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Effects of Climate Change on Agroclimatic Suitability of Areas for Selected Cereal Crops Production over Gamo Gofa Zone, Ethiopia

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Authors' contributions

This work was conducted in collaboration among all authors. All authors initiated and carried out the research. Author TAT wrote the first draft manuscript and authors AA and ASM revised the manuscript. All authors read and approved the final manuscript.

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ABSTRACT

This study assessed effects of climate change on agroclimatic suitability of areas for Maize, Wheat and Barley production in Gamo Gofa zone, Southern Ethiopia between September 2014 and February 2015. Geographic Information System (GIS) was used to analyze the changes in suitability of areas for cereal production due to climate change. The analysis was conducted using data collected from different sources. Climate change scenarios of average monthly rainfall and temperature for the period 2050s (average of 2040-2069) and 2080s (average of 2070-2099) were downloaded for 16 General Circulation Models (GCMs) in climate wizard tools. Ensemble mean of B1 and A2 scenarios were calculated using their values of the 16 GCMs. The mean changes of rainfall and temperature were added to the baseline datasets of the period 1961-1990 to produce the future climates. Agroclimatic suitability of areas for major selected cereal crops (Maize, Wheat and Barley) were analyzed using the climate requirements of the crops based on four parameters

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namely average annual rainfall, mean temperature, altitude and slope both for the baseline and future scenarios. For 2050s and 2080s B1 and A2 emission scenarios, the rainfall and temperature of the zone would increase beyond the thresholds of crops climatic requirements with A2 to be worst scenario. Due to climate change, a maximum of 11%, 25% and 7% reduction of suitable area are expected by 2050s for Maize, Wheat and Barley respectively; by 2080s the reduction would be respectively 23%, 34% and 8.35%, all for A2 emission scenario. Future climates would have significant negative influence on the suitability of areas for cereals production and food security particularly for the study area and generally for Ethiopia that suggests adaptation measures need to be implemented.

Keywords: Gamo Gofa; agroclimatic suitability; climate change; cereal crops.

1. INTRODUCTION

The impacts of climate change on agriculture are expected to be widespread across the globe, although studies suggest that African agriculture is likely to be most affected due to heavy reliance on low-input rain-fed agriculture and due to its low adaptive capacity [1]. [2] also stated that Sub-Saharan Africa is expected to be affected worst, given that temperature is generally already high, and most of the region's inhabitants depend for their livelihoods on rain-fed agriculture. According to [3], the Intergovernmental Panel on Climate Change predicts that during the next decades billions of people, particularly those in developing countries will face changes in rainfall patterns that will contribute to severe water shortages or flooding, and rising temperatures. Rain-fed agriculture remains as the dominant source of staple food production for the majority of the rural poor in Ethiopia. In the country, the agricultural sector, which is dominated by small-scale, subsistence farming, forms the foundation of the national economy and constitutes the primary source of livelihood for the overwhelming majority of the population [4]. [5] stated that due to climate change suitable land and potential production for stable cereal crops will decrease markedly in sub Saharan Africa. They also pointed that crops likely to suffer significant decreases in suitable areas for their cultivation are typically cold weather crops, for example 18% for wheat at 2055. [6] stated that Maize is cultivated mostly at lower altitudes along the western, southwestern, and eastern peripheries of Ethiopia but now-a-days it is competing for land with wheat and teff in the high and mid-altitudes.

The livelihood of the people of Gamo Gofa zone is dependent on rain-fed small holding farmer's agricultural production which is more vulnerable to the adverse effects of climate variability and change. Historical crop production failure and yield variability in the zone is partly attributed to climate instability. Thus, it was a common feature of the study area that facing significant yield reductions of major cereal crops (Maize, Wheat and Barley) which are staple food sources in the zone next to root crops due to climate variability. The problem is likely to be continued with increasing dimensions and rate as far as the climate change is unequivocal and adequate adaptation mechanisms are not implemented. This necessitates exploring valuable informations regarding suitability of areas for production of major cereals in relation to climate parameters. Hence the major objective of this study is to examine effects of climate change on the agroclimatic suitability of areas for Maize, Wheat and Barley crops production over Gamo Gofa zone.

2. MATERIALS AND METHODS

2.1 Location of the Study Area

The study was conducted in Gamo Gofa zone of Southern Nations, Nationalities and Peoples Regional State, Southern Ethiopia, about 250 Km from the Regional capital, Hawassa and about 430 km south of Addis Ababa. It is geographically located between 5°37' to 6°42'N and 36°23' to 37°56'E and between 517 m and 4207 m above sea level, Fig. 1.

2.2 Data Types and Methods of Collection

For future rainfall and temperature scenario construction, changes between baseline and 2050s and 2080s (B1 and A2) scenarios at stations of the study area (Fig. 2) were downloaded from climate wizard tool [7]. These data are projections of changes in monthly rainfall and temperature relative to the baseline (1961-1990). However, instrumental station data in the stations is lacking for the baseline period while it was required to get the climate scenarios for the two future periods. Hence, Climate Research Unit (CRU) time series 3.21 rainfall and temperature data were downloaded from Koninklijk Netherlands Meteorological Institute (KNMI) climate explorer [8] for the baseline period. Digital Elevation Model (DEM) was downloaded from Dem explorer [9] and boundary map of study area was collected from Central Statistical Agency of Ethiopia. Annual rainfall, temperature, altitude and slope requirements of Maize, Wheat and Barley crops were obtained from (Ethiopian Institute of Agricultural Research) EIAR [10], Gamo Gofa zone Agriculture and by referring different literatures. Excel spreadsheet and ArcGIS softwares were employed to accomplish the analysis.

2.3 Data Analysis

2.3.1 Future climate scenarios

Climate change scenarios of average monthly rainfall and temperature for the period 2050s (average of 2040-2069) and 2080s (average of 2070-2099) were downloaded at stations for 16 General circulation models (GCMs). Ensemble mean of B1 and A2 scenarios were calculated using their values of the 16 GCMs. Ensemble mean or median of General Circulation Models simulations is an effective means to improve the outcomes of climate simulations that is often better than any individual future climate projections [11]. The mean changes of rainfall and temperature were added to the baseline datasets of the period 1961-1990 to produce the future climates.

2.3.2 Agroclimatic suitability of areas for cereal crops

Agroclimatic suitability of areas for major selected cereal crops (Maize, Wheat and Barley) were analyzed using the climate requirements of the crops based on four parameters namely average annual rainfall, mean temperature, altitude and slope. Table 1 shows agroclimatic requirements of the major cereal crops and used for mapping of agroclimatic suitability. Suitable areas represent roughly the productivity of a region but sustainable yields may change year to year. Two suitability categories (suitable and non-suitable) were considered to be consistent

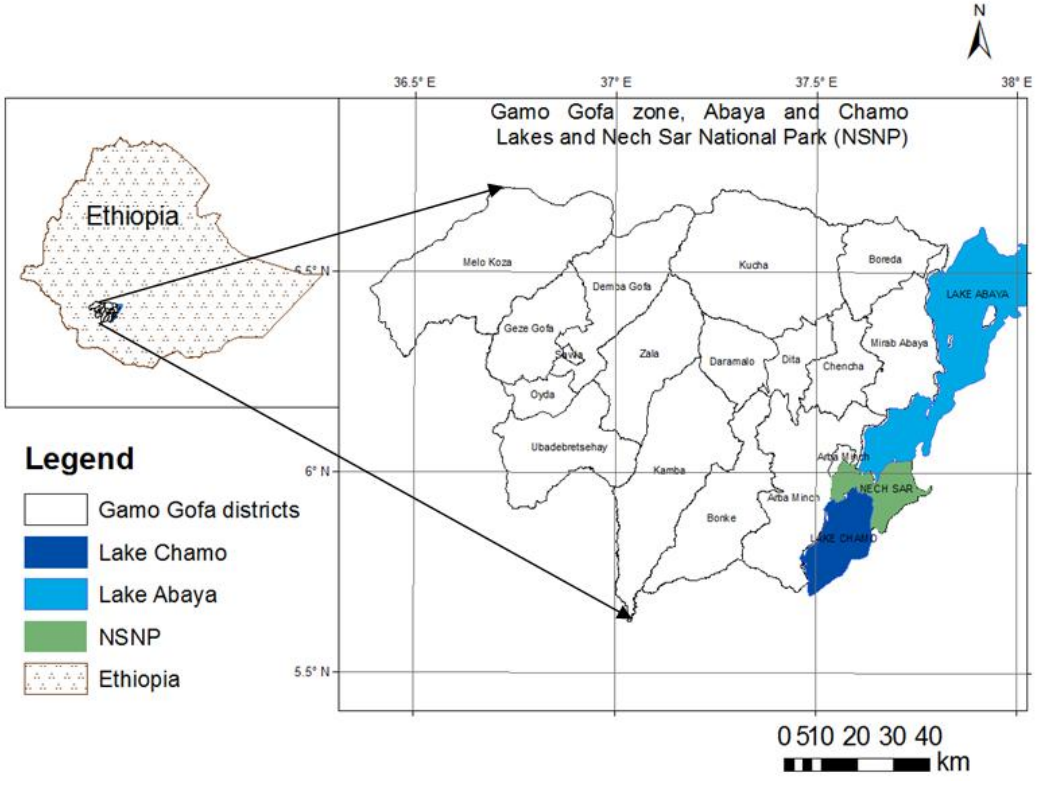

Fig. 1. Map of the study area and its administrative divisions

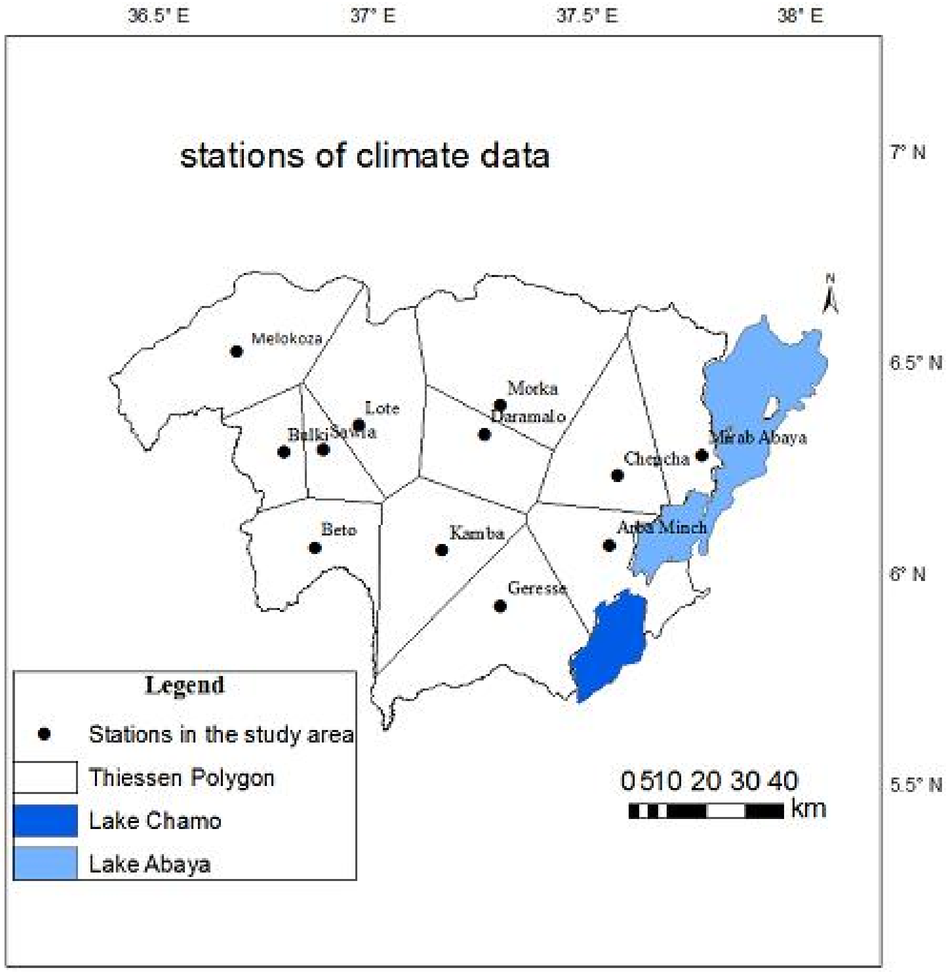

Fig. 2. Meteorological stations & thiessen polygons of the study area

Table 1. Agroclimatic requirements of crops

Crop type	RF (mm)	Annual mean temp (°c)	Altitude (m)	Slope (%)	Remark
Maize	460-1200	16-32	1000-2000	0-15	High & lowlands
Wheat	600-1200	15-23	1800-2700	0-20	Durum
Barley	500-1000	10-22	1800-3000	0-20	Food & beer

Source: EIAR (2007), Rakhmonov (2011), Virmani (1999), Gamo Gofa zone agriculture

with optimum climate ranges for crops which are released by Ethiopian Institute of Agricultural Research (EIAR). In Table 1 values inside the ranges are considered suitable. Maps were developed using each parameter as inputs in ArcGIS.

Each map was reclassified for suitable and non-suitable categories based on the crops requirements of the parameters. The reclassified maps were then overlaid to obtain the agroclimatic suitability maps for each crop for different scenarios depending on equal weights (25%) given for each parameter. Agroclimatic suitability maps for the baseline period were developed using altitude, slope and baseline climate parameter maps. However, future scenario suitability maps were produced by replacing the baseline climate parameter maps by future climate scenario maps.

3. RESULTS AND DISCUSSION

3.1 Climate Scenarios of 2050s

Constructed future annual rainfall scenarios of 2050s in Table 2 shows for B1 scenario it would increase by 6.6% at Lote and 8.5% at Mirab Abaya. For A2 scenario the minimum increment was found to occur at Bulki by 7.5% and maximum at Daramalo by 9.5%. The results are in agreement with National Adaptation Program of Action (NAPA) of Ethiopia which projected annual rainfall between 3.1% and 11.6% by 2050s for A1B scenario over the country [12]. [13] also showed a general trend of increased annual rainfall projection by 2050 in western and eastern Africa. [14] also reported that by 2050 annual rainfall over Ethiopia is expected to increase between 5 to 9% using Hadley Center for Climate prediction and Research (HADCM3) and Parallel Climate models (PCM). Future mean temperature scenarios (B1 and A2) for 2050s and the changes in mean temperature between the baseline and 2050s scenarios are presented in Table 3. It shows, for B1 scenario minimum increment was expected at Geresse and Beto by 1.4°C and maximum at Daramalo and Arba Minch by 1.64°C. For A2 scenario minimum increment was expected at Geresse, Sawla and Beto by 2°C and maximum at Mirab Abaya and Daramalo by 2.2°C. The results are consistent with [15] which states if the recent (1960-2009) warming trend continues, most parts of Ethiopia will experience more than 1°C increase in air temperature between 2010 and 2039.

The temperature simulations conducted by [13] for 2050 across Maize mega environments within Sub-Saharan Africa show a consistent general trend of warming with maximum temperature predicted to increase by 2.6°C and the average by 2.1°C.

3.2 Climate Scenarios of 2080s

Increments of rainfall amount would be expected for future period (2080s) of B1 and A2 scenarios. For B1 scenario the rainfall would increase by minimum of 7.9% at Melokoza and maximum of 19.7% at Chencha. Regarding the amount of rainfall, a maximum amount of 256 mm would be received at Chencha and minimum of 71 mm would be received at Mirab Abaya for B1 scenario. For A2 scenario the minimum percent increment would occur at Mirab Abaya (15.4%) and maximum at Arba Minch (20.4%). These results are also consistent with National Adaptation Program of Action (NAPA) report of Ethiopia that projects annual rainfall between 5.1% and 18.9% by 2080s for A1B scenario over the country [12]. [16] described that by 2100 annual rainfall will increase over Ethiopia between 12 to 22% for Hadley Center for Climate prediction and Research and Parallel Climate models. Warming situations were expected for all the stations in the zone for the period 2080s. The average temperature of the stations in the zone would increase with different rates for the two emission scenarios. For B1 scenario maximum increment would occur at Daramalo (2.2°C) and the minimum would occur at Bulki (1.6°C). For A2 scenario maximum of 3.6°C increment would occur at Mirab Abaya and Daramalo and minimum of 2.3°C at Geresse. The results are in consistence with [12] of Ethiopia which projects mean temperature will be between 2.7°C to 3.4°C by 2080s for A1B scenario over the country.

Table 2. Baseline, 2050s and changes between baseline and 2050s average rainfall for locations in Gamo Gofa

Stations	Baseline RF (mm)	B1			A2		
		2050s (mm)	Change (%)	Change (mm)	2050s (mm)	Change (%)	Change (mm)
Arba Minch	812	875	7.7	63	885	9	74
Beto	850	917	7.8	67	930	9.4	80
Bulki	1316	1408	7	92	1415	7.5	99
Chencha	1300	1404	8	104	1413	8.7	113
Daramalo	849	917	8	68	930	9.5	81
Geresse	1298	1402	8	104	1414	8.9	116
Kamba	1201	1287	7.2	86	1299	8.2	98
Melokoza	1156	1234	6.7	78	1241	7.6	88
Lote	1096	1168	6.6	72	1180	7.7	84
Mirab Abaya	775	841	8.5	66	848	9.4	73
Morka	1051	1125	7	74	1131	7.6	80
Sawla	1048	1121	6.9	73	1131	7.9	83

Table 3. Baseline, 2050s and the changes in-between of mean temperature for locations in Gamo Gofa

Stations	Baseline RF (°C)	B1			A2		
		2050s (°C)	Change (%)	Change (°C)	2050s (°C)	Change (%)	Change (°C)
Arba Minch	22.3	23.9	7.4	1.64	24.4	9.4	2.1
Beto	23.6	25	6.4	1.4	25.6	8.5	2
Bulki	18.9	20.4	7.9	1.5	21	11.1	2.1
Chencha	18	19.5	8.3	1.5	20.1	11.7	2.1
Daramalo	23.4	25	7	1.64	25.5	9.2	2.1
Geresse	19.9	21.3	7	1.4	21.9	10.1	2
Kamba	20.9	22.4	7.2	1.5	23	10	2.1
Melokoza	21	22.5	7.1	1.5	23.1	10	2.1
Lote	20.5	22	7.3	1.5	22.6	10.2	2.1
Mirab Abaya	21.5	23.1	7.3	1.58	23.7	10.2	2.2
Morka	23.6	25.2	6.8	1.6	25.8	9.3	2.2
Sawla	20.5	22.1	7.8	1.6	22.5	9.7	2

3.3 Effects of Climate Change on Suitable Areas for Cereal Production

3.3.1 Maize

Table 4 and Fig. 3 show agroclimatically suitable and non-suitable areas of Gamo Gofa zone for Maize cultivation based on agroclimatic requirements of the crop for the baseline, 2050s and 2080s B1 and A2 scenarios. From the total area of the zone, 72% was obtained suitable for Maize cultivation for the baseline scenario. Suitable area for the crop would be declined to 62% and 61% for 2050s B1 and A2; 52% and 49% for 2080s B1 and A2 respectively. The results indicate that additional10% and 11% of zonal area in 2050s; 20% and 23% in 2080s would be non-suitable respectively for B1 and A2 scenarios which could result in huge loss of production and negative influence on food security in the zone due to changes in climate. [16] found using the National Center for Atmospheric Research (NCAR) model, the extent of Sub-Saharan land with severe environmental constraints to crop agriculture declines by about 15 million ha due to significant increases in precipitation and milder temperature increases. The results were also consistent with that of [17] who found that by 2055 Ethiopia will lose 91,350 tons of Maize production in small holder rain-fed production system due to climate change compared with the baseline production in 2000. [13] have also given consistent suggestion that an increment in temperature of 2°C would result in a greater reduction in Maize yield within Sub-Saharan Africa. In the contrary, [5] found that 5.34% and 7.8% increment of suitable area are expected respectively for Hadley Center for Climate Prediction and Research and Canadian Centre for Climate Modeling and Analysis (CCCMA) climate models over the world by 2055. One reason for the disagreement could be due to their consideration of global average decline in suitable area which balances reduction of suitable area in Sub-Saharan Africa and Caribbean with the increments in Europe and North America in the future. The other reason could be their consideration of individual General Circulation Models, Hadley Center for Climate prediction and Research and Canadian Centre for Climate Modeling and Analysis, which differ from consideration of mean of 16 GCMs in this study.

Table 4. Suitability of areas for maize cultivation over Gamo Gofa zone

Period	Scenario	Suitable		Non-suitable	
		Km^2	Percent	Km^2	Percent
Baseline	Baseline	8001	72	3052	28
2050s	B1	6895	62	4158	38
	A2	6755	61	4298	39
2080s	B1	5867	52	5416	48
	A2	5529	49	5754	51

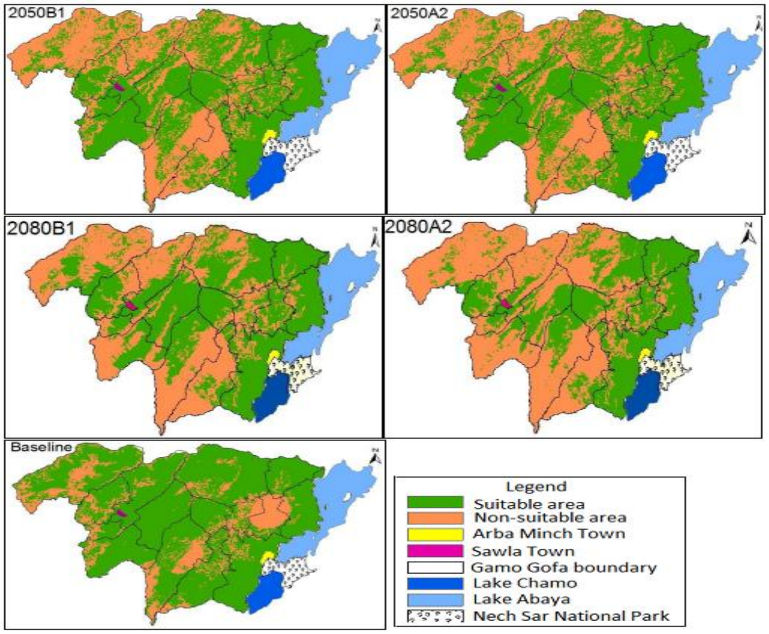

Fig. 3. Suitability map of maize production for baseline and future scenarios

3.3.2 Wheat

Table 5 and Fig. 4 show agroclimatically suitable and non-suitable area and their percents over the study area for Wheat production based on agroclimatic requirements of the crop for the baseline, 2050s and 2080s B1 and A2 scenarios. From the total area of the zone, 49% area was obtained suitable for the baseline scenario. For 2050s B1 and A2 scenarios, respectively 29% and 24% areas were found to be suitable for the crop. Suitable area for Wheat cultivation would be reduced to 22% and 15% respectively for B1 and A2 scenarios by 2080s. The results indicated that additional 20% and 25% of the zonal land by 2050s and 27% and 34% by 2080s would be non-suitable for Wheat cultivation respectively for B1 and A2 scenarios. Studies conducted by [2] using projected climate of 2050 by Decision Support System for Agro-technology Transfer (DSSAT) crop model in Sub-Saharan Africa reveal that more than 20% of wheat yield will be reduced due to changes in climate. [5] had obtained that by 2055 areas suitable for Wheat production will be reduced by 30.86% and 4.48% respectively for Hadley Center for Climate prediction and Research and Canadian Centre for Climate Modeling and Analysis over the world.

3.3.3 Barley

Table 6 and Fig. 5 show agroclimatically suitable and non-suitable area and their percents over the zone for Barley production based on agroclimatic requirements of the crop for the baseline, 2050s and 2080s B1 and A2 scenarios. For the baseline scenario area, suitable for barley production was found 12%. For 2050s B1 scenario 6% and A2 scenario 5% areas

Table 5. Suitability of areas for wheat cultivation

Period	Scenario	Suitable		Non-suitable	
		Km^2	Percent	Km^2	Percent
Baseline	Baseline	5441	49	5612	51
2050s	B1	3200	29	7853	71
	A2	2685	24	8368	76
2080s	B1	2482	22	8801	78
	A2	1692	15	9591	85

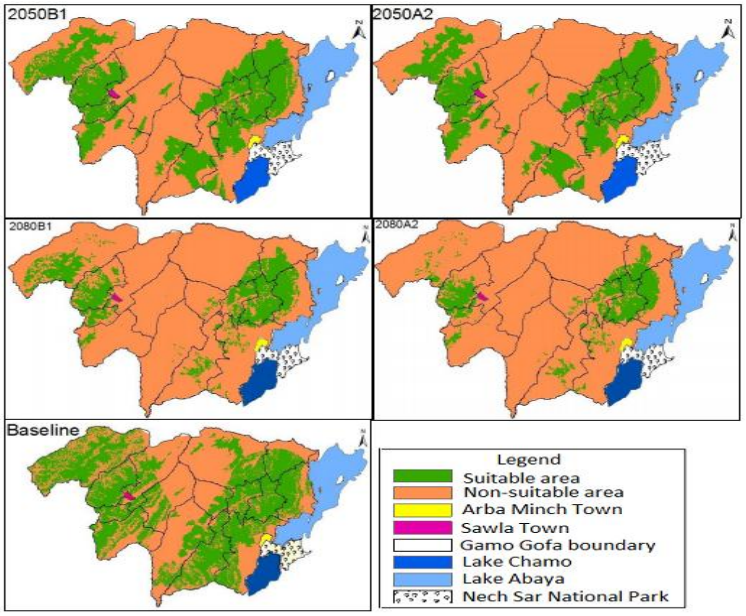

Fig. 4. Suitability map of wheat production for baseline and future scenarios

were found to be suitable. For 2080s B1 and A2 scenarios respectively 4% and 3.65% area would be suitable for Barley crop cultivation. The results showed that additional 6% and 7% of the zonal land by 2050s and 8% and 8.35% by 2080s would be non-suitable respectively for B1 and A2 scenarios compared with baseline scenario. [18] reported consistent findings in Atlantic Canada that stated due to climate change by 2040 to 2069 different Barley varieties will decrease in yields respectively by 8 and 12% compared to present day yields. They further suggested that this will likely lead to significant decrease in land area seeded to Barley. [5] also found that by 2055 areas suitable for Barley production will be reduced by 2.53% for Hadley Center for Climate prediction and Research model over the world.

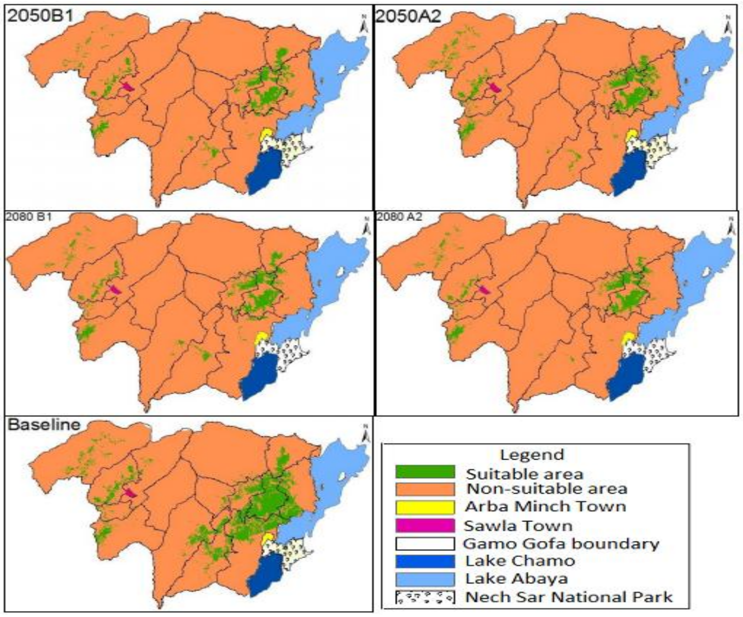

Fig. 5. Suitability map of barley production for baseline and future scenarios

Table 6. Suitability of areas for barley cultivation

Period	Scenario	Suitable		Non-suitable	
		Km^2	Percent	Km^2	Percent
Baseline	Baseline	1338	12	9715	88
2050s	B1	684	6	10369	94
	A2	570	5	10483	95
2080s	B1	451	4	10834	96
	A2	411	3.65	10972	96.35

4. CONCLUSIONS AND RECOMMENDATIONS

The study revealed that climate change would result in increments of both rainfall and temperature in the study area. It suggests the increments would go beyond the maximum thresholds of crop requirements that would disturb productive potentials of cereals. This implies decreasing productivity for rain-fed cereal production, affecting geographic distribution of suitable areas and influencing food security negatively particularly for the study area and generally for Ethiopia. Therefore, developing new cereal crop varieties that would be tolerant and more productive in high rainfall and temperature stressed situations and efforts towards exploring suitable adaptive agronomic practices are recommended.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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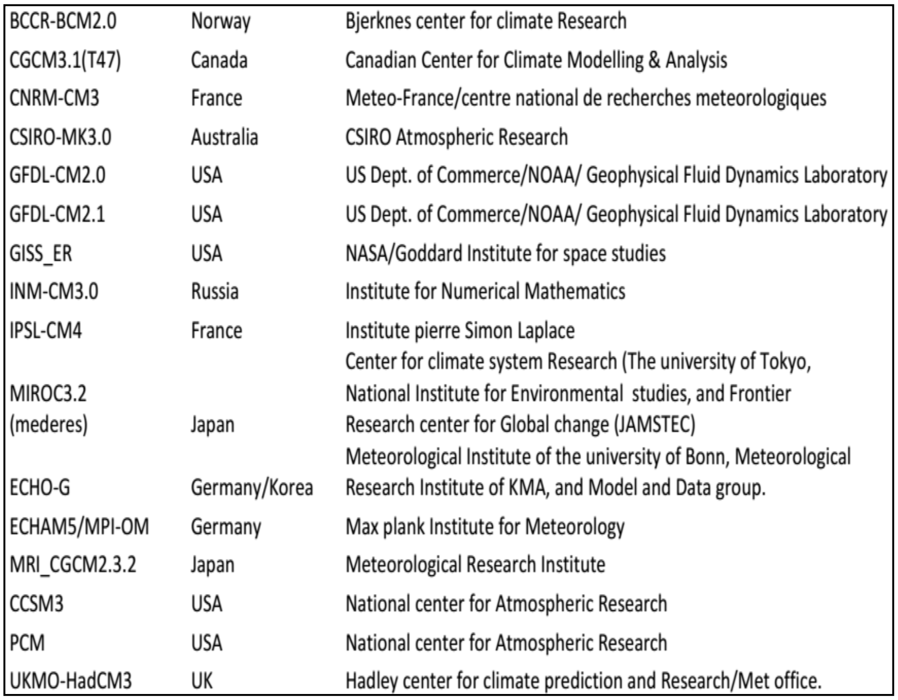
APPENDIX

16 GCMs in the Climate wizards tools (source: climate wizard tool, 2012)



BCCR-BCM2.0	Norway	Bjerknes center for climate Research
CGCM3.1(T47)	Canada	Canadian Center for Climate Modelling & Analysis
CNRM-CM3	France	Meteo-France/centre national de recherches meteorologiques
CSIRO-MK3.0	Australia	CSIRO Atmospheric Research
GFDL-CM2.0	USA	US Dept. of Commerce/NOAA/ Geophysical Fluid Dynamics Laboratory
GFDL-CM2.1	USA	US Dept. of Commerce/NOAA/ Geophysical Fluid Dynamics Laboratory
GISS_ER	USA	NASA/Goddard Institute for space studies
INM-CM3.0	Russia	Institute for Numerical Mathematics
IPSL-CM4	France	Institute pierre Simon Laplace
MIROC3.2 (mederes)	Japan	Center for climate system Research (The university of Tokyo, National Institute for Environmental studies, and Frontier Research center for Global change (JAMSTEC)
ECHO-G	Germany/Korea	Meteorological Institute of the university of Bonn, Meteorological Research Institute of KMA, and Model and Data group.
ECHAM5/MPI-OM	Germany	Max plank Institute for Meteorology
MRI_CGCM2.3.2	Japan	Meteorological Research Institute
CCSM3	USA	National center for Atmospheric Research
PCM	USA	National center for Atmospheric Research
UKMO-HadCM3	UK	Hadley center for climate prediction and Research/Met office.

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