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Research Article

Analysis of Rainfall and Temperature Variability Impacts on Coffee (Coffea arabica L.) Productivity in Habro District, West Harerghe Zone, Eastern Ethiopia

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ABSTRACT

The study was undertaken to investigate the relationship between rainfall and temperature characteristics and coffee productivity. Daily rainfall, temperature, and coffee yield data of Sixteen years were used for analysis. Correlation, regression, rainfall and temperature parameters characterization was carried out by Instat V3.37 software. Moreover, resemble of GFDL-ESM2M, BCC-CSM1-1, NorESM1-M and CSIRO-Mk3-6-0 model under RCP 4.5 emission scenarios of IPCCAR5 were used for rainfall and temperature projection. Seasonal and annual rainfall totals were highly variable. Pearson correlation revealed belg rainy day had a positive strong correlation with coffee yield whereas end date, kiremt rainy day, kiremt rainfall total, belg rainfall total and length of the growing period had positive moderate correlations. However, the onset date had a negative moderate correlation. Moreover, belg and kiremt mean temperature showed a negative strong correlation. The influence of rainfall and temperature variability on coffee productivity was statistically significant (P=0.03). In the future, due to the expected impacts of rising belg and kiremt mean temperature, late-onset and shortening of the length of growing period and weakening of kiremt rainfall amount in general, the productivity of Coffea arabica is expected to decrease in the study area. Therefore, there is a need for more research on suitable coffee shade, drought and high-temperature resistant varieties, water conservation strategies and moving coffee establishments at higher elevations.

Keywords: *Coffea arabica* L.; Rainfall and temperature variability; Habro

INTRODUCTION

Africa in general and Sub-Saharan Africa, in particular, is the most vulnerable region in the world to climate variability and climate change [1]. Ethiopia, being part of Sub-Saharan Africa, has been experiencing a series of climatic vagaries with many episodes of cyclic droughts and floods that claimed the lives of thousands of people and slashed economic development [2,3].

The agricultural sector is a pillar of the economy of Ethiopia [4]. This sector which is rain-fed by its nature, is highly sensitive to climate change and variability [3]. Ethiopia is believed to be the country of origin of *C. arabica* [5]. Ethiopia is the leading *C. arabica* producer in Africa, ranking the fifth largest *C. arabica* producer and tenth in coffee exports worldwide [6]. Ethiopian economy is strongly dependent on *C. arabica*, for example, more than 25% of the country's foreign exchange earnings, over 5% of the Gross Domestic Product, 12% of the agricultural output, and 10% of the government revenues are accounted for by coffee export [7]. However, climate change and variability are threatening coffee production in every coffee-producing region of the world. Higher temperatures, long droughts punctuated by intense rainfall, more resilient pests and plant diseases all of which are associated with climate change and in most cases have reduced coffee production [8].

There is evidence that *C. arabica* production is currently influenced by climate change in Ethiopia. For example, Davis, suggest that the coffee ecological range is currently being narrowed by climate change in Ethiopia and it will be likely more narrowed in the future [9]. There are also predictions of increased coffee disease and pests as temperature increases in Ethiopia [10-12].

The importance of *C. arabica* in Ethiopia is clear because it is one of the most valuable primary products in-country trade and Harar coffee takes premium prices in the world market. Harar coffee contributes about 10% of the total country's coffee acreage and 8% of the country's coffee export [13]. Hararghe is endowed with

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enormous genetic diversity and different coffee types with unique tastes and flavors. Despite the immense potential, the productivity and quality of coffee production remained low. For example, West Hararghe average productivity is 512 kg/ha [14], which is below the national average of 619 kg/ha [15]. Temperature and precipitation are the most important climatic factors affecting the yield of coffee [16]. According to Tesfaye, *C. arabica* tolerates an annual precipitation range between 700 mm-2019 mm and the optimum condition is between 1502 mm-1854 mm [17]. Similarly, Tesfaye, reported C. arabica tolerates the annual mean temperature range between 14°C-27°C and the optimum condition is between 19°C-22°C [16]. Currently, in Habro district *C. arabica* producers are replacing it with Catha edulis and other annual crops because of the poor performance of coffee (waiting for long years cycle of production) and drying up of *C. arabica* stands as climate change. This study was, therefore designed to investigate the relationship between rainfall and temperature characteristics and *C. arabica* productivity and predict future coffee yields based on projected rainfall and temperature characteristics in the Habro district.

MATERIALS AND METHODS

Description of study area

The study area (Figure 1) Habro district is geographically located between at 8.57°N to 8.91°N and 40.34°E to 40.69°E in West Harerghe zone, eastern part of Ethiopia. Gelamso town is the administrative capital of the district.

The elevation of the district ranges from 1400 m.a.s.l. to 2400 m.a.s.l. The district is characterized by plateaus, mountains, hills, plains and valleys and generally classified into three agro-ecologies, the lowland, the midland and the high land constituting 5%, 80% and 15% of the total area of the district respectively [18].

Thirty years (1988-2017) data of Gelemso meteorological station indicates that the study area receives a mean annual rainfall of 966.7mm. The rainfall pattern in the area is bi-modal with a high amount of rainfall occurring during kiremt (June, January, August and September) season and the short rainy season belg (February, March, April and May). The highest rainfall is received in August and followed by April. The mean annual temperature was 19.97°C with the hottest months being May and June and the coldest month being November and December.

Five major soil types found in Habro district are: vertic luvisols, rendzic leptosols, haplic luvisols, eutric vertisols and eutric leptosols. Of these soil types, vertic luvisols occupy a major portion of the area followed by rendzic leptosols, eutric leptosols, haplic luvisols and eutric vertisols [19].

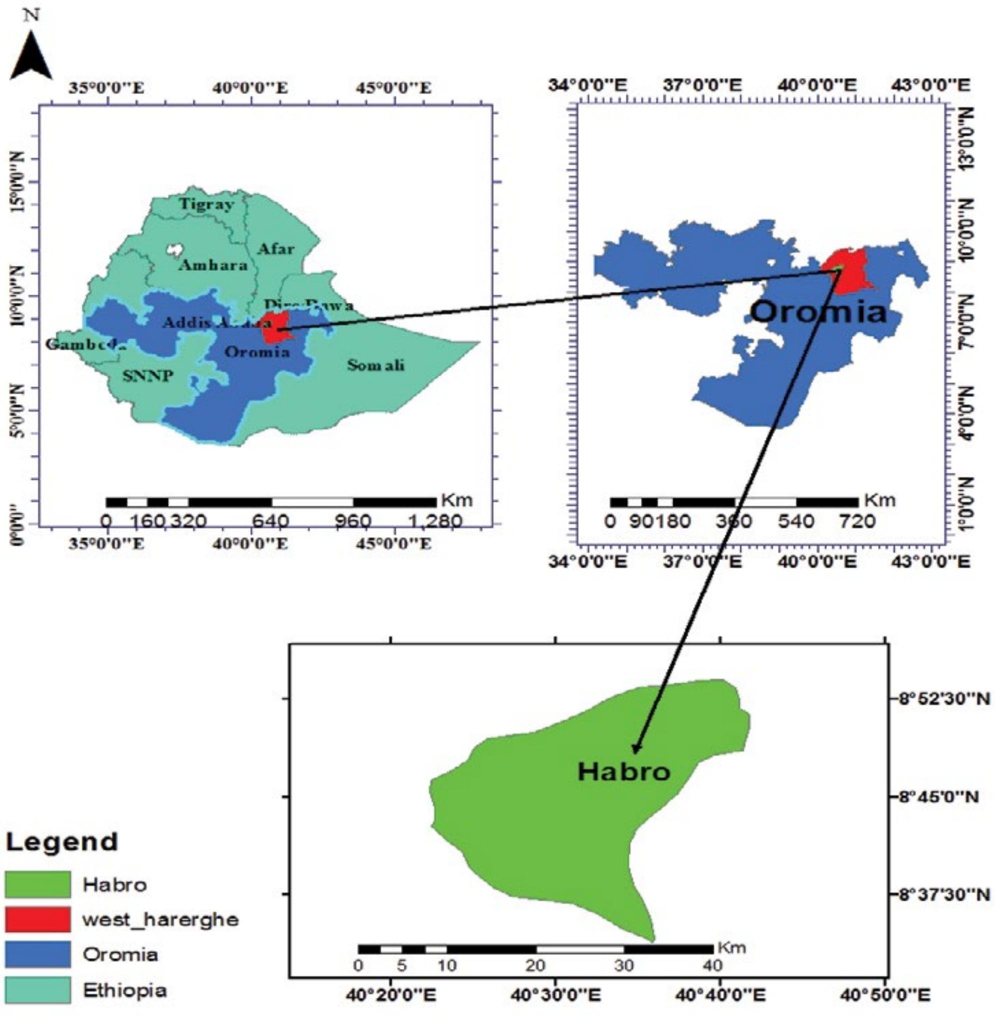

Figure 1: Map of the study area.

Mixed crop-livestock agriculture is a common farming system in the study area. The main crops grown in the area are cereals such as teff *(Eragrostis tef)*, maize *(Zea mays)*, wheat *(Triticum aestivum)*, barley *(Hordeum vulgare)*, common bean (*Phaseolus vulgaris*) and sorghum (*Sorghum bicolor*) and cash crops such as coffee (*Coffea arabica*), chat (*Catha edulis*), pepper (*Capsicum species*) and onion (*Alluim cepa*). The major animals kept in the area are cattle, goats, donkeys, chickens and bees [18].

The district has a population of about 214,591, of which 103,472 (48.2%) are females. Young, economically active and old age populations accounted for 45.3%, 52.4% and 2.3%, respectively. The average family size for rural areas is 5 persons. The crude population density of the district estimated as 289 persons per km^2 [18].

Data and source

Station observed rainfall and temperature data and coffee yield (2001-2016) were obtained from National Meteorological Agency, Habro District Coffee and Tea Development and Marketing Authority respectively. Future rainfall and temperature data were downscaled using Marksim GCM; under an average of GFDL-ESM2M, BCC-CSM1-1, NorESM1-M and CSIRO-Mk3-6-0 model for RCP 4.5 emission scenarios of IPCC AR5.

The start date of the rainy season was declared when a total rainfall of more than 20 mm recorded in three consecutive days that were not followed by greater than 10 days of dry spell length within 30 days from planting day was used. No drier spell exceeding 10 days within the 30 days taken as extra criteria embedded in INSTAT (V 3.37) helps to avoid false onset.

The end date of the rainy season was adopted in this case is defined as any day after the first of September, when the soil water balance reaches zero. In determining the end date, site-specific evapotranspiration was determined and a fixed 3.66 mm per day and 100 mm of plant-available soil water were considered [20]. Using the above definitions, Instant Statistical program Version 3.37 was used for analysis using January to December calendar [20]. The length of the growing period was determined by subtracting belg onset date from *kiremt* end date of rainfall.

Finally, in determining the number of rainy days, multiple criteria are available for use. In the context of Ethiopia, Segele and Lamb employed three rainfall thresholds to define a rainy day (0.1 mm, 0.5 mm and 1 mm) [21]. However, Ward and Hadgu defined a rainy day as, a day with 1 or more mm of rainfall amount [22,23]. In this study, 1 mm per 24 hrs, rainfall threshold was adopted. Seasonal rainfall amount was decided by adding the amount of rainfall recorded for both belg and kiremt rainy season for this study area.

Data quality control

Data of rainfall, minimum and maximum temperature were captured into microsoft excel, 2013 spreadsheet following the days of a year (DOY) entry format. Data quality control was done by careful inspection of the completeness and temporal consistency of the rainfall and temperature records in the study area. Missing values in the data series were filled by using Markov chain first-order simulation models of INSTAT [20]. This is because first-order doesn't exaggerate the result and it gives accurate model estimates [20,24]. Data outlier detection, homogeneity and multicollinearity tests were carried out using XLStat software.

Projected rainfall and temperature data

Marksim is a spatially explicit daily weather generator that uses a third-order Markov chain process to generate daily rainfall and temperature [25]. It requires geographical location to downscale and generates daily future data for a given site [26]. According to Yang, out of 43 models of the Coupled Model Inter-comparison Project Phase5 (CMIP5) historical experiment involved in the study CSIRO MK 3.6.0 was the only model that captures both the East African precipitation climatology and the East African long rains-SST relationship in the observation [27].

Generally, for this study, Atmosphere-Ocean GCM was selected among the 17 GCMs after each one had downscaled separately and compared with observed at station. Accordingly, GFDL-ESM2M, BCC-CSM1-1, NorESM1-M, and CSIRO-Mk3-6-0 models were selected due to their better estimation of areal rainfall compared to Gelemso station data for the period 2012-2016 on annual basis, by plotting values on bar graphs for visual inspection. Accordingly, future rainfall and temperature data (2018-2047) for Gelamso Meteorological station were downscaled with validated Atmosphere-

Table 1: Pearson's lower triangular correlation matrix of rainfall and temperature characteristics and coffee yield 2001-2016.

	Yield	BMT	KMT	OS	ED	BRD	KRD	KRFT	BRFT	LGP
Yield	1									
BMT	-0.63**	1								
KMT	-0.51*	0.22	1							
OS	-0.24	0.27	0.43	1						
ED	0.42	-0.3	-0.47*	-0.4	1					
BRD	0.53*	-0.06	-0.2	0.22	-0.2	1				
KRD	0.2	-0.07	-0.35	-0.45*	0.12	0	1			
KRFT	0.26	-0.19	-0.58**	-0.49*	0.44*	-0.27	0.64**	1		
BRFT	0.46*	-0.1	-0.1	-0.04	-0.08*	0.49*	-0.25	-0.11	1	
LGP	0.42	-0.34	-0.54*	-0.70**	0.93**	-0.24	0.27	0.53*	-0.05	1

**Correlation is significant at the 0.01 significant level; *Correlation is significant at the 0.05 significant level; BMT: Belg Mean Temperature; KMT: Kiremt Mean Temperature; OS: Onset of Rainy Season; ED: End Date of Rainy Season; BRD: Belg Rainy Day; KRD: Kiremt Rainy Day; KRFT: Kiremt Rainfall Total; BRFT: Belg Rainfall Total; LGP: Length of the Growing Period

Ocean GCM for RCP 4.5 emission scenarios of IPCCAR5 using a web-based software tool (http/: WWW.Marksim GCM Weather Generator.Com) under resemble of GFDL-ESM2M, BCC-CSM1-1, NorESM1-M and CSIRO-Mk3-6-0 model.

Correlation and regression analysis

Using observed rainfall and temperature and coffee yield data from 2001 to 2016, the regression model was computed as follows:

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_nx_n + e \quad \text{(equation 1)}$$

Where Y=the value of the dependent variable (Coffee yield in kg/ha), a=Y-intercept, b_1, b_2, b_3, b_4,...b_n=regression coefficients (each b represents the amount of change in Y (yield) for one unit of change in the corresponding x-value when the other *x* values are held constant; x_1, x_2, x_3, x_4,..x_n=the rainfall independent variables (i.e. rainfall onset, cessation, LGP, seasonal rainfall totals and number of rain days) and temperature-independent variables (i.e. belg mean temperature and kiremt mean temperature), e: the error of estimate or residuals of the regression.

Pearson correlation coefficient (r) was used to analyze the correlation between coffee yield (kg/ha) with temperature and rainfall characteristics, the value of r ranges between -1 to +1, a correlation coefficient close to +1 indicates a strong positive correlation, a correlation coefficient close to -1 indicates a strong negative correlation similarly a correlation coefficient of 0 indicates no correlation. Apart from the coefficients of the independent variables (temperature and rainfall variables), the coefficient of multiple determinations (R^2) was used to determine the percentage explanation achieved jointly. If the P-value of F exceeds 0.05 (confidence level) the explanatory variable does not predict the response variable. Similarly, a Student t-test in a multiple regression was used to assess whether the independent variable adds unique and predictive value as a predictor for statistical significance was calculated using XLStat [28,29]. To assess how serious the multicollinearity problem is the VIF was determined by XLStat. If the VIF is 1 there is no multicollinearity at all, if the VIF is large such as 10, collinearity is the serious problem.

Impacts of projected temperature and rainfall characteristics on coffee yield

Impacts of future temperature and rainfall characteristics on coffee yield were analyzed by substituting analyzed projected temperature and rainfall characteristics, into a developed regression model based on the sensitivity of yield to observed rainfall and temperature variables for a period of 2001-2016 using Instat software [20].

RESULTS

As presented in Table 1, from rainfall variables, only belg (February, March, April and May) rainy day had positive strong correlation (r=0.53) with coffee production. Other variables, end date of rain (r=0.42), kiremt (June, January, August and September) rainy days (r=0.20), kiremt rainfall total (r=0.26), belg rainfall total (r=0.46) and length of growing period (r=0.42) had positive moderate correlations with coffee production. However, the onset date of the rainy season (r=-0.24) had a negative moderate correlation with coffee production (coffee production decline in the year, with late-onset of rain). In general, except onset date of the rainy season, statistical analyses showed that all rainfall variables had a positive relationship with coffee yield in the study area.

Belg mean temperature (r=-0.63) and kiremt mean temperature (r=-0.51) showed a strong negative correlation with coffee yield, which indicates a rise in both belg and kiremt temperature significantly reduced coffee production in the study area during 2001-2016 (Table 1).

Multiple regression analysis of the study showed that the coefficient of multiple regressions (R^2) was 0.84 (i.e., 84% of the variations in coffee yield have been explained by the above-mentioned climatic parameters jointly). The length of the growing period has removed from the predictor position in the regression model because of the multicollinearity problem. The analysis of variance (ANOVA) showed that the influence of climate variables on the yield of coffee is statistically significant (p=0.03) (Table 2). This indicated that the conditions of rainfall and temperature parameters of the

Table 2: Summary of regression values for rainfall and temperature characteristics and coffee yield 2001-2016.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Sig.
	0.917	0.841	0.66	1.41	0.03

Table 3: Coefficients of regression analyses for the effect of rainfall and temperature characteristics on coffee yield 2001-2016.

	Unstandardized Coefficients		Standardized Coefficients		
Model	B	Std. Error	Beta	t	Sig.
(Constant)	40.483	37.229	-	1.087	0.313
Belg mean temperature (BMT)	-2.011	0.726	-0.457	-2.799	0.027
Kiremt mean temperature (KMT)	-0.412	1.438	-0.072	-0.307	0.768
Onset date of rain (ODR)	0.012	0.039	0.064	0.303	0.771
End date of rain (EDR)	0.03	0.018	0.329	1.694	0.134
Belg rainy day (BRD)	0.091	0.054	0.414	1.687	0.135
Kiremt rainy day (KRD)	0.048	0.076	0.162	0.637	0.545
Kiremt rainfall total (KRT)	0.001	0.007	0.059	0.207	0.842
Belg rainfall total (BRT)	0.004	0.003	0.282	1.377	0.211

Table 4: The predicted coffee yield based on projected rainfall and temperature characteristics at the study area.

Year	X1	X2	X3	X4	X5	X6	X7	X8	Yield(qt/ha)
2030	22.7	23.34	107	300	40	39	642.4	389.6	3.21
2035	22.83	23.45	107	301	40	39	645.7	389.9	2.95
2040	22.96	23.58	110	302	36	39	641.6	428.4	2.48
2045	23.09	23.69	110	294	36	43	624.4	422.9	2.08
2050	23.15	23.74	110	294	36	43	624.9	422.5	1.94

X1: Belg mean temperature (°C); X2: Kiremt mean temperature (°C); X3: onset date of rain (DOY); X4: end date of rain (DOY); X5: belg rainy days (days); X6: kiremt rainy days (days); X7: kiremt rainfall total (mm); X8: belg rainfall total (mm)

production year are the major determinant factors for the coffee productivity.

According to the estimated model below, the variation in coffee yield (kg/ha) was accounted variation, because of climate variable as follow; belg mean temperature (-2.011 qt/ha), kiremt mean temperature (-0.412 qt/ha), onset date of rain (0.012 qt/ha), end date of rainy season (0.03 qt/ha), belg rainy day (0.091 qt/ha), kiremt rainy day (0.048 qt/ha), kiremt rainfall total (0.001 qt/ha) and belg rainfall total (0.004 qt/ha) (Table 2).

$$Y = 40.483 - 2.011X_1 - 0.412X_2 + 0.012X_3 + 0.03X_4 + 0.091X_5 + 0.048X_6 + 0.001X_7 + 0.004X_8 \quad \text{(equation 2)}$$

Where, Y: predictable coffee yield (qt/ha); X_1: Belg mean temperature (°C); X_2: Kiremt mean temperature (°C); X_3: onset date of rain (DOY); X_4: end date of rain (DOY); X_5: belg rainy days (days); X_6: kiremt rainy days (days); X_7: kiremt rainfall total (mm); X_8: belg rainfall total (mm) (Table 3).

DISCUSSION

In line with the result presented in the table 1, Koge determined the insignificant, but positive correlation between rainfall and coffee yield. Another study also showed that drought is a major climatic limitation for coffee production [30,31]. Low rainfall also causes the coffee husk to stick to the bean hindering maturation and thus fewer coffee berries are harvested [32].

Moreover, relationship of temperature with coffee yield indicated in the table 1 agrees with Davis, in which they showed that the growing success of coffee plants is directly linked to accelerated climate change, but there is a profoundly negative trend in this relationship [9]. As temperatures rise, *C. arabica* production will decrease. This will negatively impact Ethiopia's coffee industry. Similarly, Jaramillo states that even the smallest increases in temperature could cause extensive damage to coffee production [33]. They stated since *C. arabica* has such picky temperature requirements, climate change could lead to disastrous impacts on the worldwide coffee industry.

The analysis of variance (ANOVA) showed that the influence of climate variables on the yield of coffee is statistically significant (p=0.03).

As indicated in Table 4 due to the impacts of projected rising belg and kiremt mean temperature, the slight increase in the late onset of rain and the slight decrease in LGP and kiremt rainfall, coffee productivity is expected to be low and decrease in the future in the study area.

Moreover, this study has predicted, average annual temperature and rainfall for the period of 2018-2047 to be 21.59°C -22.26°C and 1114 mm-1145 mm respectively in the study area. However, Tesfaye has determined the optimum annual average temperature and precipitation/rainfall condition required for *C. arabica* ranges between 19.14°C-21.66°C and 1502 mm-1850 mm respectively [17]. Thus, the hotter temperature and moisture stress is expected to be an influential factor for *C. arabica* growth and production in the Habro district in the future. Similarly, Taye, stated temperature and rainfall are the two most limiting factors for coffee growth. In general, replacing the same year climatic variable predicted values (belg mean temperature, kiremt mean temperature, the onset date of rain, end date of rain, belg rainy day, kiremt rainy day, kiremt rainfall total and belg rainfall total) in the prediction model, the predicted coffee yield showed decreasing trend in the study area [34].

CONCLUSIONS

Correlation results indicated that from rainfall variables only belg rainy day had positive strong correlation (r=0.53) with coffee production. Others variables; end date of rain (r=0.42), kiremt rainy day (r=0.20), kiremt rainfall total (r= 0.26), belg rainfall total (r=0.46) and length of growing period (r=0.42) had positive moderate correlations. However, onset date of the belg rainy season (r=-0.24) had a negative moderate correlation. Moreover, belg mean temperature (r =-0.63) and kiremt mean temperature (r=-0.51) had shown a negative strong correlation with coffee yield. This indicated a rise in belg *and* kiremt temperature caused a significant reduction in coffee production 2001-2016 in the study area.

The analysis of variance (ANOVA) showed that the influence of climate variables on the yield of coffee is statistically significant (p=0.03). According to the estimated model, the variation in coffee yield (qt/ha) at Gelemso station was accounted for variation, because of climate variable as follow; belg mean temperature (-2.011 qt/ha), kiremt mean temperature (-0.412 qt/ha), onset date of rain (0.012 qt/ha), the end date of the rainy season (0.03 qt/ha), belg rainy day (0.091 qt/ha), kiremt rainy day (0.048 qt/ha), kiremt rainfall total (0.001 qt/ha) and belg rainfall total (0.004 qt/ha).

The result of projected belg and annual rainfall total trend indicated that there will be a slight increase in rainfall amount by 0.30 mm and 0.20 mm every year. However, kiremt rainfall total showed a slight decreasing trend by -0.16 mm per year. Similarly, the study found, a trend of late-onset dates of belg rainy season increase by 0.16 days per year. But, the length of the growing period will decrease by -0.07 days per year. Projected belg, kiremt and annual maximum temperature will is expected to increase significantly by 0.028°C, 0.03°C and 0.027°C respectively per year. Similarly, both seasonal and annual minimum temperature will significantly increase by 0.02°C per year in the study area for 2018-2047. In the future, due to the impacts of; remarkable increasing belg and kiremt mean temperature, a slight increase in late-onset of rain and slightly decreasing in the length of growing period and weakening of kiremt rainfall in general, projected coffee yield is expected to decrease in the future in the study area.

RECOMMENDATIONS

The results of this study indicated that C. *arabica* has been and is expected to be negatively influenced by climate variability in the study area. Therefore, the following recommendations were forwarded to improve and sustain C. *arabica* productivity in the study area and similar agro-ecology zones where coffee has been growing.

1. A resolute effort should be made to identify and move the establishment of coffee to new higher altitude coffee areas i.e., low moisture stress and cooler temperature.
2. Growth of suitable shade trees in between rows of coffee trees to create cooler temperature and reduce evapotranspiration.
3. Attention should be paid to new and emerging water conservation strategies to store rainwater for use during prolonged dry spells and low rainfall.
4. More research on exploring drought and high-temperature resistant varieties.
5. Communicating projected climate change and variability among farmer, researcher and decision-makers.

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