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Observed and Future Climate Variability and Extremes Over East Shoa Zone, Ethiopia

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Abstract

This study has been conducted with the aim to analyze variability and extremes of daily values of maximum and minimum temperatures, and precipitation. The future data are downscaled using delta method based on outputs from four global climate models (GCMs). The data are simulated for three future 30 year periods, centered at 2030's (2010-2039) and 2050's (2040-2069) and for the two scenarios (A2 and B1). Analysis of the 27 core set of extreme weather indices, which are defined by ETCCDI, is carried out on six selected sites and all the results were reported in detail. In addition comparisons in variability has made between models and values of these indices observed in the base climate period (1981-2010) and values of projected periods.

Among precipitation indicators, significant increasing trends in annual total wet-day precipitation, number of heavy and very heavy precipitation days and decreasing trends in consecutive wet days, simple daily intensity index and precipitation on extremely wet days were found. Yet, the trends show no spatial coverage. In contrast to precipitation indices, the results indicate that most temperature indices showed significant changes in majority of stations. Nevertheless, the trends show less spatial coherence except cold days and summer days indicators.

Regionally, summer days and tropical nights showed significant increases while warm nights, cold days and warmest day showed significant decreases during the base period. On the other hand, for the projected climate, while summer days and warm days would significantly increases but coldest day and cold days would decrease on regional level.

The observed decreasing changes in warm extremes (i.e., warm night and warmest night) which are inconsistent with a warming planet and the heterogeneous behavior identified in most temperature extreme indicators suggested that local factors may play a major role in the study area.

Keywords: Base period; Climate models; Extremes; Indices; Projections; Variability

Introduction

Changes in climate variability and extremes have received increased attention in recent years, since they can have overwhelming impact on environment and society [1]. The large impacts climate extremes can have, and their tendency to change substantially in frequency with even small changes in average climate, mean that changes in extremes can be the first indication that climate is changing [2,3].

The Intergovernmental Panel on Climate Change's Fourth Assessment concluded that some extremes are changing, and will likely continue to change, due to human influences on the weather [4]. It is thus of great interest to analyze climate extremes since it can also be important in understanding future changes [5].

The study of climate extremes is rather complex due to the excessive statistical limitations inherent to extremal analysis (due to the obvious smallness of the samples to be analyzed). To tackle this challenge, the Climate Variability and Predictability (CLIVAR) Expert Team on Climate Change Detection and Indices (ETCCDI), has developed a set of indices on moderate extremes that represents a common guideline for regional analysis of climate.

Many studies have been published on changes in climate extremes around the world using these standard indices [6-18]. However there have been no studies done on precipitation or temperature related extremes in Ethiopia.

The objectives of this paper are to describe temporal trends in extreme weather events and their spatial distribution and to identify indicators which are representative of climate trends across east Shoa zone, Ethiopia. The paper also intends to see how the changes will evolve in the future. This analysis is important for the region which is characterized by high local climate variability.

Hence, the most representative indicators can then be used as predictors in climate-health research. Furthermore, the identification of geographic variation in sensitivity to climate change may also be helpful in resource allocation and policy decisions.

Materials and Methods

Data and quality control

Daily precipitation, maximum and minimum surface air temperature data were obtained from National Meteorological Agency (NMA) from 6 meteorological stations across East Shoa zone, Ethiopia, between 38-40.5°N latitude and 6.75-9.25°E longitude.

The period of record was between 1980-2010. The study area and station locations are shown in Figure 1.

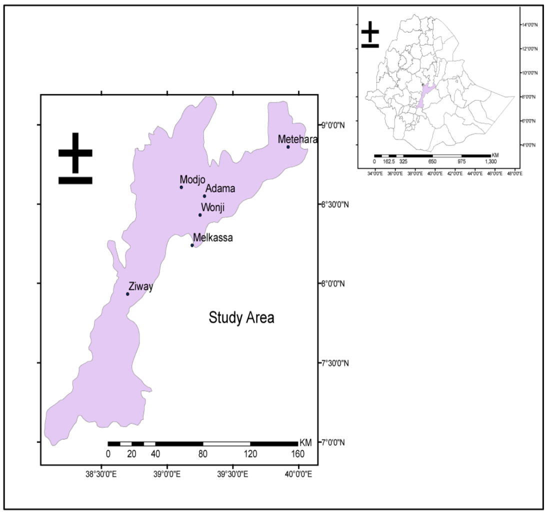

Figure 1: Map of the study area, East Shoa zone, Ethiopia.

In this study an exhaustive data Quality Control (QC) was applied. Initially, data from 10 meteorological stations were available, and after the QC, only stations with less than 10% of missing data for a period of at least 30 years were considered resulting in 6 locations (Table 1).

Station Name	Long(E)	Lat(N)	Elevation(m)
Melkassa	39.19	8.24	1531
Metehara	39.92	8.86	944
Modjo	39.11	8.61	1763
Adana	39.28	8.55	1622
Wonji	39.25	8.43	1540
Ziway	38.7	7.93	1640

Table 1: Meteorological stations used for the analysis.

Methodology

Climate downscaling

Future projections of precipitation, maximum and minimum temperature were generated based on outputs from four Global Climate Models (GCMs) namely: csiroMK3.0, gfdlCM2.1, ncarCCSM3.0 and ukmoHADCM3.

Outputs from the four GCMs were downscaled for all the stations used during the base period using delta method of downscaling [19,20] under two emission scenarios (A2 and B1) and two 30-year future periods centered at 2030 (2010-2039) and 2050 (2040-2069).

In the delta method (also called the constant scaling or perturbation method), the observed station historical daily rainfall series is scaled by a constant factor, determined as the ratio of the mean future GCM grid cell rainfall divided by the mean historical rainfall, to obtain the future daily rainfall series.

For temperature time series, the scaling factor is determined as mean future GCM grid cell temperature minus the mean historical temperature.

Extreme indices analysis

A summary of the temperature and precipitation indicators which were developed by ETCCDI is presented in Table 2. We calculated indices of climate extremes for individual stations for the base period as well as the downscaled future projections. We used linear regression to assess trends in these extreme indicators for each station.

The slopes of the annual trends and their statistical significance to climate indices were calculated based on non-parametric Mann–Kendall test in order to detect trends within the time series. The Mann–Kendall test has proven to be useful in determining the possible existence of statistically significant trends assuming a 95% probability level [5,21]. A trend was termed significant if the t test for the estimate of the slope was significant at $\alpha=0.05$ level.

The percentile weather indicators were calculated by summing the number of days for which daily values exceed a time of-year-dependent percentile. These percentiles are determined for each day of the year, using data from that day and 2 days on either side of it over the course of the base period. For easy comparison of indices across stations with records of various lengths, the thresholds were computed from a base period, namely 1981–2010 for all stations.

The sample estimates of these indicators in the base years may not be reliable and there may be a discontinuity in the expected rates for the years on the boundaries of the base period [22].

Therefore, the RClimDex program was used to perform a bootstrapping procedure to provide cross-validation of these values [23]. The bootstrapping makes the estimation of the threshold exceedance rate for both the in-base and out-of base periods comparable [24].

The estimated decadal trends for each station were mapped using thematic maps to describe regional trends in temperature and precipitation extremes for the base period. All statistical analyses were done using R open source software (R Foundation for Statistical Computing, Vienna, Austria).

ArcGIS also was used to map the distributions of extreme climate trends across the study area. Finally we calculated zonal wide temporal trends and presented statistically significant trends.

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Indices	Name	Definition	Units
CDD	Consecutive dry days	Maximum number of Consecutive days with RR<1 mm	Days
CWD	Consecutive wet days	Maximum number of Consecutive days with RR ≥ 1 mm	Days
PRTOT	Annual total wet day precipitation	Annual total PRCP in wet days (RR ≥ 1 mm)	mm
R10	Number of heavy precipitation days	Annual count of days when PRCP ≥ 10 mm	Days
R20	Number of very heavy precipitation days	Annual count of days when PRCP ≥ 20 mm	Days
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days	mm
R95pTOT	precipitation on very wet days	Annual total PRCP when RR ≥ 95th %	mm
R99pTOT	precipitation on extremely wet days	Annual total PRCP when RR ≥ 99th %	mm
RX1day	Max-1 day precipitation amount	Maximum 1-day precipitation	mm
RX5day	Max-5 day precipitation amount	Maximum 5-day precipitation	mm
TN10P	Cold nights	Percentage of days when TN<10th %	Days
TN90P	Warm nights	Percentage of days when TN>90th %	Days
TN10P	Cold days	Percentage of days when TN<10th %	Days
TN90P	Warm days	Percentage of days when TN>90th %	Days
TNn	Coldest nights	Monthly minimum value of daily TN	°C
TNx	Warmest nights	Monthly maximum value of daily TN	°C
TXn	Coldest days	Monthly minimum value of daily TX	°C
TXx	Warmest days	Monthly maximum value of daily TX	°C
DTR	Diumal temperatute range	Monthly mean difference between TX and TN	°C
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX <90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN <10th percentile	Days
SU25	Summer days	Annual count when TX>25°C	Days
TR20	Tropical nights	Annual count when TN>20°C	Days

Table 2: Definition of extreme weather indicators.

Results

Extremes in the base period (1980-2010)

Temporal trends

Precipitation indicators: Decadal trends across the study area from 1980 to 2010 for the indices of extreme precipitation are presented in Table 3. The bold values represent significant level of 5% ($p<0.05$). The spatial distribution of trends of precipitation related extreme indicators are also shown in Figure 2. Among specific precipitation indicators, annual total wet-day precipitation (PRTOT), number of heavy (R10) and very heavy precipitation days (R20) showed significant increases (121.3, 4.3 and 2.5 mm per decade respectively) over Modjo.

In terms of duration of dry and wet days, Consecutive Wet Days (CWD) decreased significantly by 1 day/decade over Melkasa station. The Simple Daily Intensity Index (SDII) showed significant decrease (0.8 mm per decade) over Adama. Precipitation on extremely wet days (R99pTOT) indicator also showed significant negative trend of 25.8 mm per decade over Wonji station. Spatially, however, none of the indices showed homogenous significant trends, i.e., either positive or negative.

Temperature indicators: Decadal trends across the study area from 1980 to 2010 for the indices of extreme temperature are presented in Table 4. The bold values represent significant level of 5% ($p<0.05$). The analysis result evidence that most indices showed significant changes across most stations. Among the indicators, cold nights (TN10P) showed significant decreases of -3.8 and 9.0 days per decade over Adama and Wonji respectively. Similarly, warm nights (TN90P) decreased significantly by 3.5, 5.6 and 15.3 days per decade over Melkassa, Modjo and Wonji respectively, yet it increased over Adama and Metehara by 3.3 days per decade.

Indices	Adama	Melkassa	Metehara	Modjo	Wonji	Ziway
CDD	-247	-2.41	+2.62	-4.8	-5.69	-3.91
CWT	+0.06	-1.04	+0.07	+0.45	-1.00	+0.08
PRTOT	-11.84	+24.937	+11.3	+121.29	+12.58	+12.41
R10	-1.87	+0.69	0.05	+4.27	+0.91	+0.41
R20	-0.6	+0.23	+0.87	+2.51	+0.32	+0.54
R95pTOT	-21.13	-2.14	+10.7	+37.03	-5.58	+7.42
R99pTOT	-13.7	-2.51	-3.94	+16.71	-25.84	+3.69
RX1day	-0.89	-0.17	-0.64	+7.57	-3.67-	-1.13
RX5day	-2.32	-7.83	+4.63	+7.34	-2.11	-1.14
SDII	-0.82	+0.31	-0.04	+0.54	+0.11	-0.17

Table 3: Decadal trends in extreme precipitation indicators.

On the other hand, cold days (TX10P) consistent significant decreased by 3.0, 4.6, 7 and 11 days per decade over Modjo, Melkassa, Ziway and Wonji respectively. In terms of warm days (TX90P), the indicator showed significant positive trends of 3.6, 5.1 and 7.7 days per decade over Ziway, Metehara and Modjo respectively, while it decreases significantly over Adama and Wonji (+6.6 and 11.7 days per decade respectively).

Among absolute indicators, coldest night (TNn) is the only indicator which did not show any significant change. Warmest nights (TNx) showed significant negative trend of 0.73, 0.96 and 1.3 degree Celsius per decade over Modjo, Melkasa and Wonji stations respectively. Yet the trend was a significant increase (+0.75°C per decade) over Metehara. Similarly, warmest days (TXx) showed significant decreases of 0.59°C and 1.0°C per decade over Adama and Wonji, respectively; however, it significantly increased over Metehara and Ziway by 0.8°C and 0.7°C decade, respectively. On the other hand, coldest days (TXn) showed significant positive trends of 0.77°C and 0.7°C per decade over Melkasa and Wonji, respectively. Regarding to duration indicators, only warm spell duration indicator (WSDI) showed significant decreases over Wonji by 0.96 days per decade.

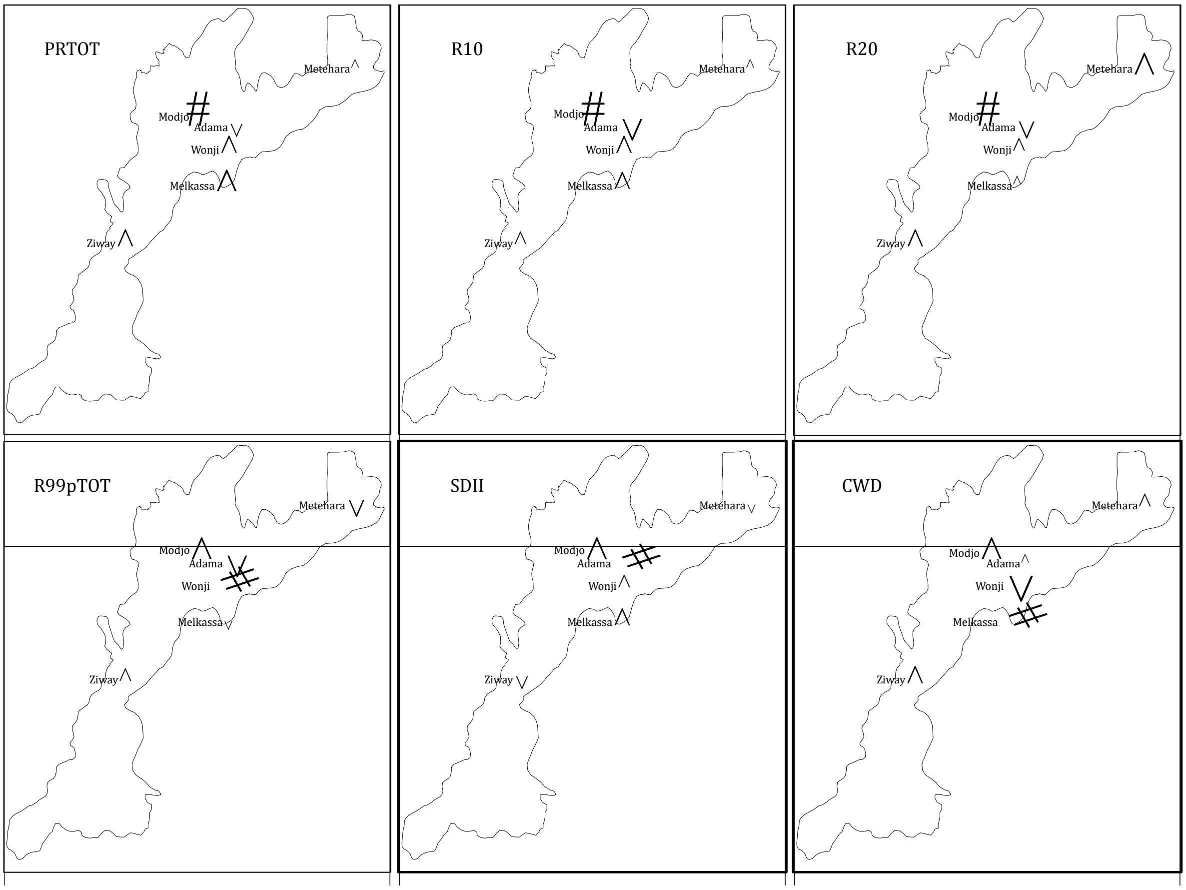

Figure 2: Distribution of trends of precipitation indicators. Upward and downward triangles indicate positive and negative trends respectively. Significant trends represented by the black color and uncolored ones indicate non–significant trends. The size of the triangles represents the magnitude of the trend.

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Indices	Adama	Melkassa	Metehara	Modjo	Wonji	Ziway
TN10P	-3.79	-0.27	+0.4	+4.41	-9.01	-2.69
TN90P	+3.3	-3.5	+3.32	-5.58	-15.31	+1.14
TX10P	+1.14	-4.56	+0.83	-3.01	-10.98	-7.01
TX90P	-6.6	-1.81	+5.08	+7.73	-11.73	+3.57
TNn	-0.09	+0.12	-0.22	-0.37	+0.14	+0.11
TNx	+0.09	-0.96	0.75	-0.73	-1.31	+0.37
TXn	-0.67	+0.77	-0.12	+0.09	+0.7	+0.44
TXx	-0.59	-0.54	+0.81	+0.28	-1.02	+0.7
CSDI	-0.27	+0.14	0.02	+0.21	-0.23	+0.07
WSDI	-1.18	-0.02	+0.29	+0.87	-0.96	+0.11
DTR	-0.88	+0.31	+0.08	+1.18	+0.17	+0.4
TR20	-0.26	-0.24	+14.04	-0.04	-0.12	0.04
SU25	-6.94	+8.8	-0.07	+11.49	+14.27	+26.28

Table 4: Decadal trends in extreme temperature related indicators.

With regards to threshold indicators, summer days (SU25) showed consistent significant positive trends of 8.8, 14.3 and 26.3 days per decade over Melkassa, Wonji and Ziway, respectively. On the other hand, tropical nights (TR20) showed significant increase of 14 days per decade over Metehara, yet the trend over Melkasa were negative and small (i.e., -0.24 days per decade) though it were significant. Similarly, diurnal temperature range (DTR) showed significant increase (+1.2°C per decade) over Modjo and significant decrease (-0.88°C per decade) over Adama (Figure 3).

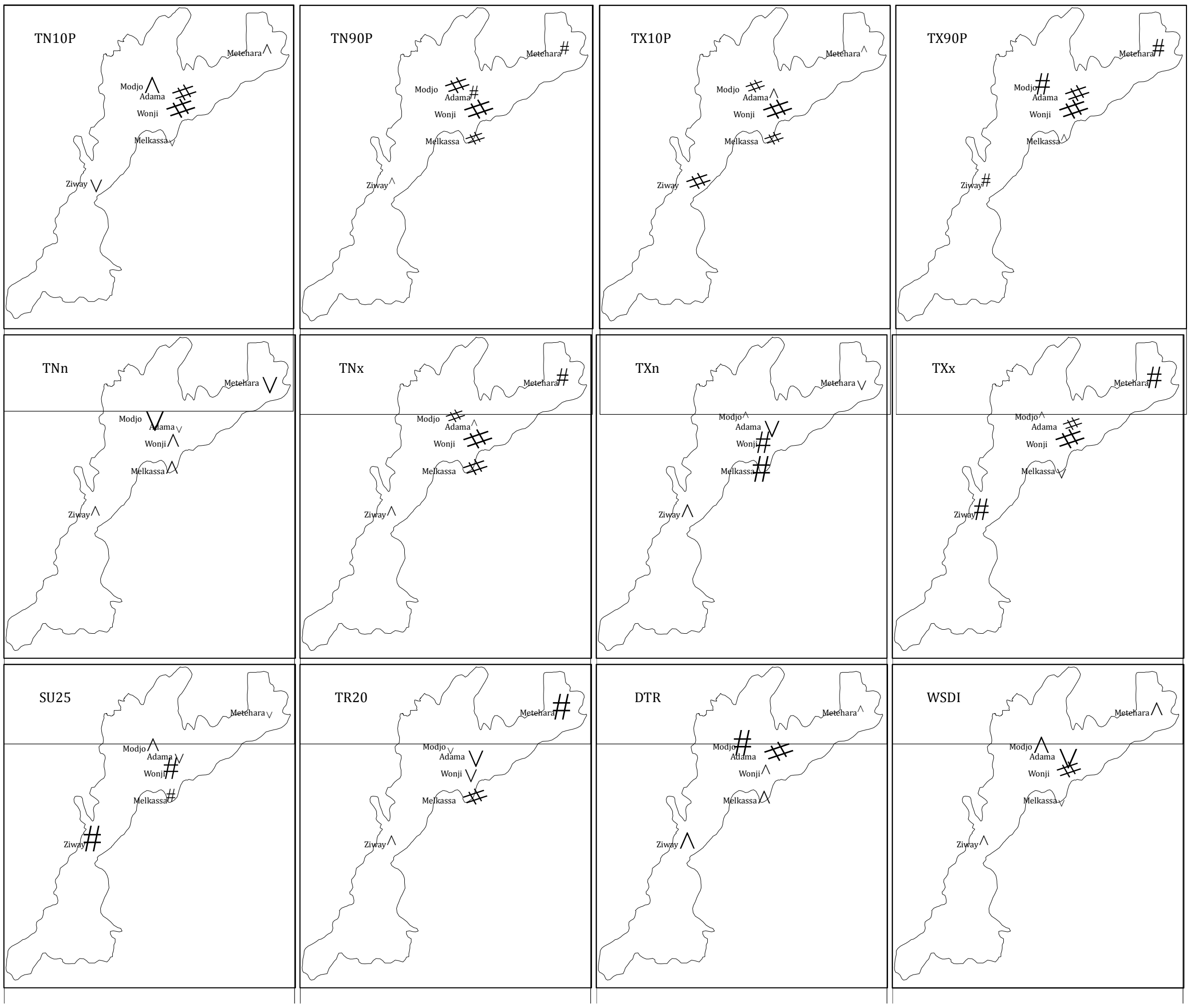

Figure 3: Distribution of trends of precipitation indicators. Upward and downward triangles indicate positive and negative trends respectively. Significant trends represented by the black color and uncolored ones indicate non-significant trends. The size of the triangles represents the magnitude of the trend.

Future extremes

Precipitation indicators: Significant decadal trends of downscaled future daily precipitation extreme indicators across the study area are presented in Table 5. Future projections in all model simulations showed the observed trends in CWD (over Melkasa), PRTOT, R10 and R20 (over Modjo) and SDII (over Adama) would continue in both scenarios. Unlike the base period, projections from gfdlCM2.1 model showed R20 would significantly increase over Metehara (i.e., A2-30's and B1-50's). On the other hand, only projections from gfdlCM2.1 model in A2 scenario showed that the significant negative trend in R99pTOT observed in the base period over Wonji would continue decreasing in the in future (i.e., in 2030's and 2050's).

		csiroMK3_0_A2_30				gfdlCM2_1_A2_30				ncarCCM3_0_A2_30				ukmoHADCM3_A2_30			
		A2		B1		A2		B1		A2	B1	A2	B1	A2	B1	A2	B1
INDEX	Station	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
CWD	Melkasa	-0.11	-0.11	-0.11	-0.11	-0.12	-0.11	-0.09	-0.11	-0.11	-0.10	-0.09	-0.11	-0.10	-0.11	-0.10	-0.11
PRTOT	Mojo	13.1	13.5	13.1	13.5	13.4	12.7	13.8	14.6	14.9	14.9	14.7	14.8	13.3	13.5	12.7	13.5
RIO	Mojo	0.47	0.49	0.47	0.49	0.48	0.47	0.49	0.53	0.62	0.54	0.59	0.56	0.52	0.51	0.45	0.53
R20	Metehara	-	-	-	-	0.11	-	-	0.11	-	-	-	-	-	-	-	-
	Mojo	0.32	0.31	0.32	0.31	-	-	0.31	0.30	0.35	0.35	0.33	0.37	0.30	0.29	0.28	0.27
R99pTOT	Wonji	-	-	-	-	-2.75	-3.05	-	-	-	-	-	-	-	-	-	-
SDII	Adama	-0.10	-0.09	-0.1	-0.09	-0.08	-0.08	-0.09	-0.08	-	-	-	-	-0.09	-0.09	-0.09	-0.09

Table 5: Significant decadal trends in precipitation indicators for 2030's (2010-2039) and 2050's (2040-2069) in both A2 and B1 scenarios from the four GCM's. *The table shows only significant trends.

Temperature indicators

Significant decadal trends of downscaled future daily precipitation extreme indicators across the study area are presented in Table 6. While all projections in all models in both scenarios for both periods showed the negative trend in TN10P would continue over Wonji, no model showed significant change over Adama unlike the base period. Similarly, all projections showed the observed trends in the base period would continue in all stations with the exceptions that projections in A2 scenario in 2050's from ukmoHADCM3 model over Modjo and Ziway were not significant. In terms of TN90P, most projections showed the trend over Melkasa, Metehara and Wonji would continue in similar fashion as observed in the base period. Yet, exceptionally, projections from gfdlCM2.1 and ncarCCSM3.0 in A2 scenario in 2050' over Melkasa and projections for the 2050's in both scenarios from all models were not significant. On the other hand, only in 2050's projections from gfdlCM2.1 model (in both scenarios) and from ncarCCSM3.0 model (in A2 scenario) showed that the observed trend would continue over Modjo. Most model projections also showed consistent TX90P trends with the base period (over Metehara, Modjo, Adama and Ziway stations) except the trends over Adama (in all models) and Metehara (in ukmoHADCM3 under A2 scenario) were not significant in 2050's period. Though, all trends except ncarCCSM3.0 and ukmoHADCM3 (in B1 scenario) were significant, the trend on the reverse would be increasing in the second period, i.e., in 2050's over Wonji.

With respect to Absolute indicators, all model projections showed that the trends in TXx, TXn and TNx observed in the base period would continue consistently except the trend in TXx were not significant in any projections over Adama. Projection also showed that, unlike the base period, TNn would significantly deceases over Modjo with the exception of projections from csiroMK3.0 in 2030's and ukmoHADCM3 in 2050 (i.e., in both A2 and B1 scenarios). Projections showed the observed positive trends in summer days would increase in the future; yet, all trends were not significant in all the projections and in all station. For instance, projections for 2050's period were not all significant except ukmoHADCM3 (over Melkasa) and ncarCCSM3.0 (over Melkasa and Ziway) in projections in B1 scenario.

		csiroMK3.0				gfdlCM2.1				ncarCCSM3.0				ukmoHADCM3			
		A2		B1		A2		B1		A2	B1	A2	B1	A2	B1	A2	B1
INDEX	Station	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050	2030	2050
TN1O P	Wonji	-0.57	-1135	-57	-1135	-1154	-0.26	-0.57	-0.39	-0.54	-0.28	-62	-0.48	-58	-0.27	-1162	-0.41
TN9O P	Mlelkaia	-0.65	-0.6	-0.65	-0.6	-0.73	-	-0.64	-0.67	-0.69	-	-64	-0.74	-64	-0.68	-0.6	-0.74
	Metehar a	0.8	0.75	0.8	0.75	0.86	1166	1180	1196	87	1166	1176	1190	11135	1159	1193	0.99

	Mojo	-	-	-	-	-	-0.91	-	-0.85	-	-0.9	-	-	-	-	-	-
	Adama	0.91	1.11	0.91	1.11	0.97	1198	0.89	1.14	1.01	1196	88	1.06	1188	1.09	1184	1.15
	Wonji	-1.5	-	-1.5	-	-1.54	-	-1.83	-	-1.4	-	-1.66	-1.24	-1.68	-	-1.91	-0.62
TX1OP	Melkasa	-0.28	-0.16	-0.28	-0.16	-0.25	-0.11	-0.27	-0.17	-0.26	-0.12	-0.27	-0.23	-0.27	-0.13	-0.29	-0.2
	Mojo	-0.21	-0.17	-0.21	-0.17	-0.2	-0.12	-0.2	-0.16	-	-0.13	-0.22	-0.19	-0.23	-	-0.22	-0.17
	Wonji	-0.62	-0.31	-0.62	-1131	-1160	-0.22	-0.64	-0.37	-	-0.23	-68	-52	-65	-	470	-0.4
	Ziway	-0.46	-0.24	-0.46	-0.24	-43	-0.18	-0.42	-0.27	-0.43		-45	-36	-0.44	-0.17	-0.46	-0.28
TX9OP	Melkasa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	Metehara	1.18	1.11	1.18	1.11	1.26	0.51	1.22	1.22	1.27	0.75	1.12	1.33	1.25	-	1.16	0.83
	Mojo	1.34	1.58	1.34	1.58	1.38	1.13	1.32	1.49	1.42	1.23	1.28	1.46	1.33	1.32	1.27	1.57
	Adama	-0.87	-	-0.87	-	-0.87	-	-0.86		-0.88		-29	-	-26	-	-0.85	-
	Wonji	-0.87	-	-1187	0.77	-1175	1.05	-	0.58	-0.64	1.07	-1.01	1.1	-90	-	-1.13	1.33
	Ziway	0.93	-	0.93	1.41	1.03	1.43	-	1.33	1.03	1.34	0.94	-	0.92	-	0.85	
TNn	Mojo	-0.09	-1104	-	-1104	-1105	-0.05	-0.05	-0.06	-0.05	-0.05	-0.06	-0.05	-94	-	-4	-
	Melkasa	-	-0.09	-0.09	-0.09	-0.1	-0.1	-0.1	-0.1	-	-0.1	-10	-0.1	-99	-0.09	-0.09	-0.09
	Meehan	-0.08	toe	mos	mos	0.09	ons	ons	1109		1109	1110	1110	1109	1108	1109	1109
	Mojo	-1113	-0.08	-0.08	-0.08	-0.08	-0.08	-0.09	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.08	-0.09	-0.09
	Wonji	0.08	-1113	-1113	-1113	-0.15	-0.15	-0.14	-0.14	-0.15	-0.15	-0.15	-17	-0.13	413	413	-0.13
lin	Melkaia	0.07	0.08	0.08	0.08	0.08	0.09	0.08	0.09	0.08	0.09	0.1	0.08	0.07	0.07	0.08	0.08
	Wonji	0.09	0.08	0.07	0.08	0.08	1109	1108	1109	1108	1109	1109	1108	1107	1107	1107	1107
	Metehara	-1110	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.1	0.1	0.1	0.09
	Wonji	0.08	-1110	-1110	-1110	-1110	-0.1	-0.1	-0.09	-0.1	-0.1	-0.1	-0.1	-0.11	411	410	4.1
	Z nvay	-0.1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08
	Mellcasa	1.35	-1342	-1110	-0.42	-0.21	-0.84	-0.14	-0.47	-0.19	-0.53	-0.13	-22	-11	-1166	-1110	-0.23
	Metehara	0.26	-	1.35	-	-	-	1.23	-	-	-	-	-	1.22	-	1.23	1.36
	Adama	-0.06	0.62	0.26	0.62	0.36	0.88		0.67	36	0.86		32	0.25	0.85	-	0.46
	WO.*	0.44	-0.37	-0.06	-0.37	-0.1	-0.61	-0.08	-0.34	-0.11	-0.65	-0.05	-0.14	-0.08	-0.53	-	-0.22
SU25	Melia	0.67	-	0.44	-	0.44	-	1146	-	1145	-	1146	0.38	1146	-	0.48	-
	WoMi	1.85	0.3	0.67	0.3	0.73	0.22	0.75	42	0.7	0.23	0.84	0.61	0.79	0.2	0.82	42
	Ziway	-	-	1.85	-	1.77		1.88	-	1.82	-	1.86	1.64	1.84	-	195	122
WSDI	Melkasa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
DTR	Metehara		-1118		-1118				-0.28	-	-	-	-	-	-	-	-
	Mojo	0.46	-	-	-	-	-	-	-	-	-	-	-	-	-0.2	-	-
	Adama	-0.15	0.48	0.45	0.48	0.49		0.55	54	1147		0.48	0.48	0.47	0.4	1344	-

	Wort	-	-0.09	-0.15	-0.09	-	-0.09	-	-0.07	-	-0.09	0.29	-	-	-0.1	0.16	0.11
	Ziway	0.13	-	-	-	-	-0.31	-	-	-	-0.29	-	-	-	-0.3	-	-
	Mojo	-10	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
	Adama	-	-1110	-1110	-1110	-1110	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-0.1	-1110	-1110	-1110

Table 6: Significant decadal trends in temperature indicators for 2030's (2010-2039) and 2050's (2040-2069) in both A2 and B1 scenarios from the four GCM's. *The table shows only significant trends.

Similarly, projections were not all consistently significant in TR20 changes specifically over Metehara station. For instance, only 6 out of 16 projections were significant trends over Metehara namely: csiroMK3.0 (for 2030's in both scenarios), gfdlCM2.1 (B1 2030's) and ukmoHADCM3 (except A2 for 2050's). All projections would show the trends in DTR over Modjo and Adama would continue as observed in the base period. Comparisons between the base period in future projections and even among models showed that much difference is apparent with respect to trends in WSDI index. Unlike the only significant decreasing over Wonji, WSDI indicator would show significant trends over all stations except Melkasa. Yet, all models would not show significant trends over all stations except over Adama and Wonji. In fact, among the significant trends over Wonji, WSDI index would increase in ncarCCSM3.0 (in 2030's) and ukmoHADCM3 (in both periods) projected climate under B1 scenario. Furthermore, while the WSDI index would decrease for the rest of the stations, the trend over Adama would be increasing and at the same time relatively higher in magnitude.

Regional trends

The average temporal trends across east Shoa Zone from 1980 to 2010 for statistically significant trends of indices of extreme weather are presented in Table 7. Out of the 26 extreme weather indicators calculated, SU25 and TR20 showed significant increases while TN90, TX10P and TNx showed significant decreases during the base period. However, the trends in TN90P and TR20 indicators are found to be statistically insignificant in the projected future climate. On the other hand, unlike in the historic data, TX90P indicator would increase significantly regionally in the projected future climate. In this regard, most models showed that the TX90P indicator would be significant increase especially in the second period, i.e., in the 2050's. For the 2030's period however, only in gfdlCM2.1 in both scenarios and ncarCCSM3.0 in A2 scenario, TX90P would increase significantly over the region.

Indices	**Base**	**csiroMK3.0**				**GfdlCM2.1**				**ncarCCSM3.0**				**ukmoHADCM3**			
		A2		**B1**		**A2**		**B1**		**A2**		**B1**		**A2**		**B1**	
		30's	**50's**	**30's**	**50's**	**30's**	**50's**	**30's**	**50's**	**30's**	**50's**	**30's**	**50's**	**30's**	**50's**	**30's**	**50's**
SU25	+11.4	+5.2	+2.9	+5.2	+2.9	+5.2	-	+5.3	-	+5.2	+2.5	+5.4	+4.4	+5.5	+2.2	+5.7	+3.3
TY90P	-3.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TNx	-0.39	-0.28	-0.3	-2.8	-0.3	-33	-0.33	-0.34	-0.31	-0.32	-0.31	-0.28	-0.23	-0.27	-0.28	-0.28	-0.27
TR20	+2.11	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TX10P	-4.7	-2.3	-1.3	-2.3	-1.3	-2.2	-0.9	-2.2	-1.4	-2.2	-1.0	-2.4	-1.9	-2.4	-1.1	-2.5	-1.6
TX90P	-	-	+6.5	-	+6.5	+2.7	+6.0	-2.2	+5.7	+2.9	+6.1	-	+4.0	-	-5.4	-	+4.4

Table 7: East zone average decadal trends. *The table shows only significant trends.

Discussion

Results of the analysis show that no consistent pattern of changes in precipitation extremes could be detected for the majority of precipitation indices. Similarly, among temperature indices, TX10P and SU25 indicators showed relatively homogenous pattern across the region which is in agreement with the regional analysis. The study identified heterogeneous behavior i.e., positive and negative significant trends ($p<0.05$) observed in TN90P, TX90P, TXx and TNx indicators evidence that changes in routine observing practices may have introduced in homogeneities of non-climatic origin that severely affect the extremes. For instance, Metehara is found in lower altitude and Wonji are found near large sugarcane farms and of course large sugar factory. The nearby lake to Ziway station and the higher topography which encircle Adama station are also other local factors which can impact the local climates of the stations.

The analysis for climate extreme indices for the projected climate also evolves quite in similar fashion as observed in the base period despite little differences among the GCM's in simulating individual climate extreme indices in some stations. The only significant difference observed among the models was the variations in simulating the trends in WSDI indices. This due to the downscaling method we used was simple statistical downscaling method.

The zonal average analyses, SU25 and TR20 showed significant increases while TN90, TX10 and TNx showed significant decreases during the base period. For the projected climate, SU25, TNx and TX10P would show similar trends as observed in the base period. Nevertheless, the trends TR20 and TN90P were not statistically significant in all projected climate. Additionally, we found significant increases in TX90P index in most projected climates in the zonal average analysis.

Conclusion

In this paper, we have examined the spatial and temporal distribution of trends in climate extremes using standard indices to describe for the last quarter of the 20th century when the largest changes occurred. In addition temporal trends of climate extremes in projected future climate for two periods centered at 2030 and 2050 under two scenarios A2 and B1are also investigated. Our study found neither consistent trend in precipitation extreme indicators nor homogenous trends across the study area. Similarly, the study identified TX10P and SU25 as representative indicators across the study area. The heterogeneous behavior identified in most temperature extreme indicators suggested that local factors play major role in the study area. Furthermore, the observed decreasing changes in warm extremes (i.e., TN90P and TNx) which are inconsistent with a warming planet evidenced the impact of these nonclimatic factors. It should be noted that the results presented in this paper are from small area and the downscaling method was also simple statistical downscaling method i.e., delta method. Therefore, we recommend further research using these representative indicators for longer period of data over larger area and using other downscaling method to better understand the impact of changing climate extremes.

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