

# Trends of Hydro-meteorological Indices in Tendaho Catchment Part of Awash River Basin, Ethiopia

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**Abstract:** The variability in the intensity and frequency of extreme hydro-meteorological events due to climate change have an enormous impact in managing water resources in developing countries. Frequently it has been recognized sudden droughts and a severe floods. This study analyzed the spatial and temporal trends of five meteorology indices: annual maximum precipitation (AMP), annual precipitation (AP), mean areal precipitation (MAP), annual maximum temperature (AMaT) and annual minimum temperature (AMiT) and three stream flow indices: mean annual flow (MAF), annual maximum flow (AMaxF) and total mean annual flow (TMAF) over the Tendaho Catchment. Mann-Kendall (MK), Spearman Rho (SR), Sen's slope (SS) test in R-program modifiedmk package and Sen innovative trend test were used to detect trends of 16 meteorological and one stream flow stations from 1979-2017. The result showed that there is a statistically significant temporal trends only in AMP, AP, AMaT and AMiT at 6, 19, 56 and 50% of the stations respectively. The remaining indices have no statistically significant trend in all the stations. It also dictates that the catchment is characterized by a slightly increasing AP and AMP; a slightly decreasing MAP and a significant increasing AMaT and AMiT trends. Except AMaT, there is no particular spatial pattern of AP, MAP and AMiT on the majority of the stations. Whereas, all stream flow indices showed a slightly decreasing temporal trend at 95% confidence. From this, we can conclude that the decreasing flow trend could be due to the decrement of MAP, an increment of temperature and construction of reservoirs in the catchment.

**Keywords:** Climate change; Trend; Precipitation; Temperature; Stream flow; Tendaho Catchment

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## 1. Introduction

The spatial and temporal variability of the hydrological and meteorological indices due to climate change have an enormous impact on environment, society, proper water resources management and infrastructure safety. Trend identification plays a significant role in climate change studies to make future predictions about possible consequences on the urban environment, agriculture, water availability, etc.(1). During the twentieth century, the intensity and frequency of extreme events have significantly altered globally due to climate change. A large spatial and temporal variability of rainfall leads to an increasing incidence of extreme events like floods and droughts (2).

Spatial and temporal trends of extreme precipitation and other hydro-meteorological variables have been investigated by many researchers at global, regional and local scales. Among these different studies were conducted to assess the trend and variability of rainfall in different part of Ethiopia.(3,4) in Awash River Basin of Ethiopia, (2) in Lake Tana Basin of Ethiopia,(5) in Upper Blue Nile River basin of Ethiopia, (6) in the Central Rift Valley of Ethiopia, and (7) in 13 different watersheds of Ethiopia agreed that there is no statistically significant and consistent trend in the

annual rainfall pattern. Contrasting results of annual and seasonal rainfall trends in some study areas of Ethiopia also reported by (8,9). These studies were used methods of slopes of regression lines using the least squares, Sen's slope estimator, Mann–Kendall trend test, Spearman's rho and Innovative Sen Trend test to detect the trends.

Similarly,(10) investigated the temporal variability of extreme precipitation on Konya Closed Basin in Turkey. The trend analysis of extreme precipitations was conducted using Spearman's Rho (SR), Mann-Kendall (MK) and Innovative Sen Trend test. The result examined non-significant decreasing trends of the majority stations. (11) investigated the increasing incidence of extreme hydro-climatic conditions, particularly drought, plays a vital role in regulating water resource availability in Southeast Florida. In this study, the presence of rainfall monotonic trends was analyzed using linear regression and Mann–Kendal trend tests. Pettit's single point detection test examined the presence of an abrupt change of rainfall. (12) studied the trend of annual temperature and precipitation time series data in Trarza region, Mauritania using the Mann–Kendall, the Spearman's rho, and the Sen trend test. The result of this study showed a significant increasing precipitation and temperature trend in most of the stations and all of the stations respectively.

The main aims of this study are 1) Analyze the temporal trends, and 2) Investigate the spatial trend patterns of hydro-meteorological variables of Tendaho Catchment. We have analyzed historical daily rainfall data in and near-by the catchment stations from 1979 to 2017. For such long term historical data, the hydro-meteorological trend were evaluated using the modified version of R-program modified-MK package. Based on the overall analyses, we have evaluated and conclude the temporal and spatial variability of the hydro-meteorological variables over the study catchment.

## 2. Experiments

### 2.1. Data

For hydro-meteorological trend assessment in this study using R-program modifiedmk package long term stream flow, temperature and precipitation data were used. Daily precipitation and temperature data from 1979 to 2017 were collected from Ethiopia National meteorology service Agency and the stream flow data from 1979 to 2005 were collected from Ministry of Water, Irrigation and Energy. 16 meteorology and one hydrology stations at the catchment outlet were used.

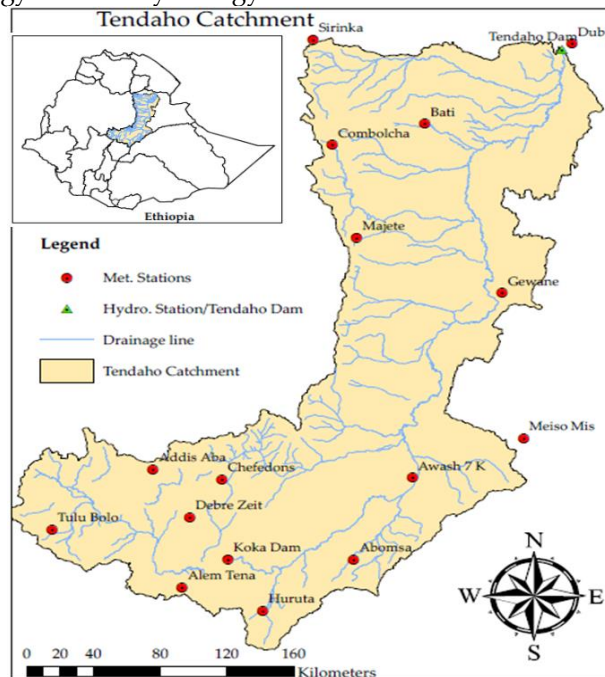


Figure 1. Location map of Tendaho Catchment and hydro-meteorology stations

## 2.2. Methodology

For detecting significant trends in hydro-meteorological data, two techniques are always used: parametric and non-parametric. The main assumption in all techniques is the independence of the data and the non-parametric methods were the most widely used for trend analysis (4,13,14). In this study, four different non-parametric trend methods (Mann-Kendall (MK), Sen's slope (SS), Spearman's Rho (SR) and the Sen innovative trend method) were used to detect the trends of annual maximum, areal mean, annual precipitation, annual average minimum and maximum temperature and annual stream flow of Tendaho catchment. Before use all-time series data were checked for autocorrelation and pre-whitening procedure is performed at a 5% significant level.

## 3. Results

### 3.1. Data Quality Assessment

Daily precipitation, Temperature, data of 16 stations from 1979-2017 and the available stream flow data from 1979-2005 at the outlet of the catchment have been calculated into monthly, annual maximum, annual totals. For the independent sample data, the stations selected have no much missed data and in some stations the missed data were filled and outliers were checked. However, to avoid autocorrelation problem, the serial correlation between the data set was checked and was not found to be auto correlated and hence to use it for further statistical analysis pre-whitening is done using the modifiedmk package. From the result of AP, AMP, AMaT and AMiT autocorrelation test 31.25%, 6.25%, 87.5% and 75% of the stations have a significant autocorrelation respectively.

### 3.2. Temporal Trends

#### 3.2.1. Analysis of Precipitation

The annual maximum precipitation (AMP) series was analyzed for each station to identify significant temporal trends. The results from MK, SR and Sen's Slope test show that, one station (Gewane) shows a statistically significant (Sig) increasing trend at 5% significant level. For the remaining 15 stations, 80% stations shows a slightly increasing while the remaining 20% stations shows a slightly decreasing and statistically none significant trend (Table 1).

**Table 1.** Summary of MK and SR test for AMP.

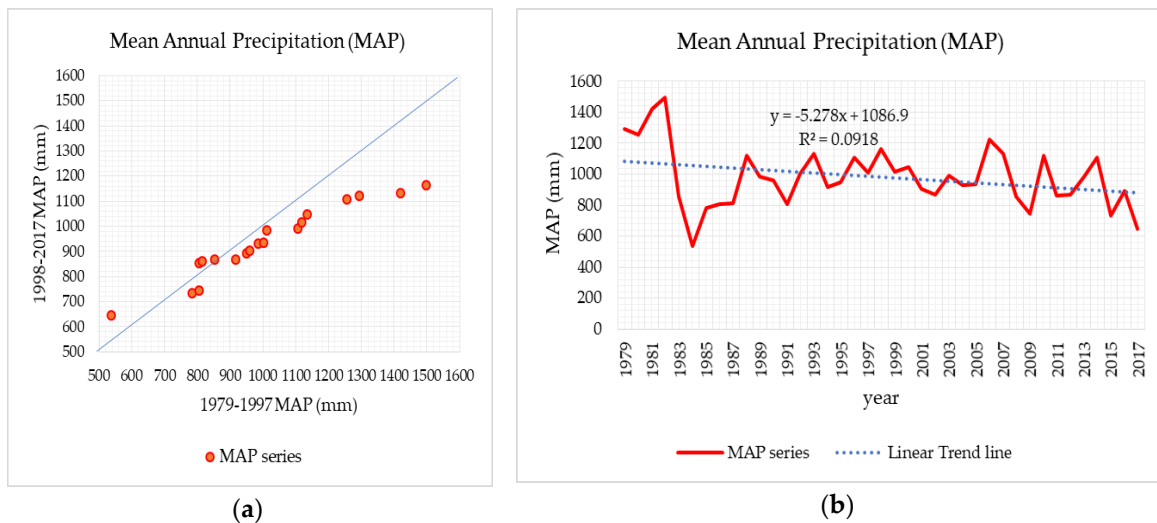
Station Name	MK-Z	P-value	Sen's Slope	Pre-whitened SS	Var(S)	SR-Z	Sig Trend	Trend type
Abomsa	0.275	0.783	0.058		5841.3	0.389	no	Increasing
Addis Aba	0.490	0.624	0.113		6326	0.506	no	Increasing
Alem Tena	0.490	0.624	0.113		6326	0.506	no	Increasing
Awash 7 K	-1.378	0.168	-0.444		3802.7	-1.441	no	Decreasing
Bati	0.750	0.453	0.388		2841	0.745	no	Increasing
Chefedonsa	-1.597	0.110	-0.289		6326	-1.639	no	Decreasing
Combolcha	0.379	0.704	0.059	0.054	5846	-0.161	no	Increasing
Dubity	0.101	0.920	0.059		6325	-0.161	no	Increasing
Gewane	2.080	0.038	0.727		5844	2.131	yes	Increasing
Huruta	-0.692	0.489	-0.113		6326	-0.735	no	Decreasing
Majete	0.257	0.797	0.187		2562	0.287	no	Increasing
Sirinka	0.257	0.797	0.187		2562	0.287	no	Increasing
Tulu Bolo	-0.541	0.589	-0.541		6319.3	-0.618	no	Decreasing
Meiso	0.022	0.982	0.024		2057.3	0.048	no	Increasing
Koka Dam	0.022	0.982	0.024		2057.3	0.048	no	Increasing
Debre Zeit	1.171	0.241	0.258		4549.3	1.187	no	Increasing

The result of the trend analysis for the annual precipitation (AP) Series are shown in Table 2. From MK, SR and Sen’s Slope test, three (18.75%) out of the 16 stations shown statistically significant trend. Two (Abomsa and Awash 7kilo) of the stations indicate a decreasing trend and one (Gewane) station has an increasing trend. Although the 13 (81.25%) of the stations have no statistically significant trend, eight (61.54%) of the station shows slightly increasing trend and the remaining five (38.46%) stations have a slightly decreasing trend. The maximum increase and decrease rate of annual precipitation was found to be +11.018mm/year at Gewane and -7.814mm/year at Abomsa stations, respectively.

**Table 2.** Summary of MK and SR test for AP.

Station Name	MK-Z	P-value	Sen's Slope	Pre-whitened SS	Var(S)	SR-Z	Sig Trend	Trend type
Abomsa	-2.120	0.034	-7.814		2842	-2.111	yes	Decreasing
Addis Aba	1.634	0.102	4.427		6327	1.782	no	Increasing
Alem Tena	0.982	0.326	0.284		3138.7	1.265	no	Increasing
Awash 7 K	-2.108	0.035	-5.541	-4.121	3461.7	-2.604	yes	Decreasing
Bati	-0.581	0.561	-2.324		2842	-0.563	no	Decreasing
Chefedonsa	1.659	0.097	5.100		6327	1.915	no	Increasing
Combolcha	0.589	0.556	7.828	6.402	5846	0.431	no	Increasing
Dubity	0.957	0.339	0.310		2840	1.129	no	Increasing
Gewane	3.283	0.001	11.018		5846	3.031	yes	Increasing
Huruta	0.830	0.407	1.704		6327	0.841	no	Increasing
Majete	-0.083	0.934	-5.814	-0.506	2301	-1.229	no	Decreasing
Sirinka	-0.232	0.817	0.076	-0.046	5390	0.449	no	Decreasing
Tulu Bolo	-0.528	0.597	-2.858		6327	-0.425	no	Decreasing
Meiso	0.970	0.332	4.949		2058.3	0.863	no	Increasing
Koka Dam	-0.510	0.610	-3.418	-1.830	5846	-1.159	no	Decreasing
Debre Zeit	0.356	0.722	0.646		4550.3	0.563	no	Increasing

On the other hand, analysis of the mean annual precipitation (MAP) for the catchment area using Sen innovative trend and linear trend test result indicates there is a slightly decreasing trend (Figure 2(a) and (b)).



**Figure 2.** Trends of mean annual precipitation (MAP): (a) Sens innovative trend; (b) linear trend and time series of MAP in the studied catchment.

### 3.2.2. Analysis of Temperature

The annual maximum Temperature (AMaT) and annual minimum temperature (AMiT) trends were analyzed using MK and Sen's slope trend test methods. The result of the AMaT using MK and Sen's slope test indicates that nine (56.25%) stations have significant trends; the remaining seven (43.75%) stations have no significant trend and an increasing trend for all stations except Combolcha. The maximum increment in temperature is 0.061 °C/year (Table 3).

**Table 3.** Summary of MK and Sen's slope test for AMaT and AMiT.

Station Name	Annual Maximum Temperature (AMaT)					Annual Minimum Temperature (AMiT)				
	MK-Z	Sen's Slope	Pre-whitened SS	MK Sig	MK Trend	MK-Z	Sen's Slope	Pre-whitened SS	MK Sig	MK Trend
Abomsa	3.433	0.063	0.061	yes	Increasing	2.045	0.029	0.020	yes	Increasing
Addis Aba	3.746	0.034	0.022	yes	increasing	1.986	0.058	0.013	yes	Increasing
Alem Tena	1.986	0.058	0.013	yes	Increasing	0.431	0.053	0.009	no	Increasing
Awash 7 K	3.454	0.039	0.031	yes	Increasing	1.411	0.023	0.007	no	Increasing
Bati	0.769	0.039	0.011	no	Increasing	-2.997	-0.046		yes	decreasing
Chefedonsa	0.490	0.145	0.014	no	Increasing	5.424	0.071		yes	Increasing
Combolcha	0.000	0.120	-0.001	no	Decreasing	3.294	0.059	0.040	yes	increasing
Dubity	3.170	0.043	0.033	yes	Increasing	5.424	0.071		yes	Increasing
Gewane	1.766	0.085	0.017	no	Increasing	1.399	0.064	0.029	no	Increasing
Huruta	1.584	0.029	0.009	no	Increasing	3.017	0.067	0.054	yes	Increasing
Majete	4.090	0.053		yes	Increasing	0.250	0.009	0.003	no	Increasing
Sirinka	3.596	0.026		yes	Increasing	0.302	0.002		no	Increasing
Tulu Bolo	1.257	0.062	0.033	no	Increasing	-0.994	0.017	-0.017	no	Decreasing
Meiso	3.350	0.050	0.048	yes	Increasing	0.176	0.004	0.008	no	Increasing
Koka Dam	0.114	0.037	0.003	no	Increasing	-2.301	-0.110	-0.042	yes	Decreasing
Debre Zeit	2.154	0.023	0.017	yes	Increasing	-0.418	-0.008	-0.005	no	Decreasing

(+) indicates an increasing trend and (-) indicates a decreasing trend type

The annual Minimum Temperature (AMiT) test using MK and Sen's slope method show half of the stations have statistically significant trend. Both the methods indicate most of the stations have an increasing trend except Bati, Tulubolo, Koka Dam and Debrezeit. The magnitude of the largest increasing trend of AMiT is 0.071 °C/year (Table 3).

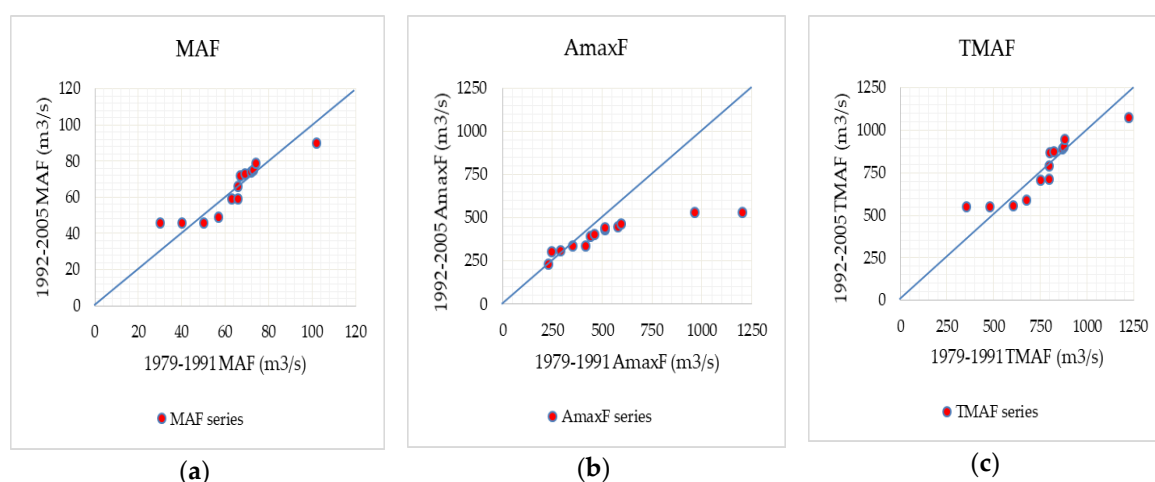
### 3.2.3. Analysis of Observed Stream Flow

For the discharge trend analysis, the available stream flow data from 1979-2005 period at the outlet (Tendaho station) of Tendaho catchment was used. The summary of the result using MK, Sen's slope and SR trend test for mean annual flow (MAF), annual Maximum Flow (AMaxF) and total mean annual flow (TMAF) are Witten in Table 4 and Figure 3.

The result of the trend for all MAF, AMaxF and TMAF indicates there were no statistically significant trend with  $Z=-0.669$ ,  $Z=-0.573$  and  $Z=-0.750$  respectively at 95% confidence. But there was slightly decreasing trends.

**Table 4.** Mean annual Flow (MAF), Annual Maximum Flow (AMaxF) and Total mean Annual Flow (TMAF) trends of Tendaho station using MK and SR methods.

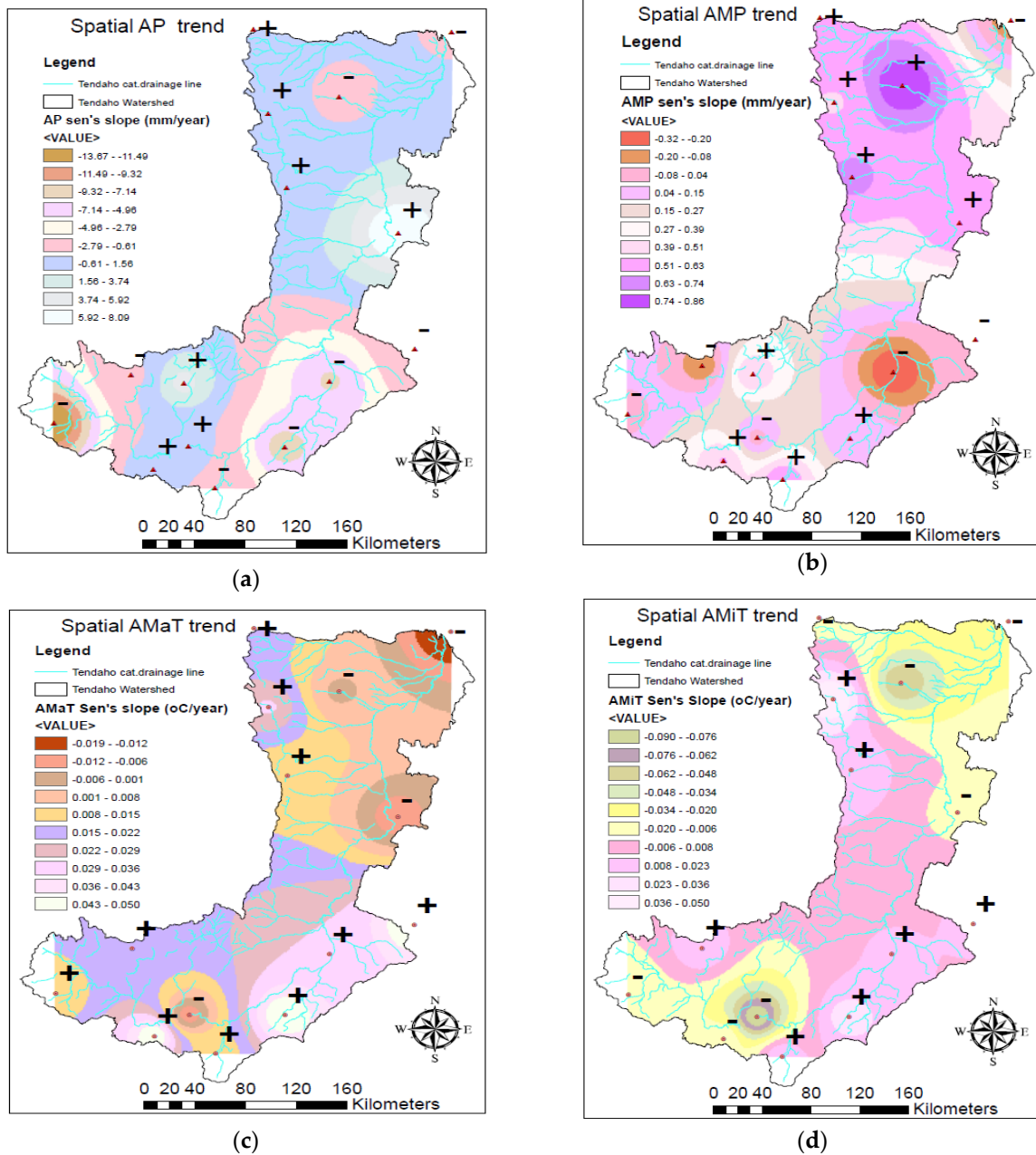
Indices	MK-Z	P-value	Sen's Slope	Pre-white ned SS	MK Sig	MK Trend	SR-Z	SR sig	SR Trend
MAF	-0.669	0.504	-0.333		no	Decreasing	-0.738	no	Decreasing
AMaxF	-0.573	0.567	-6.630	-2.91	no	Decreasing	-1.382	no	Decreasing
TMAF	-0.750	0.453	-3.889		no	Decreasing	-0.772	no	Decreasing



**Figure 3.** Observed stream flow using Sen innovative trend at the outlet gauging station: (a) Mean annual flow (MAF); (b) Annual Maximum Flow (AMaxF); (c) Total mean annual flow (TMAF).

### 3.3. Spatial Trends

For the regional trend analysis, it is preferred that all considered stations shall have the same period of record (14). Thus, in this section, a recent common period of record (1991-2017) was selected and 15 stations for precipitation and 14 stations for Temperature were included in order to investigate the spatial distribution of annual trends in the case study. The spatial distribution of trends and magnitudes in annual maximum precipitation (AMP), annual precipitation (AP), annual minimum Temperature (AMiT) and annual maximum Temperature (AMaT) are shown in Figure 4. The result indicate that there is no particular pattern in the spatial distribution of AP, MAP and AMiT with statically significant trend on the majority of the stations. Whereas the AMaT shows an increasing pattern except in the lower eastern part of the catchment with significant trend. In this study, the inverse distance weighting method (IDW) was used to interpolate rainfall trends of the available stations in order to produce continued raster surface for Tendaho catchment.



(+) indicate slightly increasing trend and (-) slightly decreasing trend pattern.

**Figure 4.** Spatial trends : (a) Annual precipitation (AP); (b) Annual maximum precipitation (AMP); (c) Annual maximum Temperature (AMaT); (d) Annual minimum Temperature (AMiT).

#### 4. Discussion

In this study, the result showed that the Annual maximum precipitation (AMP), annual precipitation (AP) and areal mean annual precipitation (MAP) in most of the stations detected statistically non-significant trend. But the study argue that Tendaho catchment is characterized by a slightly increasing AP and AMP and a slighting decreasing trend of areal MAP. Regarding AP and AMP, are consistent with those obtained from a previous trend study in most stations of Awash River basin (13). This results revealed that the AP trends was significantly increasing in most of the stations and slightly decreasing in some other stations. The other study which agree with this study was (15) review, which was reported by Africa climate change resilience Alliance (2011) and McSweeney et al.

(2008) specified that there is no a statistically substantial trend in observed mean precipitation in any season in Ethiopia between 1990 and 2006. The spatial trend both rainfall indices (AP and AMP) indicated that there is no particular pattern in the spatial distribution of the stations with significant trends across the catchment. The result obtained by (3) also indicate the direction and magnitude of the seasonal rainfall trend was not uniform throughout different stations.

On the other hand, the annual maximum temperature (AMaT) and the annual minimum temperature (AMiT) show a significant increasing trend over 1979-2017 reflecting warming of most part of the catchment. Generally there is a rising tendency in temperature in the study area. According to the literature (13) revealed that the annual temperature trends in Awash river basin were significantly increasing in most of the stations and slightly decreasing in some other stations. (15) reported that McSweetney et al. (2008) confirmed that the average yearly temperature in Ethiopia has raised by 1.3°C from 1960 to 2006, with the average increment rate of 0.28°C per decade.

The trend of the stream flow assessment indicate there is no statistically significant trend but a slightly decrement at the outlet gage. This result of the study much with previous studies that reported no significant trends in stream flow variables over Ethiopian (16). Similarly the Sen innovative trend test showed that the high values of AMaxF decreased more than the lower values during the study period. (13) studied for Awash basin gives similar conclusion that the discharge in the basin showed a decreasing trend. Generally the decrement of stream flow indices could be due to the decrement of mean annual rainfall and an increment of Temperature in the catchment area as explained earlier. Other activities, such as man-made structures like diversions and land use and land cover changes besides the annual and seasonal distribution of rainfall.

Regarding the trend tests used in the study, the result of Mann-Kendall, Spearman rho, Sen's slope and innovative trend test are almost the same in the majority of the stations.

## 5. Conclusions

This study examines the trend of the hydro-meteorological variables in Tendaho catchment and their significance. From the study we can conclude that the majority stations temporal trend for the precipitation indicate statistically insignificant trend with slightly increasing trend of AP and AMP. While a slightly decreasing trend of MAP. For the temperature indices (AMaT and AMiT) the majority of the stations shown a significant increasing trend. These result will reflect warming of the study region as a whole. Unlike the temperature, the stream flow indices (MAF, AMaxF and TMAF) indicate that there is a slightly decreasing trend and statistically insignificant trend.

For the spatial trend, the detected AMP, AP and AMiT trends do not form systematic pattern. Nevertheless, most of the detected trends are a slightly increasing (+) trend. On the other hand the spatial trend of the AMaT indicates an increasing (+) Pattern except the lower eastern catchment area.

In general, the results of this study can be used as a reference to adoptive water resource management by local government and different stakeholders, where in this catchment Irrigation and Agricultural productions are intense. Keeping in mind that the historical rainfall and stream flow records used in the study ended in 2017 and 2005 respectively, the analysis might not include the recent observed extremes. Thus it is recommended to collect a recent records to determine the possible climate change effect and the exact cause of the decreasing stream flow in the catchment.

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**Conflicts of Interest:** The authors declare no conflict of interest.



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