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Trend Analyses of Temperature and Rainfall and Their Response to Global CO_2 Emission in Masha, Southern Ethiopia

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Abstract

Ethiopia is one of the most vulnerable countries to climate change and often signifies higher probabilities of droughts that have historically affected millions of farmers. The variability in rainfall patterns and drought have disrupted crop production and exacerbated food insecurity in many parts of Ethiopia. This study aimed to investigate seasonal and annual temperature and rainfall trends and their association to the global CO_2 emission. Temperature and rainfall data obtained from the Masha meteorological station and CO_2 from EDGAR 4.3.2 dataset recorded for 36 years. The Linear regression model was used to analyse seasonal temperature and rainfall trends. Pearson's correlation coefficient employed to measure the relationship between temperature and rainfall and global CO_2 emission. The results showed that there were significant warming trends of seasonal and annual mean temperatures while summer season and annual rainfall significantly declined. The prediction results showed that the summer and annual mean temperatures would be significantly increased while the rainfall decreased for the next 35 years. The cumulative global CO_2 and annual mean temperature and rainfall were correlated significantly at $P = 0.0004$ and 0.006 for temperature and rainfall, respectively. The results demonstrated clearly that the increasing of temperature and the decreasing of rainfall had a direct relationship with the global CO_2 emissions and suggested that there should be a sound soil and water management, short season seed supply and pipe irrigation practices to reduce the future crop damage in the area.

Keywords: correlation coefficient, cumulative CO_2, linear regression, rainfall, temperature

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INTRODUCTION

Changes in rainfall and temperature are one of the most critical factors, which determine the overall change in climate. The rapid changes that have occurred since the middle of the past century have caused emission of greenhouse gases into atmosphere largely by human beings. Other human activities also affect the climate system, including emissions of pollutants and other aerosols and changes to the land surface, such as urbanization and deforestation (WMO, 2010). The change in atmospheric concentrations of greenhouse gases and aerosols, land cover changes and solar radiation alters the energy balance of the climate system. The Earth's climate change is caused by changing of climate system components, whether inside or outside of the system. The average annual temperature is one of important climate indicators. The temperatures can differ greatly from day to day and over the course of a year because of natural climate variability. The climate challenge can mostly be framed total cumulative emissions of carbon dioxide (CO_2). Even though CO_2 is one of

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contributors to global warming, it is the most important greenhouse gas causing temperature changes that are largely irreversible by natural processes on the time scales relevant to human societies (Matthews et al., 2018). The average land surface temperature data as calculated by a linear trend showed a warming of 0.65 °C to 1.06 °C over the period of 1880–2010 and maximum and minimum temperatures over land have increased in excess of 0.1 °C per decade since 1950. A pronounced increase in the global temperature occurred over the four decades of 1971–2010. The global temperature increased at an average estimated rate of 0.17 °C per decade during that period (WMO, 2010). Ama et al. (2018) also stated that the projected mean surface temperature difference between 2 °C and 1.5 °C is higher than 0.5 °C over nearly all land points, reaching 0.8 °C over Sudan and northern Ethiopia.

The increments of global temperature have led likely to affect food security at the global, regional and local level. Climate change can disrupt food availability, reduce access to food and affect food quality (Brown et al., 2015). The projected increases in temperatures, changes in precipitation patterns, changes in extreme weather events and reductions in water availability may all result in reduced agricultural productivity (Hatfield et al., 2014). Increasing variability of precipitation and increases in the frequency of droughts and floods are likely to reduce yields in general. Although higher temperatures can improve crop growth, studies have documented that crop yields decline significantly when daytime temperatures exceed a certain crop-specific level (FAO, 2017). Pollination is one of the most sensitive phenological stages to temperature extremes across all species and during this developmental stage, temperature extremes would greatly affect production (Hatfield and Prueger, 2015).

The manifestation of the change and the effect of climate vary from place to place. In eastern Africa, the past climate change induced extreme events like droughts have had severe negative impacts on key socioeconomic sectors of most countries. In the late seventies and eighties, droughts caused widespread famine and economic hardships in many countries of the continent (Haggag et al., 2016). There is evidence that future climate change may lead to a change in the frequency and severity of extreme weather events, potentially worsening these impacts. In addition, future climate change will lead to increases in average mean temperature and changes in annual and seasonal rainfall.

Ethiopia is one of the most vulnerable countries that facing negative impacts of climate change and often signifies higher probabilities of droughts that have historically affected millions of rural poor farmers, pastoralists, domestic and wild animals and have grave ramifications for the environment and social instrument. Both climate variability and change have been occurring in Ethiopia (Zegeye, 2018). The variability in rainfall patterns and drought have disrupted crop production and exacerbated food insecurity in many parts of Ethiopia. Consequently, crop failure, water stress, crop disease and high food prices affect the population (Mahoo et al., 2013). Crop model simulations indicated that between 1982 and 2014, parts of eastern Amhara and eastern Oromia experienced increasing water deficits during the critical sowing, flowering and ripening periods of crop growth (Brown et al., 2017).

Therefore, this study is very crucial to understand the spatial and temporal variation of climate within a zone or region and their relationship with other factors and to monitor and design natural resources management systems such as environmental planning, land use planning, water resources planning and irrigation planning while implementing sustainable agricultural development in the area. The extreme temperature and rainfall can prevented from becoming major disasters by reducing the vulnerability and exposure of agricultural sector.

The study aimed to investigate a time series trend of seasonal and annual temperature and rainfall and the relationship between the two climatic factors (temperature and rainfall) and commutative global CO_2 emissions using historical data recorded during 1980-2015. To achieve the objectives, it was hypothesized that the local temperature and rainfall are neither normally distributed and nor independent to the global CO_2 about the mean and standard deviation.

MATERIALS AND METHOD

Location of study area

The Mash is one of the districts in the Sheka Zone of the Southern Nations, Nationalities and Peoples of Ethiopia (Figure 1). It is bordered by the Anderacha district from the south, Oromia National Regional state from west and north and Keffa Zone from the east. The area is located between 7° 44′ 00″ - 7° 82′ 00″N latitude and 35° 29′ 00″ - 35° 66′ 00″E longitude with an elevation of 2,223 meters above sea level (Kebede, 2002). The district is lying in Subtropical zone and its elevation ranges between 1,830-2,440 meters. Based on the Central Statistical Agency of Ethiopian (2013), the total population of the district is estimated to 53,053 people, of which 26,151 males and 26,902 females and of its population, 83.37% are rural and 16.63% urban dwellers. The four seasons exist in Masha are winter, the dry season that extended from January to March; spring, the small rainy season (from February to May); summer, the main rainy season (from June to August) and autumn, the relatively wet season (from September to December). These are locally known as bega, belg, kiremt and tseday, for winter, spring, summer and autumn, respectively (Kibriye, 2003).

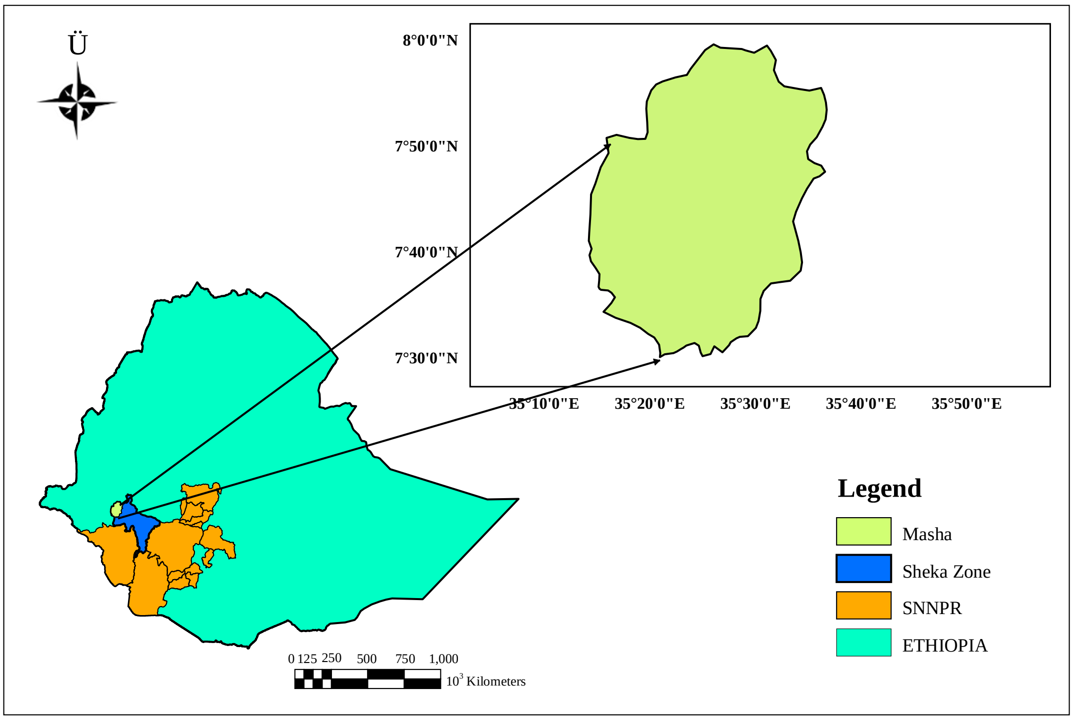

Figure 1. Map of the study area

Data description and collection

In this study, data are restricted to the period between 1980 and 2015 to attain mutual part of rainfall, temperature and CO_2 emission data in order to avoid preferences. Raw data of rainfall and temperature obtained from Masha Meteorological Station, branch of Ethiopia Meteorology Agency (EMA) while data of global CO_2 emission from EDGAR 4.3.2 dataset (EC-JRC/PBL 2016) that provided for the period of 36 years. The EDGAR 4.3.2 dataset covers all countries with consistent time series. However, the raw data from Masha is highly subjected to outliers and missing data needs adjustment to avoid potential biases. Fresh data with internal variation of outliers would affect the absolute values of mean and total, the moving average process of time series (Leys et al., 2018). Therefore, replacement from mean values of proximate points used to ensure the internal variations of outliers, exhaustive data elimination or reduction techniques and quality control procedures including time of observation and transformations of missing data. The mean of the seasonal temperature and rainfall was obtained by summing the corresponding mean monthly variables, which was originally derived from the decadal temperature rainfall dataset.

Trend analyses methods

A time series of trend analyses was determined using regression analyses (parametric test) after doing a normality test to identify data distribution.

A regression analysis was conducted with time as the independent variable and rainfall and temperature as the dependent variable. The regression analyses could carried out directly on the time series and forecasts of temperature were generally expressed as a range of expected values (for example, 17.06 ℃ –16.15 ℃ for mean temperature). These trends and prediction of time series were computed by using Autoregressive Integrated Moving Average (ARIMA) model. This model is very flexible and quite hard for computing and for the understanding of the results. It demands quality and a large number of dealing dates (it is assumed at least 50 dealing or observations (Chu et al., 2013). A linear equation:

$$\gamma = \beta t + c \qquad (1)$$

Where: γ is a temperature or rainfall variables, β is a trend (slope), c is a constant or y intercept and t is a time series (1980-2015). However, the rate of change (β) in percent and constant or y intercept (c) of the equation is calculated as follows.

$$\beta(\%) = \left[\frac{(N\sum\gamma t) - (\sum t)(\sum\gamma)}{\left(N\sum t^2 - (\sum t)^2\right)}\right] x100 \qquad (2)$$

$$\text{Intercept}(c) = \left(\frac{\sum\gamma - \beta(\sum t)}{N}\right) \qquad (3)$$

Where: N is total sample sizes that can be fitted by regression. When β is positive value, it indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in time series. The normally distributed data for seasonal and annual mean temperatures and rainfalls were predicted for the time series between 1980 and 2050 using time series models of SPSS version 20 software.

Pearson’s correlation coefficient was employed to determine the relationship between temperature and global CO_2 emission as well as between CO_2 and rainfall. It is the most popular method to calculate the direction and degree of the relationship between variables to understand the response of local temperature and rainfall against global CO_2 emissions. The relationships between the variables were calculated using the following formula developed by Buonocore and Pirozzi (2014).

$$\mathbf{r} = \frac{\sum(X-\bar{X})(Y-\bar{Y})}{\sqrt{\sum(X-\bar{X})^2}\sqrt{(Y-\bar{Y})^2}} \qquad (4)$$

Where X = cumulative CO_2, Y = annual temperature $\bar{X}$ = mean of cumulative CO_2 and $\bar{Y}$ = mean of temperature. The value of r is always between -1 and +1: $-1 \le r \le 1$. If r = -1, then, it is a perfect negative relationship between X and Y. If -0.99< r < = -0.5, then, it is moderately negative relationship. If -0.49< = r >0, then, it is weak negative the relationship. If r = 0, then it refers to no relationship between the two variables. If 0< r < = 0.49, then, the relationship is weak positive. If 0.5< = r > = 0.99, then, the relationship is moderately positive and If r = +1, then, it is a perfect positive relationship between X and Y variables

RESULTS AND DISCUSSION

Trends of temperature and rainfall

The analyses of temperature and precipitation revealed a variety of changes in extreme values during the last 36 years in Masha. Although this is true for both climate elements, changes in temperature have a much higher degree of spatial coherence.

Temperature

Observations confirmed that an ongoing, seasonal and local temperature change, which is a key indicator for presence of climate change. The analyses of the annual temperature trends indicated that changes in temperature over the 1980-2015 reflect strong warming trends in the area. The result showed that all seasonal and annual temperatures were significantly increased over the year ($P<0.05$). The slope (β) values of linear equations with different rates in percent were: 2.34, 3.1, 3.4 and 1.6 for winter, spring, summer and autumn, respectively. The mean temperature of the summer season was significantly a higher warming trend as compared to other three seasons. According to Abebe (2017), the annual average temperature has raised by 1.65 ℃ from 1955 to 2015 in Ethiopia. In addition, Asfaw et al. (2018) also reported that the mean, maximum and minimum temperature had shown increasing trends from 1901 to 2014 in northcenteral Ethiopia. An increasing maximum temperature during the seasons in Ethiopia also reported by Suryabhagavan (2017), which is the real concern for agricultural activities in the country. The reason behind higher mean temperature in summer might be related to the summer equinox occurs when the sun passes directly above the equator because of the tilt of the earth (Scherrer and Scherrer, 2014). In general, the mean of annual temperature was increased by 2.6% per a year and warming trends in temperature were extended to 0.91 ℃ at the end of 2015 (Table 1). The average increase in land as well as sea surface temperature is primarily due to the increase in greenhouse gas concentration from human activities. During the past five decades, the earth has been warming at a rather high rate (0.12 ℃) per decade (Stips et al., 2016).

Table 1. Trends of seasonal and annual temperature and rainfall during the periods of 1980-2015

Model statistics	Mean temperature (℃)					Total rainfall (mm)				
	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual
Mean	17.15	17.41	15.68	16.17	16.60	67.60	187.00	317.42	199.33	192.84
Std. deviation	0.25	0.32	0.36	0.17	0.28	1.03	11.42	19.60	8.07	9.51
Maximum	17.57	17.95	16.27	16.45	17.06	69.31	205.00	349.97	212.74	208.64
Minimum	16.74	16.87	15.08	15.89	16.15	65.89	168.10	284.87	185.92	177.04
Range (trend)	0.83	1.08	1.19	0.56	0.91	3.43	37.93	65.10	26.81	31.61
Slope (β) (%)	2.40	3.10	3.40	1.60	2.60	0.10	-1.08	-1.86	-0.77	-0.90
t	82.05	57.45	60.04	101.62	79.18	10.06	15.69	22.26	21.38	28.86
Sig.	0.019	0.033	0.01	0.04	0.01	0.75	0.09	0.02	0.11	0.01

Rainfall

The results indicated that there were variations in rainfall distribution among the seasons. Trends of rainfall were insignificantly changed with different rates since 1980-2015 in all seasons except summer. The value of rainfall change or slope (β) of linear equations of rainfall in percent were 0.1, -1.08, -1.86 and -0.77 for winter, spring, summer and autumn, respectively. The negative values indicate a decrease of rainfall on time series. The average change of rainfall in summer season was significantly following declining trend ($P<0.05$). The change of rainfall in spring and autumn was linear and moving downwards, but it was not significant. However, a non-significant increase of rainfall is found with very small patterns of positive trends in winter. The overall annual changes of rainfall during 1980-2015 declined significantly at $P<0.012$ significant level (Table 1).

Similarly, Mulugeta et al. (2017) reported that mean annual rainfall had been fluctuating in 1981– 2009 in Ethiopia. However, according to Birega et al. (2017), who has conducted the study in Arbaminch town, one of southern Ethiopian town, the trend of annual precipitation was non-significantly increasing during the period of 1995-2014. The deceasing trends of rainfall might be related to the shift of the atmospheric-oceanic conditions. Matthews et al. (2018) stated that the co-action on the global warming with ENSO like decadal variability can significantly enhance drying trends of East Africa. This observation suggested that a 1 ℃ increase in El Niño-3.4 SSTs produces a 79 mm decrease in East Africa rainfall. Therefore, the uses of soil and water conservation practices to retain soil moisture, the short season crop varieties which can be grown faster under water stress and uses of pipe irrigation which can protect evaporation due to the increase of the temperature are important climate change adaptation strategies (Gashaw et al., 2014).

Prediction of temperature and rainfall

The statistically changed trend of seasonal and annual mean temperature and rainfall were forecasted using the linear regression model. The results revealed that the warming up of temperatures and moving down of rainfall could be continue for the coming 35 years. The predicted values of temperature is significantly increased in all seasons while declining for rainfall, merely in summer season and annual basis over the years 1980-2050. A different response is found in the trend looking at the amount of temperature and rainfall coming in summer season. In this season, the raising mean temperature and the moving down of rainfall are forecasted to be superior in the next 35 years. The predicted values of annual average surface temperature was significantly increased and its values estimated to reach 1.83 ℃ at 2050, but the value of rainfall estimated to be decreased to 63.21 mm at similar time series (Table 2). Various studies indicated that over the last 3 decades rainfall has decreased over eastern Africa between March and May or June. Precipitation in eastern Africa shows a high degree of temporal and spatial variability dominated by a variety of physical processes (IPCC, 2013).

Table 2. Prediction of seasonal and annual mean temperature and rainfall (1980-2050)

Model statistics	Temperature (°C)					Rainfall (mm)	
	Winter	Spring	Summer	Autumn	Annual	Summer	Annual
Mean	17.57	17.95	16.28	16.45	17.06	284.87	177.04
Std. deviation	0.49	0.64	0.70	0.33	0.54	38.39	18.64
Maximum	18.39	19.02	17.46	17.01	17.97	349.97	208.64
Minimum	16.74	16.87	15.08	15.89	16.15	219.76	145.43
Range (trend)	1.65	2.16	2.38	1.12	1.83	130.20	63.21

From analyses of annual mean temperature, the area was predominantly affected by cold temperature (32% below the average) during 1986 and the marginal increase temperatures were observed in the years 1992 and 1998 (Figure 2).

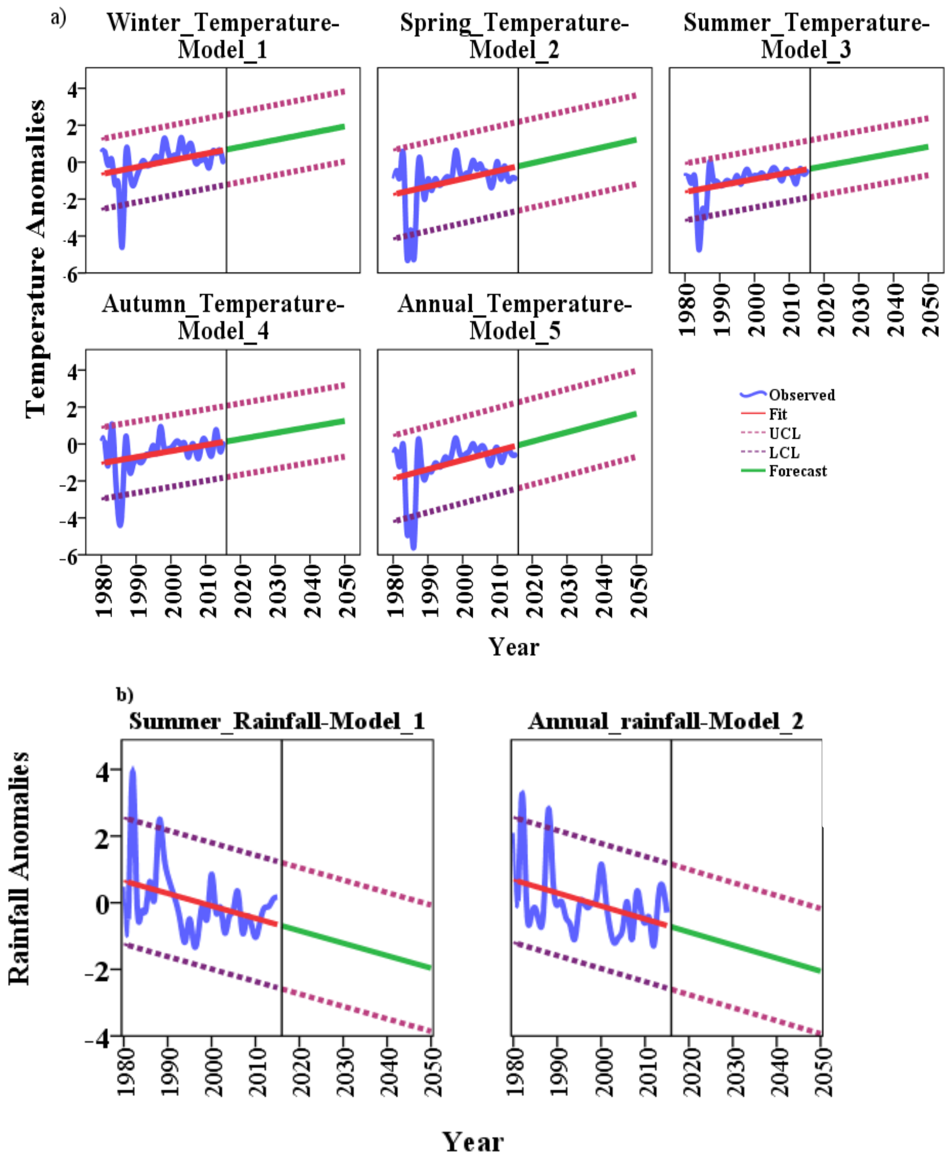

Figure 2. Prediction of seasonal and annual temperature (a) and rainfall (b)

The reason behind the higher temperature during these years might be related to El Niño events. The El Niño of the 1991/92 and 1997/98 were identified as moderate and extreme warm temperature, respectively as compared to the normal years (Cai et al., 2014). In addition, the rising temperature might also be related to the rising of water vapor in the atmosphere. The rising energy absorption of vapor is reducing the out coming long wave radiation window and amplifying warming regionally and in a different way around the globe (Soares, 2010). Unlike CO_2, water vapor in the atmosphere is rising in tune with temperature changes, even in a monthly scale.

Relationship between climatic parameters and cumulative global CO_2

There is a clear phase relationship between the change of local temperature and rainfall with the corresponding increase of cumulative global CO_2 in the atmosphere. A cumulative global CO_2 levels and local annual average of temperature and rainfall for decades were correlated significantly at P<0.01. The values of R, correlation coefficients between cumulative global CO_2 and the two climatic variables were 0.56 and -0.45 for temperature and rainfall, respectively.

The result showed that the relationship between global CO_2 and temperature was a moderate positive correlation, which means that there was a tendency for high global CO_2 scores gone with high temperature scores and vice versa. However, the relationship between global CO_2 and rainfall was a weak negative correlation where high global CO_2 scores gone with lower rainfall scores (Figure 3).

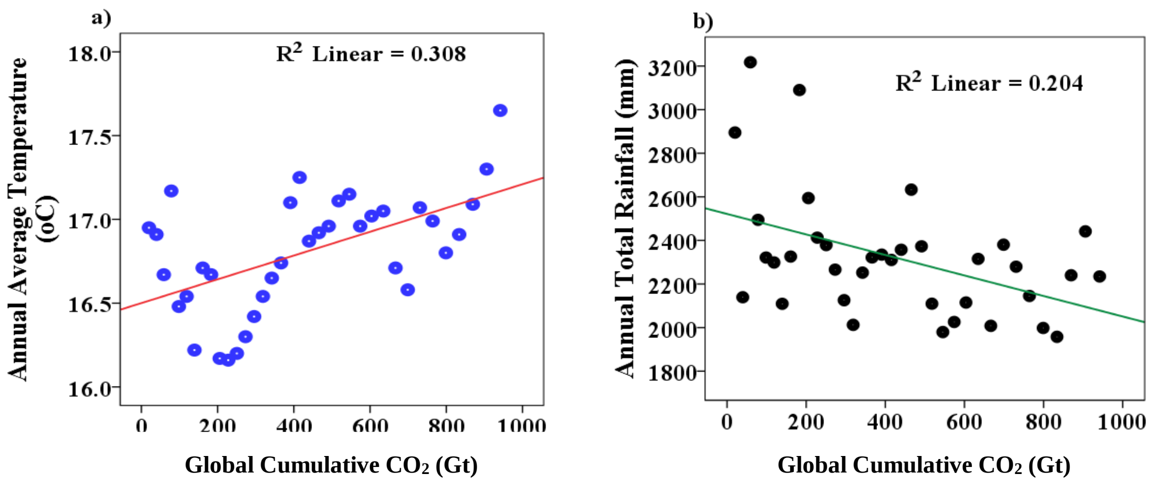

Figure 3. Correlation between Temperature (a) and rainfall (b) and cumulative global CO_2

The value of R^2, the coefficients of correlation determination between the global CO_2 and variables were 0.308 and 0.204 for temperature and rainfall, respectively. It means that 30.8% of the variation in the temperature and the 20.4% of the variation in the rainfall was determined by the linear relationships between temperature and global CO_2 and between rainfall and global CO_2, respectively.

The P- values of the relationships between global CO_2 and the two climatic factors were 0.0004 and 0.006, respectively and thus, the results were high significant relationships at P<0.01. The reason behind the substantial increase of the temperature with CO_2 rise might be due to ability of CO_2 molecules to absorb and re-emit infrared energy. UCAR (2012) stated that the energy from the infrared photon causes the CO_2 molecule to vibrate and thereafter, the molecule gives up this extra energy by emitting another infrared photon. An elevated temperature can cause increase evaporation from the earth's surface and lead to decline in the amount of precipitation at lower latitude and increases in the amount of precipitation at higher latitudes, because, highly energized air would then carry the water vapor to higher latitude. However, the excess water would eventually fall out as increase precipitation over these regions. Numerous studies indicate that the increase in temperature and CO_2 levels will affect the composition of crop biodiversity by altering the species competition dynamics due to changes in optimal growth rates (Thornton et al., 2015; Rojas-Downing et al., 2017).

CONCLUSIONS

Trend analyses of temperature and rainfall show clearly a significant change of climate. In all seasons, the temperature was significantly increased while the summer, annual rainfall was decreased and these could continue moving until 2050 year. These phenomena might be related to the rising of atmospheric CO_2. The global CO_2 was correlated with temperature and rainfall at different significant levels. Annual temperature was increased as global CO_2 increased while rainfall was decreased. This increase of temperature and global cumulative CO_2 and decline of rainfall can affect agricultural production of the region. Therefore, to reduce the risks of climate change, soil and water management, short season seed supply and pipe irrigation practices should be improved.

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