ;MoA :Ministry of Agriculture; MoARD: Ministry of Agriculture and Rural Development; MoFED :Minstry of finance and Economic Development; NSIA: National Seed Industry Agency; PGRFA:Plant Genetic Resources for Food and Agriculture; SNNP: South Nation and Nationality People; USAID: United States Agency for International Development; WBISPP: Woody Biomass Inventory and Strategic Planning Project;.

Declarations

Ethics approval and consent to participate: All authors aware and participate in draft of the publication.

Consent for publication: The authors declare their approval for publication.

Availability of data and materials: The data attached used in the manuscript

Competing interest: The author(s) declare no conflict of interest of commercial or financial relationships.

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Author's contribution: All authors contributed substantially to write this article.

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Figures

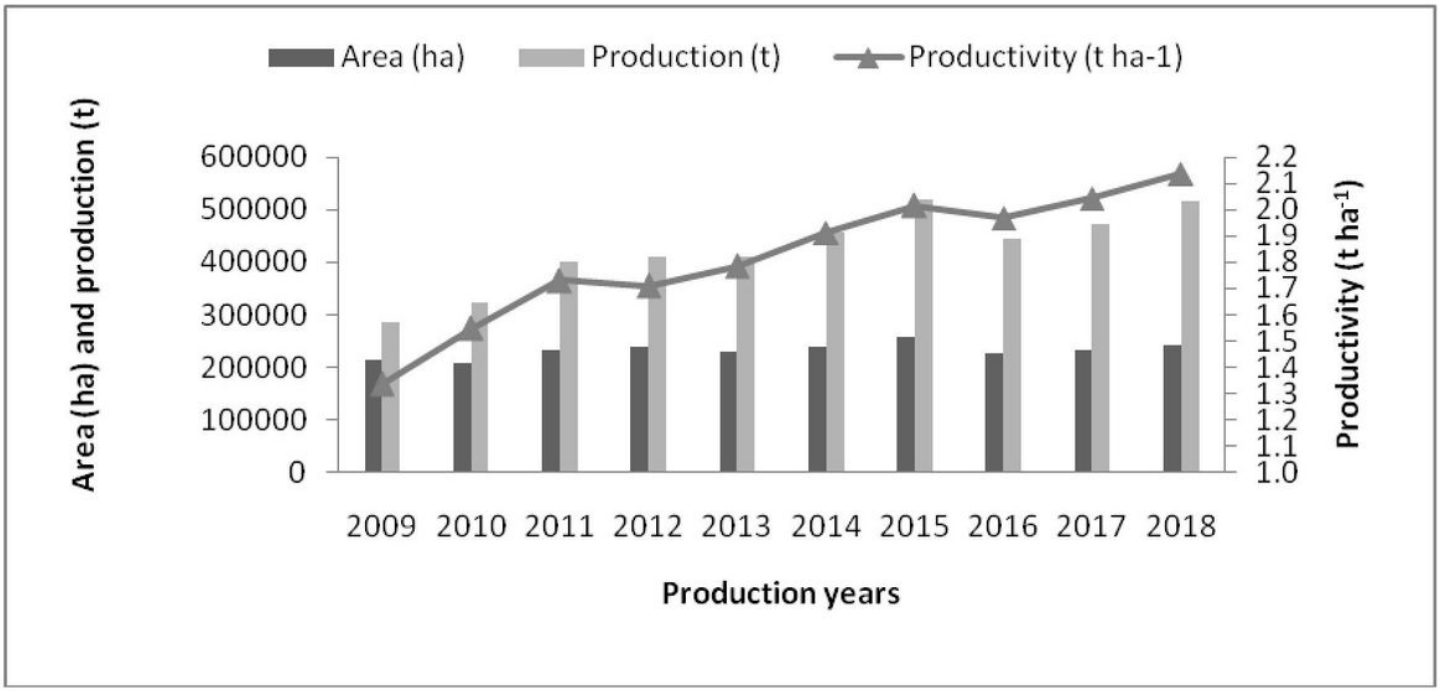

Figure 1

Area harvested, production and productivity of chickpea in Ethiopia Source: FAO (2019)

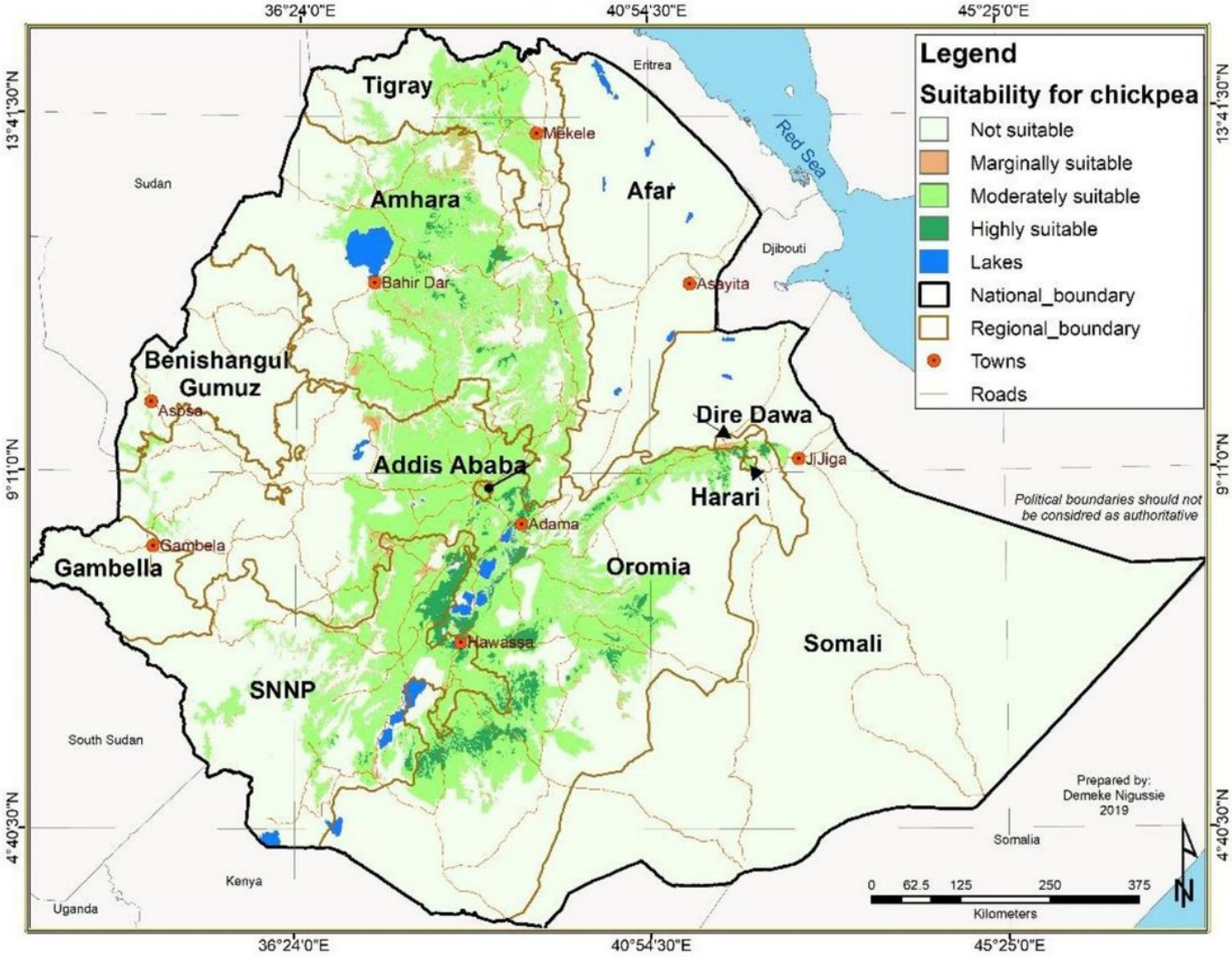

Figure 2

Land suitability map for chickpea Source: Demeke (2018) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

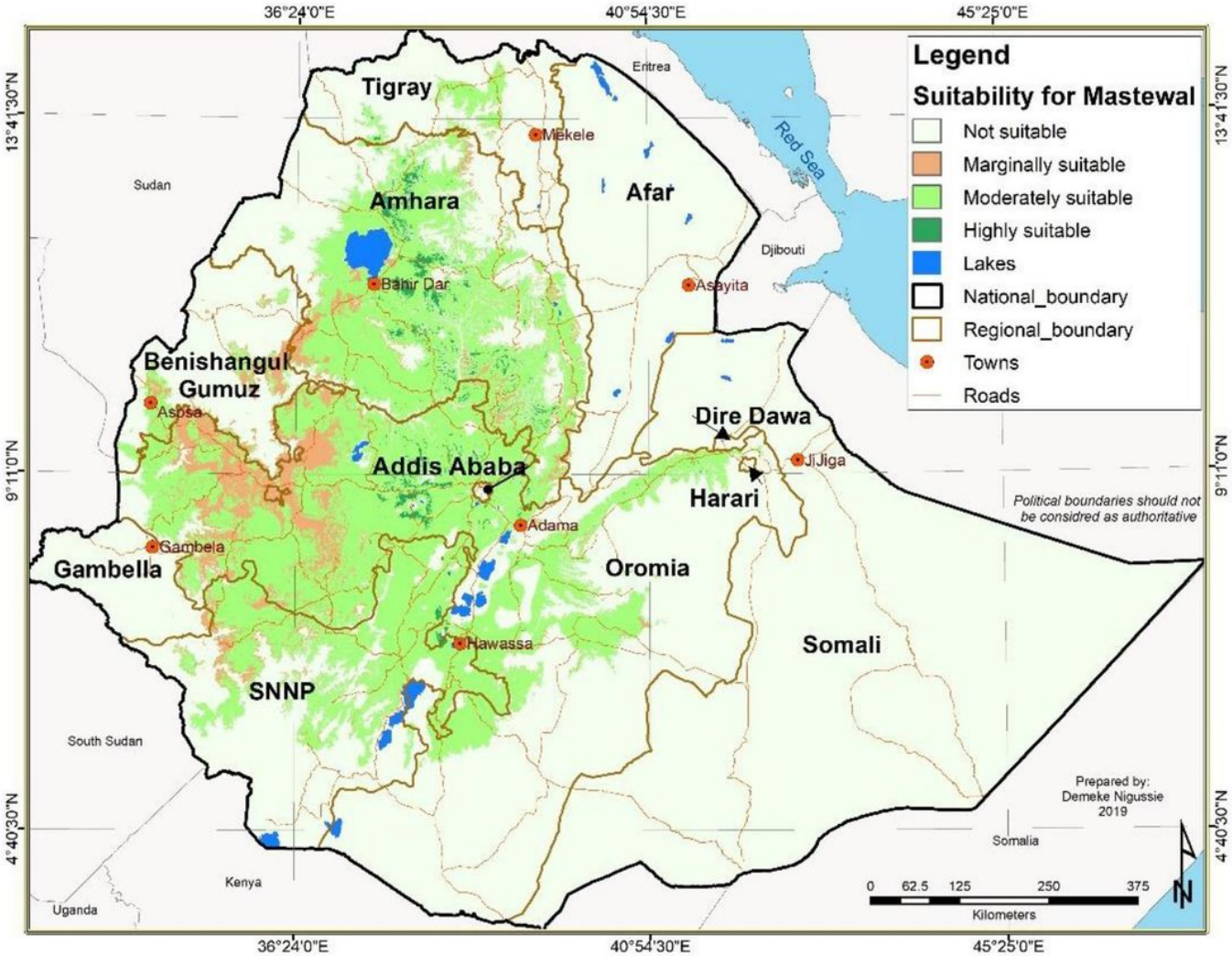

Figure 3

Land suitability map for chickpea var. Mastewal Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

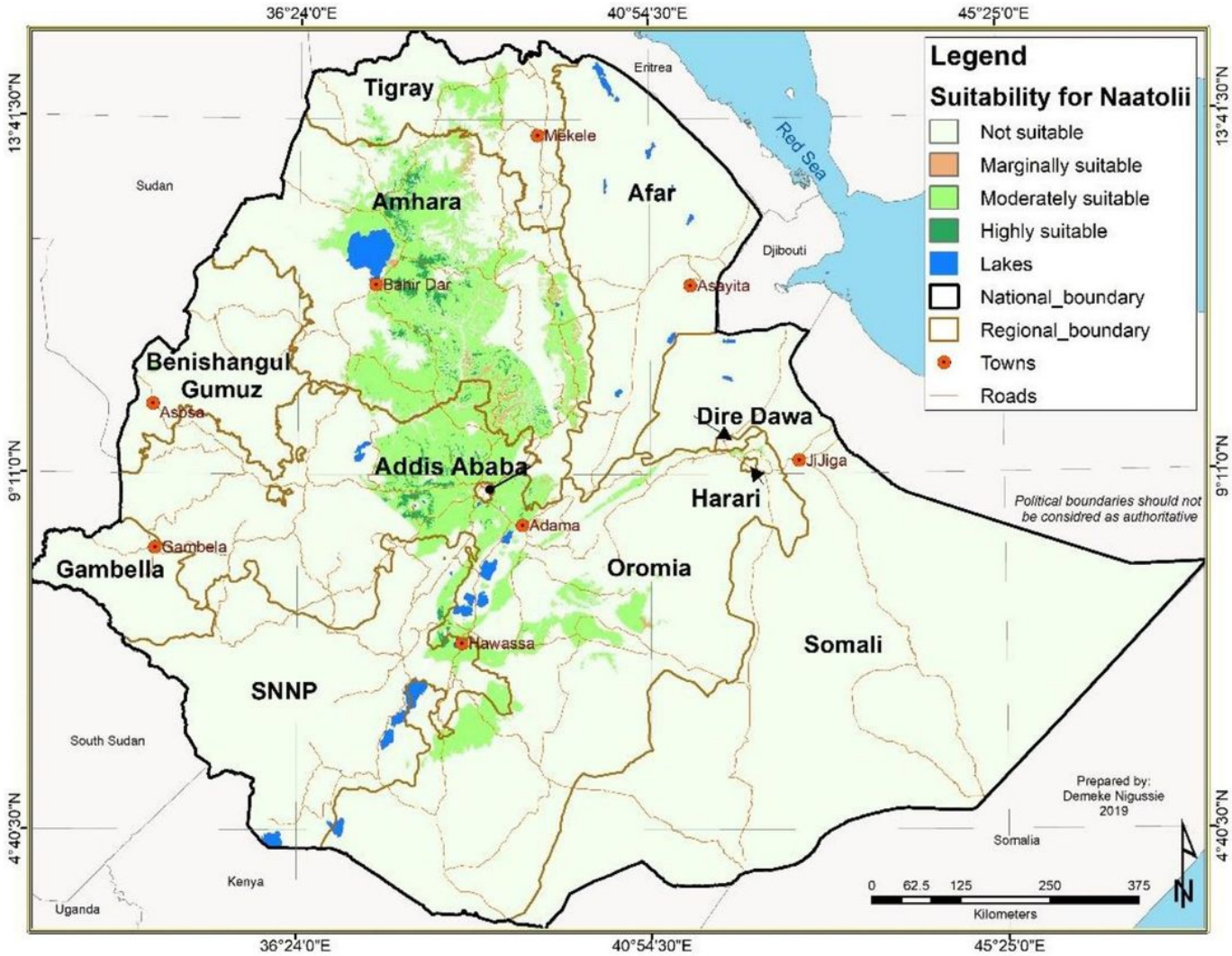

Figure 4

Land suitability map for chickpea var. Naatolii Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

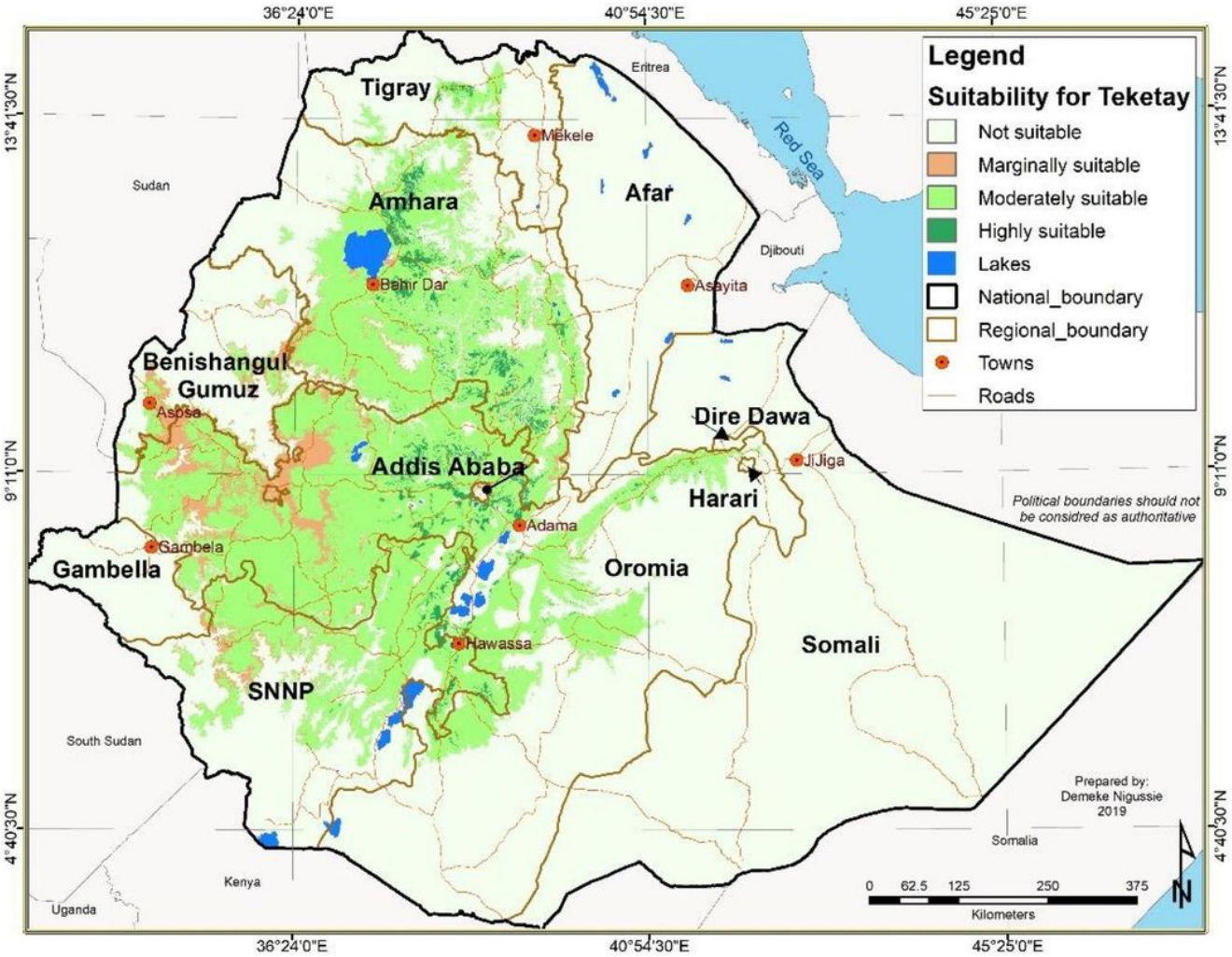

Figure 5

Land suitability map for chickpea var. Teketay Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

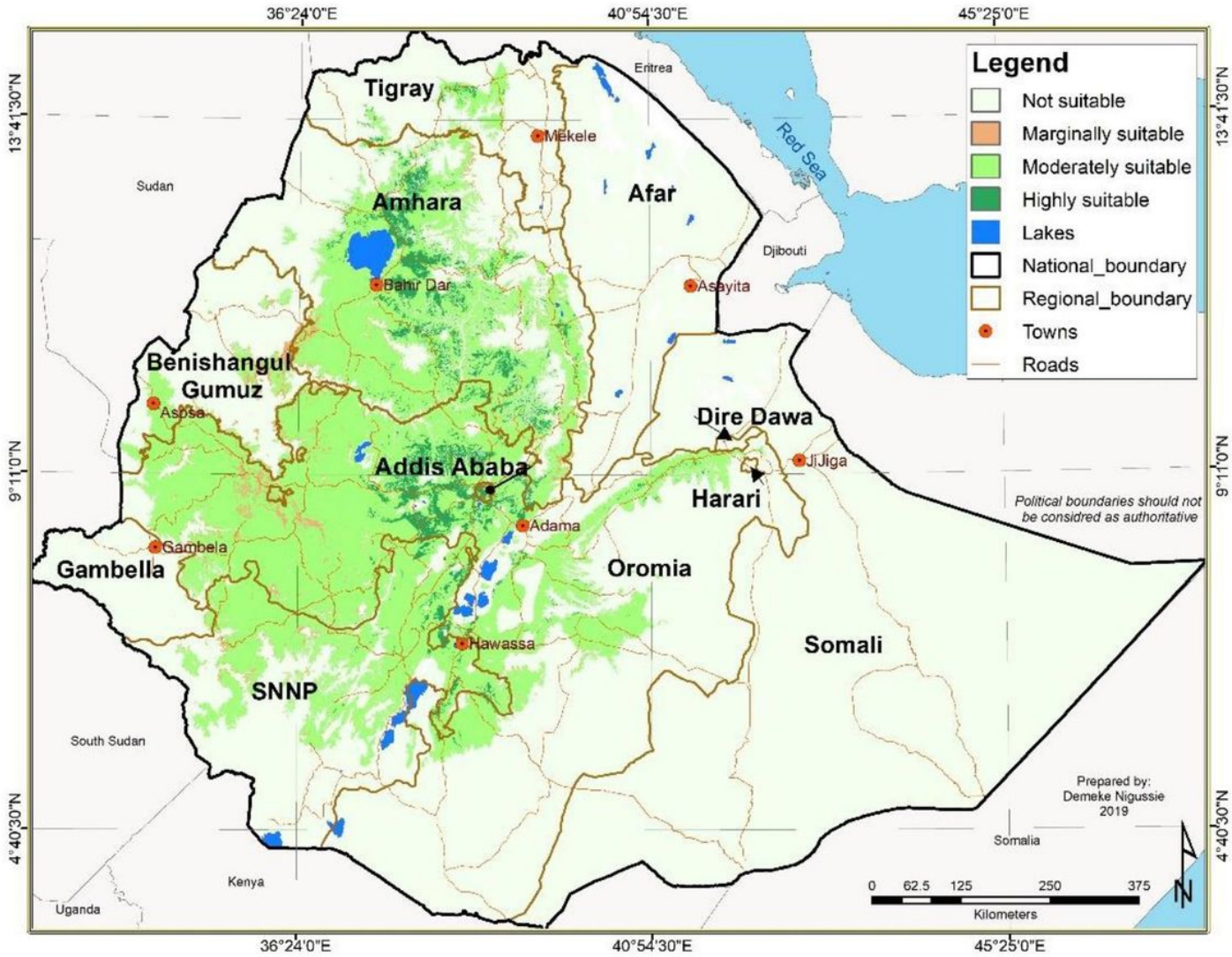

Figure 6

Land suitability map for chickpea var. Arerti Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

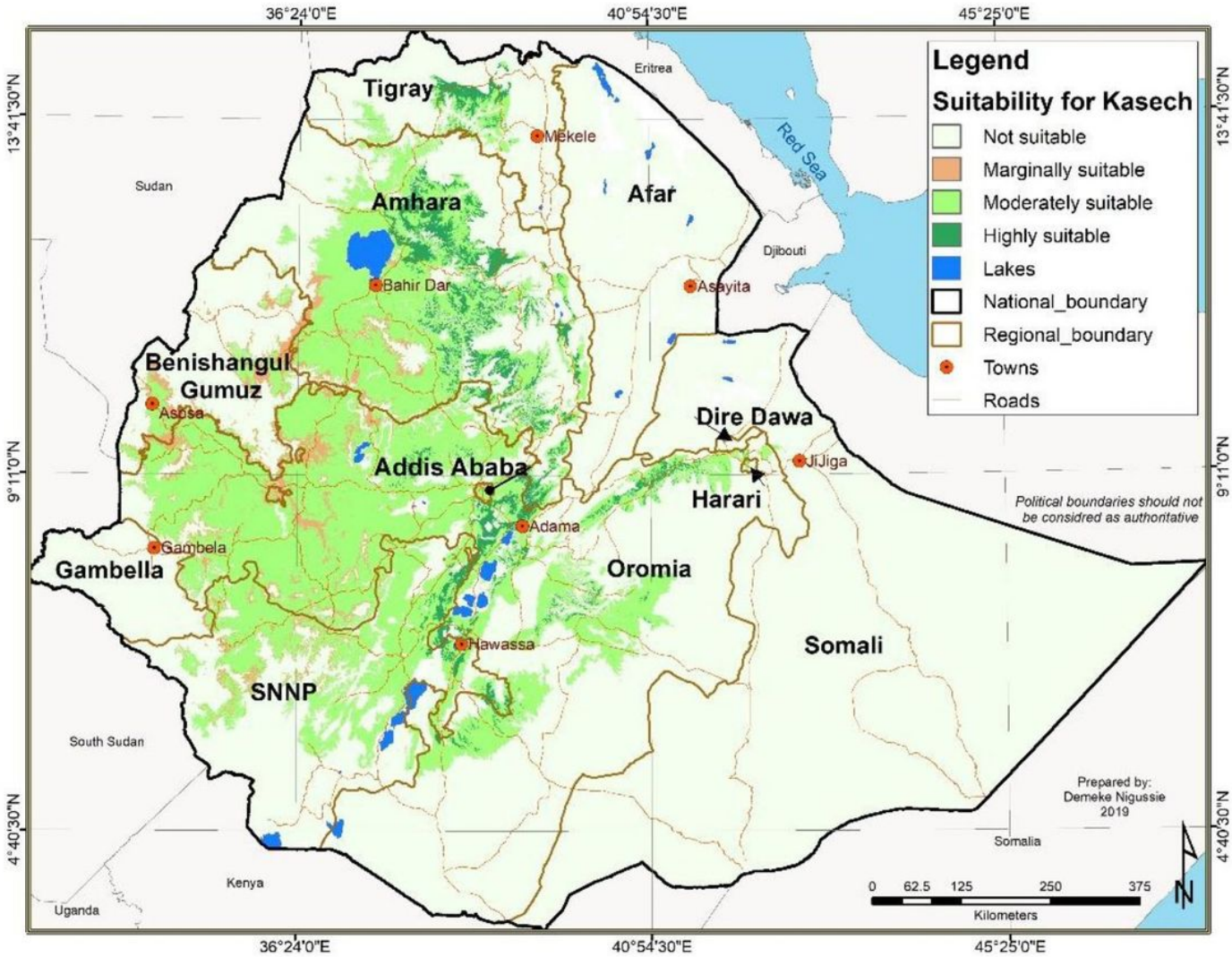

Figure 7

Land suitability map for chickpea var. Habru Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

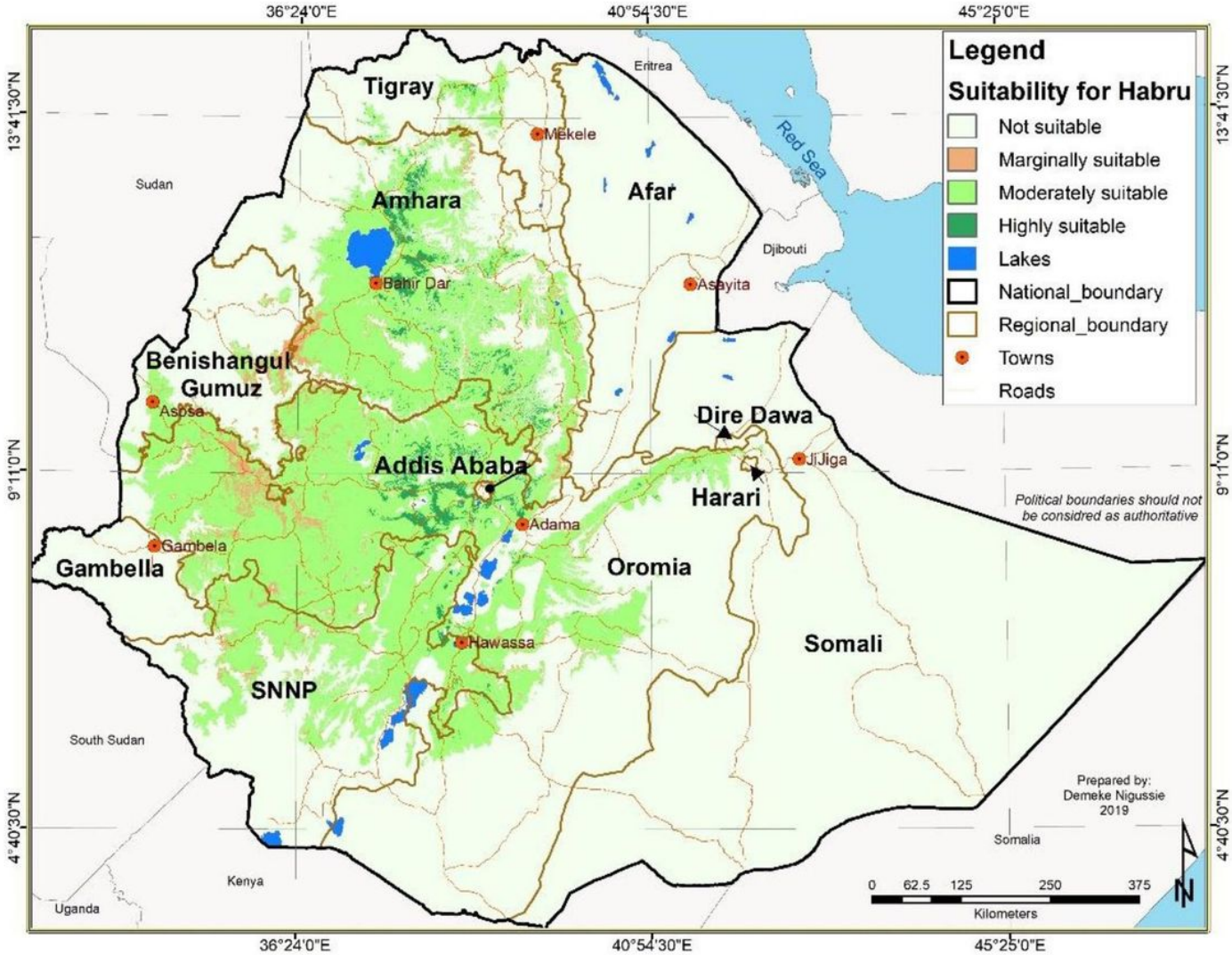

Figure 8

Land suitability map for chickpea var. Kasech Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

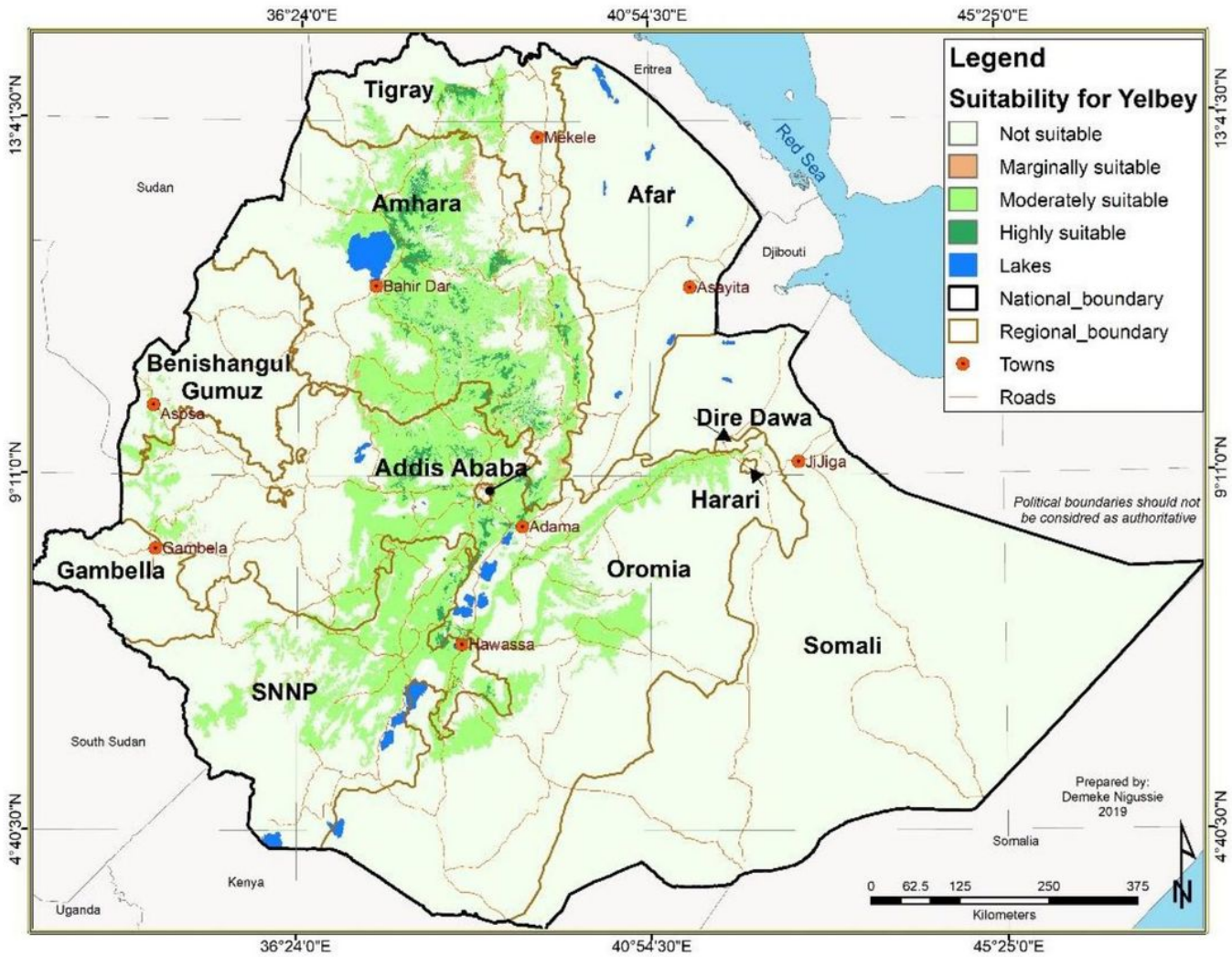

Figure 9

Land suitability map for chickpea var. Yelbey Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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