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Research Article

Farmers' Perceptions of Climate Change Trends and Adaptation Strategies in Semiarid Highlands of Eastern Tigray, Northern Ethiopia

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This study examined smallholder farmers' perception about climate change and variability compared with the observed metrological data and their adaptation strategies in response to the perceived impacts of climate change. The multistage sampling method was employed to select 358 rural farmers in Hawzen and Irob districts located in semiarid highlands of Eastern Tigray, northern Ethiopia. Moreover, areal gridded surface monthly rainfall and temperature data between 1983 and 2015 were collected from National Meteorology Agency of Ethiopia. The results revealed that about 98.56 and 92 percent of farmers perceived a decrease in annual rainfall. In addition, 87 and 90 percent of farmers noticed that temperature was increased in Hawzen and Irob districts, respectively. Harmoniously, the modified Mann–Kendall trend test confirmed that annual rainfall was decreased by 32.38 mm and 121.33 mm during the period of analysis. Furthermore, mean annual temperature increased statistically significant ($p < 0.001$) by about 0.40°C and 0.39°C per decade during the period of analysis cognate with the farmers' perception. To reduce the perceived impacts of climate change, farmers adopted various farm-level adaptation strategies that vary significantly between the two groups. Soil and water conservation, planting trees, crop varieties, changing crop calendar, biological conservation, and irrigation were among the dominant adaptation strategies, respectively, in the study area. The results of this study provide baseline information for local governments, subsequent researchers, and policy-makers in terms of farmers' perception of climate change and adaptation strategies.

1. Introduction

An increase in intensity and frequency of extreme weather events and climate variability have raised broad concerns over global climatic changes since they affected human livelihood activities and strategies [1, 2]. Rainfall and temperature are the most indispensable hydrology climatic variables often used for characterization of climate change and variability [3]. Rainfall variability and other climatic risks account for a significant share of agricultural production decline in developing countries [4, 5]. The global mean surface temperature (GMST) increased by 0.89°C during 1901–2012 because of human action greenhouse gas concentrations [6]. As a result, globally, the average temperature will warm between 1.48°C and 5.88°C by 2100 that leads to frequent extreme weather events and risks [7].

In sub-Saharan Africa, warming temperature is expected to be higher than the global average temperature, and in some parts of the region, rainfall will decline [8]. The overall summer rainfall had an increasing trend during 1901–1955 but a decreasing trend since the 1950s [9]. Farm households in rural Ethiopia primarily depend on low-productivity rainfed agriculture that determines the socioeconomic challenges including food insecurity [10]. Ethiopia's GDP growth is strongly correlated with rainfall and negatively affected by rainfall variability [11, 12].

Several studies have been conducted to investigate the spatiotemporal variability of rainfall and temperature in Ethiopia [13–17], among others. However, their results were inconclusive because of the difference in time and unit of analysis in addition to being carried out at regional, basin, and national levels. Ahmad et al. [18] suggested that, for efficient and effective decision-making, climate variable trend analysis on low-scale time-series data is more preferential. The spatio-temporal variation in temperature and rainfall existing around the globe confounds generalities over large areas because nonuniformity is expected to occur [19]. Moreover, none of the above empirical studies in Ethiopia incorporated local people's perception because actual climatic trends are often not equally perceived among small-scale farmers [20]. Ayal and Leal Filho [21] confirmed farmers' perceptions of changes in temperature were similar with meteorological station data but different with meteorological rainfall trends in Ethiopia. Similarly, Limantol et al. [22] reported that farmers' perceptions of increased temperature coincided with climatic data, but their perception of decreased rainfall did not corroborate with rainfall climatic data in Ghana. Contrary to these studies, Moroda et al. [23] revealed that the majority of respondents' perceived changes in temperature and rainfall tally with meteorological data in East Shewa, Ethiopia. Hence, climate change system modeling and impacts may coincide with the perception of farmers in some cases but not in others. But the link between the two is helpful for climate change adaptation by influencing farmers' risk perception behaviors [24]. Tripathi and Mishra [25] identified although farmers are aware of temperature and rainfall change, they fail to recognize these changes as climate change. Farm households distinctly perceive the same stimulus depending on their past personal experiences and cultural differences [26, 27]. Local people's perception of rainfall behavior is an idiosyncratic manifestation of their experience and various environmental aspects [28].

Little is known about farmers' climate perceptions and their effects on adaptation decision as a result of climate information facility although farmers' perception of climate change impacts is a prerequisite for the adaptation strategy [25, 29]. Recently, the integration of local farmers' climate change awareness with nearby weather monitoring stations or meteorology data has received broad attention to improve farmers' adaptation strategies [30]. Therefore, the objective of this study is to examine rural farmers' perceptions of climate change and variability as compared with the observed metrological data of rainfall and temperature. Besides, it assesses the adaptation strategies in response to the perceived impacts of climate change in Hawzen and Irob districts located in semiarid eastern highlands of Tigray, northern Ethiopia.

2. Materials and Methods

2.1. Selection of the Study Area. The study area located in Eastern Tigray National Regional State, northern Ethiopia, is a semiarid climate zone characterized by a heavy rainy season (June to August), a small rainy season (March to May), and a major dry season (October to March) [31, 32]. The eastern highlands receive an average annual rainfall of 520–680°mm, and the average annual temperature ranges between 16°C and 20°C with diurnal variations being larger than seasonal changes [33]. This study involves Hawzen and Irob districts (*woredas* in Amharic), a local administrative unit above village (*kebele* in Amharic), the smallest administrative unit. Geographically, the districts are found between latitude 13°78′ and 14°18′N and longitude 39°18′ and 39°58′E and latitude 14°35′ and 14°58′N and longitude 39°50′ and 40°26′E, respectively. According to population estimation [34], the total population of Hawzen and Irob districts in 2018 was 127,265 (52.4 percent females) and 33,912 (50.77 percent females), respectively. Out of them, 93 and 95 percent live in rural areas mainly dependent on a subsistence mixed agriculture livelihood system. The main crops grown in the rainy season are barley (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*), maize (*Zea mays*), and teff (*Eragrostis tef*). The total area estimated was about 1,892.69 km^2 and 850 km^2 for Hawzen and Irob, respectively, characterized by rugged mountains, hills, high plateaus, and deep valley bottoms. The average elevation of the study districts ranges from 2000 m in Irob to 2243 m.a.s.l. in Hawzen, respectively.

Of the Hawzen district climatically, 60 percent belongs to midlands (*woinadega*, 1500–2500 m.a.s.l.), 35 percent lowlands (*kolla*, 500–1500 m.a.s.l.), and 5 percent highlands (*dega*, 2500–3500 m a.s.l.) according to the country's traditional agroecological zones, respectively. Likewise, Irob accounts for 75 percent midland, 15 percent highland, and 10 percent lowland agroecological zones. Rainfall is marked by a weakly bimodal pattern, with small showers of rain during the months of March to May with a long rainy season in summer during the months of June to August. Irob and Hawzen received the mean annual rainfall ranging from 470 to 613 mm during 1983–2015, respectively, with erratic, highly spatial, and temporal variations. The mean annual temperature varies from 19°C in Hawzen to 20°C for Irob with diurnal variations being larger than seasonal changes. According to information from the Finance and Planning Office, both districts are identified among the most vulnerable areas exposed to chronic food insecurity, adverse extreme climate events, severe land degradation, and declining soil fertility. Specifically, during the *El Niño*-induced drought conditions in 2016, about 40 percent of the total population of the Hawzen district were exposed to chronic food insecurity. Likewise, about 74 percent of the total population of Irob were beneficiaries of the Productive Safety Net Program in the same year.

2.2. Sampling and Data Collection. In this study, a multistage sampling method was employed to select rural farm households. In the first stage, Hawzen and Irob districts were selected using the purposive sampling method since both districts represent the semiarid eastern highlands of Tigray that involve diverse ecological zones, socioeconomic conditions, and occurrences of frequent extreme weather events. In the second stage, using the stratified sampling method, two *kebeles* were selected from each district considering the available similarities. In this study, the sampled Selam Kebele and Alitena Kebele fall under midlands, while Degamba Kebele and Hareze-Sebata Kebele were categorized under highland agroecological zones. In Hawzen, 1856 and 1395 household heads in Selam and Degamba, were found, respectively, while in Irob, 1607 and 355 household heads in Alitena and Hareze-Sebata were found, respectively, in 2016. Finally, using the simple random sampling method, 208 and 150 households were selected from Hawzen and Irob districts proportional to the total number of farm household heads. Hence, a total of 358 rural household heads were enumerated from the study area.

In addition, a structured questionnaire was designed, pretested, and administered at the household level to obtain the primary data. The survey was conducted between January and February 2018, administered by trained enumerators who speak the local language, and supervised by local agricultural extension agents in the study districts. Moreover, to compare farmers' perceptions of climate change with the actual meteorological data monthly maximum, minimum temperatures and monthly total rainfall data were collected. The data are based on areal gridded data (4 km by 4 km) spatial resolution over the period between 1983 and 2014. The gridded dataset merging two datasets includes station gauge data (rainfall and temperature) from National Meteorology Agency of Ethiopia and satellite rainfall and temperature estimates from European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) and the US National Aeronautics and Space Administration (NASA). Finally, the satellite temperature and rainfall estimates were combined with station gauge data by National Meteorological Services Agency together with its international partners.

The total sample size from each kebele was computed using the following standard formula:

$$n = \frac{N}{1} + N(e)^2, \quad (1)$$

where N = total population of the sample kebele, n = sample size to be computed, and e^2 = acceptable error (level of precision), which is assigned a value of 5 percent (0.05).

Then, the sample size distributed to each kebele proportional to the total household size is calculated using the following formula:

$$n_i = n * \frac{N_i}{\sum N_i}, \quad (2)$$

where n_i = sample size of the i^{th} kebele to be computed, n = sample size of the i^{th} kebele, and N_i = total household heads of the i^{th} kebele.

2.3. Trend Analysis Methods. Tests for the detection of significant trends in climatologic time series are grouped as parametric and nonparametric methods [35]. Coefficient of variation (CV) and standardized rainfall anomaly (SRA) from parametric methods and Mann–Kendall's test and Sen's slope estimator from nonparametric methods were applied to examine the temporal trends of temperature and rainfall. CV is a widely used technique to analyze interannual variability of rainfall computed as the ratio of standard deviation to mean value over the given period [21, 36]. A rainfall amount with a CV less than 0.20 is less variable, that with a CV between 0.20 and 0.30 is moderately variable, and that with a CV greater than 0.30 is highly variable [37]. SRA is calculated as the difference between long-term mean annual rainfall and observed annual rainfall to the ratio of standard deviation assuming that the observations are normally distributed [38]. It helps to examine the pattern of rainfall that exhibits dry and wet years over time [36]. A negative anomaly of rainfall at 25% and 50% refers to dry and very dry conditions, respectively [37].

2.3.1. Mann–Kendall's Trend Test. The basic assumption of the Mann–Kendall trend (MKT) test, proposed in [39, 40], is a test of random series ordered against nonrandom series in time [41]. The null hypothesis H_0 of the MK test assumes that the data are independent and randomly ordered; that is, there is no significant trend against the alternative hypothesis which assumes there is a trend [42]. The test has been suggested by the World Meteorological Organization to assess trends in environmental time-series data because it does not require normally distributed data [43]. The Mann–Kendall test is useful to identify the direction and magnitude of significant trends because of its low sensitivity to abrupt breaks and permitted missing values [44]. The Mann–Kendall test is not significantly affected by single data errors or outliers [41]. Moreover, the data should be free from serial independence that causes unreliable results. In case any serial autocorrelation exists, the modified Mann–Kendall (MMK) test was employed to remove the impact of autocorrelation [45]. Hence, before starting a monotonic trend test, lag 1 autocorrelation for temperature and rainfall time series was checked using the autocorrelation function. The test has been applied by many researchers using the same applications [41, 45, 46].

The MKT test method primarily involves the standardized test statistic Z and Sen's slope β parameters. The Mann–Kendall test statistic computes the difference between the later measured values and all early measured values for a time series of interest over time. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the contrary, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S using the following formula:

$$S = \sum_{k=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}\left(x_j - x_i\right), \quad (3)$$

where n denotes the length of a dataset and x_j and x_i are the sequential data values at times j and i $(j > i)$:

$$\operatorname{sgn}\left(X_j - X_i\right) = \begin{cases} +1, & \text{if } \left(x_j - x_i\right) > 0, \\ 0, & \text{if } \left(x_j - x_i\right) = 0, \\ -1, & \text{if } \left(x_j - x_i\right) < 0, \end{cases} \tag{4}$$

where sgn denotes the sign function that takes the values 1, 0, or −1 if $x_j > x_i$, $x_j = x_i$, or $x_j < x_i$, respectively. Positive S values indicate an increasing (upward) trend, and negative values of S reveal a decreasing (downward) trend in the time-series data.

For samples, $n \geq 10$, the S statistic is approximately normally distributed with mean and variance as follows [47]:

$$\begin{aligned} E(S) &= 0, \\ \sigma^2 &= \frac{1}{18}\left[n(n-1)(2n+5)\right]. \end{aligned} \tag{5}$$

If there is a tie in the data, then the variance (σ^2) statistic is given as

$$\sigma^2 = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i\left(t_i - 1\right)\left(2t_i + 5\right)\right], \tag{6}$$

where m is the number of tied groups and t_i is the number of observations in the i^{th} group. The standardized MK test statistic Z_{MK} which follows the standard normal distribution with mean zero and variance one is as follows:

$$Z_{\text{MK}} = \begin{cases} \dfrac{s-1}{\sqrt{\delta^2}}, & \text{if } s > 0, \\ 0, & \text{if } s = 0, \\ \dfrac{s+1}{\sqrt{\delta^2}}, & \text{if } s < 0. \end{cases} \tag{7}$$

A positive (negative) value of S indicates an increasing (decreasing) trend for the period. The trend is insignificant if Z_{MK} is less than the standard normal variate $Z\alpha/2$, where α is the significance level. Testing trends is done at the specific α significance level. When $|Z_s| > Z_{1-\alpha/2}$, the null hypothesis is rejected and a significant trend exists in the time series.

The parameter β (the trend magnitude), indicating the variation rate within the time series, given by Sen's slope estimation test computes both the slope and intercept [48, 49]. A positive value of β indicates an "upward trend" (increasing values with time), while a negative value of β indicates a "downward trend." In general, the slope between any two values of a time series x can be estimated from the following formula:

$$\beta = \operatorname{median}\left[\frac{X_j - X_k}{j - k}\right], \tag{8}$$

where X_j and k are data values at times j and k ($j > k$), respectively.

Tau [50] measures the strength of the monotonic relationship between x and y. Therefore, Kendall's tau correlation coefficient is given by

$$\tau = \frac{S}{n(n-1)/2}. \tag{9}$$

A positive value of τ indicates an increasing trend, and vice versa. The summation of the Mann–Kendall test statistic (S) indicates how strong the trend of temperature and precipitation is and whether it is increasing or decreasing. The final analyses of the socioeconomic data and MKT tests were carried out using STATA v.14 and XLSTAT 2018 statistical software packages.

3. Results and Discussion

3.1. Sample Household Characteristics. Table 1 presents the summary of sociodemographic and local institution environments of the sampled household heads. Therefore, of the surveyed households, 77 percent were male-headed households, with an aggregate mean age of 52.4 years implying that respondents were relatively elderly with more farming experience. Studies [51, 52] used age as a proxy measure of farming experience; hence, farmers with more farming experience are more likely to have perceived climate change. Household heads on average had 2.26 years of education that may impair their climate change perception behavior and understanding skills [53].

The self-reported subjective measurement of climate information indicated that 71 percent of household heads received access to weather information from various media outlets and rural local institutions. Climate information services involve provision of climate forecasts together with agronomic advice to overcome the uncertainties that constrain farm decision-making against climate risks [54]. Furthermore, Table 1 presents ANOVA, chi-square, and bivariate correlation tests. ANOVA Scheffe's and χ^2 tests were used to examine whether there was a difference in means of continuous and categorical variables between the two districts, respectively. Hence, a statistically significant mean difference was found ($p < 0.001$) between Hawzen and Irob sample household groups.

Pearson's correlation test was also used to measure the strength and direction of the linear relationship between access to climate information and household characteristics [55]. Climate information or access to weather forecast was positively correlated with training received at the farmer training center (FTC) ($r = 0.22$, $p < 0.001$) and a number of social networks ($r = 0.22$, $p < 0.001$) but negatively correlated with distance to the market ($r = -0.48$, $p < 0.001$). Households who have limited contacts with local farmer institutions can get agricultural technology information from their family social networks [56]. But increased distance from local market centers is a proxy measure of poor access to local weather condition information [57].

Furthermore, household age was negatively correlated with access to weather information ($r = -0.15$, $p < 0.001$). Older farmers have limited social networks and poor interactions with local institutions, which ultimately negatively influences access to climate information [58]. Moreover, Kirui et al. [59] underlined that older farmers preferred indigenous knowledge over modern climate information

Table 1: Means, standard deviations, and pairwise correlations among variables ($n = 358$).

Variables	Mean	SD	p value	1	2	3	4	5	6	7	8	9
Sex of HH (% males)	0.77	0.42	0.001									
Age of HH	52.4	12.27	0.001	0.28[a]								
Education of HH	2.26	2.98	0.359	0.29[a]	−0.34[a]							
Access to AESs (% yes)	0.62	0.48	0.001	−0.08	−0.13[b]	0.07						
Climate information (% yes)	0.71	0.45	0.001	−0.14	−0.15[a]	0.04	0.66[a]					
HH's own radio/TV (% yes)	0.40	0.49	0.196	0.11[b]	−0.05	0.17[a]	0.14[b]	0.04				
Access to FTC	0.28	0.45	0.001	0.01	−0.08	0.13[b]	0.27[a]	0.22[a]	0.11[b]			
Number of off-farm activities	0.86	0.66	0.001	0.10[b]	−0.16[a]	0.12[b]	−0.21[a]	−0.08	0.06	−0.03		
Distance to the market (minutes)	52.48	69.87	0.001	0.13[b]	0.13[a]	−0.08	−0.47[a]	−0.48[a]	−0.01	−0.15[a]	0.16[a]	
Number of social networks	1.41	1.53	0.001	0.02	−0.14[a]	0.22[a]	0.25[a]	0.22[a]	0.22[a]	0.26[a]	−0.05	0.22[a]

[a]Significant at the 0.01 level; [b]significant at the 0.05 level; HH = household head. p value stands for ANOVA and chi-square tests of continuous and categorical variables, respectively.

services. However, access to agricultural extension services (AESs) positively correlated with access to climate information ($r = 0.66$, $p < 0.001$). Agricultural extension services influence farmers' decision to change their farming practices in response to climate change [60]. Generally, households' access to climate information was enriched through provision of training at the FTC, access to agricultural extension services, and the number of social network households participated. Access to rainfall forecast information is helpful to farmers for better selection and timely growth of crops [51].

3.2. Farmers' Perceptions of Climate Change and Variability

3.2.1. Farmers' Perception of Rainfall Variability. Table 2 shows the households' perception of climate change and variability in terms of rainfall distribution, amounts, and increasing temperatures over the last fifteen years. Households had no wide perception in climate change, and an undeniable majority of households perceived a notable change in rainfall and temperature. Out of the total households, 98.56% and 92% perceived a decrease in rainfall amount in Hawzen and Irob, respectively. The χ^2 test was employed to determine whether there were differences between the household groups in their perception behaviors. A significant difference was found (χ^2 test, $p < 0.01$), indicating that households who had been in Hawzen were more likely to perceive a decrease in rainfall compared to those in Irob. Besides to perceiving the decreased rainfall in the study area, almost 40 percent and 20 percent of households believed that variability in onset and cessation time of rainfall is more in the last 15 years, respectively.

Furthermore, around 29 percent and 39 percent of households in the Hawzen and Irob districts noted that the number of rainy days decreased; that is, there was no rain for a full month within the rainy season. Nonetheless, few households suggested that even when it rains, the intensity of rainfall is increased. Only 5 percent of households from Hawzen observed abnormality in rainfall timing, and distribution was increased. Furthermore, almost 37 percent of households in Irob understood that the occurrence of drought frequency was increased, while only 2.4 percent viewed contrarily to this opinion in Hawzen. Regarding rainfall patterns of the last summer, around 82 and 92 percent of households from Hawzen and 99 and 98 percent of households from Irob report that rainfall came too late and stoped too early, respectively. In addition, around 25 percent of households in Hawzen witnessed rain during the harvest time last year. This inadequacy of rainfall and unreliability of raining time impede the agricultural planning that attracts appropriate adaptation strategies and reliable scientific climate information to mitigate the climatic shocks.

3.2.2. Farmers' Perception of Temperature Variability. Moreover, 87 and 90 percent of households felt that temperature increased, while about 3 and 8 percent believed that temperature decreased in the last 15 years in Hawzen and Irob, respectively. The significance (χ^2 test, $p < 0.001$) showed that households who had been in Irob were more likely to perceive an increase in temperature compared to those in Hawzen. Furthermore, about 77 and 78 percent of households perceived an increase in hot days, while 7 and 5 percent noted the decrease of coldness in cold seasons, respectively. Generally, the majority of households are aware about the presence of climate change and variability. They revealed their local experience of climate change and variability using variability in onset and cessation time of the rainy season, the decreased number of rainy days, a raise of drought severity, and the increased number of hot days.

3.3. Actual Variability and Trends of Rainfall and Temperature

3.3.1. Variability of Rainfall. Monthly values of rainfall were aggregated to obtain seasonal rainfall for each district. Seasons were defined using the standard meteorological definition: winter (December, January, and February), spring (March, April, and May), summer (June, July, and August), and autumn (September, October, and November) which is also aligned with study [61].

Table 3 illustrates that the long-term mean annual rainfall varies from about 614 mm in Hawzen to 471 mm in Irob, respectively, during the period of analysis analogous to the semiarid climate zone [31]. Kiros et al. [17] found 555 mm and 633 mm mean annual rainfall for the Hawzen

Table 2: Farmers' perception of climate change and climate shocks ($n = 358$).

Perceptions of climate parameters	Hawzen Percent*	Irob Percent	χ^2 test	p value
Rainfall decrease in the last 15 years			13.32	0.004
Yes	98.56	92.00		
No	—	4.67		
Stayed the same	0.96	3.33		
Do not know	0.48	—		
Local perceptions of rainfall variability			120.78	0.001
Variability in onset and cessation time of the rainy season	39.42	19.33		
Decreased number of rainy days	28.85	38.67		
Increased intensity of rainfall	4.33	2.00		
Increased occurrence of untimely rainfall	5.23	—		
Increased frequent drought occurrence	2.40	36.67		
Temperature increase in the last 15 years			13.32	0.004
Yes	87.02	90		
No	2.88	8.00		
Stayed the same	7.69	2.00		
Do not know	2.40	—		
Local perceptions of temperature variability			36.38	0.001
Increased number of hot days	76.92	78.33		
Increased number of warm nights	2.00	3.33		
Decreased coldness in cold seasons	7.21	5.33		
Rainfall occurrence last summer			28.06	0.001
On time	16.82	0.00		
Too early	1.44	1.33		
Too late	81.73	98.66		
Rainfall termination last summer			11.84	0.003
On time	7.21	0.00		
Stopped too late	0.96	2.00		
Stopped too early	91.82	98.00		
Rain during the harvest time last year			42.88	0.001
Yes	24.52	0.00		
No	75.48	100		

*Does not add up to 100 because of multiple responses.

Table 3: Mean (μ), standard deviation (σ), and CV (%) of rainfall (mm) during 1983–2015.

Annual and seasonal	Hawzen			Irob		
	μ	σ	CV	μ	σ	CV
Annual	613.71	294.02	47.90	470.97	280.06	59.46
Spring	118.18	110.82	93.77	153.43	119.39	77.83
Summer	425.46	184.87	43.45	236.01	155.67	65.96
Autumn	60.04	44.82	74.65	71.35	44.68	62.62
Winter	10.02	11.99	119.66	10.16	13.15	129.43

district and northern Tigray region over the period 1971–2013, respectively. Summer, the main rainy season, and spring, the short rainy season, rainfall contributes around 69% and 50%, and 19% and 33% to mean annual rainfall for Hawzen and Irob, respectively. Hence, about 88% and 83% of the total annual rainfall occurs in the two seasons over the period of analysis. Summer rainfall dominates the seasonal pattern, and spring also considerably contributes to the annual rainfall in northern Tigray [62]. The contribution of spring rainfall over the north and northeastern highlands is ranging from 5% to 30% [10].

The long-term mean annual and seasonal rainfall was unevenly distributed in both districts. High long-term mean annual rainfall variability (CV) ranged from 47.9% in Hawzen to 59.46% in Irob, respectively. A rainfall amount with CV above 30% is an indication that both districts were vulnerable to drought [37]. Hadgu et al. [63] consistently reported a high coefficient variation in the main rainy season in Tigray, northern Ethiopia. Summer CV is less than spring CV in both districts, indicating that summer rainfall was relatively less variable than spring rainfall. Higher rainfall variability is experienced during the small rainy season than the main rainy season and annual rainfall [64]. Rainfall variability and uncertainty in semiarid areas have substantial influence on agricultural production [31]. One-way ANOVA was employed to test the null hypothesis constructed that there is no significant difference in mean annual and mean summer season rainfall between Hawzen and Irob districts. The F-test result revealed that the observed significance value F for annual and summer rainfall is 3.95 ($p < 0.050$) and 19.66 ($p < 0.001$), implying that there is a significant difference in annual and summer rainfall between the two districts.

The mean annual SRA analysis showed that there were 8 and 6 very dry and 10 and 4 dry years in Hawzen and Irob, respectively, over the period of analysis. 3-month and 12-month accumulated precipitation SRA is calculated to determine seasonal and intermediate-term drought indexes [65]. Drought occurs when the SRA initially drops below zero and ends with the first positive value [66]. The proportion of negative mean annual rainfall anomalies in Irob ranges between 63% and 79%, while summer rainfall in Hawzen ranges between 61% and 63% of the total observations, respectively. Certain rainfall patterns show that a dry year is followed by another one or two very dry years and *vis-à-vis* for the wet years. Rainfall has been declining in northeast Ethiopia since 1996 [67].

3.3.2. Trends of Rainfall. The monotonic trend of temperature and rainfall time series was measured using the Mann–Kendall trend test assuming no serial correlation in the dataset. The most widely applied test for detecting serial correlation is the Durbin–Watson d statistic that is defined as the ratio of the sum of squared differences in successive residuals to the residual sum of squares [68]. Prior to the Mann–Kendall test, a serial correlation analysis for rainfall and temperature was assessing the Durbin–Watson d statistic. The estimated Durbin–Watson d statistic values were above one and less than 2, hence not rejecting the null hypothesis suggesting that there is statistically significant evidence of positive autocorrelation in the residuals.

Therefore, the modified Mann–Kendall (MMK) test was used in order to analyze the true trend value. The trend test for annual and seasonal rainfall did not show statistically significant results for both districts (Table 4). However, negative trends are evident in both annual and seasonal rainfall except a positive trend observed in summer rainfall for Hawzen during the period of analysis. In Hawzen and Irob, annual rainfall has been decreasing by about 32.38 and 121.33 mm per decade. Contrarily, in Hawzen, the main rainy season rainfall was increasing by 28.5 mm per decade although there was an absolute decrease in mean annual rainfall amount. This implies no circumstances of agricultural drought and enhanced crop production and livelihoods. For Hawzen and Irob, total annual rainfall decreased by 106.85 mm and 400.39 mm, respectively, in the period of analysis (Table 4 and Figure 1). This result agreed with the results in [17] where no statistically significant trends with a blend of positive and negative trends were found in annual rainfall except at one of the seven stations, Geba River Basin located in the Tigray region of northern Ethiopia, over the period of 1971 to 2013. Correspondingly, Hadgu et al. [63] confirmed a nonsignificant trend in both annual and seasonal rainfall measures in five stations in Tigray, northern Ethiopia, between 1980 and 2009. Overall, studies [10, 62] reported a nonsignificant trend of annual and seasonal rainfall in northern Ethiopia.

3.3.3. Variability of Temperature. The mean annual temperature data were computed as an average of the maximum and minimum temperatures. Mean and standard deviation values of temperature during the study period of analysis are presented in Table 5. The mean maximum ($T_{\max}$), minimum ($T_{\min}$), and annual (T_{mean}) temperatures were 27.06°C, 11.30°C, and 19.18°C for Hawzen. Correspondingly, 27.96°C, 11.88°C, and 19.92°C were for Irob, respectively, over the period of analysis. Generally, Irob had been recording slightly higher mean temperatures compared to the Hawzen district. In Hawzen, the lowest and the highest mean annual temperature variability was 25.61°C and 28.38°C recorded in 1986 and 2013, respectively. Similarly, 26.86°C and 30.00°C were the lowest and highest temperatures recorded in 1989 and 2008 for Irob, respectively, implying that temperature was recently rising in both districts. In Hawzen, spring and summer were the hottest and coldest seasons that reported 20.73°C $\pm$ 0.96σ and 9.73 $\pm$ 0.67σ, while in Irob, summer and winter were the hottest and coldest seasons with 22.45°C $\pm$ 0.69σ and 17.96°C $\pm$ 0.68σ, respectively.

3.3.4. Trends of Temperature. Warming trends of maximum and mean annual temperatures were observed in Hawzen and Irob districts at statistically significant levels ($p < 0.001$ and $p < 0.05$, respectively). The warming trends of maximum and mean annual temperatures were 0.65°C and 0.4°C per decade in Hawzen. Likewise, for Irob, the warming trends of maximum and mean annual temperatures were 0.55°C and 0.39°C per decade over the period of analysis, respectively. Generally, the mean annual temperature trend was increased by about 1.32°C and 1.29°C for Hawzen and Irob, respectively, in the period of analysis (Table 6 and Figures 2 and 3). Moreover, the maximum temperature increased faster than the minimum temperature for both districts. However, Gebrehiwot and van der Veen [69] found the average annual minimum temperature (0.72°C) increased faster than the average annual maximum temperature (0.36°C) per decade in the Tigray region of northern Ethiopia during the period 1954–2008.

3.4. Farmers' Perceptions of Climate Change and Meteorological Data. Farmers' self-reported climate perception is not sufficient to generalize about the actual trends of climate change and variability. Their perception of climate change is highly personal, site specific, and influenced by a number of factors [20]. Therefore, it is helpful in comparing farmers' climate change perception and the actual meteorological data in the study area to know the adaptation strategies. The majority of farmers believed total rainfall decreased in the last fifteen years in their localities (Table 2). Meteorological rainfall data analysis was also congruous with farmers' perception of rainfall decline in both districts (Table 4). In Hawzen, the mean main rainy season rainfall showed an increased trend somewhat consistent with farmers' local perception that the intensity of rainfall increased by about 4% (Table 2). Except the main rainy season for Hawzen, the perceived reduction in annual and seasonal rainfall is consistent with meteorological results in agreement with the findings in [70]. Households' local perceptions of increased numbers of hot days and warm nights were in harmony with the meteorological records of mean temperature trends in their vicinities (Tables 2 and 6). This

Table 4: Annual and seasonal rainfall trend analysis for Hawzen and Irob in 1983–2015.

District	Annual rainfall (mm)				Main rainy season (mm)				Spring season (mm)			
	Kendall's tau	S	p value*	Sen's slope	Kendall's tau	S	p value	Sen's slope	Kendall's tau	S	p value	Sen's slope
Hawzen	−0.170	−90.00	0.916	−3.238	0.053	28.00	0.285	0.285	−0.371	−196.00	0.999	−3.328
Irob	−0.481	−254.00	0.500	−12.133	−0.352	−186.00	0.998	−3.904	−0.496	−262.00	1.000	−5.422

*Two-tailed test.

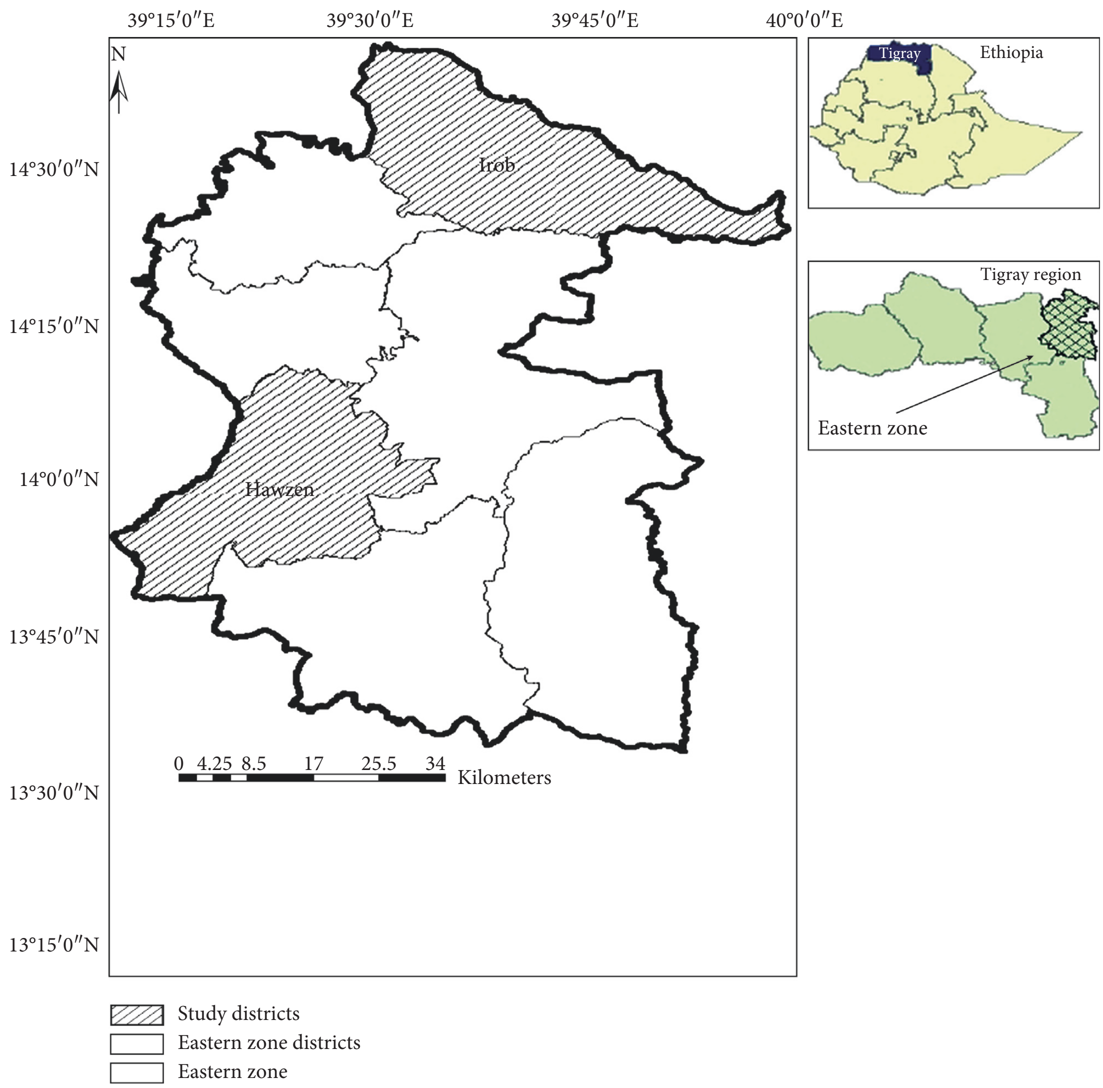


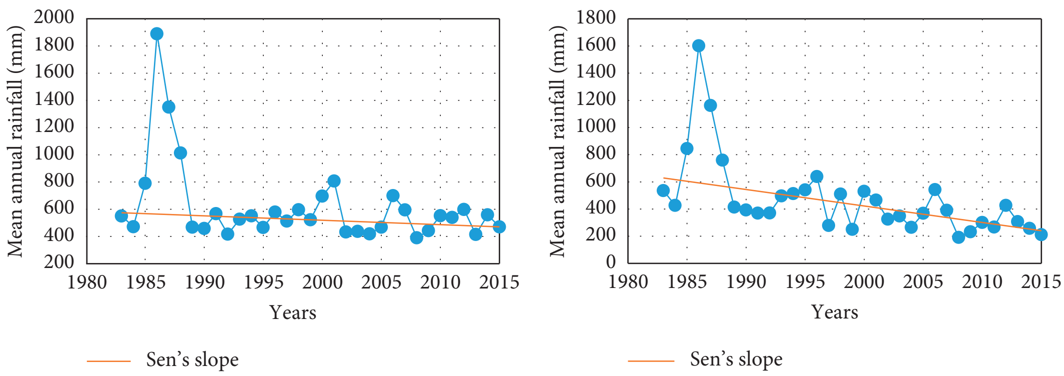
Figure 1: Map of the study areas.

Table 5: Mean maximum, minimum, and annual temperatures (°C) in Hawzen and Irob in 1983–2015.

Annual and seasonal	T_{max} (°C)				T_{min} (°C)				T_{mean} (°C)			
	Hawzen		Irob		Hawzen		Irob		Hawzen		Irob	
	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ	σ
Annual	27.06	0.70	27.96	0.65	11.30	0.60	11.88	0.62	19.18	0.65	19.92	0.64
Spring	28.85	1.06	28.70	0.97	12.60	0.85	12.85	0.75	20.73	0.96	20.78	0.86
Summer	25.86	0.72	29.61	0.72	13.60	0.63	15.28	0.65	9.73	0.67	22.45	0.69
Autumn	26.47	0.85	27.61	0.61	10.14	0.76	10.45	0.76	18.31	0.81	19.03	0.67
Winter	27.06	0.71	25.91	0.89	8.85	0.64	8.93	0.67	17.96	0.68	17.42	0.78

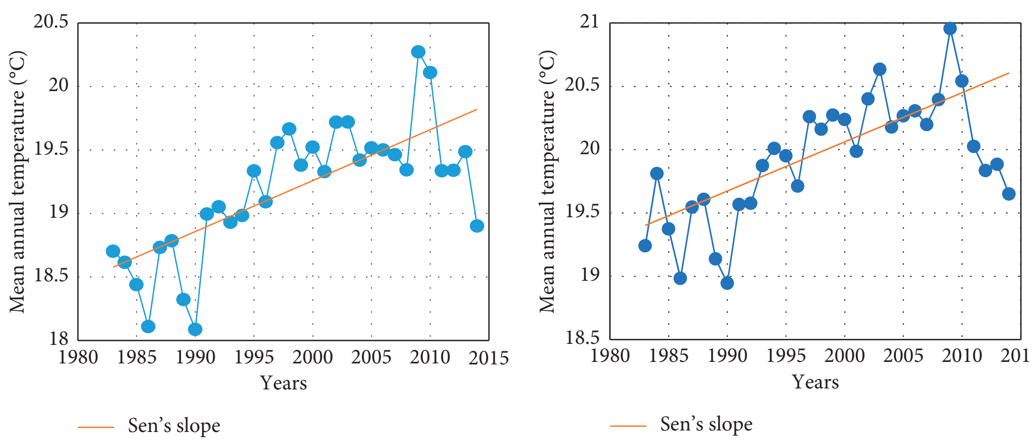
Table 6: Annual and seasonal temperature trend analysis by the MKT test for Hawzen and Irob in 1983–2014.

District	T_{max} (°C)				T_{min} (°C)				T_{mean} (°C)			
	Kendall's tau	S	p value	Sen's slope	Kendall's tau	S	p value	Sen's slope	Kendall's tau	S	p value	Sen's slope
Hawzen	0.685	340.00	0.001	0.065	0.181	90.00	0.140	0.025	0.500	248.00	0.001	0.040
Irob	0.657	326.00	0.001	0.056	0.181	90.00	0.153	0.027	0.492	244.00	0.001	0.039



(a) (b)

Figure 2: Mean annual rainfall trends for Hawzen (a) and Irob (b) districts during 1983–2015.



(a) (b)

Figure 3: Mean annual temperature trends for (a) Hawzen and (b) Irob districts during 1983–2015.

harmony between farmers' perception of an increased temperature trend and meteorological results is also supported by previous works [23, 70, 71].

3.5. Adaptation Strategies to Perceived Climate Change. Rural farmers in developing countries are vulnerable to climatic and nonclimatic induced stressors that caused high income and consumption fluctuations [72, 73]. Nevertheless, they are not passive receivers of shocks; rather employing an adaptation strategy is a policy option to reduce the negative impact of climate change [74]. According to ([75]: 225), adaptation in the climate change context refers to "adjustments in ecological-social-economic systems in response to actual or expected climatic stimuli, their effects, or impacts." Adaptation based on purposefulness can be classified as autonomous and planned adaptation [75]. An autonomous adaptation also referred to as reactive adaptation is an action undertaken by vulnerable people without direct interventions of a public agency to reduce risks posed by climatic stimuli [7]. However, Stern [76] argued that an autonomous adaptation is inefficient and reduces courtesy to necessary planned interventions. Conversely, planned adaptation is the result of deliberate policy decisions by government agencies aimed at promoting appropriate and effective adaptation measures. Generally, households can adopt more than one adaptation strategies based on their long-term knowledge and perceptions of climate changes.

The main climate change adaptation strategies were soil and water conservation (SWC) (87.71%), planting trees (84.64%), crop varieties (81%), changing crop planting times (64.25%), biological conservation (43.58), and irrigation (19%) in the study area. These adaptation strategies have been widely in use in Ethiopia for a long period of time in response to historic climate change [36, 51, 77]. But it is not required to link all of these strategies directly to reduce climate change impacts [29]. For instance, the aim of adoption of new crop varieties might be to increase production and household income.

SWC is the dominant planned adaptation strategy farmers employed to ease the adverse effects of climate change and variability. Specifically, in Irob, currently 2 percent land is under cultivation of the total area because of severe land degradation and steeped land slope. Consequently, the average land holding size per household head is estimated around 0.02 hectares. Hence, farmers adopted different SWC practices including built bench terrace, soil bunds, and check dam based on the land use types to improve soil fertility and extensive farming. Besides, SWC farmers planted trees as an adaptation and mitigation measure to prevent land erosion caused by heavy rainfall. The rainfall of the area is a weakly bimodal pattern; hence, during the short rain season, farmers grow potato and sorghum that are drought-resistant and short maturing varieties of crops followed by maize, wheat, and barley crop varieties with a long main rainy season. The rainfall variability in terms of length of the growing season has always been indeterminate because of high variability of onset and cessation of the rainy season (Table 2). This demands a correct planning of the lean period (sowing, growing, and harvesting) and selection of the crop type and variety. During the late-onset small rainy season, farmers reschedule the crop calendar by sowing crop varieties to be harvested (barely, teff, and wheat) on the onset of the main rainy season in October–December. Overall, yields damage meaningfully with either a late onset or an early cessation of the growing season in the study area.

However, there were differences in the intensity of the adaptation strategy between the districts except for planting trees (Table 7). This indicates that households living in the Hawzen district were in a better position to ameliorate climate change risk impacts compared to households in the Irob district employing these adaptation measures. Generally, local knowledge-based adaptation strategies are more effective over the national-level adaptation strategy [78].

4. Conclusion and Policy Implications

Integrating farmers' perceptions of climate change and variability with the observed meteorological data that influence adaptation strategies has not been extensively studied. This study analyzed farmers' perceptions about rainfall and temperature corresponding to the observed metrological data and their adaptation strategies to the perceived climate change. The multistage sampling method was employed to select 358 rural farmers in Hawzen and Irob districts located in semiarid highlands of Eastern Tigray, northern Ethiopia. Moreover, areal gridded data on rainfall and temperature were collected from National Meteorology Agency of Ethiopia.

There is a positive correlation among farmers' access to weather information, farmers' access to training in agronomic practices, access to agricultural extension services, and number of social networks in which farmers have membership. The majority of the farmers had perceived climate change and extreme weather events in their locality in the last fifteen years. Specifically, about 98.56 percent and 92 percent farmers perceived a decrease in rainfall amount in Hawzen and Irob districts, respectively. However, a statistically significant difference was found between the two districts, indicating that farmers who had been in Hawzen were more likely to perceive a decrease in rainfall compared to those in Irob. The mean annual rainfall variability in Hawzen and Irob varies between 47.9 percent and 59.5 percent. As a result, a significant difference in annual rainfall was observed in the two districts. Furthermore, in Hawzen and Irob, the proportion of negative anomalies ranges from 63 percent to 79 percent of the total observations. Farmers realized the manifestation of rainfall variability in terms of change in the onset and cessation of the rainy season, decreased number of rainy days, increased intensity, and unpredictable rainfall distribution. Moreover, 87 percent and 90 percent of farmers felt that temperature was increased in the last 15 years in Hawzen and Irob, respectively. The statistical result indicated that households who had been in Irob were more likely to perceive an increase in temperature compared to those in Hawzen. The noticed increased temperature evidences the increase in the number of hot days, warm nights, and decreased coldness in cold seasons.

The actual meteorological data coincide with farmers' perceptions of climate change and variability that demonstrate decreasing mean annual rainfall and increasing temperatures. Specifically, the modified MKT test showed that, in Hawzen and Irob, mean annual rainfall had decreased by 32.38 mm and 121.33 mm per decade, respectively, except an increased trend that was observed at the summer rainy season in the Hawzen district. Conversely, the mean annual temperature had been increasing by about 0.4°C and 0.39°C per decade, respectively, during the period of analysis.

The study results indicated that SWC, planting trees, crop varieties, changing crop calendar, biological conservation, and irrigation were the dominant adaptation strategies farmers adopted to ameliorate the perceived impact of climate change risks. Thus, the results of this

Table 7: Adaptation strategies to perceived temperature and rainfall changes ($n = 358$).

Adaptation strategy	Hawzen Percent	Irob Percent	p value
Improved crop varieties	96.15	60.00	0.001
Soil and water conservation	83.65	93.33	0.006
Planting trees	83.60	86.00	0.544
Changing planting time	79.81	42.67	0.001
Biological conservation	57.69	24.00	0.001
Irrigation	13.46	26.67	0.002

study provide valuable information to policy-makers and extension works. First, an increase in local weather station sites improves access to weather information, thereby advancing the adaptation strategies against adverse climate change impacts. Second, local government and NGOs are required to disseminate and present weather information in newspapers and Internet to promote the capacity of rural agricultural extension workers and farmers. Third, since farmers used family social networks to find weather information under poor climate information dissemination, local governments should strengthen social networks' capacity and develop a link with local public institutions.

Data Availability

The household survey primary data and climate data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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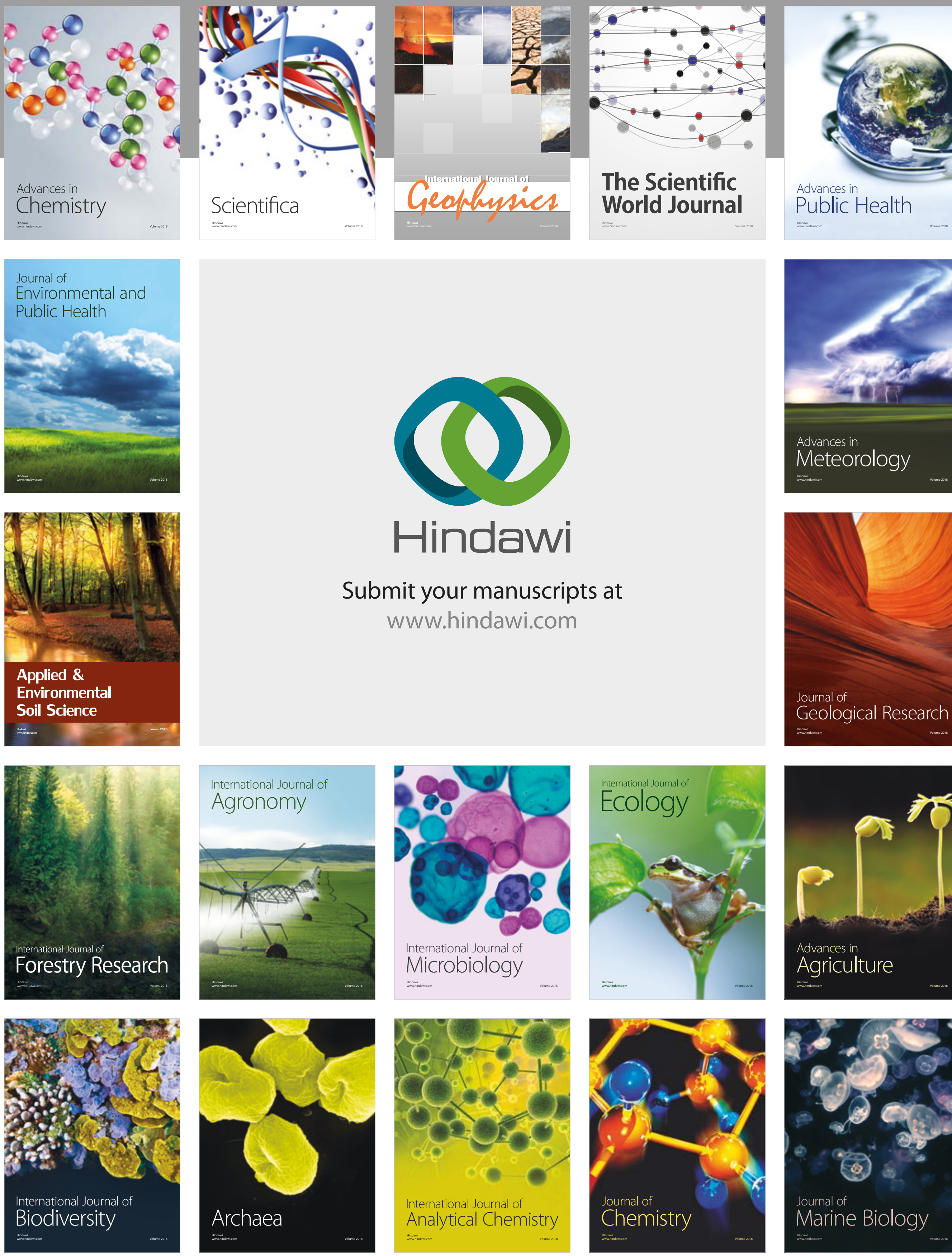
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