Climate Variability Patterns and Farmers' Perceptions of Its Impact on Food Production: A Case Study of the Gelda Watershed in the Lake Tana Basin in Northwest Ethiopia

Author: Anteneh, Mesfin

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Mesfin Anteneh

Bahir Dar University, Ethiopia

ABSTRACT: This study looked at patterns of erratic climate and farmer perceptions in the Gelda watershed of Lake Tana Basin in northwestern Ethiopia. The National Meteorological Agency of Ethiopia provided essential climatic data for the period between 1981 and 2011. A household survey and focus group discussions were also used to understand about local communities' perceptions of climate variability and its impact on food production. Time series trend analysis of observed rainfall and temperature conditions was detected using linear regression analysis. To compare the means of climatic parameters and determine whether the average difference was significantly different from zero, the paired sampled *t*-test was used. The study found that the average annual temperature trend increased by 1.1°C, while the amount and distribution of annual and monthly rainfall decreased, varied across the catchment, and fluctuated during the study periods (1981–2011) at mean temperature rise with an average rate of 0.17°C in the last decade. The variability of annual and monthly rainfall in terms of intensity and distribution has decreased and varied across the watershed. The analysis revealed that annual rainfall variability was variable in the upper catchment (CV > 11.7%) and lower catchment (CV > 14.4%). The amount and intensity of temperature, on the other hand, increased throughout the study watershed, despite observed variation both spatially and temporally (stated decades). Farmers' understanding and expression of climate variability in terms of erratic rainfall distribution, decreasing amount, and increasing temperature over the last three decades, however, matched the observed data. Moreover, farmers are pointed out that high population pressure; deforestation and intensified agriculture are responsible factors for the variability of climate in the study watershed. Therefore, based on the findings, scientist and policymakers has to design appropriate adaptation measures that can tackle the aggravation of climate variability for future.

KEYWORDS: Climate, variability, spatial-temporal, perceptions, food production, agro-ecology, Ethiopia

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CORRESPONDING AUTHOR: Mesfin Anteneh, Department Geography and Environmental Studies, Bahir Dar University, Bahir Dar P.O. Box 79, Ethiopia. Email:mesfin74@yahoo.com

Background

Over 90% of agriculture in Ethiopia is almost entirely rainfed (Causapé, 2019). Given such a heavy dependency of Ethiopian agriculture on patterns of rainfall and temperature, climate variability and change has posed significant threats to food security and economy of the country. The threats from changing patterns of rainfall distribution and temperature variations lead to harvest failure or a significant decline in yield (Verdin et al., 2005). A delay or inadequate rainfall occurrence leads to higher probabilities of agricultural droughts that have historically affected millions of rural poor farmers and pastoralists; domestic and wild animals have also borne the brunt of environment and social crises and associated impacts from climate variability (Seleshi & Zanke, 2004). In this context, there is a need to have a clear understanding of the trends and changes in the rainfall and temperature patterns at national and local levels, both for better preparedness and policy making in food production sector.

Ethiopia's climate is changing, and various projections indicate that the rate of change will accelerate in the future. The average annual temperature has risen by 1.3°C at a rate of 0.28°C per decade (Environmental Protection Authority, 2011). The country will experience further warming in all seasons ranging from 0.7°C to 2.3°C by the 2020s and 1.4°C to 2.9°C by the 2050s (Conway, 2000a). Cereal production is expected to fall by 10% to 12% as a result of this, owing primarily to an increase in evapotranspiration, which causes moisture shortages (Ababa, 2007).

Several studies in Ethiopia have revealed various findings about the patterns and perceptions of climate variations at different spatial and temporal scales. In general, the volume and length of annual and seasonal rainfall in the country are decreasing (Asfaw et al., 2018; Conway, 2000a, 2000b; Gebrehiwot, 2013; Mekonen & Berlie, 2020; Meze-Hausken, 2004; Viste et al., 2013; Wagesho et al., 2013). However, some researchers have reported a non-significant trend in annual and seasonal rainfall amounts across the country (Teyso & Anjulo, 2016). (Meze-Hausken, 2004). Similarly, the amount and distribution of annual and seasonal rainfall over Ethiopia's highlands vary greatly over time (Bewket & Conway, 2007; McSweeney et al., 2010; Rosell & Holmer, 2007; Suryabhagavan, 2017; Teyso & Anjulo, 2016). Irrespective of these various findings, there is a general agreement among most of the researchers that rainfall variability is increasing in various parts of Ethiopia. Drought years, according to these studies, have resulted in low agricultural production, affecting millions of rural subsistence farmers and animals. It also has serious consequences for the country's food security and economy, as a result of low farm productivity and the effects on the rural environment and livelihoods (Wubie, 2015).

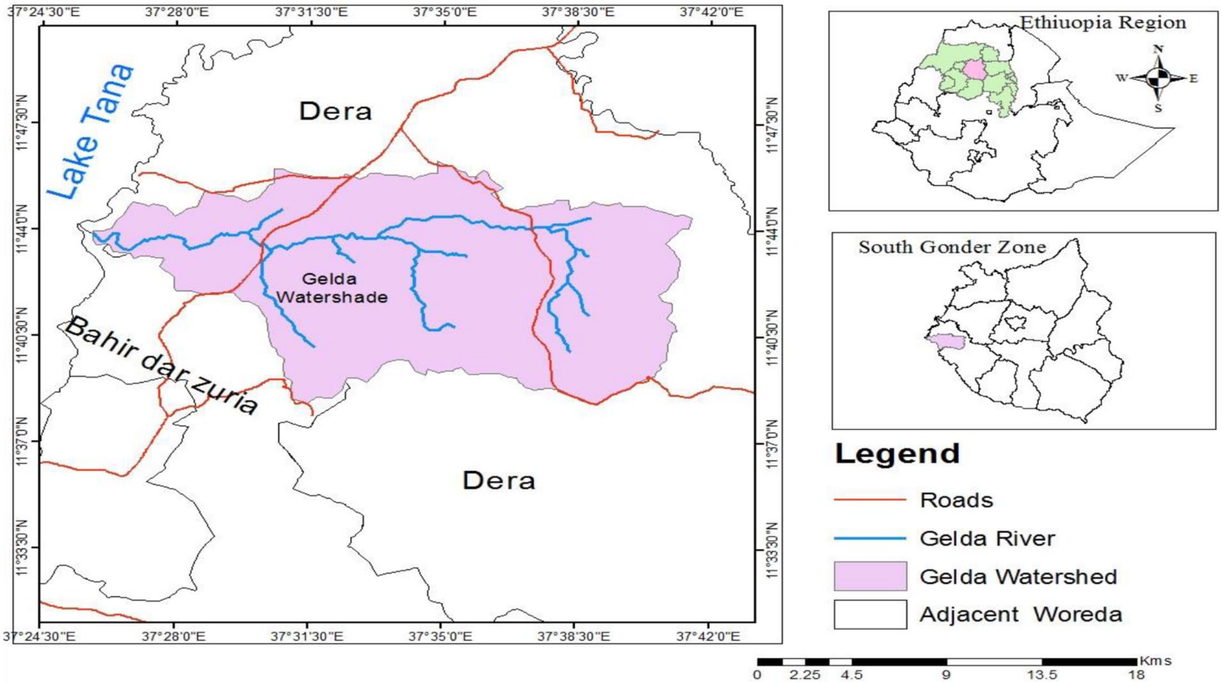

Figure 1. Map of the Gelda watershed.

However, annual or seasonal rainfall variations may not be the sole source of many environmental and agricultural issues (White, 2010). Excessive rainfall can also occur in non-drought years, affecting food production. While annual rainfall is normal in amount and distribution, environmental degradation can occur, for example, in the form of extreme wet and uneven rainfall distribution during the growing season (Verchot et al., 2007). In any of the crop growing season cycles, late onset, and/or dry spells typically cause stress on total biomass production, with economic and environmental consequences. Similarly, extreme wet events can significantly alter the normal distribution of rain during the growing season, as well as cause land degradation through increased run-off and soil loss. Droughts, on the other hand, may have an impact on agriculture and result in economic losses. They may also have long-term consequences for other land resources and ecosystem services, such as biodiversity loss, loss of land cover, degraded soil and biomass transfer, and disruption of hydrological and nutrient cycles. Clark et al. (2001) discovered that degradation of land surface in the form of loss of vegetation cover is a cause of persistent drought, with loss of vegetation cover having the greatest effect in areas where the moisture deficit is recurring. Erosive factor (R) values, on the other hand, increase with size.

Farmers' perceptions and reactions to existing climatic problems differ depending on the environment. As discussed in this paper, the mosaics of the case study agricultural landscapes have been shaped over time by a variety of factors, both non-climatic (land quality, socioeconomic conditions, and political contexts) and climatic (rainfall distribution and water resource availability). Agricultural practices, on the other hand, have evolved explicitly or implicitly in response to the risks associated with seasonal to multi-year climatic change. Weather pattern variability has a risky impact on agricultural production, reducing crop yields, and forcing farmers to implement new agricultural practices in response to changing conditions (FAO, 2003).

The purpose of this study is to look into the patterns of climate variability and change in the Gelda watershed over the course of 30 years (1981–2011), as well as farmers' perceptions, understanding, and coping strategies. As a result, the study combined scientific climate data with local perspectives to generate policy-relevant evidence for future adaptation strategies, primarily in the food production sector.

Materials and Methods

Study area description

The Gelda watershed is in northwestern Ethiopia, between latitudes 11°38′ and 11°46′ N and longitudes 37°25′ and 37°41′ E (Figure 1). The elevation ranges from 1,778 to 2,678 m above mean sea level (amsl). It has a total area of 26,131 hectares (ha) and is part of the Lake Tana basin, which is located in northwestern Ethiopia and serves as the source of the Blue Nile. The upper stream is represented by mountainous and hilly dissected terrains with steep slopes, whereas the lower stream is represented by rolling topography and gentle slopes. Several smaller streams drain the area, including Gelda (the watershed's largest stream), which flows into Lake Tana.

Much of the watershed's soils are classified as clay loam, sandy loam, and clayey to silt clayey. Clay loam soils are poorly drained soils found in the Fogera-Dera flood plains adjacent to Lake Tana, where the Geleda river terminates. The

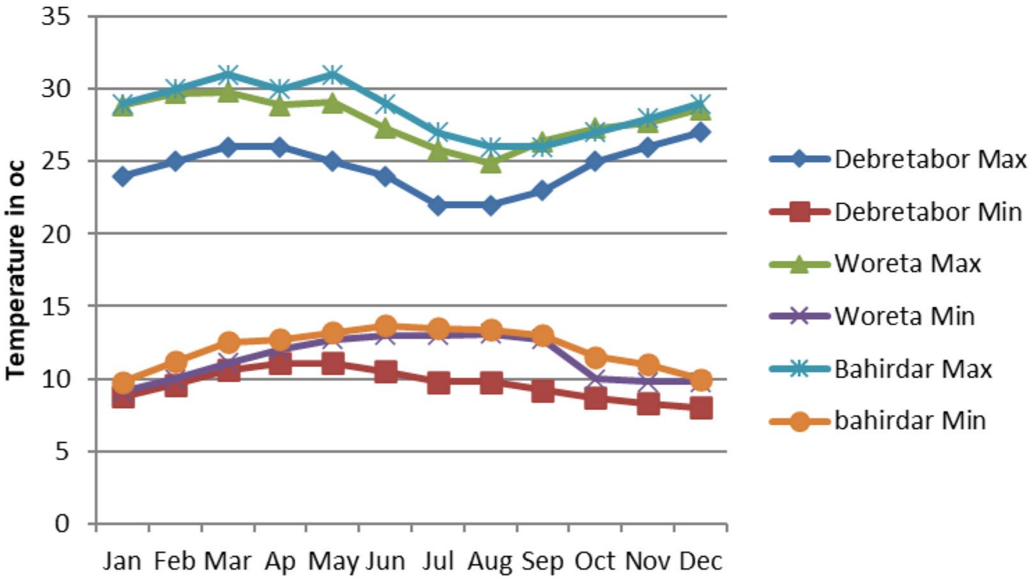

Figure 2. Monthly mean maximum and mean minimum temperatures of Gelda watershed.

well-drained sandy loam soils are shallow and eroded, and they cover steeper slopes. Clay to silt clay soils exist on nearly level to gently undulating land in the watershed's mid-stream and downstream areas.

The weather is typically humid. The average annual temperature is around 20.50°C, and the total annual rainfall is around 1,300 mm. More than 75% of total rainfall falls between June and September (known locally as kiremt season) (Figure 2). Different natural vegetation types can be found in the study area, corresponding to topographic variation. *Juniperous podocarpus* (locally known as Tid) and *Juniperous procera* (locally known as Zigba) are found at elevations of 3,000 m amsl, whereas *Dodonaera anguistifola* (locally known as Kitkita) and *Euclea Schimpera* (locally known as Dedeho) are found at elevations of 1,900 to 2,200 m amsl. *Syzgim guineense* (locally known as Doqima) and *Ficus sp.* (locally known as Warka) can also be found on gentler slopes and along. stream banks.

With an average farm size of about 1 ha, subsistence mixed (crop and animal) agriculture is the main source of income in the area (ha). Maize (*Zea mays L.*), teff (Ergarostis teff Zucc), rice (Oryza galberrima), and beans are the most commonly grown crops (Phaseolus vulgaris L.). Chickpea (Cicer arietinum), potato (Solanum tuberosum), onion (Allium cepa), cabbage (Brassia aleracea), and chili pepper are other minor crops (Capsicum spp.). Similarly, cash crops include garlic (Alliium sativum), Ethiopian mustard (Brassica carrinata), oats (Avena sativa), and carrot (Dancus carota sativus). Traditional domestic animals include cattle, goats, sheep, donkeys, chickens, and bees.

Analysis of climatic data

Temperature and rainfall data were used to determine patterns of climate variability and change, spatial and temporal variability, and the effects of climate variability on household livelihoods in the study catchment. The National Meteorological Agency of Ethiopia provided the data used to analyze climate variability and change (NMA). For the analysis of climate variability and change, 30 years of temperature and rainfall records (1981–2011) were used. To determine decadal variation and trends, the records were divided into three decades (1981–1990, 1991–2000, and 2001–2011). Three meteorological stations were used as a source of climate data, representing the catchment's various biophysical environments. Debre Tabor represented the upper part, Woreta represented the middle part, and Bahir represented the lower part and Bahir Dar as the lower part of the catchment.

As part of the study of climatic variability and change patterns, the rate of change in rainfall and temperature over annual, decadal, and seasonal cycles was evaluated. A coefficients of variation analysis for temperature and rainfall data was also included. The 10-year moving averages method and the linear regression method were used to detect long-term trends. Using linear time series analysis, the nature of the phenomena reflected by the order of observation was determined.

Linear regression used to recognize time series trend analysis of rainfall and temperature was calculated as: $(Y) = a + bx$

Slope (b) was calculated by $(N\sum XY - (\sum X)(\sum Y)) / (N\sum X^2) - (\sum X)^2$ and intercept $(a) = (\sum Y) - b(\sum X)) / N$

where X and Y are the variables of respective data and time

(b) is the slope of the regression line, which indicates the status of the fit that is increasing, decreasing or no change, and

(a) is the intercept of the regression line and the Y axis and N is number of values or elements.

The paired sampled *t*-test was used to compare the mean of two variables, compute the difference between two variables for each case, and to test if the average difference was significantly different from zero. Paired sampled *t*-test was used in "before/after" studies or when the samples were the matched pairs, or the case was the control study. The test is given by

Table 1. Mean Annual, Maximum, Minimum, Correlation, and *p* Value of Temperature in Gelda Watershed Stations.

STATIONS	MEAN	CV%	MAX	MIN	SLOPES	CORRELATION COEFFICIENT	*P* VALUE
Debre Tabor	16.2	2.15	16.6	15	0.0725	.634	.000
Woreta	17.1	4.34	19.8	15.8	0.0047	.057	.581
Bahir Dar	19.5	3.25	20.1	17.5	0.0026	.231	.070
Average	17.6	9.74	19.3	16.1	0.0266	.318	.070

$$t = \frac{\bar{d}}{\sqrt{\frac{S^2}{n}}}$$

Where d bar is the mean difference between two samples,
S^2 is the sample variance
n is the sample size, and
t is paired sample t-test with $n-1$ degree of freedom

In order to validate the information obtained from the climatic data, a socio-economic survey of households have been conducted between July and September 2015. The purpose of the survey was to obtain data that would support in explaining the socio-economic and demographic circumstances of rural households and communities as well as the cause and consequences of climate change and spatial variability. For this, questionnaire was administered to 120 selected households that is, Forty households from the three elevation classes: lower (1,784–1,999 m amsl) as represented by Bahir Dar station, middle (2,000–2,499 m amsl) as represented by Woreta, and upper (2,500–2,678 m amsl) as represented by Debre Tabor meteorology stations. The data obtained from the household survey was analyzed using descriptive statistics specifically by taking the mean value of the percentage of respondents in each watershed category. Moreover, three separate focus group discussions were conducted with a group of farmers that constituted four elderly people with the age of 65 and 71, four young women and four men with the age between 23 and 25. An interview was also held with the key informants selected among the experts and elders of the village who had passable knowledge about the study area.

Results and Discussion

Spatio-temporal variability of temperature

Debre Tabor (110 51′N to 380 10′E), located in the upper catchment, has a mean annual temperature of 16.2°C and a low variability (.0725) when compared to other stations (Table 1). Bahir Dar (110 36′N–370 23′E), in the lower catchment with a mean annual temperature of 19.5°C, has comparatively higher (.0026) variability trends. Debre Tabor (.634) had a significant (p .05) positive correlation between altitude and temperature, whereas other stations had non-significant low positive correlation values (Table 1). This implies that the mean annual temperature in the upper part of the catchment was lower and less variable than in the other two low altitude positioned meteorology stations. This implies that, in Ethiopian conditions, variations in the mean annual temperature were directly related to variation in altitude. Figure 2 depicts the seasonal temperature variations at the three stations. The seasonal extent of temperature variations differed. The monthly means of maximum and minimum temperatures varied between stations within a narrow range, which is typical of tropical climatic conditions.

Table 2. Decadal Mean Annual, Maximum, Minimum, and Variance of Temperature in Gelda Watershed.

PARAMETERS	DECADAL PERIODS		
	1981–1990	1991–2000	2001–2011
Mean	17.8	17.5	18.9
CV%	5.4	2.6	3.0
Max	18.9	18.5	19
Min	16.6	16.5	17
Slope	−0.0117	0.0291	0.1493
Correlation coefficient	.529	.045	.318
p Value	.116	.838	.5836

Table 2 shows that the decadal mean, maximum, and minimum temperatures, and coefficients of variation increased in the first decade, decreased in the second, and increased again in the third. The annual mean temperature decreased by 0.3°C from the first to the second decade (1981–1990) but increased by 0.4°C from the second to the last decade (2001–2011). Thus, variability in temperature conditions was observed in the Gelda catchment over the specified decades. Temperature fell during the first 10 years of the study period, according to logistic regression analysis. From 1981 to 1990, the slope indicated that the temperature was negative and low. The temperature began to rise during this decade, from 1991 to 2000 by 0.0291 and by 0.1493 from 2001 to 2011 (Table 2). Within the second and third periods, there was an annual increase of 0.1049°C. This indicates that the temperature in the catchment has continued to rise over the last 20 years of the study period. Supporting this result (Keller, 2009), Keller (2009) previously

Table 3. Mean Annual Rainfall in the Gelda Watershed.

STATIONS	MEAN	CV%	MAX	MIN	SLOPE	CORRELATION COEFFICIENT	*P* VALUE
Debre Tabor	2,244.1	11.73	2,532.1	1,675	24.6	.457	.004
Woreta	1,594.5	15.62	1,894.4	823.5	9.3	.261	.005
Bahir Dar	1,475.4	14.41	1,744.7	804.2	3.6	.337	.003
Average	1,771.3	11.74	2,057.6	1,100.6	10.2	.379	.000

reported that temperature patterns in Ethiopia showed an increasing trend, but the rise has been more pronounced since 2000 (Assessment et al., 2009), with projected temperature increases of 1°C to 3°C between 2,040 and 2,069 for the Ethiopian highlands. In general, there was a rise in temperature in the study catchment from year to year as well as decade to decade, though it was not statistically significant.

Spatial and temporal variability of rainfall

The catchment's average annual rainfall was 1,771.3 mm, with an annual minimum of 1,100.6 mm and an annual maximum of 2,057.6 mm (Table 3). This demonstrates that the amount of rainfall within the catchment was changing, with a variation pattern of 11.7% for the entire catchment. The linear trend value was 10.2, indicating the presence of positive rainfall in the catchment. The assumption was significant at p .05, and the relationship between rainfall and recorded year was described as weak, with both patterns of increase and decrease in rainfall. This shows the variation in rainfall amount over the last 30-year study period (1981–2011) in the catchment.

In comparison to the other two stations, the upper station (Debra Tabor) had a higher mean annual maximum and mean minimum amount of rainfall. Debra Tabor's mean annual rainfall was 2,244.1 mm, and its slope (24.6%) was the highest and most positive. This indicates that the upper part of the catchment received more rainfall than the middle and lower parts, while the variation in the amount of rainfall detected in the recorded years is very small. Woreta (9.3%) and Bahir Dar (3.6%) had positive slopes for both parts of the catchment. The coefficient of variation was lower for stations with higher annual rainfall amounts than for stations with lower annual rainfall amounts. This demonstrates that the annual variability of rainfall was linked to the amount of rainfall received by the stations, which is affected by the altitude of the respective stations. In general, as opposed to temperature variations, the amount of annual rainfall decreased as one moved from north to south as elevation decreased. The amount and distribution of rainfall in the study catchment varied seasonally. However, there was variation in the number of rainy months (see Figure 3), with summer (Kiremt in local language) being the main rainy season in the catchment, lasting from June to August and/or September.

Table 4 depicts decadal rainfall trends from 1981 to 2011. Annual mean rainfall increased from 1,598.7 mm in 1981 to 1990 to 1,741.3 mm in 1991 to 2000, but then fell to 1,627.1 mm (2001–2011). This demonstrates that the mean annual rainfall varied continuously over the specified decades. During the respective decades, the coefficient of variation increased from 6.5% to 8.7% and then to 9.8%. Thus, rainfall variability was evident within decadal periods. However, the linear regression value indicated a decadal decline in rainfall amount. It was 3.4 in the first decade (1981–1990), then −10.4 and −11.8 in the second and third decades, respectively. The relationship between rainfall amount and decadal time, on the other hand, was weak in the first period, negative but relatively good in the second, and very weak positive in the last decade. As a result, rainfall amounts in the Gelda watershed showed both variability and declining trends over decadal time periods. These findings are consistent with previous research. Dereje et al. (2012), for example, observed that total rainfall in Ethiopia's north-central highlands (where the study area is located) strangely decreased in the second half of the 20th century. Similarly, Osman and Sauerborn (2002) found that rainfall in Ethiopia's central highlands was decreasing, accompanied by high temperatures.

Farmers' perceptions of climate variability

Farmers in the study area understand and express climate variability in terms of erratic rainfall distribution, decreasing amount, and increasing temperature over the three decades studied, according to the results of our household survey. Almost 88% of respondents believed that the temperature had risen over the 30-year study period, while only 4% disagreed. Other responses were provided by 8% of respondents (Figure 4). In terms of rainfall patterns, the majority of respondents (80%) reported a decreasing trend, 10% reported an increasing trend, and 7% reported no changes in the amount of rainfall in the catchment (Figure 4). According to the findings, farmers in the study area are well aware of climate variability and change, with the majority (88%) noticing an increase in temperature and a decrease in rainfall amount. Similarly, to our findings, in other parts of Africa, such as Senegal, the majority of respondents were found to be well aware of long-term changes in temperature and rainfall. The outcomes obtained in the study

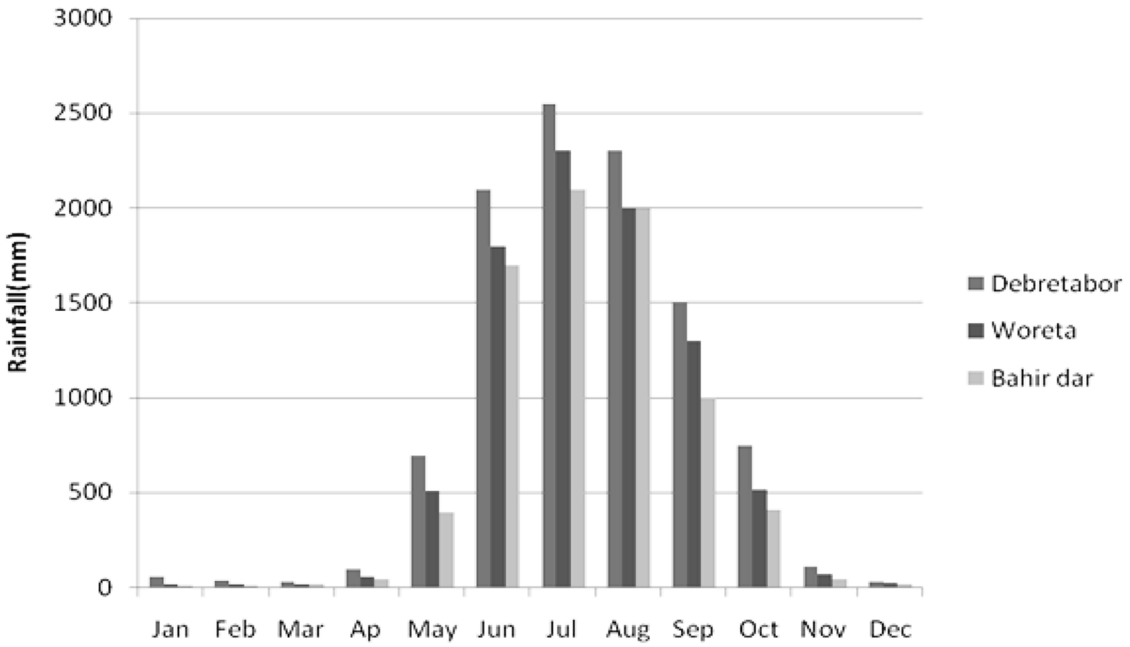

Figure 3. Mean monthly rainfall amounts at the three meteorological stations of Gelda watershed.

Table 4. Rainfall Trends in Different Decades of Gelda Watershed.

PARAMETERS	STUDY DECADES		
	1981–1990	1991–2000	2001–2011
Mean	1,598.7	1,741.3	1,627.1
CV%	6.15	8.7	9.87
Max	1,761.4	1,964.6	2,014.5
Min	1,440.1	1,482.3	1,620.2
Slope	3.415	–10.462	–11.842
Correlation coefficient	.207	–.497	.043
p Value	.000	.000	.001

catchment are also consistent with climate trends reported in the Ethiopia's First National Communications to the United Nations Framework Convention on Climate Change. According to Mertz et al. (2009), climate change in Ethiopia is plainly observed in temperature variation, with an increasing trend in time of about 0.37°C per decade.

Farmers also reported that the rainy season used to begin in May, but that it has now shifted to mid-June or the beginning of July. During the focus group discussions, farmers in all areas of the catchment revealed that in the past, they had received a large amount of rainfall in late November, signaling the start of the catchment's small rainy season.

Local farmers have also expressed concern about the unpredictability of the seasons. According to them, the beginning and end of the rainy season are becoming highly variable and completely different from what they used to be over the last 20 or so years. Participants in the focus group discussions also stated that the rainy seasons end as early as September. According to a farmer in his late 60s:

> The onset and termination of rainfall are becoming erratic. When I was younger, the main rainy season began in early May, but now it begins in the middle of June and even in July and ends in mid-September, which is confusing farmers, and as a result, the amount of produce from a plot of land has also declined from time to time, affecting our livelihoods.

Farmers also reported that the main rainy season, which used to last 4 months in the last 20 years or so, has now been reduced to 2 months, primarily in July and August. Rainfall distribution has become uneven and erratic, making it unsuitable for long maturing crops such as maize, barely, finger millet, Niger seed, and potato. As a result, in the past, people could have seen their farmland covered with fully sprouted crops until mid-July and well vegetated crops until August 22 (Teka et al., 2012). However, the rains that normally began in mid-June shifted to July and ended much earlier (mid-September) in a way that had never been seen before. Participants in the focus groups explained that in the past, rainfall distribution over the season was normal and they could manage to plan their agricultural activities (eg, sowing, planting, harvesting) properly and effectively, knowing when to expect significant dry and wet spells.

Participants in the focus group discussions also noted that farmers were now confronted with increasing spatial rainfall variation, with some areas receiving evenly distributed rainfall while neighboring areas received inconsistent rainfall. This variation affects the planting season of some crops and even the amount of crop production. Thus, changes in rainfall

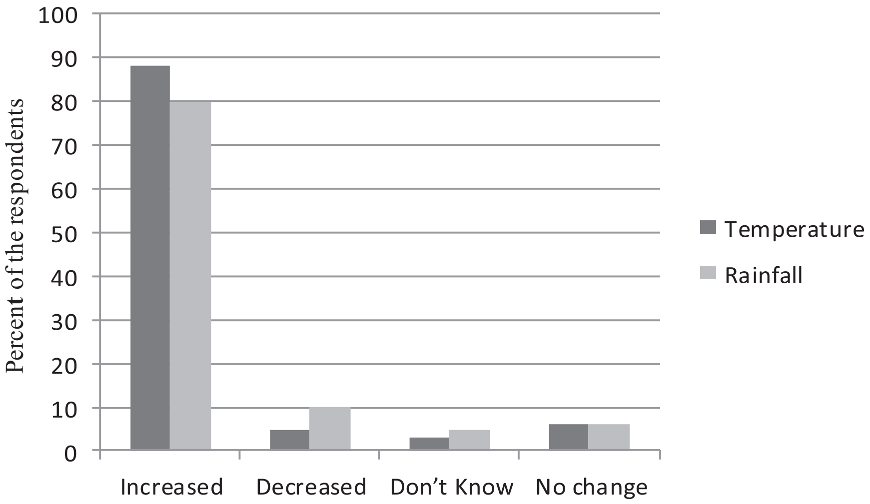

Figure 4. Farmers' perceptions on changes of amount of temperature and rainfall in the Gelda catchment.

Table 5. Causes of Climate Variability as Perceived by Farmers (Percentage).

FACTORS	UPPER CATCHMENT (RESPONDENTS IN %)	MIDDLE CATCHMENT (RESPONDENTS IN %)	LOWER CATCHMENT (RESPONDENTS IN %)	AVERAGE (RESPONDENTS IN %)
Deforestation	85	90	94	89.6
Intensified agriculture	78	80	76	78
Population pressure	90	92	95	92.3
Soil degradation and erosion	22	30	45	32.3
Use of chemical fertilizer	20	31	15	22

pattern and intensity result in changes in planting season, increased risk of crop failure, stunted growth, and crop desiccation (Lema & Majule, 2009). Farmers in the study catchment have begun replacing long maturing crops with short maturing crops, as observed during our field research, in order to cope with the risk associated with the failure of rainfall distribution.

Farmers' perceptions of causes of climate variability

The household survey data revealed that farmers' perceptions of the causes of climate variability differed. According to Table 5, 89.6% of respondents named deforestation as a contributing cause of climate variability, while 78% blamed intensified agriculture for climate variability in their communities. On the other hand, approximately 92.3% of respondents cited population pressure as the primary cause of climate variability. About 32.3% of respondents cited soil degradation and erosion as causes of climate variability. Climate variability is caused by changes in land use patterns in extended agriculture, as well as deforestation, soil degradation, and erosion (Shah & Ameta, 2008). This implies that agro-ecosystems have deteriorated dramatically in many parts of the study area in recent decades. Deforestation, soil degradation, and erosion release large amounts of carbon dioxide into the atmosphere, which is exacerbated by the introduction and use of chemical fertilizers. A focus group discussion participant in the watershed's middle catchment perceived and explained the causes of climate variability as follows:

> The increment of temperature and decline of rainfall amount here is mainly related to deforestation, which results from over cultivation and excessive pressure on natural resources. In the remote past, the banks of rivers and the hills in our surrounding were covered by thick forests. At that time, there was normal beginning and ending of the rainy season, the temperature was not as hot as today. As a result of a combination of factors such as the increasing population, degradation of farmlands and soil erosion from hills, unpredictable rainfall pattern and different natural hazards such as plant diseases and frost have become common. The temperature has increased, and the rate of change has become substantial. At the same time, the amount of rainfall has decreased, and rainfall usually starts late and ends early.

Effects of climate variability

Households in the study catchment expressed their views on the effects of climate variability, which were primarily related to farming activities. Changes in cropping pattern and cropping season calendar, declining volume and drying up of

Table 6. Perceptions of Households Sampled on Impacts of Climate Variability by Percentage.

PERCEIVED IMPACTS	UPPER CATCHMENT (RESPONDENTS IN %)	MIDDLE CATCHMENT (RESPONDENTS IN %)	LOWER CATCHMENT (RESPONDENTS IN %)	AVERAGE (RESPONDENTS IN %)
Change in cropping pattern and calendar	91	78	87	85.3
Declining volume and drying up of streams and rivers	65	88	94	82.3
Shortage of grass for animal grazing	70	87	92	83
Drying up of wetlands	68	74	91	77.6
Reduction of crop productivity	77	82	89	82.6
Forced to abandon the irrigated land	45	61	82	62.5

surface water, shortage of grass, drying up of wetlands, and the consequent impacts on crop produce and feed for animals, as shown in Table 6, were the main indicators of the effect of climate variability as perceived by households.

Climate variability affects the hydrological aspects of catchments, causing changes in water resource availability and the environment on a local level. Climate variability, such as decreased rainfall and rising temperatures, may reduce the rate of infiltration and filtration of rainwater into streams, springs, and ground water. The volume of locally available streams and rivers, as well as their flowing patterns, have decreased over time, according to information obtained from household responses (82.3%) and confirmed by focus group discussions. In the upper Nile Basin, rising temperatures and decreasing rainfall have resulted in severe water scarcity; streams and rivers that flowed all year have become seasonal (Konare et al., 2010).

Farmers in the study watershed reported that rainfall patterns had shown variability in both time and amount, which had a significant impact on cropping patterns and calendar, as well as stream seasonal patterns (Table 6). As a result, the available surface water volume has decreased, wetland has dried up and been converted to farmland, and many springs and streams have dried up. As a result, climate variability has impacted the availability of water resources, both for household use and agriculture (eg, irrigation and animal rearing). As a result, during the dry season, farmers and livestock must travel long distances, on average for 2 hours per day, to obtain water and even pasture for their cattle. A 65-year-old participant in a focus group discussion stated the situation in this way:

> Unlike in the 1970s when we grazed our livestock in our nearby village, now we are forced to move our livestock to the mountains and hilly areas for about 4 to 5 km to search for pasture and water. In the old days, animals used to be grazed anywhere without any problem, but now we are forced to buy straw and other crop residues as animal feed to compensate for shortage of grass.

They are also forced to dig and prepare open water wells in their backyard gardens (Figure 5) and use them for domestic purposes such as cooking, washing, and drinking, making the people in the study area vulnerable to water-borne diseases (due to increased use of unsafe water for household purposes) (Figure 6). Farmers are being forced to abandon their lands used for growing supplementary food crops and vegetables due to declining water volume and drying up of nearby streams.

Furthermore, variations in temperature and rainfall in the study catchment affect cropping patterns and agricultural activities in the local community. Taking crop moisture requirements and growing cycle length into account, two cropping periods were observed in the Gelda watershed: short and long growing crops. Crops that are prioritized for an extended rainfall condition are usually long maturing crops because they are expected to provide more biomass than short growing crops. Furthermore, long-growing crops have special qualities during times of intermittent and erratic rain because they can use all of the moisture available throughout the growing season. Except for the very fine cereal crop known as teff, other crops such as peas, beans, and chickpeas were typically grown to combat soil fertility issues and to cope with rainfall uncertainties. Farmers in the study catchment also use local and indigenous knowledge, and they replace crops grown previously when there are indications of better rains ahead and the previous crops do not appear to be promising. However, local farmers cannot afford the additional costs for inputs such as drought-resistant seeds and chemical fertilizers to deal with rainfall uncertainty and soil fertility issues.

Despite the stability of inter-annual rainfall, there were uncertainties in the monthly distribution of rainfall required for the growing season. Rainfall uncertainties may complicate cropping patterns in areas where moisture deficit is a serious problem, particularly in the catchment's lower reaches. Even the most preferred long maturing crops have frequently failed in these areas due to moisture deficits occurring during critical moisture requirement periods. Farmers in all parts of the Gelda watershed, in both high and low rainfall areas, have reported a high frequency of uneven

Figure 5. Residents digging wells in search of water in the Gelda watershed.

Figure 6. A woman fetching unclean water from pond in the Gelda watershed.

rainfall during the crop growing season, such as late onset, early cessation, and dry spells in between (Figure 7). As a result of the current spatial and temporal stratification of crop species and farming systems, various measures taken by farmers to mitigate the risk of moisture and other production constraints should not be overlooked. Crops have several critical phonological stages that necessitate different timing of the growing factors (moisture, nutrients, temperature, etc.). Furthermore, uncertainties in the availability of adequate crop moisture requirements at a critical time make traditional rainfed agriculture vulnerable and unpredictable.

Farmers, according to the focus group participants, usually expect extended rain at the start of a late onset. They also stated that the issue of early cessation and the occurrence of dry spells during the cropping season were the two most impactful events for farmers, rather than the late onset of rains. However, when two or more of the constraints occur within one growing season, such as late onset with extended dry spells or late onset with early cessation, or when all three occur in one growing season, the situation becomes unmanageable.

The other major variable that can cause crop failure is an early cessation of rain. In fact, it is dependent on how early the rain stops in relation to the growing stages of the crops in the season. If the rains fall into either of the aforementioned variability types (Figure 7), farmers can expect torrential or stormy rains, causing crop and soil damage. The likelihood of dry and wet events (Figure 7) in the study catchment suggests that farmers may also experience torrential rains at the start of the rainy season, with rains exceeding the required amount.

Conclusion

The purpose of this study was to examine patterns of climate variability as well as farmers' perceptions and understanding of it in the Geleda watershed of the Lake Tana Basin in northwestern Ethiopia. Climate data from 1981 to 2011 were used for this purpose. Additional data from a household survey, focus group discussions, and key informant interviews were then used to better understand local communities' perceptions of climate variability and change. Furthermore, the causes and effects of climate variability are evaluated by taking into account the perceptions and experiences of local farmers in the study watershed.

According to the analysis, the average annual rainfall for the entire watershed was 1,771.3 mm, with an annual minimum of 1,100.6 mm and an annual maximum of 2,057.6 mm. The three studied meteorological stations revealed an uneven pattern of spatiotemporal variation in rainfall and temperature conditions in the study watershed. These changes were discovered to occur on seasonal, annual, and decadal time scales. The study also revealed that elevation affected the amount of annual mean maximum and minimum rainfall, with high amounts recorded in the upper parts of the catchment (ie, Debra Tabor). Furthermore, mean annual temperature and rainfall amount were less variable in the upper part of the catchment than in the lower part.

Farmers recognized the observed temperature and rainfall variations, as confirmed by field surveys and focus group discussions. They perceived climate variability and change as an increase in temperature, a decrease in rainfall amount, and seasonal and annual fluctuations. Farmers' perceptions of climate variability revealed the existence of similar patterns of change with observed rainfall and temperature data. Farmers positively associated climate variability with increased occurrences of plant diseases, low crop production, water shortages for agriculture, home and animal uses, and reduced feed resources. They also discovered that high population pressure, which causes deforestation and intensified agriculture, was one of the factors responsible for the observed climate variability and change in the study catchment.

According to the study, farmers in the study watershed are becoming more aware of the causes, trends, and effects of climate variability and change. During the study period, they were subjected to the negative effects of climate variability, which had an impact on their lives and livelihoods. Among the major effects of climate variability and change in the watershed, according to results from the sampled households, are changes in cropping pattern and calendar, a lack of grass for animal grazing, a decrease

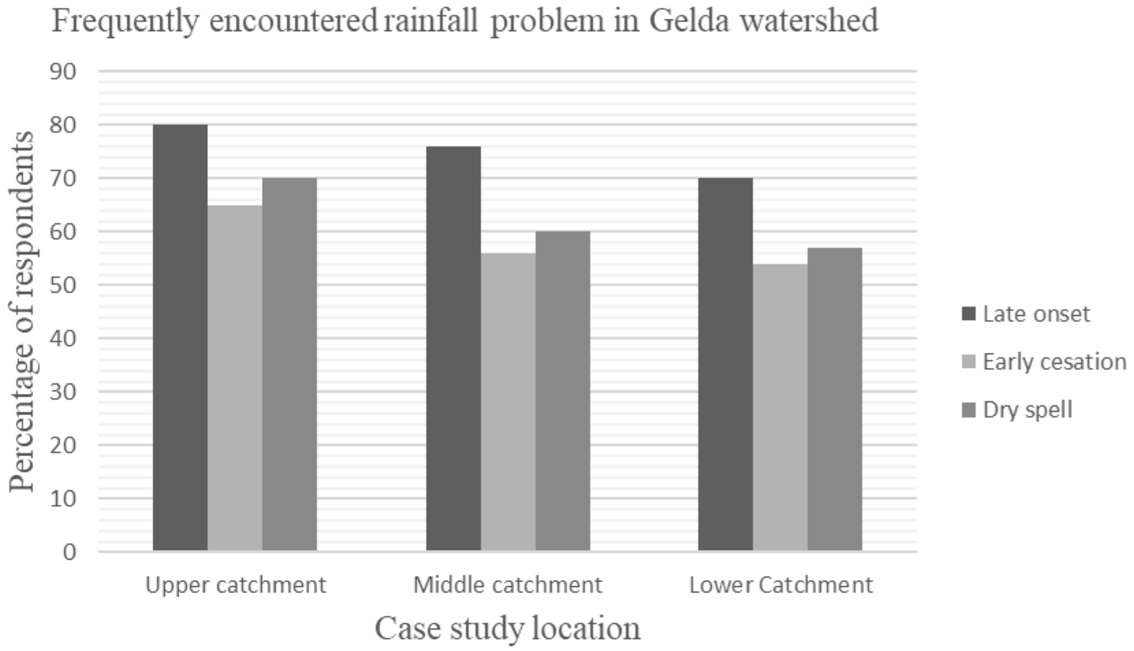

Figure 7. Assessment of the recurrent rainfall problem based on the percentage of respondents.

in crop productivity, a decrease in volume, and the drying up of streams and rivers. Furthermore, the study found that farmers' perceptions of climate variability reflect meteorological analysis to a greater extent, despite being based on local climatic experiences. Based on these findings, we recommend that scientists and policymakers collaborate to co-design appropriate adaptation measures with input from local communities in order to effectively respond to future increases in climate variability and change, particularly in terms of addressing community food security and livelihood challenges.

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Author Contributions

The Author designed the study, Collected, analyzed and interpreted the data and wrote the manuscript.

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ORCID iD

Mesfin Anteneh https://orcid.org/0000-0003-1657-7413

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